International Journal of Sustainable and Green Energy
2015; 4(3-1): 34-50
Published online January 13, 2015 (http://www.sciencepublishinggroup.com/j/ijrse)
doi: 10.11648/j.ijrse.s.2015040301.16

Behaviour of ferrocement slabscontaining SBR under impact loads

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To cite this article:
Abdulkader Ismail A. Al-Hadithi, Khalil Ibrahim Aziz, Mohammed Tarrad Nawar Al-Dulaimi. Behaviour of Ferrocement SlabsContaining SBR Under Impact Loads. *International Journal of Sustainable and Green Energy*. Vol. 4, No. 3-1, 2015, pp. 34-50.
doi: 10.11648/j.ijrse.s.2015040301.16

Abstract: The main aim of this work is to investigate the behavior of Ferrocement slabs under impact loading. A total of 48 Ferrocement slabs were constructed and tested, 36 slabs tested under low velocity impact and 12 slabs tested under high velocity impact, in addition,the main parameter considered in the present investigation was number of wire mesh layers, content of (SBR) polymer andheight of falling mass (falling velocity). For low velocity impact,This test was performed in terms of the number of blows required to cause first crack and ultimate failure. The test was applied on square slabs of dimensions (500 × 500 × 50 mm) subjected to repeated impact blows by falling mass (1300 gm) dropped from three heights (2.4 m) , (1.2 m) and (0.83 m) at 56 day age. The number of required blows for the first crack and final failure was recorded. The mode of failure and the crack pattern were also observed. For high velocity impact test, a (500×500×50 mm) slabs were tested by 7.62 mm bullets fired from a distance of (15m) with a striking velocity of (720m/sec.). The spalling, scabbing and perforation were observed and discussed. The results exhibited that the number of blows which were required to make the first crack and failure, increased with increase of polymer content and number of wire mesh layers. Also for high velocity impact test, it can be noted that the area of scabbing and area of spalling decreased with the increase of polymer content and number of wire mesh layers compared with reference mixes. The compressive strength, splitting tensile strength and flexural strength increased with increase the polymer content. Based on extensive works , found that low velocity impact resistance of polymer modified Ferrocement slabs was greater than the reference mix slabs, it was found that the number of blows that needed to produce the first crack and ultimate failure increased with increase the polymer ratio of 3% to 5% and to 10%, and with increased the number of layers of reinforcing with wire mesh when comparing these results reference mix.

Keywords: Ferro-Cement, Impact, Wire Mesh, Low Velocity Impact, Polymer Modified Concrete

1. Introduction

1.1. Ferrocement

Ferro-cement is a composite material used in building with cement, sand, water and wire mesh material. It is fireproof, earthquake safe and does not rust, rot or blow down in storms. It has a broad range of applications which include components in a building, repair of existing building. (1) Ferro-cement has a very high tensile strength and superior cracking behavior in comparison to reinforced concrete. (2)

Ferro-cement is an attractive material for construction of walls, floors, and roofs for underground structures, underground water tanks, water control devices, canal lining and retaining walls.(3)Other uses for Ferro cement are numerous: construction of boats, barges, shell and folded plate. (4)Ferro-cement composite has been widely and successfully used for the construction of different structures which include silos, tanks, folded roofing, shells and bearing walls. (5, 6, 7, 8, 9)

1.2. Impact and Impulsive Loadings

Any time-dependent force, applied to a structure can be either cyclic or represented by a continuous function such as sine-wave function, or it can be a suddenly applied force which may be called transient such as that due to bomb blast or impact loading.

The term (impulsive load) refers to the complete force-time history applied to the structure, which is likely to be independent of the properties of the structure as in the case of bomb blast loading. Impact may be defined as the process of collision of two bodies which occurs in a very short interval of time during which the two bodies exert on each other relatively large forces, called impact loads, which depend on velocity, mass, shape, elastic and plastic properties of the collided bodies.

The problem of impacts caused by natural collisions onto concrete structure has to be given proper considerations. Examples of such cases and also the related classifications are listed in Table (1) [10] below.

Impacts on concrete structures can normally be classified into two different groups, namely soft impact and hard impact:

- **Soft impact:** causes deformation to the striking body. Propagation of stress waves is negligible and the failure mechanism is quite similar to that of the static failure.
- **Hard impact:** Barely any deformation forms on the striking body. Impact velocity is high in this case, thus complicated stress waves can be expected to be the main cause of failure.

