Original Research Article

Structural behavior of ferrocement concrete plates subjected to flexural and dynamic loadings

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ABSTRACT

Ferrocement is one of the structural materails , widely used due to its advantages from its particular behavior such as mechanical properties , and impact strengthThis paper deals with the impact studies and energy absorption properties of ferrocement slabs.For these studies, 11 different ferrocement slabs of size 50mm X 500mm X 25mm were casted with alteration in the combinations of mesh layers and test results are analyzed to find the different crack patterns .The test specimens were loaded by 3.10 kg **under its height 1.20m in the center of plates**. The ferrocement plates were divided into 4 groups reinfo rced with steel mesh , steel mesh with steel bars, percentage of rubber and fiber. . The impact energy at initial cracking stage and at failure was determined for all the slabs. Results of reinforced ferrocement plates emphasized that, increasing the number of the steel mesh layers in the ferrocement forms increases the first cracking load, ultimate load, and energy absorption. Using steel bars with steel meshes led to higher energy absorption than that obtained when using mild steel bars only. Using rubber and fiber achieved high impact energy .

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Keywords: ***Impact, Ferrocement,***

Add more Keywords.

1. INTRODUCTION

Ferrocement is a composite material consisting of rich cement mortar matrix uniformly reinforced with one or more layers of very thin wire mesh with or without supporting skeletal steel. Ferrocement has defined as "a type of thin wall re in forced concrete commonly constructed of hydraulic cement mortar, reinforced with closely spaced layers of continuous and relatively small diameter mesh". The mesh may be metallic or may be made of other suitable materials. [1]. Irrespective of conventional concrete, Ferro cement reinforcement can be assembled into its final desired shape and the mortar can be plastered directly in place without the use of a form which results in a flexible and strong enough ferrocement structures. Steel mesh is the most common type of reinforcement material used in this technique and other materialsinclude selected organic, natural of synthetic fibres which may be combined with metallic mesh. [7] Ferrocement is now recognized as a construction material with an excellent quality of crack control, impact resistance, and toughness, largely due to the close spacing and uniform dispersion of reinforcement within the material. Many investigations have clarified the physical and mechanical properties of this material, and numerous test data are available to define its performance criteria for design and construction[8,9]. Ferrocement is an excellent material for housing construction [10], Impact resistance is related to the capacity of the render to provide safety in use and to guarantee its performance after impact [11,12]. 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 dependen on the properties of the concrete [13]. Over the years researchers have realized tha 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.[14,15].

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2. EXPERIMENTAL

In this research study the impact resistance of reinforced ferrocement concrete plates reinforced with various reinforcing materials. Eleven ferrocement plates were cast with dimensions 500 × 500 × 25 mm its design, mixing and curing the plates tested according Egyptian Code Practices (E.C.P. 203/2007) [3]. Which reinforced with various types of steel reinforcement such as steel bars, welded galvanized steel mesh, expanded steel mesh , tensar mesh , rubber poly propylene fibers. The main variables were number of steel mesh at the top and bottom of plates. In this program, we tested the plates to compare the structural behavior of plates subjected to impact loadings load equal **3.100 kg from height 1.20 m**

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3. 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) [4].
The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007) [3], It was clean and nearly free from impurities with a specific gravity 2.64 t/m3 and a modulus of fineness 2.61.
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 (Sikaviscocrete 20), It meets the requirements of ASTM C494 (type A and F) [5]. The amount of HRWR was 2.0 % of the cement weight.Also used MasterEmaco (SBR 2) in rehabilitation process, it reduces the mixing time through high dispersion of the polymer and improves waterproofing, new to old concrete/plaster bonding and strength characteristics and reduces shrinkage and cracking of the mix.its relative density is .102± 0.01 at 25^{o}C.
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).
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) [3].
Silica fume ,also known as micro silica, is an amorphous (non-crystalline) polymorph of silicon dioxide silica It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150nm. The main field of application is as pozzolanic material to make high performance concrete. It has a specific gravity of 2.63. The recommended dosage is 7 – 10 % of the cement weight added to the concrete.
Fly Ash Class (F) (produced from bituminous coal) provided by SIKA. Power station, conforming to ASTM specification C618. . It has a specific gravity of 2.2 and specific surface area 8m/gm.
Rubber is classified as crumb rubber with 2 mm size and it used as areplcement of sand . The grading of rubber is illustrated shown in Fig(2)

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Reinforcing Steel

A) Reinforcing Steel Bar

Normal mild steel bars steel bars with (3mm) diameter were used in reinforcing the ferrocement plates.
b)Welded Mesh was used as reinforcement with rodes for ferrocement plates ..Technical specifications and mechanical properties as provided by producing

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company are given in Table (2). The stress–strain relationship for the welded wire mesh shown in Fig(3) .
c) Expanded Mesh was used as reinforcement with rodes for ferrocement plates . Technical specifications and mechanical properties as provided by producing company are given in Table (3). The stress–strain relationship for expanded steel mesh shown in Fig (4).
d) Tensar Mesh was used as reinforcement with rodes for ferrocement plates . Technical specifications and mechanical properties as provided by producing company are given in Table (4). The stress–strain relationship for tensar mesh shown in Fig (5).

