International Journal of Current Engineering and Technology
ISSN 2277 - 4106
© 2013 INPRESSCO. All Rights Reserved.
Available at http://inpressco.com/category/ijcet

Research Article

Influence of Reinforced Ferrocement Concrete Plates under Impact Load

Yousry B.I. Shaheen[a], Noha Mohamed Soliman[b*] and Doha El Metwally Kandil[c]

[a]Strength and Testing of Materialsat, Civil Department, Faculty of Engineering, Menoufia University, Egypt
[b]Civil Department, Faculty of Engineering, Menoufia University, Egypt
[c]Civil Department Faculty of Engineering Tanta University , Egypt

Accepted 10 October 2013, Available online 21 October 2013, **Vol.3, No.4 (October 2013)**

Abstract

The impact load such as loads acting on bridges, the train road, the roads, the airplanes and the machine. The main objective of this research is to study the impact resistance of reinforced ferrocement concrete plates reinforced with various types of reinforcing materials. Twenty ferrocement plates were designed and tested with dimensions of 500 × 500 × 25mm. The test specimens were loaded by 1.15 kg under its height 1.12m at the center of plates. The ferrocement plates were divided into five groups reinforced with skeletal steel bars, metal meshes and metal meshes with steel bars. High resistance ferrocement plates could be developed with high crack resistance and energy absorption properties. All the initial cracking impact energy, impact energy up to failure were extensively determined for all the tested plates. Results of reinforced ferrocement 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 with steel meshes achieved to higher energy absorption compared with those reinforced with steel bars only. This could be attributed to the effect of welded and expanded steel meshes in controlling the developed cracks. Increasing the number of the steel bars with welded and expanded steel mesh layers in the ferrocement composites delaying the occurrence of the first cracking as result of increasing the specific surface area of steel meshes, which leading to higher bond area. Thin ferrocement concrete plates were developed with high strength, crack resistance, high ductility and energy absorption properties very useful for dynamic applications with great economic advantages for developed and developing countries alike.

Keywords: *Impact load; Ferrocement; Concrete Plate; Reinforced Concrete.*

1. Introduction

Ferrocement as a construction technique is defined by ACI (committee 549) 2008) 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.*** (Elsakka A. M., 2007) The applications of Ferrocement were boat construction, Silos, Roofs, Tanks, Strengthening and Repairing of Reinforced Concrete Tanks, beams, slabs, Columns (E.H.Fahmy and Y.B.Shaheen (1991), E.H.Fahmy and Y.B.Shaheen (1997), Hagenbach, T. M. (1972), Washington, D.C (1973), Barberio, V. (1995), Lee S. L. et al (1983) and Paramasivam, P. (1988))

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 (Naaman, A. E. and Shah, S. P, May 1976)

Impact resistance is related to the capacity of the render to provide safety in use and to guarantee its performance after impact (CMHC and LNEC. UEATC (1982)), and it is expressed in terms of impact energy, in Joule (ISO. ISO 7361 (1986)). 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/s^2(g). (EOTA, 2003):

$$E_{imp} = E_p = g.\ h.\ m.$$

*Corresponding author **Dr. Noha Mohamed Soliman** is working as Lecturer, **Dr. Yousry B.I. Shaheen** is working as Professor; and **Doha El Metwally Kandil** is an Engineer

A distinction should be made between interior and exterior actions, by considering different types of impacts that represent a variety of impact energies. The degradation effects after impact vary as a function of the size, hardness and energy of the impact body. The impacts with higher energy level are related to the ultimate state (safety impacts) and the ones with less energy to the serviceability limit states (performance impacts) (CSTB/ MELTM (1989), ISO. ISO 7892 (1988), LNEC. UEATC (1982) and ABNT (2002)).

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 (ABNT, 2002).

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 and elsewhere (Ashwaq M. H. (2012), Atef B. et al. (2006) and Arshdeep S. C. (July 2009)). The impact tests and it measures the impact resistance was developed by ACI (committee 549/2008) and number of researchers in there researches (CMHC, Christiansen, K. A., and Williamson, R. B. (1972) and DESAI J. (2008).

In recent years small specimen test techniques have been widely used for convenience. Sub size specimens because of their smaller dimensions imply requirement of smaller load magnitudes and higher frequencies of force oscillations LNEC (1982).

The Charpy impact test, originally recommended for metals, has been employed to evaluate impact performance in terms of energy absorption capacity of steel fiber reinforced concrete relative to unreinforced matrix. A method for determining the yield force of the specimen in this test which it has been investigated using subside specimens., An iterative method is used to find the straight line, often called the Hooke's line, in the initial part of the force displacement curve. The test is normally associated with the fracture of the specimen (DESAI J. (2008), *Doha El M. K (2013))*.

2. Experimental

In this research study the impact resistance of reinforced ferrocement concrete plates reinforced with various types of reinforcing materials. Twenty ferrocement plates were designed and cast with dimensions of 500 × 500 × 25 mm its design, mixing and curing the plates tested according Egyptian Code Practices (E.C.P. 203/2007) [30].Which reinforced with various types of steel reinforcement such as steel bars, welded galvanized steel mesh, expanded steel mesh and poly propylene fibers. The main variables were the number of steel bars and number of steel mesh at the top and bottom of plates. In this program, we tested there in order to study their behavior under impact resistance. The falling load was kept constant as 1.150 kg from a height equal to 1.12m.

A) The 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 (E.S.S. 4657-1/2009).

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007), (E.S.S. 1109/2008) and (ASTM C 33, 2003). It was clean and nearly free from impurities with a specific gravity 2.6 t/m3 and a modulus of fineness 2.7.

Super Plasticizerused 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/m^3 based on the recommendations of manufacture. The chemical and physical characteristics of Polypropylene Fibres 300-e^3 are given in Table (1) and Fig (1-a).

Water was used the clean drinking fresh water free from impurities is used for mixing and curing the plates tested according Egyptian Code Practices (E.C.P. 203/2007).

Reinforcing Steel

A) Reinforcing Steel Barsuse was produced from the Ezz Al Dekhila Steel - Alexandria Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011). Normal mild steel bars steel bars (nominal diameters 6 mm) were used in reinforcing all the ferrocement plates, there yield stress was 240 MPa and there tensile strength was 350 MPa.

B) Reinforcing Meshes

a) **Expanded Metal Mesh:** Expanded metal mesh was used as reinforcement for ferrocement plates. Its chemical and physical characteristics satisfy the Egyptian Standard Specification (E.S.S. 262/2011). See table (2) and Fig (1-b)

b) **Welded Metal Mesh:** Galvanized welded metal mesh used was obtained from China. Welded metal mesh was used as reinforcement for ferrocement plates. Its chemical and physical characteristics satisfy the

Egyptian Standard Specification (E.S.S. 262/2011). See table (3) and Fig (1-c).

C) **Mortar Matrix:** The concrete mortar used for casting plates was designed to get an ultimate compressive strength at 28-days age of (350 kg/cm^2), 35 MPa. The mix properties for mortar matrix were chosen based on the (ACI committee 549 report: 2008) and Egyptian Code Practices (E.C.P. 203/2007). 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 was added and the whole patch 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 (4).

Preparation and Casting of Test Specimens: The flow chart of the conducted experimental program is shown in Fig (3). Description of the ferrocement plates used for impact resistance and there reinforcement details and dimensions of the ferrocement plates are shown in Fig (2) and Tables (5). The wooden forms of plates were coated with thin 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 levelled by using the trowel. Plates were lifted in the forms and covered with polythene sheets for 24 hours in laboratory conditions

Table 1 Physical and Mechanical Properties of Polypropylene Fibers 300-e^3

Length	Various
Type / Shape	Graded / Fibrillated
Absorption	Nil
Specific Gravity	0.91
Electrical Conductivity	Low
Acid &Salt Resistance	High
Melt Point	ºC(324º)162
Ignition Point	593 ºC(1100ºF)
Thermal Conductivity	Low
Alkali Resistance	Alkali Proof

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

until the sides of the forms were stripped away. After plates were remolded, plates immersed in water for 28 days before testing. After 28 days of curing. Then the plates were left for 4 hours in the laboratory conditions before testing.