A realistic analysis of an impact loading situation is in general complex due to many non- linearity involved. Before the development of high speed computers, this analysis was performed with approximations, which closely related to a given experimental test situation. [11]

Table 1. *Type of impact* [10]

	Example of impact phenomena	Type of impact
Single impulsive blow	Vehicular collisions onto handrails of expressways or freeways.	Soft
	Ship or vehicular collisions onto bridge piers.	Soft
	Ship collision onto offshore structures or gravity platforms for oil extraction.	Soft
	Aircraft collision onto nuclear power plants.	Soft
	Cars hitting columns in multistory car parks.	Soft
	Explosions on concrete structures.	Hard
Repeated (multiple) impulsive blows	Blows from car tires across expansion joints.	Soft
	Rocks falling onto roof of protection shelters in mountainous regions.	Soft
	Blows on concrete piles during hydraulic piling.	Soft / Hard
	Ship or iceberg brushing against offshore structures or gravity platforms.	Soft
	Meteorites falling onto concrete lunar structures (in future).	Soft

1.3. Latex modified concrete (LMC)

Latex is a polymer system consisting of very small (0.05-1 μm Dia.) spherical particles of high molecular weight polymers held suspension in water by the use of surface active agents. Adding of polymer Latex to concrete can improve strength, ductility and durability. The latex is essentially a bonding agent which can be mixed integrally with the concrete and gives it superior adhesive properties. Polymer latex modification of cement mortar and concrete is governed by the cement hydration and polymer film formation processes in their binder phase.

In order to rise the tensile strength of cement mortar and concrete by the addition of epoxies, a series of experiments had been carried out by Sauer [12] whose study demonstrated that with (15%) weight polymer added to concrete, both tensile and compressive strength are appreciably increased. The following results were obtained from this study:

- With increased resin content, there is not only strength improvement but also decreased water absorption and increased toughness and energy absorbing ability.
- In the case of concrete, these strength improvements can be realized by addition of (15%) weight polymer to the concrete while, at same time, proportionately reduced the water content to maintain comparable slump. Reducing the water-cement ratio causes improvement in compressive strength.
- Strength improvement of the order of 100 % possible in both mortar and concrete specimens by adding of appropriate amounts of polymer to the mix.

An investigation was carried out by **Ohama**[13] to show the weather ability of adhesion of polymer modified mortars to ordinary mortars by exposing specimens to normal weathering conditions for 10 years. He found that the polymer adhesion characteristic increases with time.

1.3.1. Styrene Butadiene Rubber (SBR)

SBR polymer is most widely used in concrete. The proportion of SBR latex, combined with low water /cement ratio produces concrete that has improved flexural, tensile, bond strength, lower modulus of elasticity and reduced permeability characteristics compared with conventional concrete of similar mix design. Compressive strength is typically unchanged. [14]

Folice et al[15] , tested (180) concrete samples, different in size and shape. All properties of modified concrete were analyzed depending on the quantity of polymer used. The following results were obtained from the tests:

- The greater effect on physical and mechanical properties of latex modified concrete was achieved at the optimal combination of wet and dry curing, i.e., curing in dry environment.
- Compressive strength was slightly increased with the increase of polymer/cement ratio (1 to 7 percent).
- Tensile strength increased with the increase of polymer/cement.

- Ratio and the correlation is in the form of a straight line. The increase of flexural strength for concrete modified with 7.5 percent of polymer admixture was (40) percent in relation to the reference concrete.
- Water absorption decreased with the increase of polymer/cement ratio.
- Shrinkage of the modified concrete with 7.5 percent of polymer admixture on the cement mass was almost 50 percent less than the shrinkage of the reference concrete.
- Adhesion between reinforcement and concrete increases with the polymer/cement ratio increase.
- The effect of latex quantity of 7.5 percent on the cement mass has not significantly influenced the value of static and dynamic modules of elasticity.

The ACI Committee 544 [(16)] repeated drop - weight apparatus which was designed to compare the relative merits different fiber-concrete mixtures and demonstrate the improved performance fiber-concrete compared with conventional concrete. It can also be adapted to show the relative impact resistance of different material thicknesses. In the ACI test, a 4.5 Kg steel ball is dropped repeatedly through a height of 457mm onto a concrete disc, 63.5mm thick and 152mm in diameter, and the number of blows required to cause the first visible crack and ultimate failure are recorded.