Table(1). Physical,Mechanical **Properties of Polypropylene Fibers 300-e[3]**

Particules	Value
Absorption	Nil
Specific Gravity	0.91
Electrical Conductivity	Low
Thermal Conductivity	Low
E-Modulus	3.5 GPa
Melt Point	162°C (324°F)
Ignition Point	593°C (1100°F)

Table (2) .Technical specifications , mechanical **properties of Welded mesh.**

Particules	Value
Dimensions	12.5*12.5 mm
Weight	430 gm/m2
Proof stress	400 n/mm2
Ultimate strength (n/mm2)	600
Ultimate strain $*10^{-3}$	58.8
Proof strain $*10^{-3}$	1.17

Table (3) .Technical specifications , mechanical **properties of expanded mesh .**

Particules	Value
Weight	1.3 kg /m^2
Size	16*31 mm
Dimensions of strand	1.25*1.5 mm
Proof stress (n/mm2)	199

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Proof strain *10-3	9.7
Ultimate strength (n/mm2)	320
Ultimate strain *10-^{3}	59.2

Table (4) .Technical specifications , mechanical **properties of tensar mesh.**

Particules	**Value**
Minimum Rib Thickness (mm)^{2}	1
Ultimate Tensile Strength (kN/m)^{3}	21.9
Tensile Modulus (kN/m)^{3}	321
Flexural Stiffness (mg-cm)^{5}	600.000
Aperture (mm)^{2}	46 x 51

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Fig (1) .The shape of fibers e-300 rubber

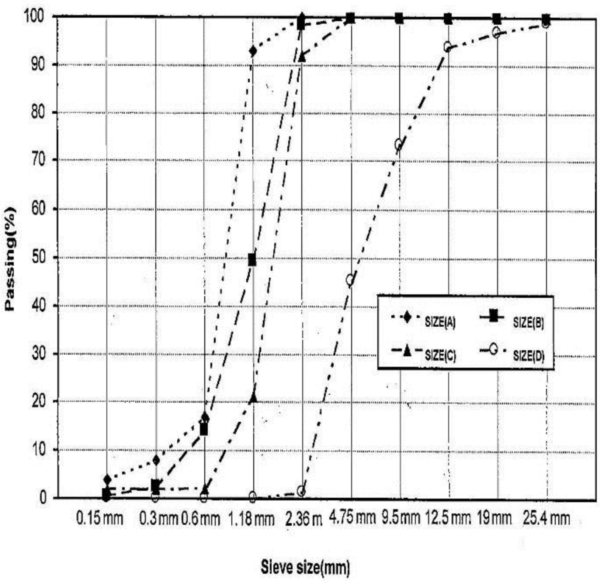

Fig. (2). Grading of used

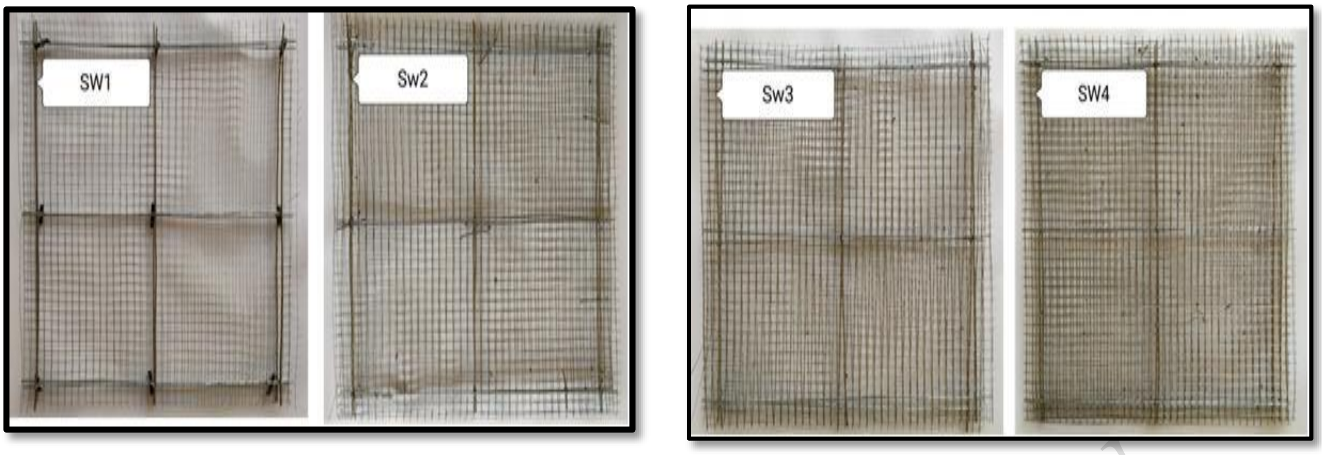

Fig (3) .The welded mesh

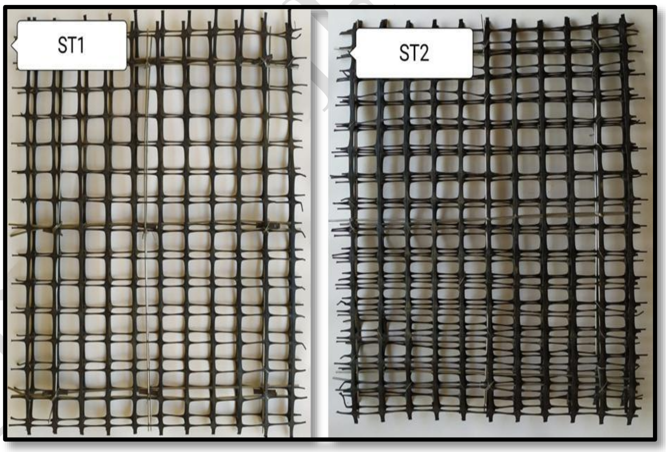

Fig (4) .The expanded mesh

Fig. (5).The tensar mesh

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4.EXPERIMENTAL PROGRAME

The mix propotions by weight were (2:1)for fine aggregate: cement , and the water – cement ratio was (0.35). superplastiizer was used with all mixes as 2.0% of weight of cement ,also flyash was used 10% , silica fume was used 5% in all .The mix properties for mortar mix were chosen based on the (ACIcommittle 549) [1]. For all mixes, mechanical mixer in the laboratory used in all mixes , materials were first dry mixed , the mix water was added and remixed again in the mixer.the mechanical compaction was applied for all specimens . The concrete mortar used for casting plates was designed to get an ultimate compressive strength at 28-days age of 350 kg/cm^2 as shown in Table (5).