Table 3 Technical Specifications and mechanical properties of Welded Metal Mesh

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

Table 4 Constituents of mortar used per m^3

Mix Design	Mix. Weight (kg/ m^3)
Cement	681.82
Sand	1363.64
Water	238.64
S.P.	6.82
Fibres	0.9

Table 5 Shows the experimental program of all series of the plates.

Series Designation	Plate Number	Type of Mesh Reinforcement	No. of layers of Reinforcement
G1	S3	Steel bars (3Φ6)	----------
	S4	Steel bars (4 Φ 6)	----------
	S5	Steel bars (5 Φ 6)	----------
	S6	Steel bars (6 Φ 6)	----------
G2	FW22	Welded mesh	Two layers at both top and bottom
	FW33	Welded mesh	three layers at both top and bottom
	FW44	Welded mesh	four layers at both top and bottom
	FW55	Welded mesh	five layers at both top and bottom
G3	FW22S2	Welded mesh and steel bar	Two layers at both top and bottom + (2 Φ 6mm)
	FW33S2	Welded mesh and steel bar	three layers at both top and bottom + (2 Φ 6mm)
	FW33S3	Welded mesh and steel bar	three layers at both top and bottom + (3 Φ 6mm)
	FW44S3	Welded mesh and steel bar	four layers at both top and bottom + (3 Φ 6mm)
	FW55S3	Welded mesh	Five layers at both top and

		and steel bar	bottom + (3 Φ 6mm)
G4	FE11	Expanded mesh	One layer expanded in both top and bottom of the plate
	FE22	Expanded mesh	two layers expanded in both top and bottom of the plate
	FE33	Expanded mesh	three layers expanded in both top and bottom of the plate
G5	FE22S2	Expanded mesh and steel bar	two layers expanded in both top and bottom of the plate+(2 Φ 6mm)
	FE22S3	Expanded mesh and steel bar	two layers expanded in both top and bottom of the plate+ (3 Φ 6mm)
	FE33S3	Expanded mesh and steel bar	three layers expanded in both top and bottom of the plate+ (3 Φ 6mm)
	FE22S4	Expanded mesh and steel bar	two layers expanded in both top and bottom of the plate+ (4 Φ 6mm)

Fig (1-a)

Fig (1-b)

Fig (1-c)

Fig. (1-a) Polypropylene Fibers 300-e3 Mesh Fig. (1-b) Expanded Metal Mesh Fig. (1- c) Welded Metal Mesh

Fig.(2) Mold ready for casting.

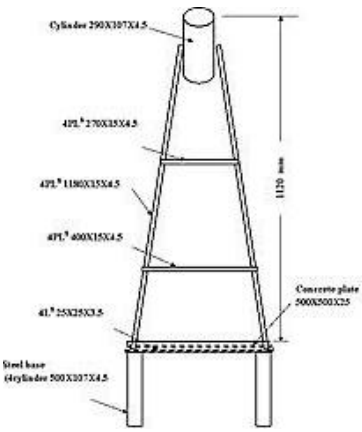
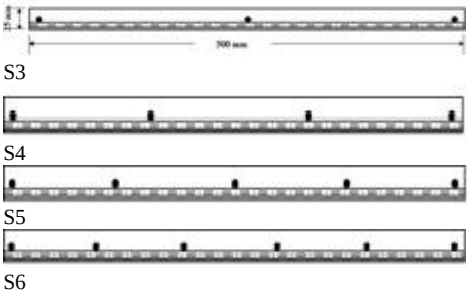


Fig.(3): schematic diagram for the impact test



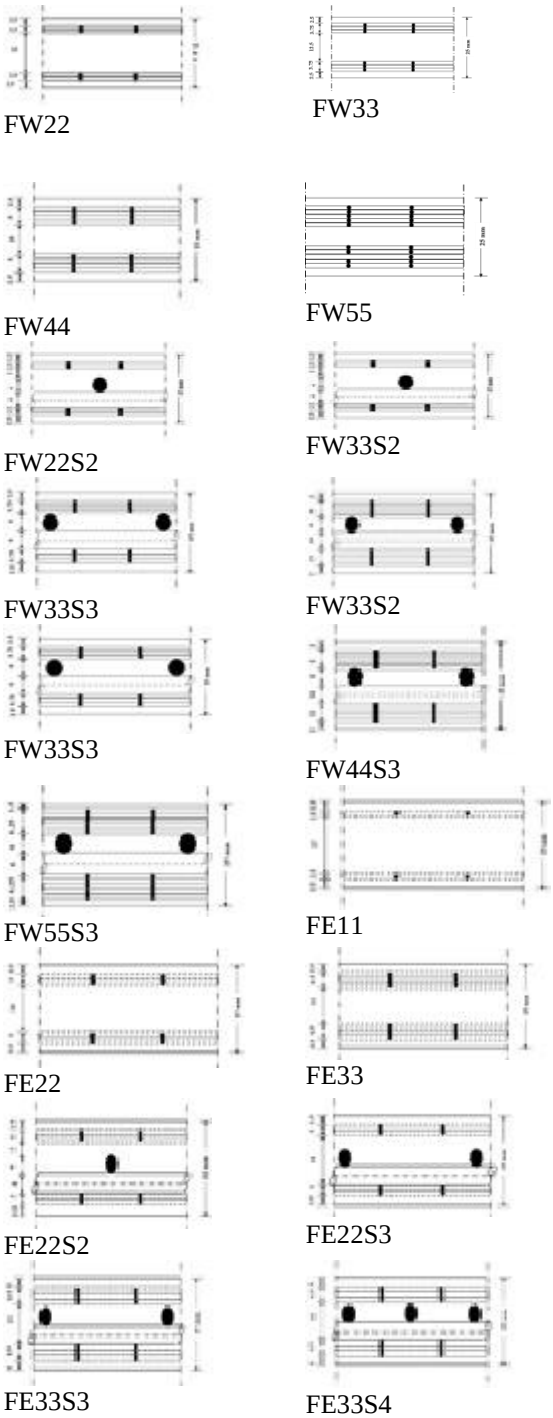


Fig (4): Reinforcement Configurations of All Plates

D) Impact Test

Impact resistance (Impact energy) is calculated by the capacity of the render to provide safety in use and to guarantee its performance after impact (CSTB/ MELTM (1989) and ISO. ISO 7892 (1988))

$$E_{imp} = E_p = g.\ h.\ m.$$

All plates were painted with diluted white lime solution to facilitate observations of cracks during testing. One day before testing, the plates were tested under impact load, frame as shown in Fig (8). The height of fall was 1.12 m and the weight of metallic ball was 1.150 kg was constant for all tested plates, were maintained constant for testing all specimens. The test set-up was so adjusted, such that the metallic ball exactly at the centre of the specimens and it was also ensured that the four edges of the specimens were freely supported). For each plate, the numbers of blows recorded for the appearance of the first crack, the failure crack were noted and then calculated impact energy initial crack load and ultimate load. Volume Fraction of Reinforcement (Vr %) and Specific Surface of the Reinforcement (Sr) for each plate depends on reinforcement of plate and calculated for each plate.

