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Structural Behavior of Ferrocement Concrete Plates Subjected to Flexural and Dynamic Loadings

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Ferrocement is one of the structural materials, widely used due to its advantages from its particular behavior such as mechanical properties, and impact strength. This paper deals with the impact studies and energy absorption properties of ferrocement slabs. For these studies, 11 different ferrocement slabs of size 50 mm X 500 mm X 25 mm were cast 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 1.20 m in the center of plates. The ferrocement plates were divided into 4 groups reinforced 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.

Keywords: Ferrocement; rubber; reinforcing metal mesh; impact.

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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]. Ferrocement behaves as a composite because the properties of its brittle mortar matrix are improved due to the presence of ductile wire mesh reinforcement. Its closer spacing of wire meshes (distribution) in the rich cement sand mortar and the smaller spacing of wires in the mesh (subdivision) impart ductility and better crack arrest mechanism to the material. Due to its small thickness, the self weight of ferrocement elements per unit area is quite small as compared to reinforced concrete elements. The thickness of ferrocement elements normally ranges from 10mm to 40mm where as in reinforced concrete elements the minimum thickness used for shell or plate element is around 75 mm [2].It is a highly versatile material with a wide range of engineering properties including flexural strength, toughness, fatigue resistance, impact resistance, and crack resistance. It is suitable for precast structural components such as walls, floors, roofs, beams, slabs, water and soil retaining structures, as well as repair work [3]. The advantages of a well builtferro concrete construction are the low weight, maintenance costs and long lifetime in comparison with purely steel constructions [4].

The goal of this research is to study the impact behavior of ferrocement plates s by varying the reinforcing mesh (layers and types)and different percentage of rubber.

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) [5]. 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 [6].

3. THE MATERIALS USED

The fine aggregate used in the experimental program was of natural siliceous sand. Its characteristics satisfy the (E.C.P. 203/2007) [5], It was clean and nearly free from impurities with a specific gravity 2.64 t/m3 and a modulus of fineness 2.61.

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) [5].

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) [7].

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) [8]. The amount of HRWR was 2.0 % of the cement weight.Also used MasterEmaco (SBR 2) in rehabitation 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.

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 [9]. It has a specific gravity of 2.2 and specific surface area 8 m/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.

3.1 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 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.

4. EXPERIMENTAL PROGRAME

The mix proportions by weight were (2:1)for fine aggregate: cement , and the water -cement ratio was (0.35). superplasticizer was used with all mixes as 2.0% of the 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, amechanical mixer in the laboratory was 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.

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
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

5. PREPARATION AND CASTING OF TEST SPECIMENS

This research aims to use rubber cement mortar for the preparation of ferrocement to evaluate their impact load behaviors and its cracks. The thickness of the slabs was kept constant, instead, the number of mesh layers and their combinations were varied to get higher energy as shown in Table 6 and Fig. 6. A special wooden mold with dimensions (500*500*25 mm) was used for casting. The forms of plates were coated with a thin film of oil layer before casting. Materials should be weighed accurately.