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Table (5) . Constituents of mortar used

Groups	Mix ID	Rubber volume %	Fibers (gm)	W/C	Cement	Sand (k.g.)	water (k.g.)	Silica fume	Flyash	S.P.
Group (1)	SC0	0%	0	35%	4	8	1.4	5%	10%	2%
	SC1	10%	0	35%	4	7.66	1.4	5%	10%	2%
	SC2	10%	8	35%	4	7.66	1.4	5%	10%	2%
Group (2)	SW1	10%	8	35%	4	7.66	1.4	5%	10%	2%
	SW2	10%	8	35%	4	7.66	1.4	5%	10%	2%
	SW3	10%	8	35%	4	7.66	1.4	5%	10%	2%
	SW4	10%	8	35%	4	7.66	1.4	5%	10%	2%
Group (3)	SX1	10%	8	35%	4	7.66	1.4	5%	10%	2%
	SX2	10%	8	35%	4	7.66	1.4	5%	10%	2%
Group (4)	ST1	10%	8	35%	4	7.66	1.4	5%	10%	2%
	ST2	10%	8	35%	4	7.66	1.4	5%	10%	2%

5.PREPARATION AND CASTING OF TEST SPECIMENS

The aim of this researsh is to use rubber cement mortar for the preparation of ferrocement to evaluate their impact load behavioursand its cracks .The thickness of the slabs were kept constant, instead the number of mesh layers and their combinations were varied in order to get higher energy as shown in Table (6) and Fig (6). Special wooden mold with dimensions (500*500*25 mm)was used for casting .The forms of plates were coated with thin film of oil layer before casting**.** materials should be weighted accurately. In order to obtain a uniform mortar mix, mixing was performed using a mixer with high efficiency by feeding the materials in the proper order and mixing them for a proper period .The materials was added while the mixer was still rotating, and after 2 minutes add water and additional gradually. The mixer is still rotate after adding water for 5 minutes to insure the full mixing. The bottom skin ferrocement layer which has the dimension 15 mm of the plate ,Then put the reinforcement , Finally the mortar was placed in the forms for casting the top skin ferrocement layer of composite plate and compacted by using the vibrating table to ensure full compaction as shown in Fig (7) .

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-Impact Test

The sketch of the arrangement of Impact Test set up is shown in Fig(8).The impact test was carried out as follows; a 3kg steel ball was released from a height of 1200mm (1.2m) to the centre surface of the plate (specimen). This process was repeated until failure of the plate. The total number of bows (impact) which caused the appearance of the first visible crack(s) and failure of the plate were noted. This procedure was repeated for all the rest of the plates. Also loss of weight calculated for every plates.

The energy absorption can be obtained by using the following formula :

E= N x (w x h),

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Where

E= energy in joules w= weight in Newton

h= drop height in meter N= blows in numbers

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Table (6) .The experimental program of all series of the composite plates.

No. Groups	Slab ID	Type of mesh	No. of layers	Reinforcement
Group.1	SC0	none	none	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SC1	none	none	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SC2	none	none	Steel Bars 3 Ø 3 Top and Bottom in two direction
Group.2	SW1	welded	One layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SW2	welded	Two layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SW3	welded	Three layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SW4	welded	four layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
Group.3	SX1	expanded	One layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
	SX2	expanded	Two layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
Group.4	ST1	tensar	One layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction
	ST2	tensar	Two layers at both top and bottom	Steel Bars 3 Ø 3 Top and Bottom in two direction