3. Experimental Results and Discussions

A. Initial cracking Impact Load and Ultimate load

Figs (5 -11) show the comparison of the first crack load and ultimate load where the first crack load is defined as the load which cause 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= 1.15 Kg

Initial crack blows and first crack load plates using steel bars (Group 1) for reinforcement plates increased by (1.11, 1.33 and 1.28 %) for plates S4 (4 Ø 6 in plate), S5 (5 Ø 6 in plate) and S6 (6 Ø 6 in plate) respectively compared to the control plate S3 (3 Ø 6 in plate). In case of plates reinforcement with welded mesh (group 2) the first crack blow and first crack load increased by (2.26, 3.1 and 4.3 %) for plates FW33 (3 layers mesh top & bottom) , FW44 (4 layers mesh top & bottom) and FW55 (5 layers mesh top & bottom) respectively compared to the control plate FW22 (3 layers mesh top & bottom). In case of plates reinforcement with welded mesh layers and steel bars (group 3) the first crack blow and first crack load increased by (2.3, 1.28, 2.3 and 1.1 %) for plates FW33S2 (3 layers mesh top& bottom and 2 Ø 6 in plate), FW33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate), FW44S3 (4 layers mesh top& bottom and 3 Ø 6 in plate) and FW55S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) respectively compared to the control plate FW22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

For plates reinforced with expanded mesh layers (group 4) the first crack blow and first crack load increased by (1.4 and 1.95 %) for plates FE22 (2 layers mesh top & bottom) and FE33 (3 layers mesh top & bottom) respectively compared to the control plate FE11(1 layer mesh top & bottom). In case of plates reinforcement with expanded mesh layers (group 5) the first crack blow and first crack load increased by (1.37 ,7.5 and 1.5 %) for plates FE22S3 (2 layers mesh top& bottom and 3 Ø 6 in plate), FE33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) and FE22S4 (2 layers mesh top& bottom and 4 Ø 6 in plate) respectively compared to the control plate FE22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

Maximum blows and ultimate loadwere increased by about (10%, 36% , 54.5%, 127%, 227%, 336%, 491%, 100%, 410%, 427%, 627%, 810%, 45%, 173%, 227%, 445%, 227%, 990% and 336%) for all plates (S4 ,S5, S6, FW22 , FW33, FW44, FW55, FW22S2, FW33S2,FW33S3, FW44S3, FW55S3, FE11, FE22, FE33, FE22S2, FE22S3, FE33S3 and FE22S4) respectively compared to the control plate (S3).

Maximum blows and ultimate load for plates using steel bars (Group 1) for reinforcement plates increased by (1.1, 1.36 and 1.53 %) for plates S4 (4 Ø 6 in plate), S5 (5 Ø 6 in plate) and S6 (6 Ø 6 in plate) respectively compared to the control plate S3 (3 Ø 6 in plate). In case of plates reinforcement with welded mesh (group 2) the maximum blows and ultimate load increased by (1.44, 1.92 and 2.6 %) for plates FW33 (3 layers mesh top & bottom), FW44 (4 layers mesh top & bottom) and FW55 (5 layers mesh top & bottom) respectively compared to the control plate FW22 (3 layers mesh top & bottom). In case of plates reinforcement with welded mesh layers and steel bars (group 3) the maximum blows and ultimate load increased by (2.54 ,2.63 , 3.63 and 4.54 %)for plates FW33S2 (3 layers mesh top& bottom and 2 Ø 6 in plate), FW33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate), FW44S3 (4 layers mesh top& bottom and 3 Ø 6 in plate) and FW55S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) respectively compared to the control plate FW22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

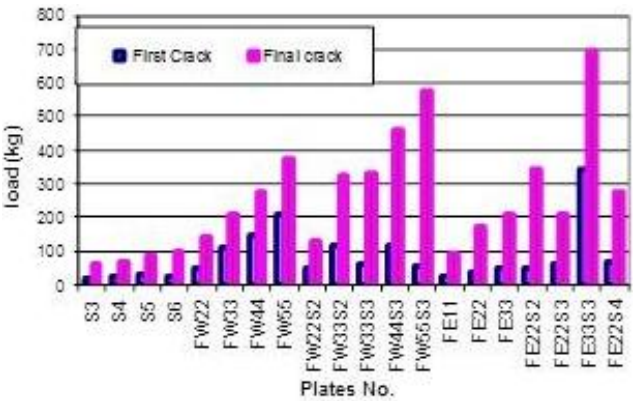


Fig (5): Comparison of First Crack &Ultimate Loads for All Plates

For plates reinforced with expanded mesh layers (group 4) the maximum blows and ultimate load increased by (1.87 and 2.25 %) for plates FE22 (2 layers mesh top & bottom) and FE33 (3 layers mesh top & bottom) respectively compared to the control plate FE11(1 layer mesh top & bottom). In case of plates reinforcement with expanded mesh layers (group 5) the maximum blows and ultimate load increased by (0.6 , 2 and 0.8 %)for plates FE22S3 (2

layers mesh top& bottom and 3 Ø 6 in plate), FE33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) and FE22S4 (2 layers mesh top& bottom and 4 Ø 6 in plate) respectively compared to the control plate FE22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

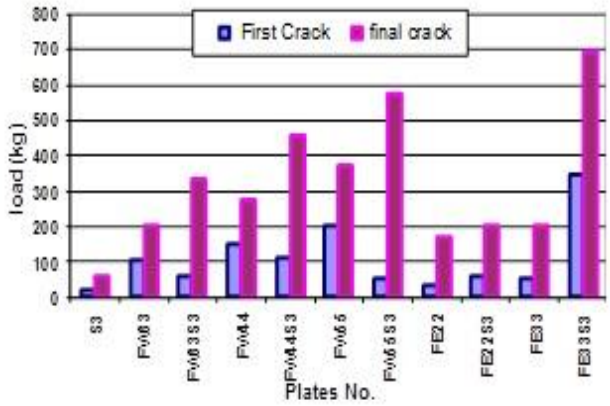


Fig (6): Comparison of First Crack &Ultimate Loads for Welded& Expanded Mesh to Steel Bars and Welded & Expanded Mesh with Steel Bars

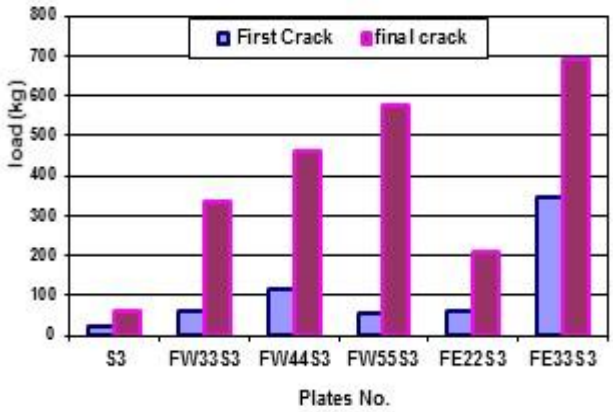


Fig (7): Comparison of First Crack &Ultimate Loads for Different Layers Welded& Expanded Mesh and 3 Steel Bars