Fig. 1. The shape of fibers e-300

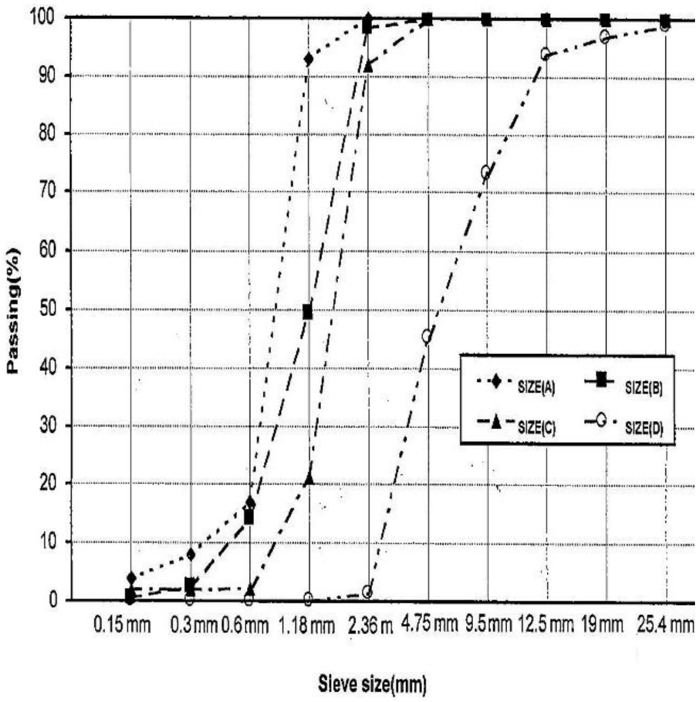


Fig. 2. Grading of used rubber

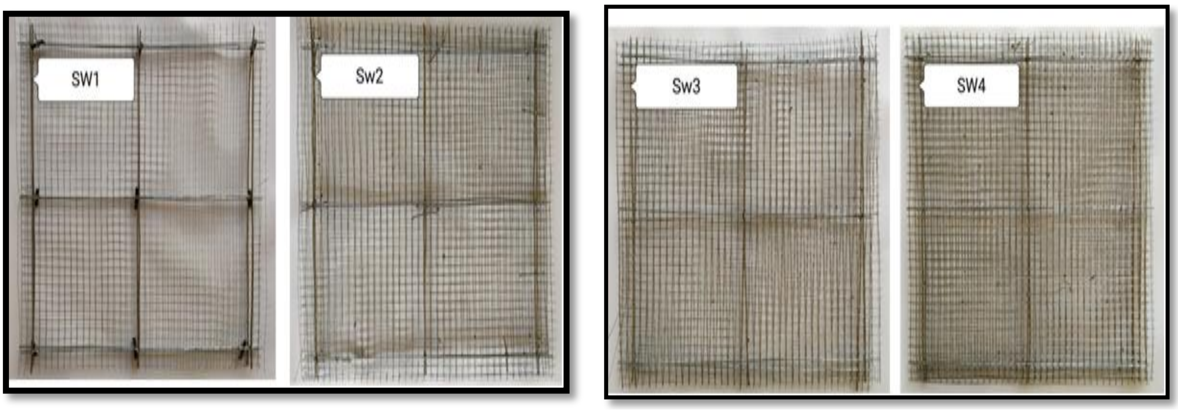


Fig. 3. The welded mesh

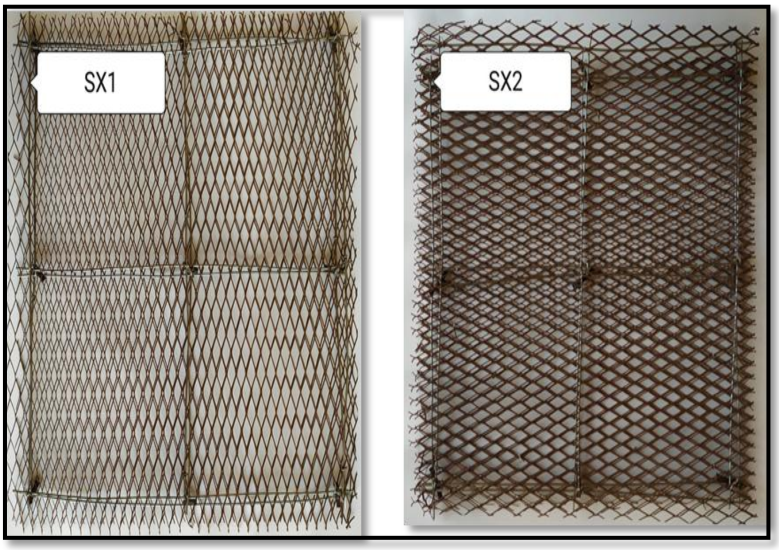


Fig. 4. The expanded mesh

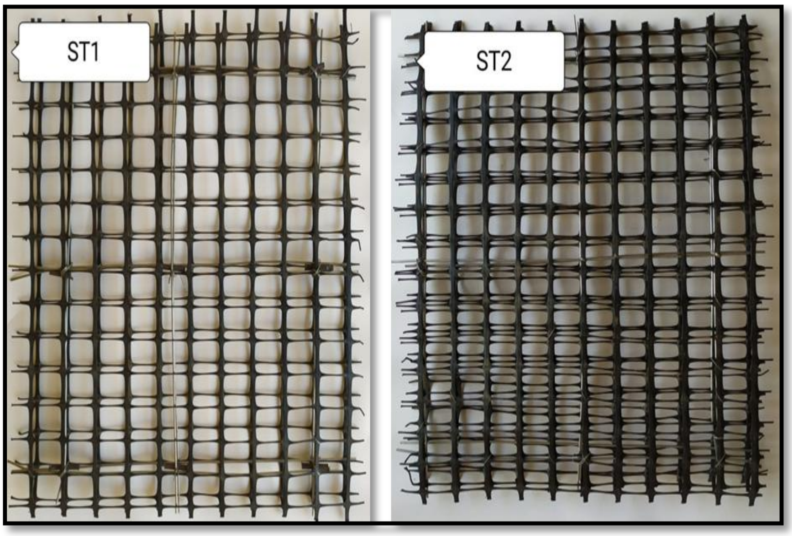


Fig. 5. The tensar mesh

Table 5. Constituents of mortar used

Groups	Mix ID	Rubber volume %	Fibers (gm)	W/C	Ceme nt	Sand (k.g.)	water (k.g.)	Silica fume	Flyas h	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%

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 were added while the mixer was still rotating, and after 2 minutes add water and add gradually. The mixer is still rotating after adding water for 5 minutes to ensure 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 the composite plate and compacted by using the vibrating table to ensure full compaction as shown in Fig. 7.

5.1 Impact Test

The sketch of the arrangement of the Impact Test set up is shown in Fig. 8. The impact test was carried out as follows; a 3 kg steel ball was released from a height of 1200 mm (1.2 m) to the center surface of the plate (specimen). This process was repeated until the 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 was noted. This procedure was repeated for all the rest of the plates. Also, loss of weight was calculated for every plate.

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

E= N x (w x h), [6]

Where

E= energy in joules w= weight in Newton
h= drop height in meter N= blows in numbers

5.2 Mortar Compressive Strength

This test is considered as the most popular test performed on concrete in construction as it gives a general idea on the all the characteristics of concrete. Based on this test, one can either accept or reject a concrete work. Eash set of mixes contained the same materials expect the ratio of rubber and fiber.

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	Steel Bars 3 Ø 3 Top and Bottom in two direction

No. Groups	Slab ID	Type of mesh	No. of layers	Reinforcement
			bottom	
	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