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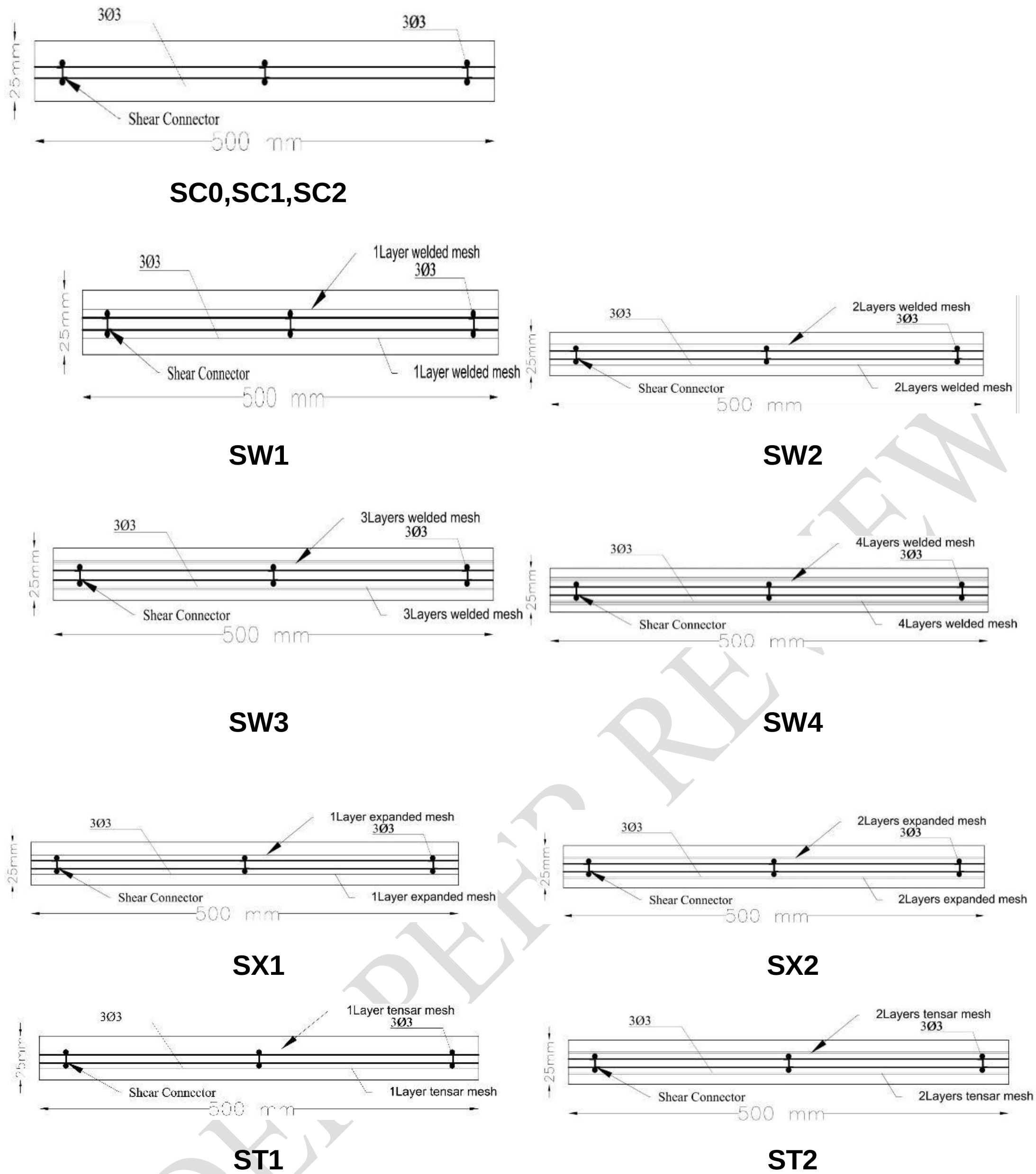

Fig .6. Reinforcement Configurations of All Plates

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a. shows casting of the bottom skin ferrocement layer

b. shows fixing the reinforcement

c. shows casting of the top skin ferrocement layer.

d. shows leveling the mortar surface

e.plates after curing

Fig .7 . Preparation and Casting plates

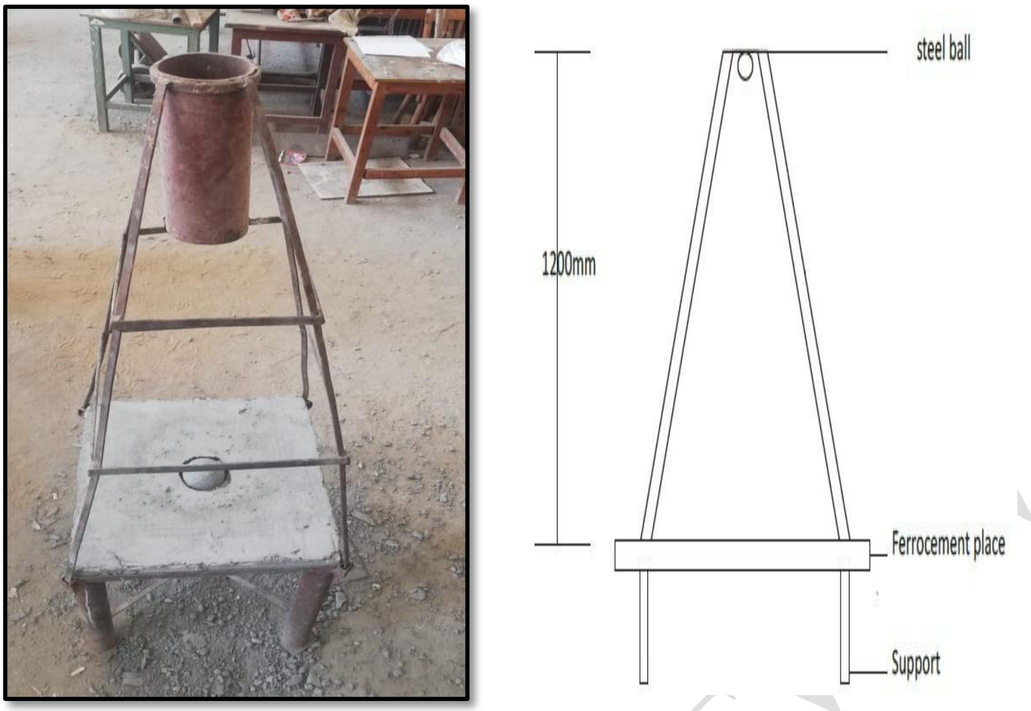

Fig .8 . impact test.

6.RESULTS AND DISCUSSION

Number of drops for 1st crack and failure , Impact energy and loss of weight shows Table(7) and in Fig (9)to Fig (11) , also Crack pattern shows in Fig (12)to Fig (15).