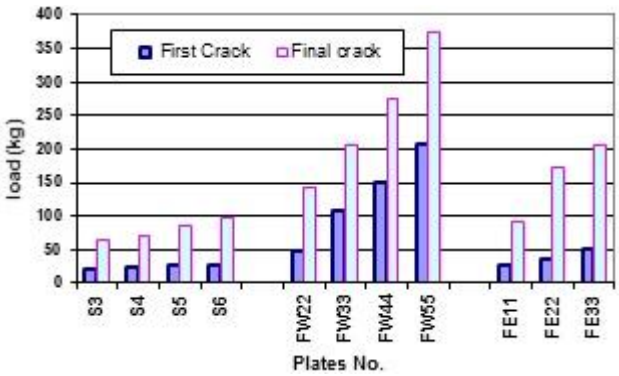


Fig (8): Comparison of First Crack &Ultimate Loads for G1,G2& G4

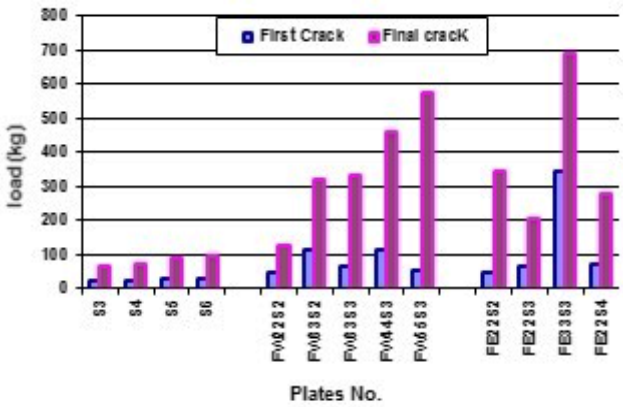


Fig (9): Comparison of First Crack &Ultimate Loads for G1,G3 & G5

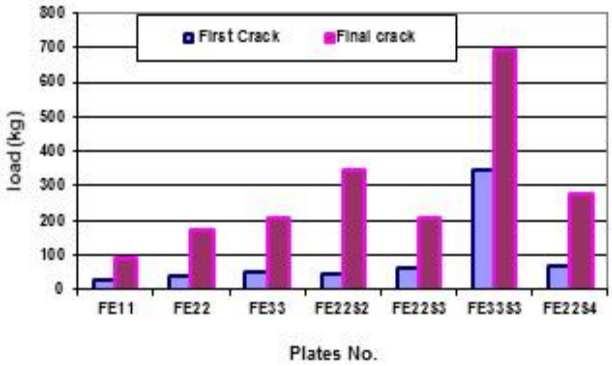


Fig (10): Comparison of First Crack &Ultimate Loads for G4& G5

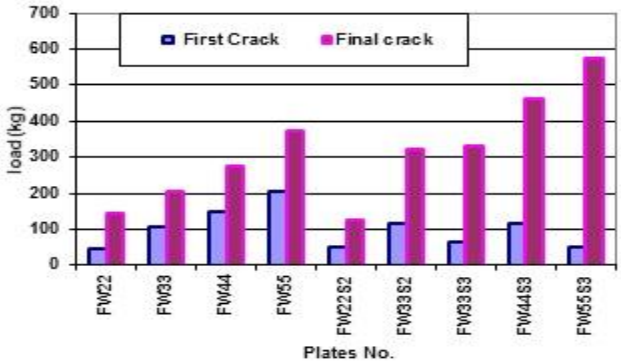


Fig (11): Comparison of First Crack &Ultimate Loads for G2& G3

B. Impact energy (J)

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. Figs (12 - 18) show the comparison of the impact energy.

Impact energy (J) = E_{imp} = E_p = I_f× M ×H× 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 (1150 g), H: is the drop height of the body (1.12 m) And g: is the acceleration of gravity (9.81 m/s^2).

The impact energy were increased by about (10%, 36% , 54.5%, 127%, 227%, 336%, 491%, 100%, 410%, 427%, 627%, 810%, 45%, 173%, 227%, 445%, 227%, 990% and 336%) for all plates (S4 ,S5, S6, FW22 , FW33, FW44, FW55, FW22S2, FW33S2,FW33S3, FW44S3, FW55S3, FE11, FE22, FE33, FE22S2, FE22S3, FE33S3 and FE22S4) respectively compared to the control plate (S3).

The impact energy plates using steel bars (Group 1) for reinforcement plates increased by (10, 36 and 54.5 %) for plates S4 (4 Ø 6 in plate), S5 (5 Ø 6 in plate) and S6 (6 Ø 6 in plate) respectively compared to the control plate S3 (3 Ø 6 in plate). In case of plates reinforcement with welded mesh (group 2) the impact energy increased by (44, 92 and 160 %) for plates FW33 (3 layers mesh top & bottom), FW44 (4 layers mesh top & bottom) and FW55 (5 layers mesh top & bottom) respectively compared to the control plate FW22 (3 layers mesh top & bottom). In case of plates reinforcement with welded mesh layers and steel bars (group 3) the impact energy increased by (154 ,163 , 263 and 354 %)for plates FW33S2 (3 layers mesh top& bottom and 2 Ø 6 in plate), FW33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate), FW44S3 (4 layers mesh top& bottom and 3 Ø 6 in plate) and FW55S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) respectively compared to the control plate FW22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

For plates reinforced with expanded mesh layers (group 4) the impact energy increased by (1.87 and 2.25 %) for plates FE22 (2 layers mesh top & bottom) and FE33 (3 layers mesh top & bottom) respectively compared to the control plate FE11(1 layer mesh top & bottom). In case of plates reinforcement with expanded mesh layers (group 5) the impact energy increased by (60, 100 and 80 %) for plates FE22S3 (2 layers mesh top& bottom and 3 Ø 6 in plate), FE33S3 (3 layers mesh top& bottom and 3 Ø 6 in plate) and FE22S4 (2 layers mesh top& bottom and 4 Ø 6 in plate) respectively compared to the control plate FE22S2 (2 layers mesh top& bottom and 2 Ø 6 in plate).

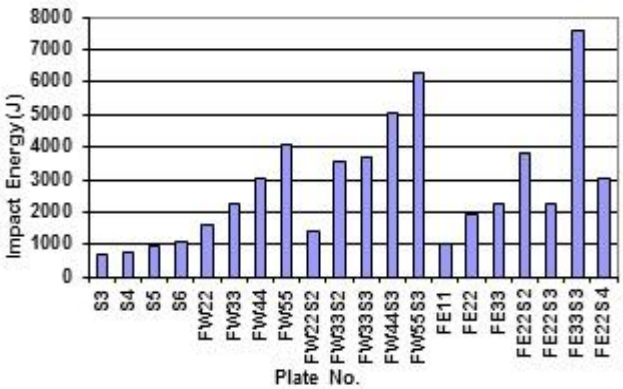


Fig (12): Comparison of Impact Energy for All Plates

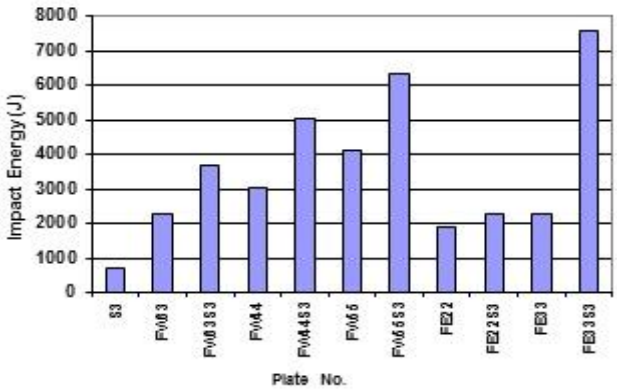


Fig (13): Comparison of Impact Energy for Welded& Expanded Mesh to Steel Bars and Welded & Expanded Mesh with Steel Bars

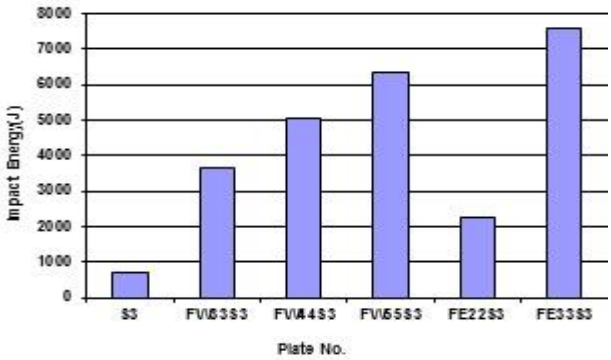


Fig (14): Comparison of Impact Energy for Different Layers Welded& Expanded Mesh and 3 Steel Bars