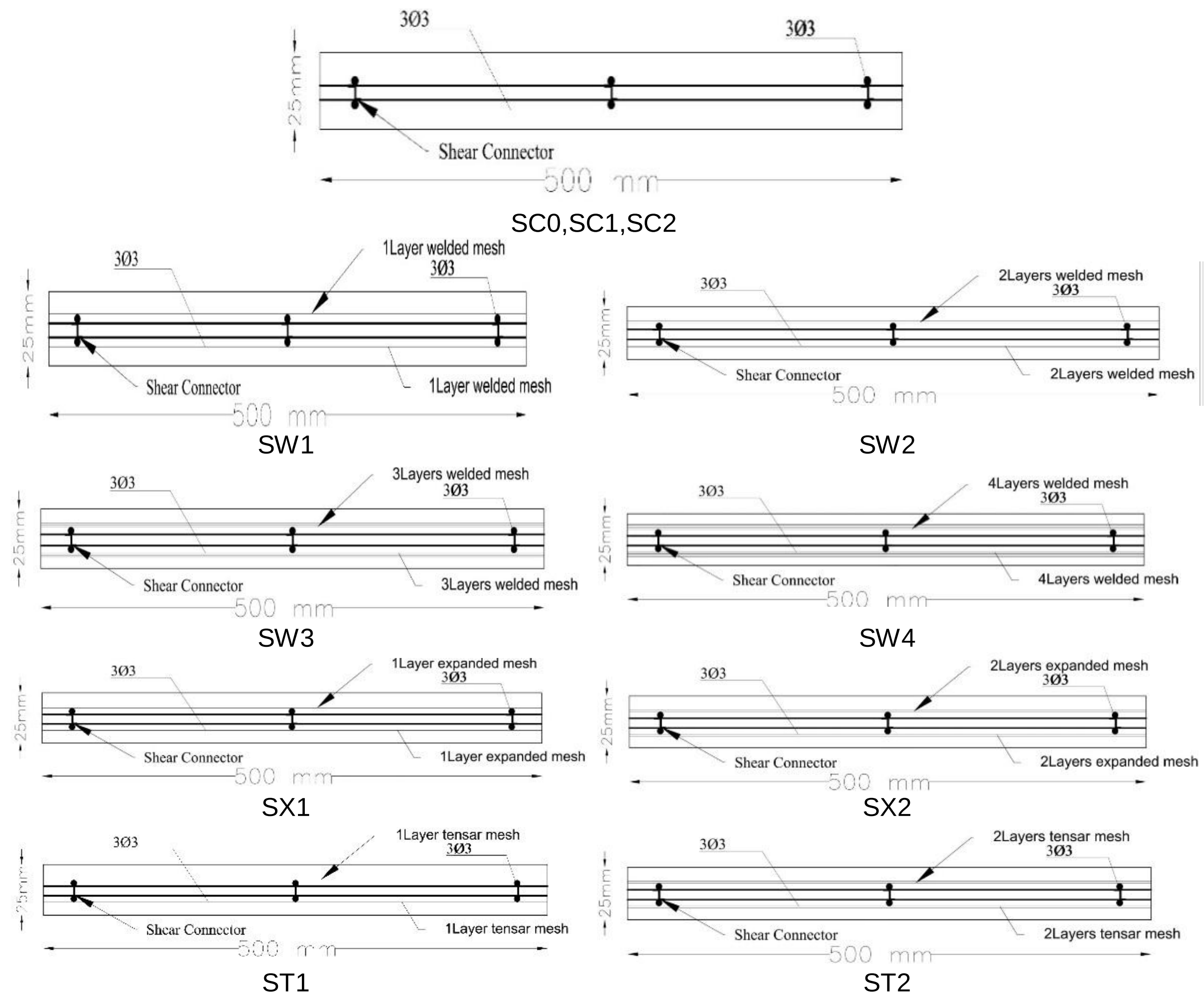


Fig. 6. Reinforcement Configurations of All Plates

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

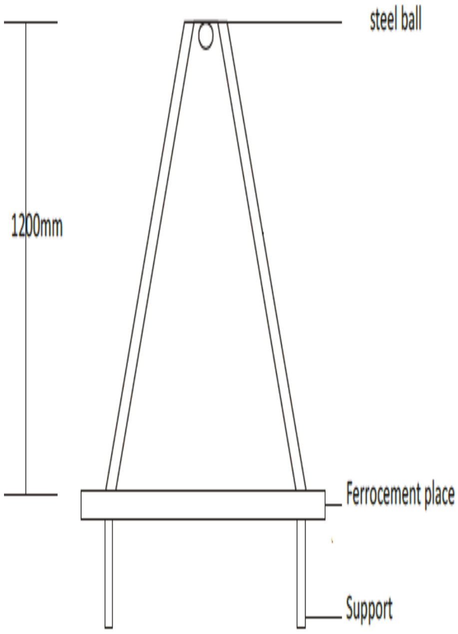


Fig. 8. Impact test

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 SW4) respectively.

-First crack of plates increasing the number of layers of expanded mesh than the control plate SC2 the first crack blow increased by (3.5 and 7%) for plates (SX1 and SX2) respectively. At failure increased by (2.2, 2.4%) for plates (SX1 and SX2) respectively.First crack of plates increasing the number of layers of tensar mesh than the control plate SC2 the first crack blow increased by (1.7 and 5 %) for plates (ST1 and ST2) respectively . At failure increased by (3.4, 4.7%) for plates (ST1 and ST2) 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 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.

-Nine specimens were prepared to study the compressive strength is the most common limit used to characterize concrete. Compressive strength at 28 days shown in Fig. 15.

- In 2018, Itamar Ribeiro Gomes studied properties of mortars containing tire rubber waste and expanded polystyrene (eps) indicated that the mortars containing 10% rubber and 7.5% EPS showed better results, but further research should be carried out in order to study the behavior of other untested properties, such as substrate adhesion strength, deformation modulus, thermal conductivity and fire spread analysis [10].

- In 2016, FAGBOHUN I. AKINLABI studied impact energy and flexural strength charectiristics of wire-mesh and steel fibres ferrocement roof panels indicated that Higher energy absorption observed could be traced to wire-mesh in controlling the developed cracks. It is more ductile and elastic than the 8mmsteel fibers [11].

- In 2020 Tamil Selvan studied Impact Behaviour of Ferrocement Slabs with High Strength Mortor indicated that number of mesh layers and spacing between the meshrods influences the impact behaviour of slab. Closely spaced mesh rods and more number of mesh layers gives good impact behaviour [2].

- In 2013, YousryShaheen, Doha Kandil studied Influence of Reinforced Ferrocement Concrete Plates under Impact Load indicated that The percentages loss of weight for plates reinforced with steel bars 2.23 %, while it reached to 1.7% this is predominant [12].