-First crack of plates contained rubber and polyproplene fiber was greater than the plates wasnot contained rubber and polyproplene by about (1.5%).Ultimate crack of plates contained rubber and polyproplene fiber was greater than the plates wasnot contained rubber and polyproplene by about (2.1%) . First crack of plates increasing the number of layers of welded mesh than the control plate SC2 the first crack blow increased by (1.3,2.6,4 and 5.4%) for plates (SW1, SW2 ,SW3 and SW4) respectively . At failure increased by (2.3,2.8,3.7 and 3.3%) for plates (SW1, SW2 ,SW3 and S) respectively.
First crack of plates increasing the number of layers of expanded mesh control plate SC2 the first crack blow increased by (3.5 and 7 %) for plates (SX2) respectively . At failure increased by (2.2, 2.4%) for plates (SX1 a respectively.First crack of plates increasing the number of layers of tensar r the control plate SC2 the first crack blow increased by (1.7 and 5 %) for plat and ST2) respectively . At failure increased by (3.4, 4.7%) for plates (ST1 ar respectively

-For Group (1)_increasing different ratio from rubber and fiberin plates reinforced with steel bars only energy improved the impact resistance by increasing rubber about (1.7%) and increasing rubber and fiber about (2.1 %).For Group (2) increasing the number of welded layer meshes than control plates SC2 improved by (2.3,2.8,3.7 and 3.3%) for plates (SW1, SW2 ,SW3 and SW4) respectively . For Group (3) increasing the number of expanded layer meshes than control plates SC2 improved by (2.2 and 4.4%) for plates (SX1and SX2) respectively . For group (4) increasing the number of

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tensar layer meshes than control plates SC2 improved by (3.4 and 4.7%) for plates (ST1 and ST2) respectively .

-For Group (1), It is shown that the loss of weight of plates decreased by increasing rubber about (1.5%) and increasing rubber and fiber about (2.3 %).For Group (2) increasing the number of welded layer meshes than control plates SC2 decresaed by (1.4,0.94and 3.1 %) for plates (SW1, SW2 and SW3) respectively , and increased by (0.38%) for plate (SW4).For Group (3) Increasing the number of expanded layer meshes than control plates SC2 decreased by (1.7 for plate (SX1) and increased by (0.47%)for (SX2) .For group (4) increasing the number of tensar layer meshes than control plates SC2 improved   by (0.9 and 0.47 %) for plates (ST1 and ST2) respectively .

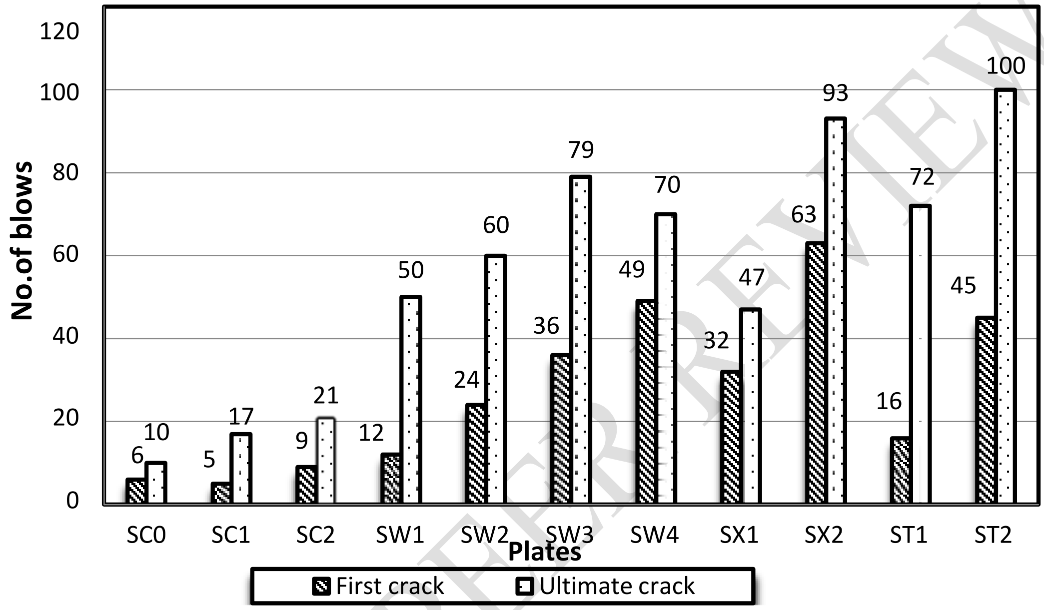

Fig .9.Comparison of first crack and ultimate crack for all plates .