Al-Hadithi[(17)]studied the improving of mechanical properties , structural behavior and impact resistance of concrete using styrene butadiene rubber SBR with different weight ratios of polymer to cement 3%,5% and 10% . Cubes, prisms and panels were made as follows: Ninety-six (100 × 100 × 100 mm) cubes for compressive strength tests, forty-eight (100 × 100 × 500 mm) prisms for flexural strength (modulus of rupture), thirty-tow (500 × 500 × 50 mm) panels for low and high velocity impact tests and eight (95 × 200 × 1600 mm) reinforced polymer modified concrete beams for structural behavior tests.

Results showed an improvement in all properties of polymer modified concrete over reference concrete and in particular in low-velocity and high-velocity impact properties. In compressive strength, the increase was (7.14%-28.79%) for PH10 (PH: Polymer Modified Concrete with Higher Compressive Strength) and polymer modified concrete mixes. In flexural strength the maximum increase was (26.64%) for PH10 mix. In conducting low-velocity impact tests, method of repeated falling mass was used (1300 gm) steel ball falling freely from three heights 2400mm, 1200mm and 830mm. In high-velocity impact tests, shooting of 7.62mm bullets was applied to slab specimens from distance of 15m. The improvements were significant in low-velocity impact resistance. The maximum increases were (33.33%, 75% and 83.33%) at ultimate failure for falling mass heights 2400mm, 1200mm and 830mm respectively. In high-velocity impact strength tests, maximum reductions recorded in spalling area were (18.5% and 27%) for polymer modified concrete with moderate compressive strength and polymer modified concrete with higher compressive strength. A maximum reduction recorded in scabbing area was (11.42% and 35.6%) for polymer modified concrete with moderate compressive strength and polymer modified concrete with higher compressive strength, respectively. The polymer modified concrete beams have a stiffer response in terms of structural behavior more ductility and lower cracking deflection than those made reference concrete.

2. Experimental Program

The brittle nature of concrete is an inherent property of material and one that is overcome by the use of reinforcing materials. The high porosity of concrete is also a disadvantage, especially in severe service conditions. Several approaches have been taken to improve concrete properties, resulting in quite different materials. One of them is Polymer Concrete. Generally, the properties of the polymer concrete materials are high in strength, good in cohesiveness, excellent in durability and resistance to water, acid and alkalis and so on. These materials can be used to mend the damaged concrete structures, such as highways, bridges, railroads, river and sea banks as well as many kinds of cement concrete structures. Also, this material can be used in corrosive environment as corrosion resisting material.

2.1. Materials

2.1.1. Cement

The cement used through this work was Ordinary Portland Cement. The chemical analysis and physical test results of the used cement are given in Tables (2) and (3), respectively.

Table 2. *Chemical Analysis of Cement*

Compound	Percentage by weight	Limits of Iraqi Specification No.5/1999(25)
SiO_2	22.6	-
Al_2O_3	6.1	-
Fe_2O_3	3.3	-
CaO	60.6	-
MgO	2.3	≤ 5.0%
SO_3	2.7	≤ 2.5%
L.O.I	1.88	≤ 4.0%
C_3S	18.57	-
C_2S	50.79	-
C_3A	10.58	≤ 3.5%
C_4AF	10.03	-

Compound	Percentage by weight	Limits of Iraqi Specification No.5/1999(25)
I.R	2.7	≤ 1.5%
L.S.F	0.8	0.66 – 1

Table 3. *Physical analysis of cement*

Physical properties	Test result	Limits of Iraqi Specification No.5/1999(25)
Fineness by Blaine method (cm^2/gm)	4000	2300 ≥
expansion Autoclave %	0.17	≤ 0.8
Setting time	150	45≥
(Vicat apparatus)	225	600≤
Initial setting (minutes)		
Final setting (minutes)		
strength Compressive		
3 days (MPa)	22.8	15≥
7 days (MPa)	25	23≥

2.1.2. Fine Aggregate

Natural yellow sand passing through 2.36mm (B.S. Sieve No.7) and conforming to the B.S 882-1992 grading requirements (zone-2) was used in production of concrete specimens used in this study. Results sieve analysis of this sand shown in Table (4).