Table 7. Summary of test results of all the tested plates

Groups	Mix ID	Loss of weight (%)	First crack	Ultimate crack	Impact energy (joul)*10^2
Group (1)	**SC0**	0.262	6	10	34.2124
	SC1	0.1648	5	17	58.161
	SC2	0.111	9	21	71.846
Group (2)	**SW1**	0.077	12	50	171.062
	SW2	0.117	24	60	205.274
	SW3	0.035	36	79	270.278
	SW4	0.287	49	70	239.487
Group (3)	**SX1**	0.0103	32	47	160.798
	SX2	0.2325	63	93	318.175
Group (4)	**ST1**	0.1220	16	72	246.329
	ST2	0.1488	45	100	342.124

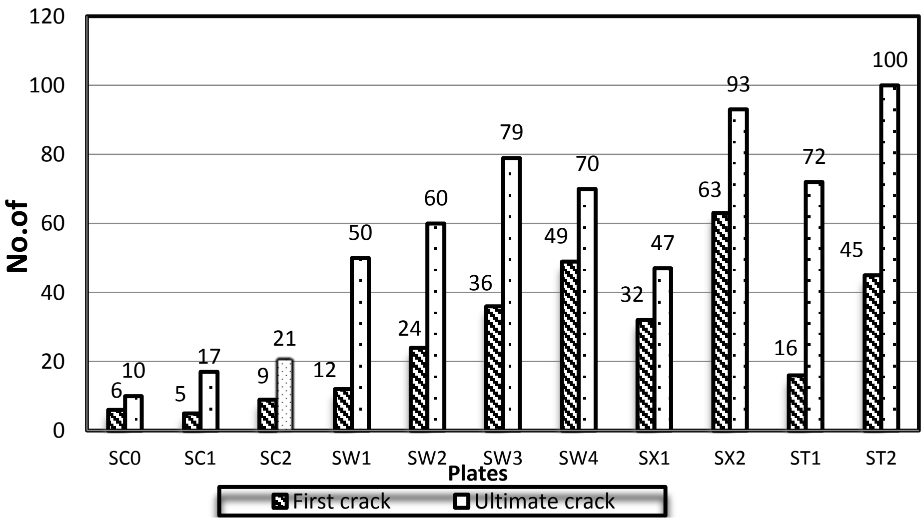


Fig. 9. Comparison of first crack and ultimate crack for all plates