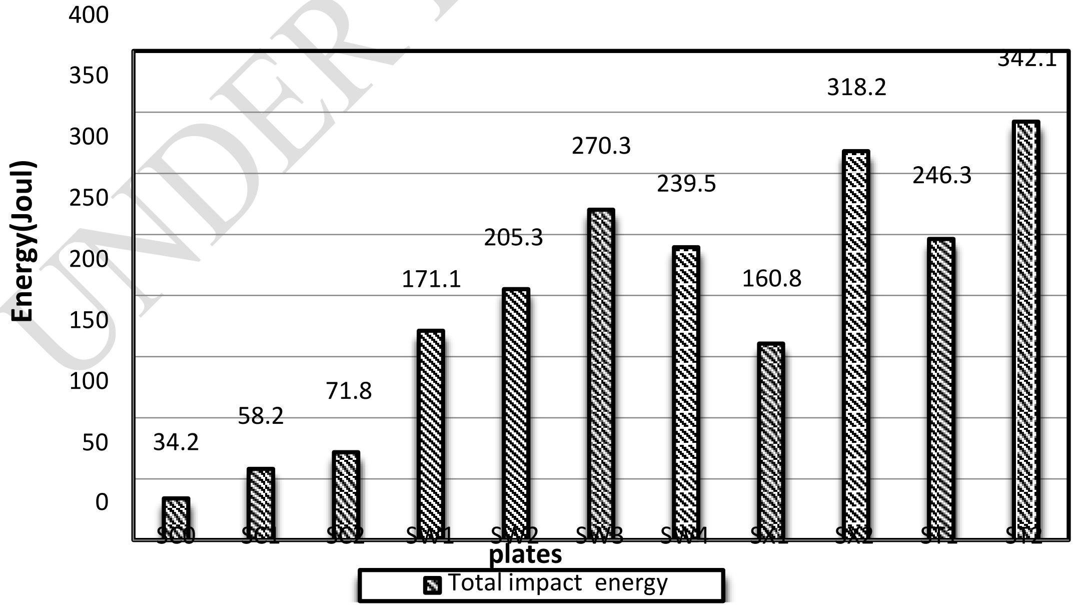

Fig .10. Comparison of impact energy for all plates .

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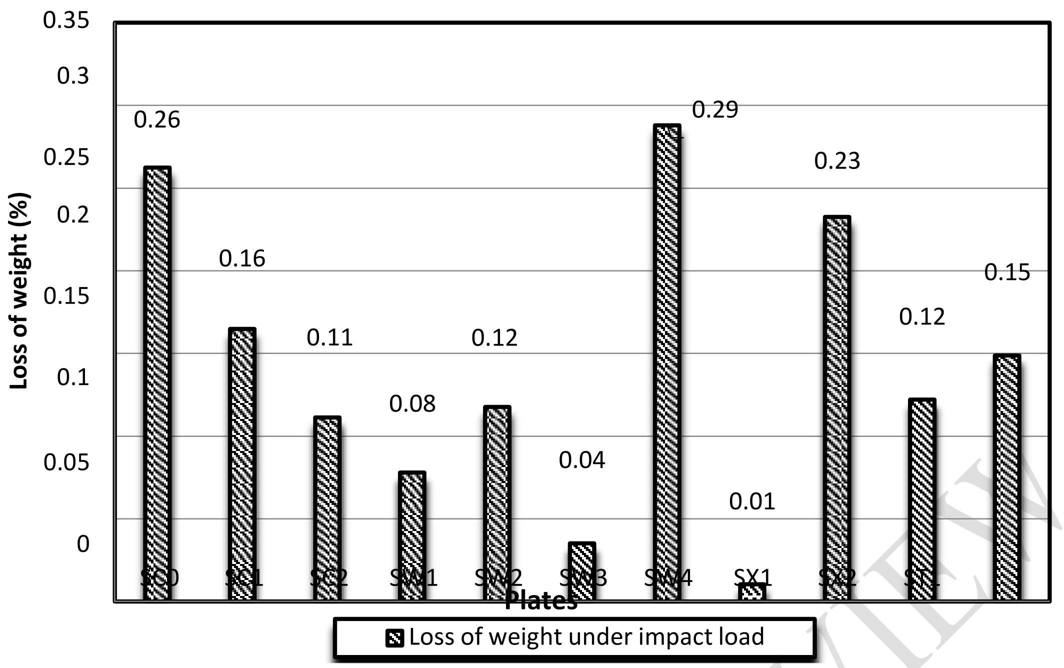

Fig .11.Comparison of loss of weight for all plates .