Table 4 *:Sieve analysis results of sand used*

Sieve NO.	Accumulated percentage passing %	Limits of B.S 882-1992[18]
2.36	100	75-100
1.18	62.43	50-85
0.6	35.77	25-60
0.3	29.2	10-30
0.15	2.52	2-10

2.1.3. Mixing Water

Ordinary drinking water was used for mixing and curing for all specimens.

2.1.4. Polymer

Styrene Butadiene Rubber (SBR) is used as polymer modifier in this study. Styrene Butadiene, an elastomeric polymer, is the copolymerized product of two monomers, Styrene and Butadiene. Latex is typically included in concrete in the form of a colloidal suspension polymer in water .

This polymer is usually a milky-white fluid. The typical properties of SBR polymer is shown in Table (5), other information is shown in Appendix. The polymer (SBR) was used as a ratio by weight of cement of 3%, 5% and 10%.

Table 5. *Typical properties of SBR polymer [26]*

No	Properties	Description
1	Appearance	White emulsion
2	Specific Gravity	1.02 ± 0.02 @ 25 ºC
3	pH Value	7 – 10.5
4	Freeze/Thaw Resistance	Excellent
5	Chloride Content	Nil
6	Flammability	Non-flammable
7	Compatibility	Can be used with all types of Portland cement

2.1.5. Reinforcement

Locally available woven wire mesh with an average diameter of (0.6)mm, square opening of wire mesh which used in this work with (10×10mm) area , Fig.1 shows the geometry and dimensions of the mesh used . Several Strands of wire taken from the mesh and tested under UTM of 100 KN capacity for tension to determine the average yield stress, the ultimate strength and modulus of elasticity. Table (6) gives the average value and standard deviation of the obtained results, and Fig. 2 shown the stress – strain curve for the tested wire mesh.

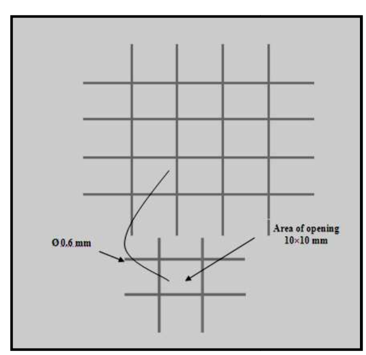

Fig. 1. *The geometry and dimensions of the mesh used*

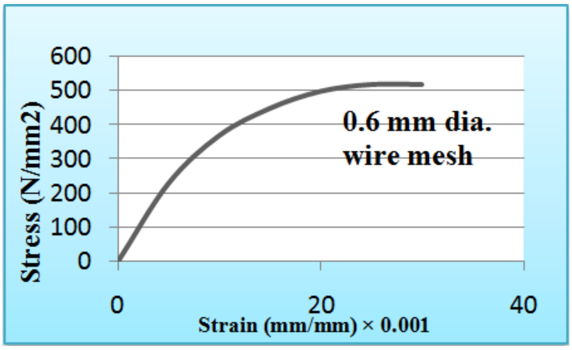

Fig. 2. *Stress - strain curve of the mesh reinforcement*

Table 6. *Yield stress, ultimate strength and modulus of elasticity of wire mesh*

Properties	Wire mesh
Yield Stress (fy), N/mm^2	300
Standard deviation	8.2
Ultimate Strength (Fu), N/mm^2	520
Standard deviation	18.6
Modulus of Elasticity (Es), N/mm^2	67000
Standard deviation	126

2.1.6. Slab Specimens

For low and high velocity impact strength, square slabs of (500 × 500 × 50) mm were used respectively.

2.2. Theexperimental Program

The experimental program was planned to investigate the effect of using polymer on the mechanical properties and impact resistance of Ferro-cement. The test variables include compressive strength, splitting tensile strength, flexural strength and Ferro-cement slabs for low and high impact tests. Table (6) shows the details of reference concrete and concrete with polymer.

2.2.1. Preparation of Mortar Specimens

Four groups of mixes were used in this research. All proportions were (1:2) cement: sand.