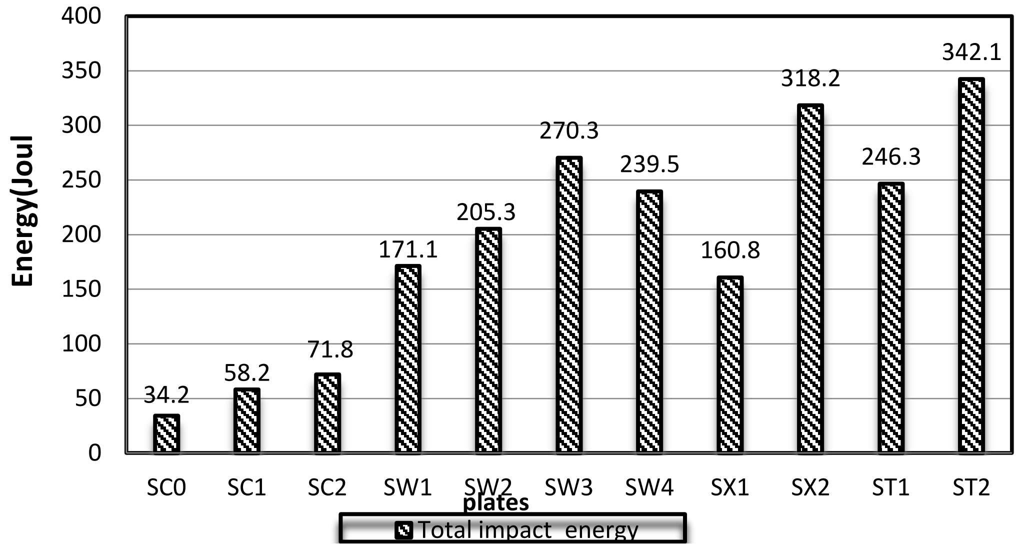


Fig. 10. Comparison of impact energy for all plates

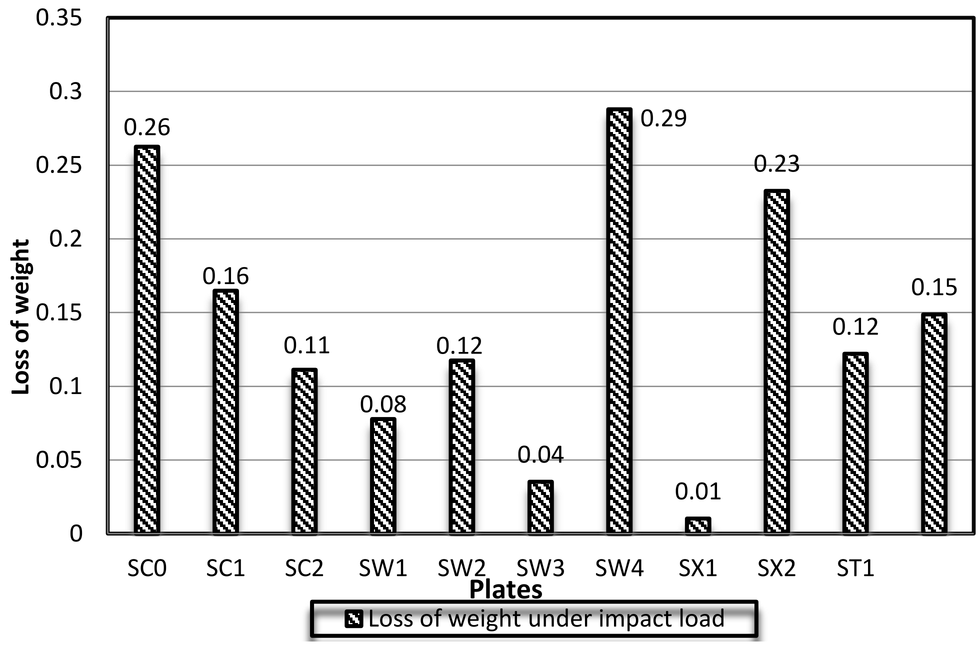


Fig. 11. Comparison of loss of weight for all plates

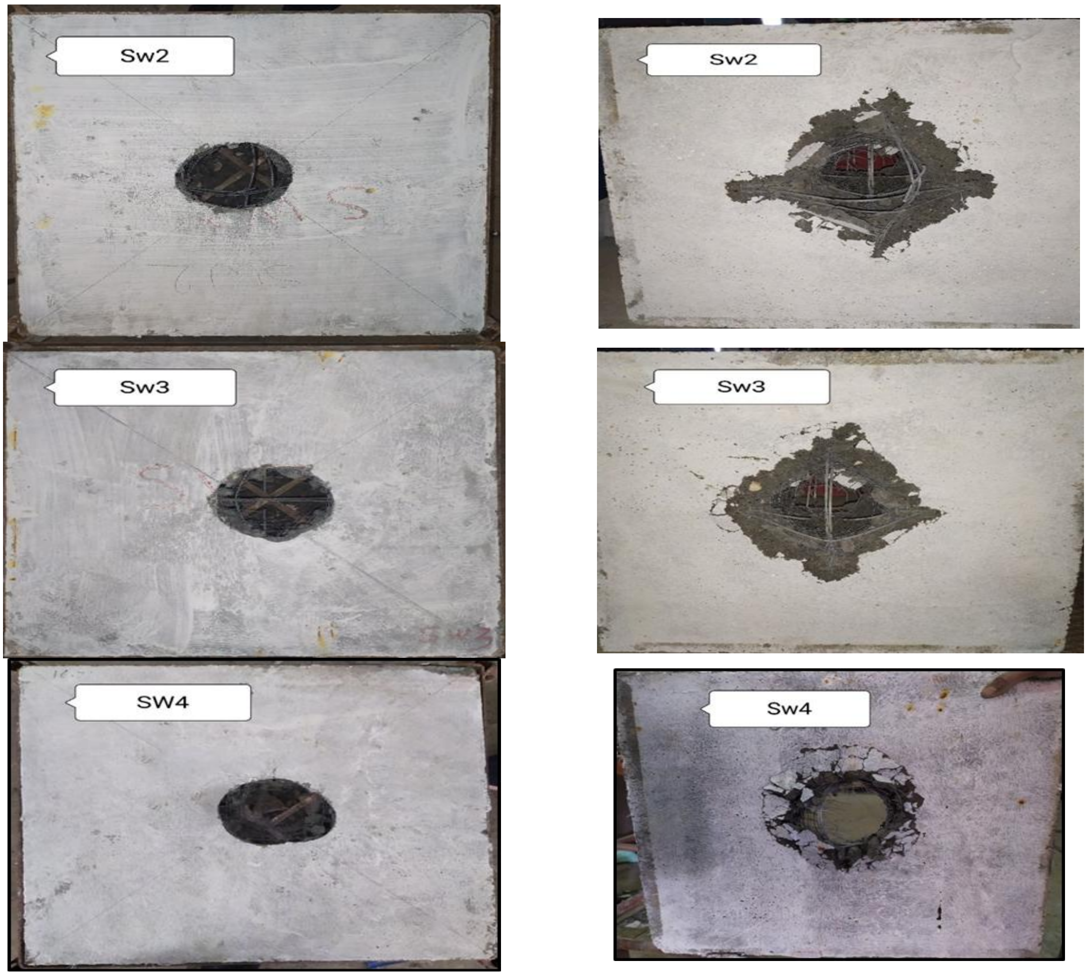
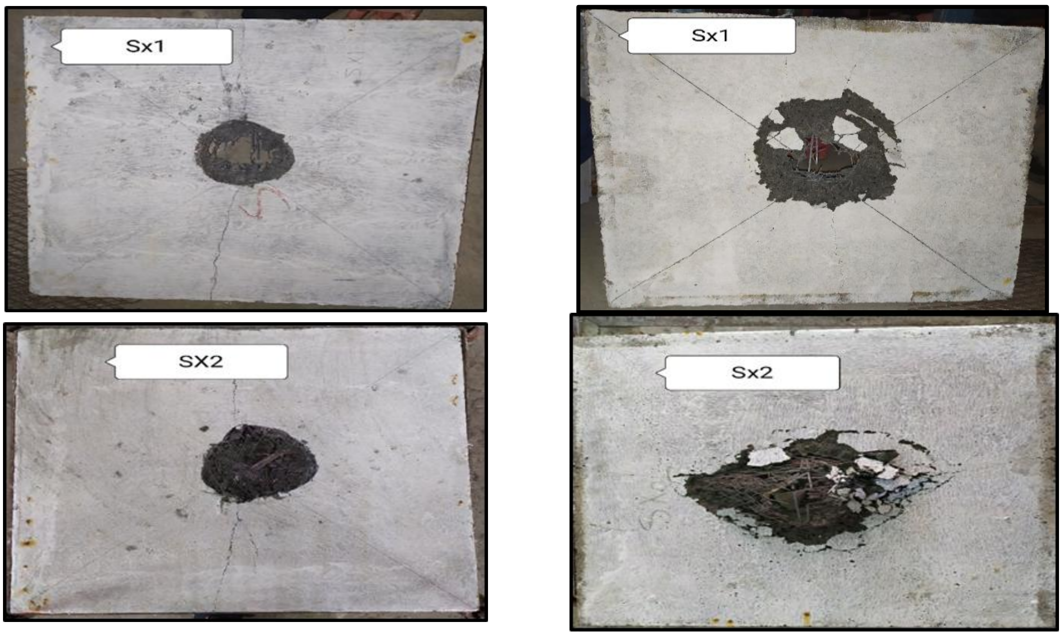