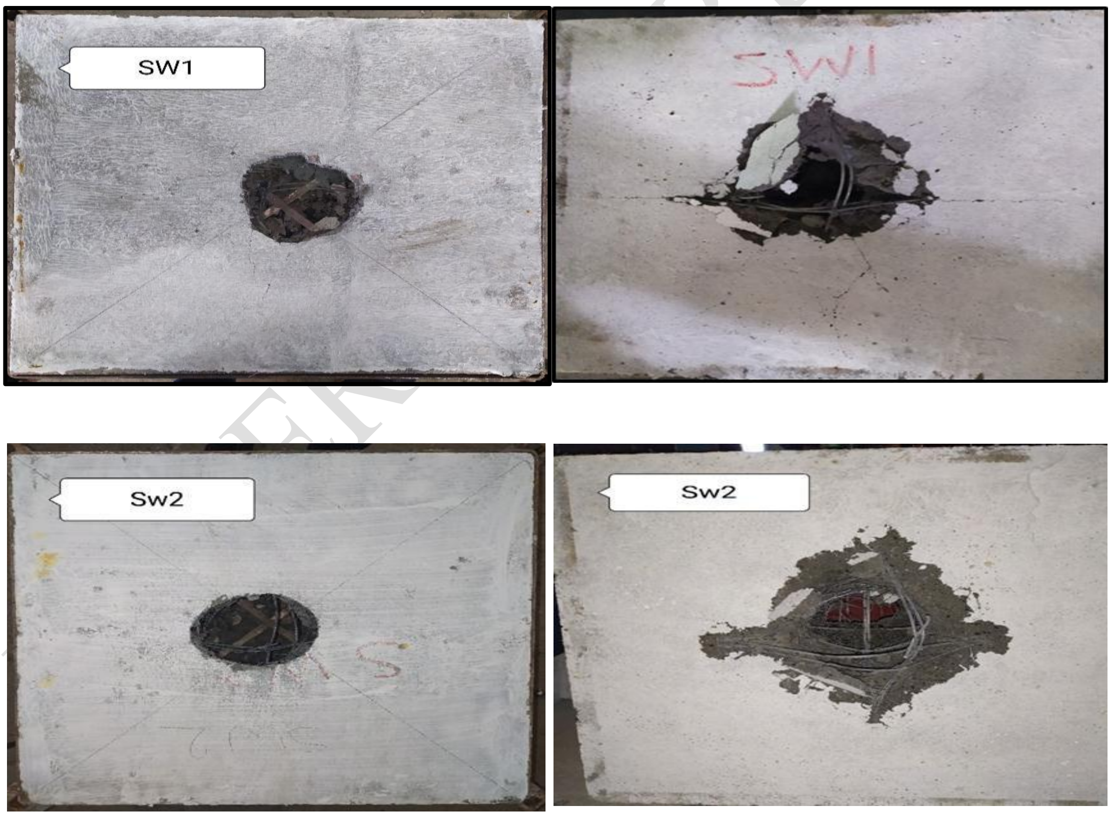

Fig 12. Crack pattern

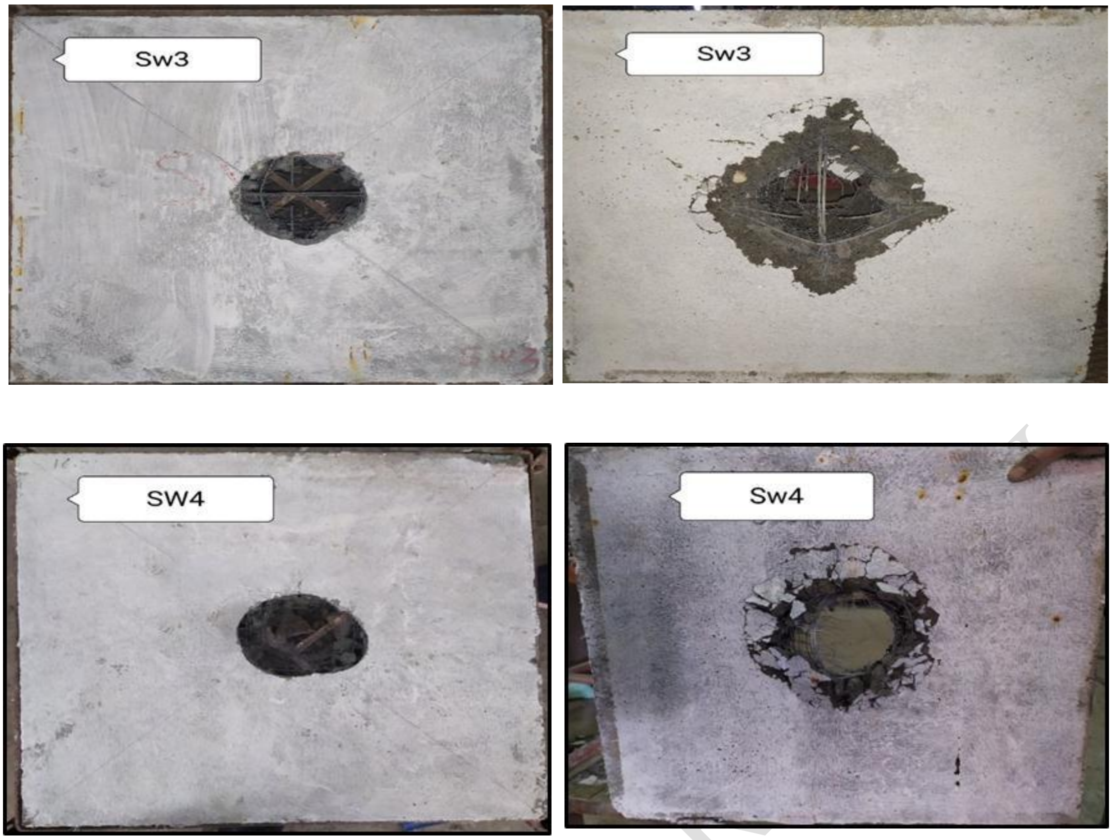

Fig (13):Crack pattern for Group (2) .