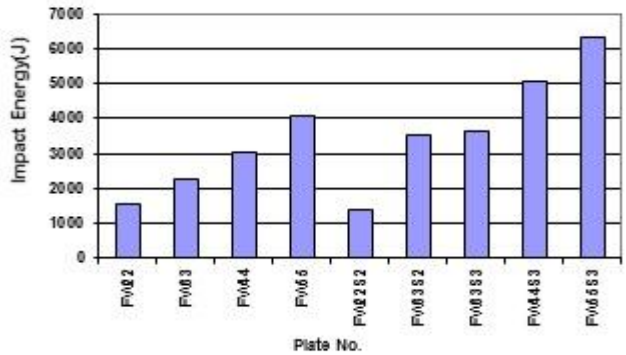


Fig (15): Comparison of Impact Energy for G2, G3

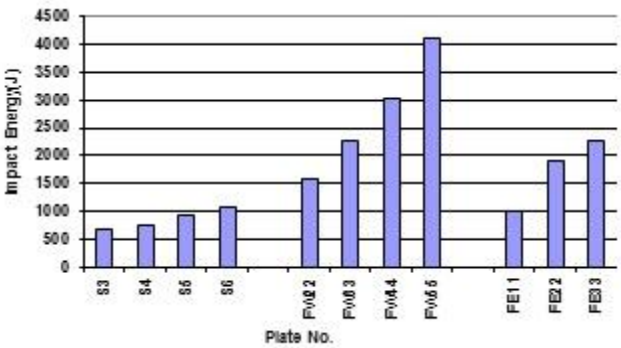


Fig (16): Comparison of Impact Energy for G1, G2, G4

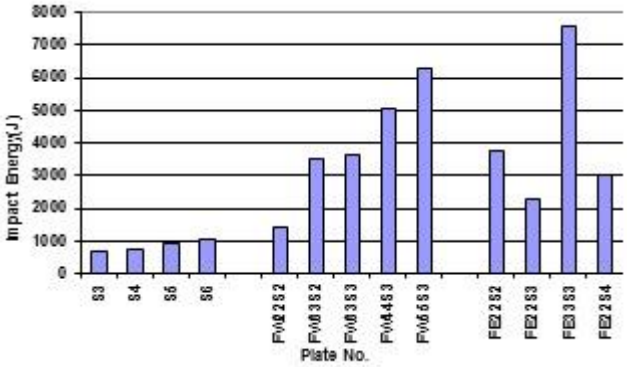


Fig (17): Comparison of Impact Energy for G1,G3, G5

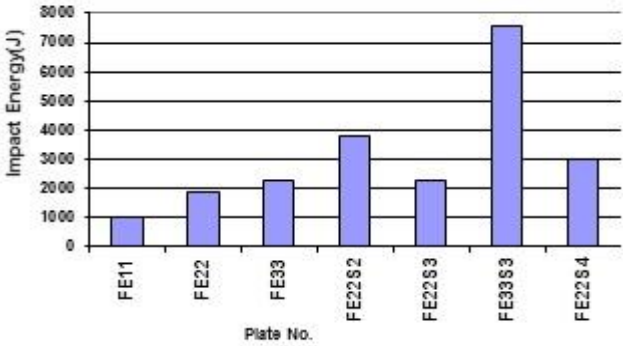


Fig (18): Comparison of Impact Energy for G4,G5

C. Volume Fraction of Reinforcement (Vr %)

Figs (19 -25) show the comparison of the volume fraction of reinforcement, 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 expanded metal mesh and expanded metal mesh with steel bars were given higher Vr% than control plates reinforced with reinforcing steel only. Plates

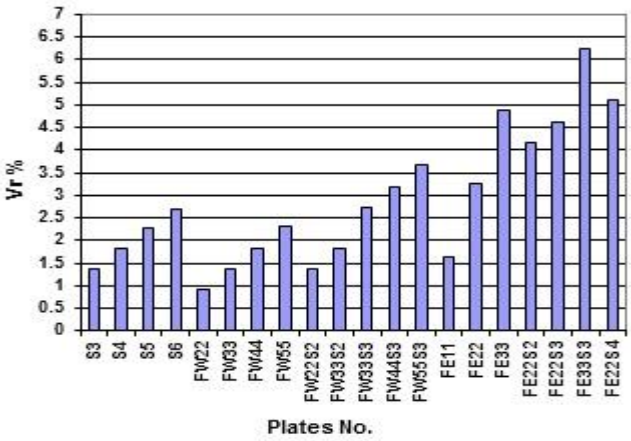


Fig (19): Comparison of Volume Fraction of Reinforcement (Vr %) for All Groups

reinforced with welded metal mesh and welded metal mesh with steel bars were given higher Vr% than control plates reinforced with reinforcing steel only. Plates reinforced with welded metal mesh were given lower Vr% than beams reinforced with expanded metal mesh. Plates with higher Vr% were given higher impact energy.

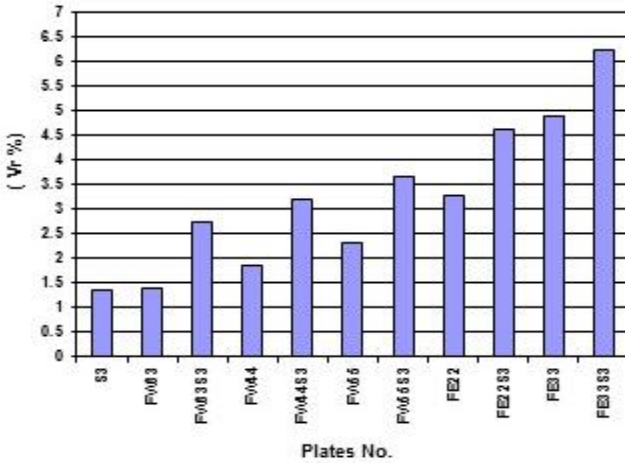


Fig (20): Comparison of Volume Fraction of Reinforcement (Vr %) for Welded& Expanded Mesh to Steel Bars and Welded & Expanded Mesh with Steel Bars

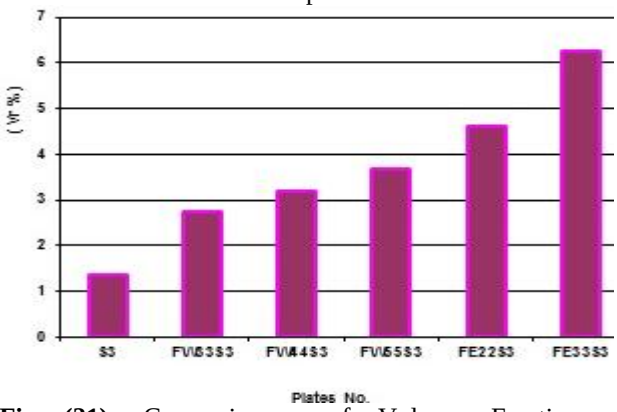


Fig (21): Comparison of Volume Fraction of Reinforcement (Vr %) for Different Layers Welded & Expanded Mesh and 3 Steel Bars