2.2.2. Mix Preparation

A mechanical mixer of the capacity (0.1) m^3 operated by electrical power was used, the fine aggregate and cement were added before adding polymer and dry mixing were continued until the dry mix became homogenous, then the polymer was added until all particles are fully coated with polymer and finally water were added and mixing continues until uniform mix is obtained, this procedure is similar to the method used by Ohama . [19]

***Table** 7. Details of the cement mortar mixes investigation throughout this work.*

Symbol	No. of Layers of Wire Mesh	C:S by weight	P:C %	W/C %	Slump (mm)
R1	0	1 : 2	0	0.4	48
R2	1	1 : 2	0	0.4	42
R3	2	1 : 2	0	0.4	47
FM1-3%	0	1 : 2	3	0.37	33
FM2-3%	1	1 : 2	3	0.37	34
FM3-3%	2	1 : 2	3	0.37	38
FM1-5%	0	1 : 2	5	0.35	37
FM2-5%	1	1 : 2	5	0.35	37
FM3-5%	2	1 : 2	5	0.35	35
FM1-10%	0	1 : 2	10	0.3	29
FM2-10%	1	1 : 2	10	0.3	31
FM3-10%	2	1 : 2	10	0.3	31

2.2.3. Determination of the workability

Workability of all types of Mortar was measured by slump test according to the procedure described in ASTM C143-82. [20] The Water/Cementations materials ratios were adjusted to maintain on workability. Results of slump test are shown in Table (7).

2.2.4. Casting, Compaction and Curing

The molds were lightly coated with mineral oil before use according to ASTM C192-88 [21] . For cubes, cylinders and prisms casting was carried out in different layers each layer is of 50mm. Each layer was compacted by using a vibrating table for (15-30) second until no air bubbles emerged from the surface of the mortar, and the mortar is leveled off smooth to the top of the molds. For Ferrocement slabs which reinforced with one layer of wire mesh, mortar casting was carried out in two layers; each layer was 2.5cm high. First, the bottom layer of cement mortar was poured in the mold and compacted for (10) seconds, then a wire mesh layer was placed followed by the second layer of cement mortar. The specimen was then compacted for (30-40) second, then, the cement mortar was leveled off smooth to the top of the molds, while for Ferrocement slabs which reinforced with two layers of wire mesh, cement mortar casting was carried out in three layers, each layer was 1.67cm high approximately, the casting procedure was a same way mortar casting of slabs which reinforced with one layer of wire mash. Then the specimens were kept in the laboratory for about (24) hrs, after that the specimens remolded carefully, marked and immersed in water until the age of test. The specimens were test at ages of 7, 28 and 56 days for compressive, splitting tensile and flexural tests and 56 days for impact test.

2.3. Testing Hardened Concrete

2.3.1. Compressive Strength Test

For compressive strength test a (100 × 100 × 100) mm concrete cubes were used according B.S. 1881 part 116.[22] A (1000KN) capacity ELE testing machine was used for the compressive test . the average compressive strength of three cubes was recorded for each testing age (7,28 and 56 days).

2.3.2. Splitting Tensile Strength Test

(100 × 200) mm concrete cylinders were prepared according to ASTM C192-88. [21] The splitting tensile strength test was carried out according to ASTM C496-86. [23]

The load was applied by using (1000KN) capacity ELE testing machine , the average of splitting tensile strength of three cylinders was recorded for each testing age (7, 28 and 56) days.

2.3.3. Flexural strength Test

A (100 × 100 × 500)mm concrete prisms were prepared according to ASTM C192-88 .[21] The test was carried out using two points load according to ASTM C78-94 [24] using ELE (50) KN capacity machine . Average modulus of rupture of three prisms was obtained for each testing age (7, 28 and 56) days.

2.3.4. Impacttest

2.3.4.1. Low velocity impact

Thirty six, 56-day age (500 × 500 × 50) mm slab specimens were tested under low velocity impact load. The impact was conducted using 1300gm steel ball dropping freely from heights 2.4m, 1.2m and 0.83m. The test rig used for low velocity impact test consists of three main components: (Fig. 3)

1- A steel frame; strong and heavy enough to hold rigidly during impact loading. The dimensions of the testing frame were designed to allow observing the specimens (square slab) from the bottom surface to show developing failure, during testing. The specimen was placed accurately on mold which were welded to the support ensure the simply supported boundary condition.

2- The vertical guide for the falling mass used to ensure mid-span impact. This was a tube of a round section.

3- Steel ball with a mass of 1300 gm.