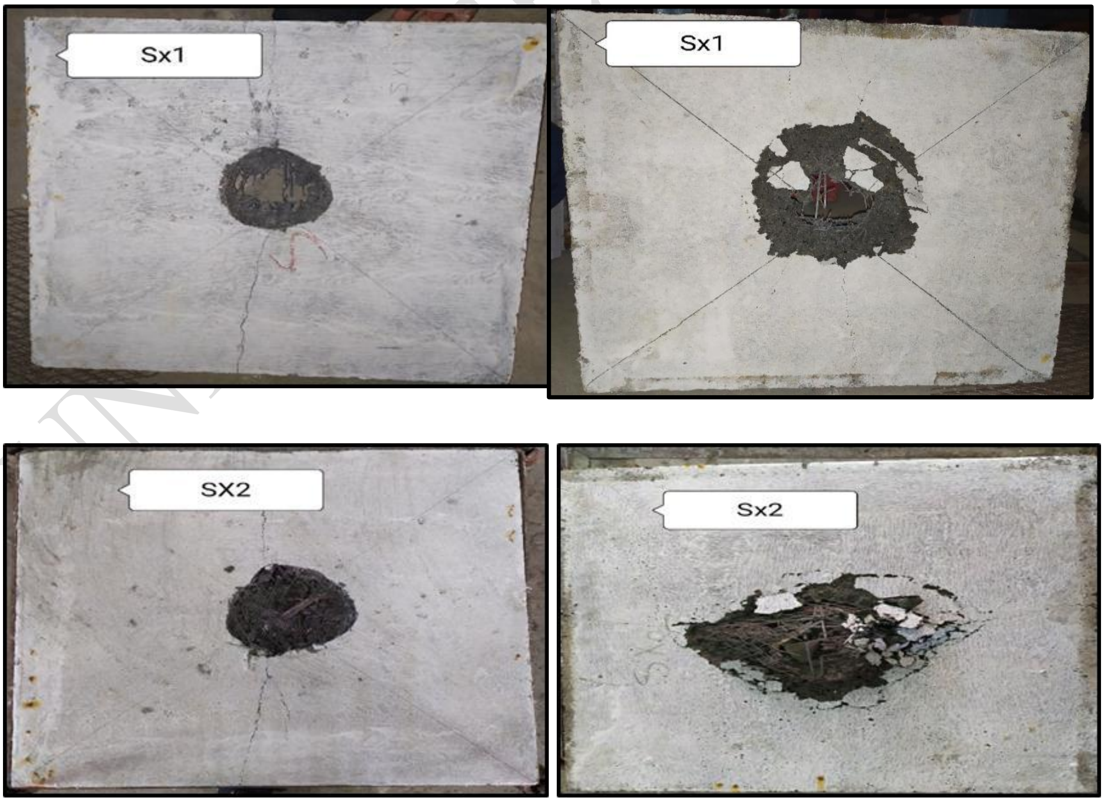

Fig .14.Crack pattern for Group (3) .

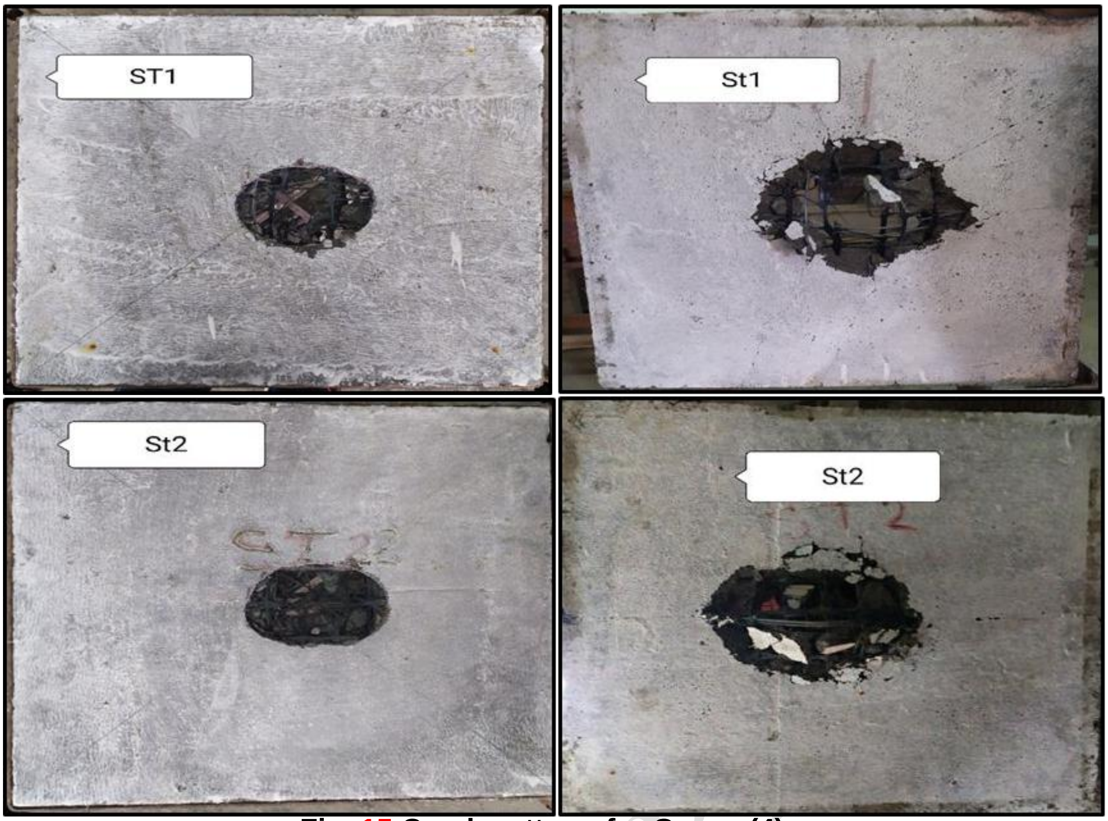

Fig .15.Crack pattern for Group (4)

7.CONCLUSIONS:

The following conclusions are derived based on the conducted experiments:

1. The existence of the ibers and rubber in the mortar mix resulted in an increase in the first crack load, ultimate load, and impact energy absorption.

2. Irrespective of the type of reinforcement, increasing the numberof meshes enhanced appreciably the cracking performance of theplates.

3.Employing more than one layer of welded metal mesh in reinforcing ferrocement plates, improve the energy absorption than those obtained using skeletal steel bars only.

4. Using two layer of tensar 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.

5. Adding rubber to mortar mix decreased the loss of weight of plates .

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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