Fig. 12. Crack pattern for group 2



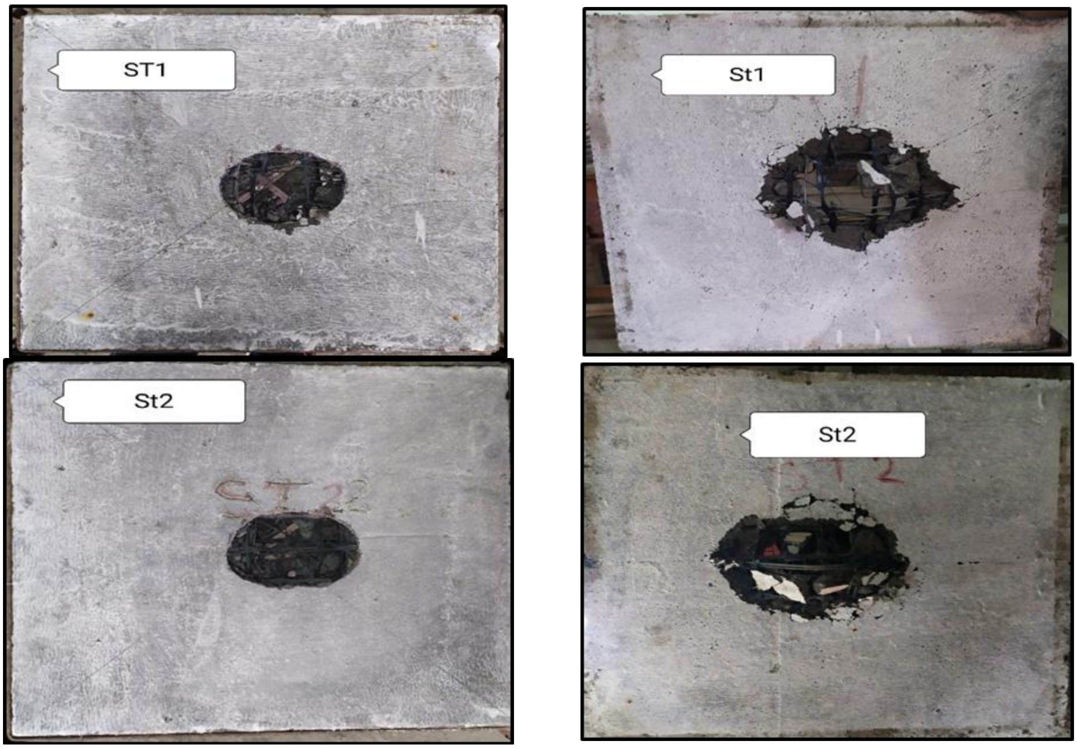


Fig. 14. Crack pattern for group 4

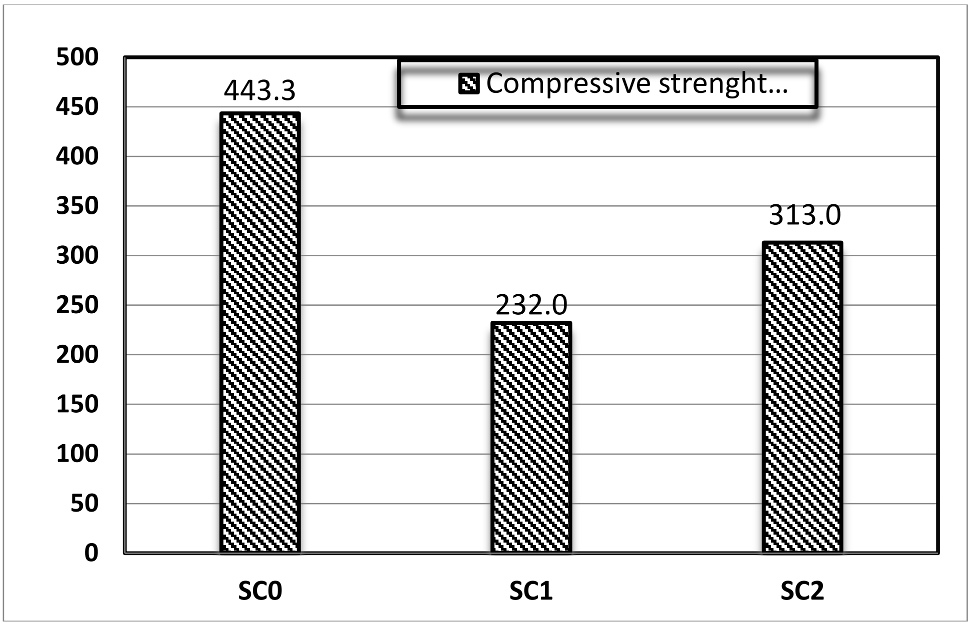


Fig. 15. Compressive strength

7. CONCLUSIONS

The following conclusions are derived based on the conducted experiments:

1. The existence of the fibers and rubber in the mortar mix resulted in an increase in the first crack, ultimatecrack , controlling crack width , and impact energy absorption.
2. Irrespective of the type of reinforcement, increasing the number of meshes enhanced appreciably the cracking performance of the plates.

3. Employing more than one layer of welded metal mesh in reinforcing ferrocement plates, improves the energy absorption than those obtained using skeletal steel bars only.
4. Using two layers 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.
6. 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.
7. Empolying Tensar mesh is effective in increasing energy absorbatic properties all durability effect in marine application .
8. The height energy absorption could by reached by empolying tensar mesh with controling of cracking which is predaminant.

The beauty of ferrocement is that it could appear in any shapes. Only imagination could limit the forms and shapes of this beautiful and cheap material. Furthermore, unskilled labour could be employed to construct its structure.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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