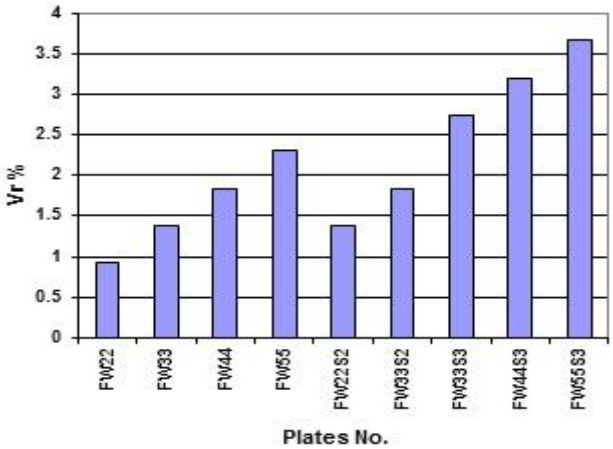


Fig (22): Comparison of Volume Fraction of Reinforcement (Vr %) for G2, G3

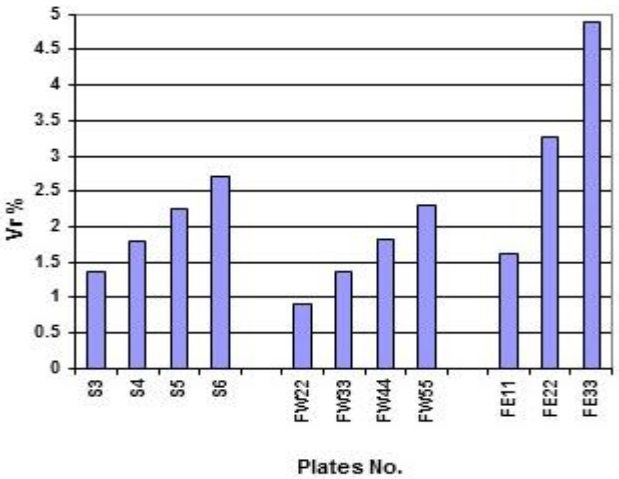


Fig (23): Comparison of Volume Fraction of Reinforcement (Vr %) for G1, G2, G4

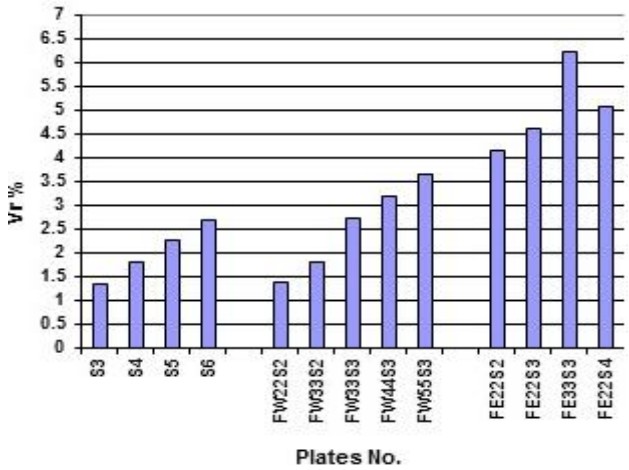


Fig (24): Comparison of Volume Fraction of Reinforcement (Vr %) for G1, G3, G5

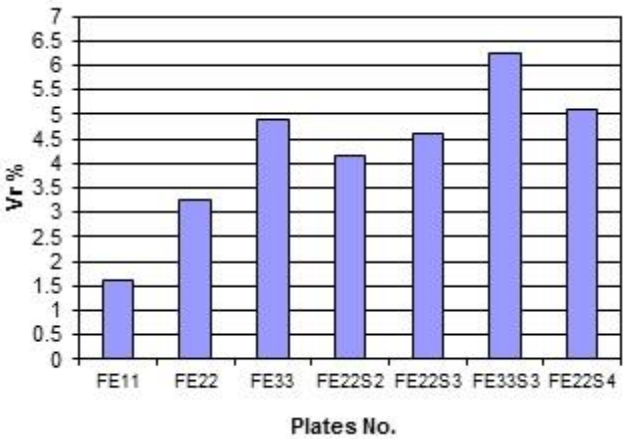


Fig (25): Comparison of Volume Fraction of Reinforcement (Vr %) for G4, G5

D. Specific Surface of the Reinforcement (Sr)

Specific Surface of the Reinforcement defined as the total bonded area of reinforcement (interface area or area of the steel that comes in contact with the mortar) per unit volume of composite. A common relation between Sr and Vf where square-grid meshes are used is: Sr=4*Vf/db (1-10) Where, db is the wire diameter. The increasing in specific surface of the reinforcement was calculated for each group as the following: Figs (26 -32) show the comparison of the specific surface of the reinforcement.

For group [1] plates reinforced with steel bars the Sr increased by (31, 65 and 100 %) for plates (S4, S5 and S6) compared to the control plate S3. Group [2] plates reinforced with welded mesh the Sr increased by (50, 100 and 151 %) for plates (FW33, FW44and FW55) compared to the control plate FW22. Group [3] plates reinforced with welded mesh the Sr increased by (46, 57, 110 and 150 %) for plates (FW33S2, FW33S3, FW44S3 and FW55S3) compared to the control plate FW22S2. Group [4] plates reinforced with welded mesh the Sr increased by (100 and 200 %) for plates (FE22 and FE33) compared to the control plate FE11. Group [4] plates reinforced with welded mesh the Sr increased by (5, 53 and 7 %) for plates (FE22S3, FE33S3 and FE22S4) compared to the control plate FE22S2.

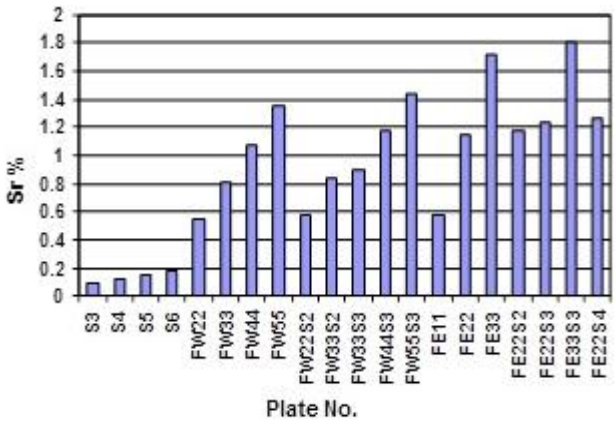


Fig (26): Comparison of Specific Surface Area of Reinforcement (Sr %) for All Groups

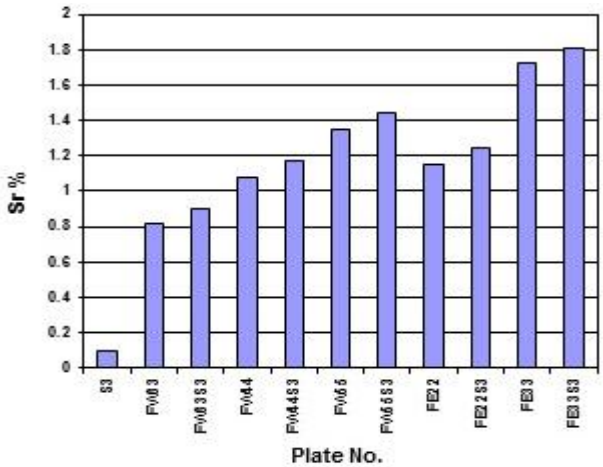


Fig (27): Comparison of Specific Surface Area of Reinforcement (Sr %) for Welded & Expanded Mesh to Steel Bars and Welded & Expanded Mesh with Steel Bars

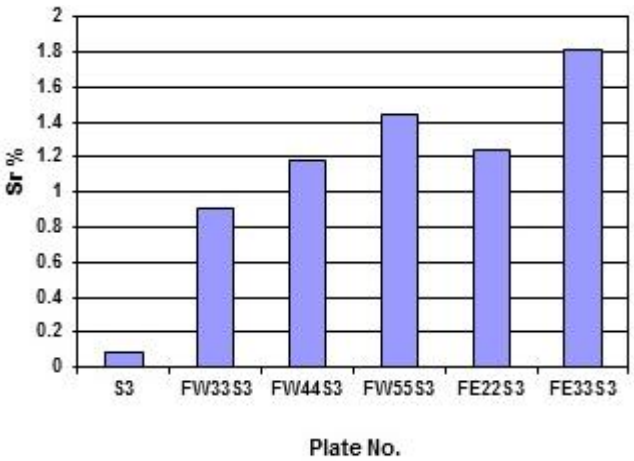


Fig (28): Comparison of Specific Surface Area of Reinforcement (Sr %) for Different Layers Welded & Expanded Mesh and 3 Steel Bars

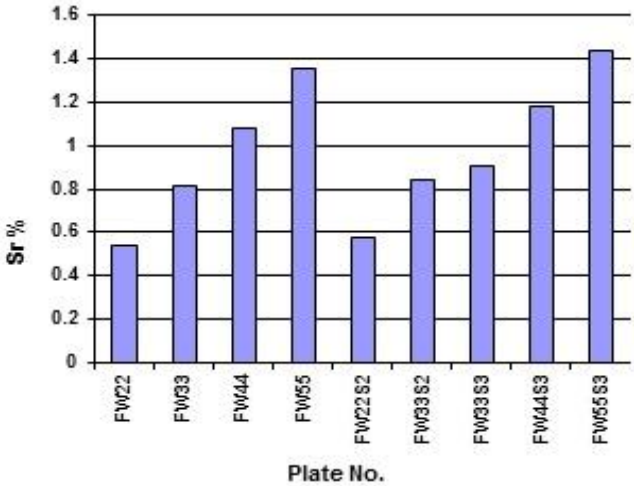


Fig (29): Comparison of Specific Surface Area of Reinforcement (Sr %) for G2, G3 Fig (29) Comparison of Specific Surface Area of Reinforcement (Sr %) for G2, G3

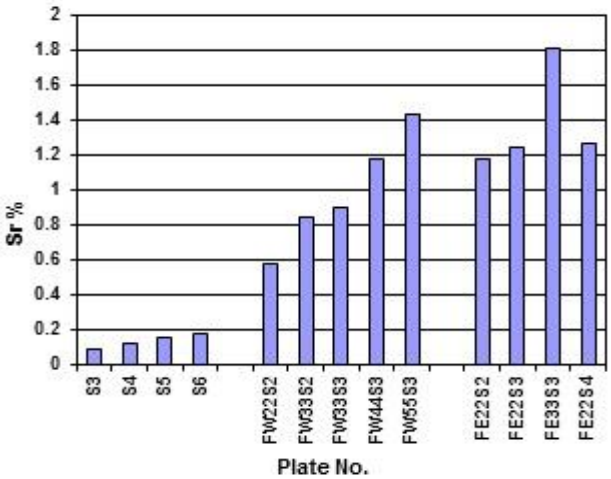


Fig (30): Comparison of Specific Surface Area of Reinforcement (Sr %) for G1, G3, G5

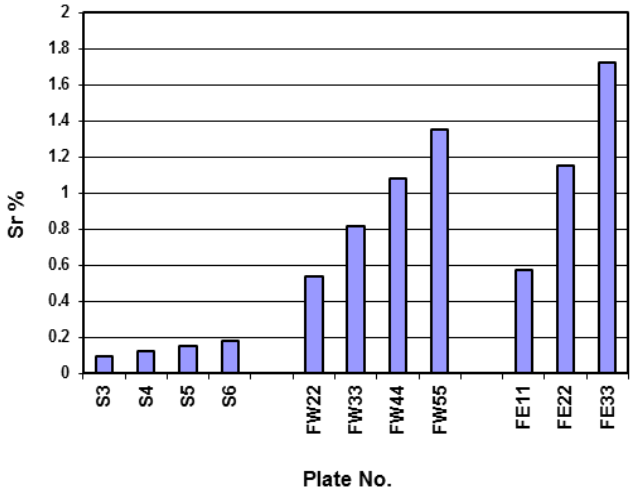


Fig (31): Comparison of Specific Surface Area of Reinforcement (Sr %) for G1, G2, G4

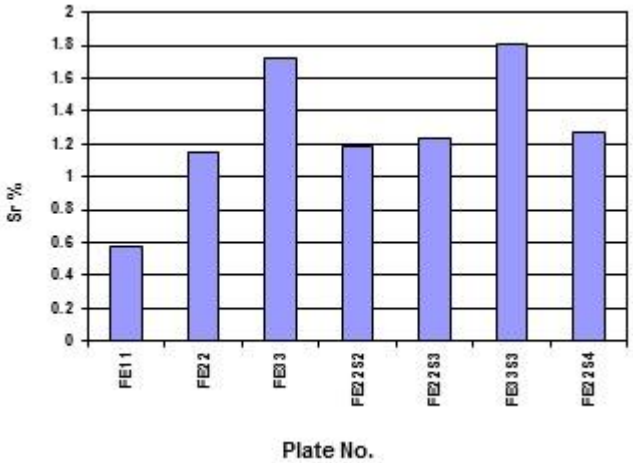
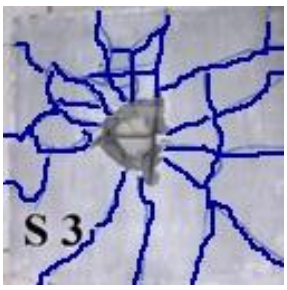
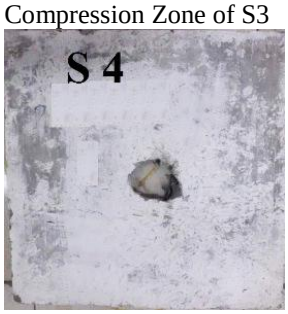


Fig (32): Comparison of Specific Surface Area of Reinforcement (Sr %) for G4, G5

Compression Zone of S3

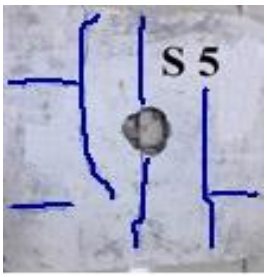


Tension Zone of S3



Compression Zone of S4

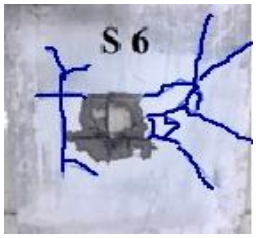
Tension Zone of S4



Compression Zone of S5

Tension Zone of S5

Compression Zone of S6



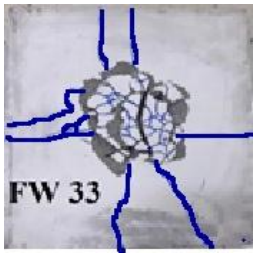
Tension Zone of S6

Crack Pattern for Group (1)

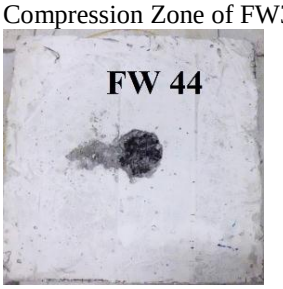
Compression Zone of FW22

Tension Zone of FW22

Compression Zone of FW33

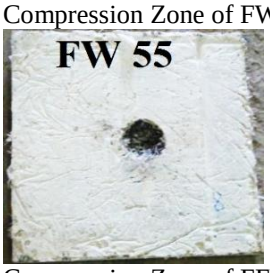


Tension Zone forFW33



Compression Zone of FW44

Tension Zone of FW44



Compression Zone of FFW55

Tension Zone of FW55

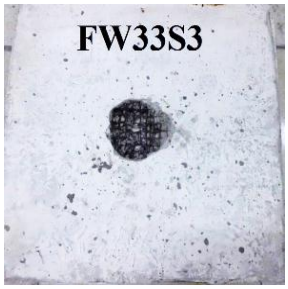
Crack Pattern for group (2)

Compression Zone of FW22S2

Tension Zone of FW22S2

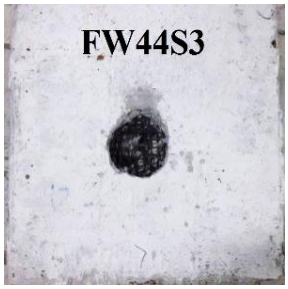
Compression Zone of FW33S2

Tension Zone of FW33S2



Compression Zone of FW33S3

Tension Zone of FW33S3



Compression Zone of FW44S3

Tension Zone of FW44S3

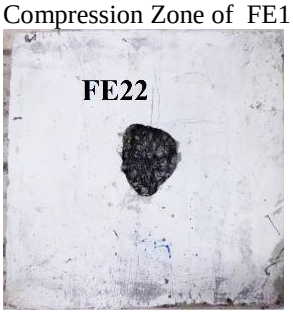
Compression Zone of FW55S3

Tension Zone of FW55S3

Crack Pattern for group (3)

Compression Zone of FE11

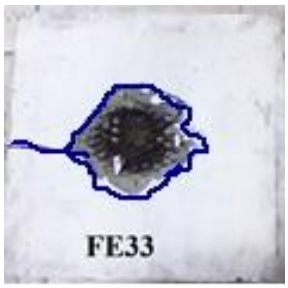
Tension Zone of FE11



Compression Zone of FE22

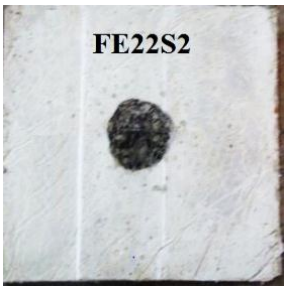
Tension Zone of FE22

Compression Zone of FE33



Tension Zone of FE33

Crack Pattern for group (4)



Compression Zone of FE22S2

Tension Zone of FE22S2

Compression Zone of FE22S3

Tension Zone of FE22S3

Compression Zone of FE33S3

Tension Zone of FE33S3

Compression Zone of FE22S4

Tension Zone of FE22S4

Crack Pattern for group (5)

Fig (33): Crack Pattern for all Tested Plates

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 synthetic fibers, specimens incorporating ferrocement permanent forms reinforced with expanded wire meshes achieved higher first crack load, Vr % and Sr ultimate load and energy absorption in comparison to those reinforced with welded steel mesh.
4. Employing (two –three – four -five) layers of welded metal meshes in reinforcing ferrocement plates, improve the energy absorption than those obtained using skeletal steel bars only.
5. Using welded steel meshes with mild steel bars 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.
6. Increasing the number of steel bars with welded steel mesh layers 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.

7. Using (one -two -three) layers of expanded metal mesh in reinforcing ferrocement plates, improve the energy absorption than those obtained, when using skeletal steel bars.
8. Using expanded steel mesh with mild steel bars in reinforcing ferrocement plates results in markedly higher energy absorption than that obtained, when using mild steel bars only.
9. Irrespective of the type of expanded metal mesh, using(two& three& four) mild steel bars with (two or three) layers expanded metal mesh leads to improve energy absorption than that obtained, when using layers expanded metal mesh only.
10. Increasing the number of the steel mesh layers in the ferrocement forms increases the first crack load, ultimate load, and energy absorption.
11. The developed plates utilizing thin ferrocement forms could be successfully used as an alternative to the traditional reinforced concrete plates, which can be of true merit in both developed and developing countries besides its anticipated economic and environmental merits.
12. The percentages loss of weight for plates reinforced with steel bars 2.23 %, while it reached to 1.7% this is predominant.
13. Thin ferrocement concrete plates were developed with high strength, crack resistance, high ductility and energy absorption properties very useful for dynamic applications with great economic and advantages.

References

ACI Committee 549.1–R08. Guide for the design, construction and repair of ferrocement. *ACI Struct J* 2008.

Elsakka A. M. (2007), Structural Behavior of Masonry Units with Openings Strengthened With Ferrocements Layers Under Compression Loadings, M_{SC}. Thesis submitted to *Menoufia University*, Egypt.

E.H.Fahmy and Y.B.Shaheen, (1991), Strengthening and Repairing of Reinforced Concrete Tanks, *Fourth Arab Structural Engineering Conference* 18-21 November,

E.H.Fahmy, Y.B.Shaheen, and Y.S.Korany,(January 1997, Repairing Reinforced Concrete Beams Ferrocement, *Journal of Ferrocement*: 27 (1).

E.H.Fahmy, Y.B.Shaheen, and Y.S.Korany, (July 1997), Use of Ferrocement Laminates for Repairing Reinforced Concrete Slabs, *Journal of Ferrocement*: 27 (3),

H. Fahmy, Y.B.Shaheen, Y.S.Korany, (April 1999), Repairing Reinforced Concrete Columns Using Ferrocement Laminates, *Journal of Ferrocement*: 29, (2), 115-124

Hagenbach, T. M.,(Oct. 1972), Experience of 300 Commercially Built Craft in More Than 20 Countries, FAO Seminar on the Design and Construction of Ferrocement Fishing Vessels, Wellington, PP. 22 (Also, Fishing News, West Byfleet, Surrey.)

Washington, D.C (Feb.1973), Ferrocement: Applications in Developing Countries, National Academy of Science, PP. 90.(Jan. 1981) Housing Application in Ferrocement, *Journal of Ferrocement (Bangkok*), 11 (1) Special Issue, 108- 112.

Barberio, V., (May-June 1975), CupulasDelgadas de Ferrocemento Para UnaInstalacionIetica en el Rio Pirino, Revista IMCYC (Mexico, D.F.), 13 (74), 20-28.

Lee, S. L.; et al., (Nov. 1983), Ferrocement: Ideas Tested at the University of Singapore, *Concrete International: Design & Construction*, 5 (11), 12-16.

Paramasivam, P.; Ong, K. C. G.; and Lee, S. L., (1988), Ferrocement Structures and Structural Elements, Steel Concrete Composite Structures, R. Narayanan, Ed., *Elsevier Applied Science Publishers Ltd*., 289-338.

Naaman, A. E., and Shah, S. P., (May 1976 Evaluation of Ferrocement in Some Structural Applications, Proceedings, 4th IAHS International Symposium on Housing Problems (Atlanta), *Pergamon Press*, Elms-ford, 1069-1085.

CMHC. Assessing the impact of thickness on the performance of stucco cladding. Research highlight, Technical series 04-123, Ottawa, Ontario,

LNEC. UEATC (1982), Directives related to impacts in vertical opaque construction elements, ICT translation 769. Lisbon: LNEC; p. 24 [in Portuguese].

ISO. ISO 7361 (1986), Performance standards in building – presentation of performance levels of façades made of same-source components, *International organization for standardization*, Switzerland.

EOTA (2003), Determination of impact resistance of panels and panel assemblies, Technical report TR001, European organization for technical approvals.

CSTB/ MELTM (1989), Manuel des performances, Tome I, La structure, l'enveloppeverticale, Centre Scientifique et Technique du Bâtiment (CSTB); p. 151.

ISO. ISO 7892 (1988), Vertical building components – impact resistance – impact bodies and general test procedures, Switzerland: International Organization for Standardization.

LNEC. UEATC (1982), Directives related to impacts in vertical opaque construction elements, ICT translation 769. Lisbon: LNEC. p. 24 [in Portuguese].ABNT (2002), Performance of dwelling buildings with up to five pavements – Part 4: Facades and partition walls. Brazilian Association of Technical Norms; [in Portuguese].

Kankam CK. (OCT 1999), Impact resistance of palm kernel fibre-reinforced concrete pavement slab, J Ferrocement; 29 (4), 279–286.

Ashwaq M. H. (2012), Structural Behavior of Ferrocement Channels Beams, MSC. Thesis submitted to *Menoufia University*, Egypt.

Atef B., Ashraf F. Ashour, Andrew K. Platten (2006) *International Journal of Impact Engineering* 32, 1907–1920

Arshdeep S. C. (July 2009), Effect of percentage of reinforcement on beams retrofitted with ferrocement jacketing, *Thapar university Patiala*-147004.

Christiansen, K. A., and Williamson, R. B., (Apr. 1972), Improvement in Ferrocement Structures, *University of California, Berkeley*, 11 pp.

DESAI J (Aug .2008), Ferrocement in Building Industries, J A Desai Ferrocement Pvt Ltd. http://www.jadferrocements.com/.

Doha El M. K. (2013), Impact Resistance of Reinforced Ferrocement Concrete Plates, MSC. Thesis to *Menoufia University*, Egypt.

E.S.S. 4756-1/2009, 2009, Egyptian Standard Specification for Ordinary Portland Cement, Egypt.

E.C.P. 203/2007, 2007, Egyptian Code of Practice: Design and Construction for Reinforced Concrete Structures, Research Centre for Houses Building and Physical Planning, Cairo, Egypt.

E.S.S. 1109/2008, 2008, Egyptian Standard Specification for Aggregates, Egypt.

ASTM C 33, 2003, American Society for Testing and Materials: Aggregates, Philadelphia, USA.

ASTM C 494-03, 2003, American Society for Testing and Materials: Chemical Admixtures, Philadelphia, USA.

E.S.S. 262-1/2011, 2011, Egyptian Standard Specification for Steel Bars, Egypt.