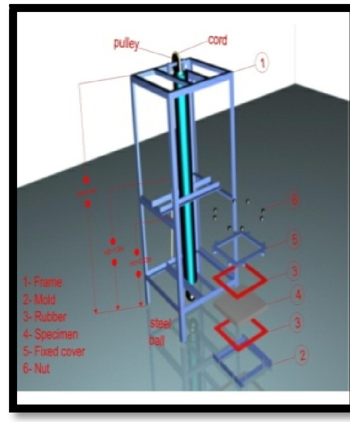

***Fig 3**. Impact test rig*

Specimens were placed in their position in the testing frame with the finished face up. The falling mass was then dropped repeatedly and the number of blows required to cause first crack was recorded. The number of blows required for failure (no rebound) was also recorded. The specimens were divided as follow:

1 Three of specimens tested without polymer and reinforcement.
2 Three of specimens tested without polymer and with one layer of wire mesh.
3 Three of specimens tested without polymer and with two layers of wire mesh.
4 Three of specimens tested with 3% polymer and without reinforcement.
5 Three of specimens tested with 3% polymer and with one layer of wire mesh.
6 Three of specimens tested with 3% polymer and with two layers of wire mesh.
7 Three of specimens tested with 5% polymer and without reinforcement.
8 Three of specimens tested with 5% polymer and with one layer of wire mesh.
9 Three of specimens tested with 5% polymer and with two layers of wire mesh.
10 Three of specimens tested with 10% polymer and without reinforcement.
11 Three of specimens tested with 10% polymer and with one layer of wire mesh.
12 Three of specimens tested with 10% polymer and with two layers of wire mesh.

2.3.4.2 High velocity impact test

Slabs with the same dimensions of low velocity impact specimens were used in this test. Twelve slab specimens were tested at 56 days of age. The specimens were divided as follow:

1 One specimen tested without polymer and reinforcement.
2 One specimen tested without polymer and with one layer of wire mesh.
3 One specimen tested without polymer and with two

layers of wire mesh.

4 One specimen tested with 3% polymer and without reinforcement.

5 One specimen tested with 3% polymer and with one layer of wire mesh.

6 One specimen tested with 3% polymer and with two layers of wire mesh.

7 One specimen tested with 5% polymer and without reinforcement.

8 One specimen tested with 5% polymer and with one layer of wire mesh.

9 One specimen tested with 5% polymer and with two layers of wire mesh.

10 One specimen tested with 10% polymer and without reinforcement.

11 One specimen tested with 10% polymer and with one layer of wire mesh.

12 One specimen tested with 10% polymer and with two layers of wire mesh.

The slabs were fixed in vertical position carefully to avoid movement. Centers of the slabs were indicated by soft pen. Slabs were tested under high velocity impact using 7.62mm bullets. The specifications armor piercing bullet is given in Table (8). After curing time of (56 days) the specimens were fixed in their position and fitted carefully to avoid any movement.

Leveling the machine gun, which was directed to the specimen center, ensured horizontal shooting from distance (15 m). Each specimen was subjected to a single hit, and after shooting, the penetration occurred, and the general condition of the specimen after test was observed and photographed.

***Table 8**. Specifications of Armor Bullets*

Bullets mm	Muzzle Velocity (m/sec)	Pressure (kg/cm^2)	Mass (gm)
7.62	714 -756	2800	7.47-7.87

3. Experimental Results and Discussion

3.1. Behavior of Ferro Cement Specimens under Low Velocity Impact

This test is performed in terms of the number of blows required to cause first crack and ultimate failure. The test was applied on square slabs of dimensions (500 × 500 × 50 mm) subjected to repeated impact blows by falling mass (1300 gm) dropped from three heights (2.4 m) , (1.2 m) and (0.83 m) at 56 day age. The increase in impact resistance at first crack and ultimate failure are plotted in Figures (4) to (15) for all concrete mixes at age of (56) days.

From table (9) , (10) and (11), it can be seen that the specimen which reinforced with one layer of wire mesh needed to number of blows to cause a first crack and ultimate failure more than unreinforced specimen and the specimen which reinforced with two layers of wire mesh needed to number of blows to cause a first crack and ultimate failure more than unreinforced specimen and the specimen which reinforced with one layer. This may be attributed to that Ferro-cement exhibited continuous increasing in impact resistance with increases in volume of reinforcement [27]. Also, results demonstrated that the increase in (P/C) ratio leads to that the increase in impact resistance at first crack and ultimate failure especially at (P/C) ratio (10 %) compare with reference concrete. This may be attributed to that the polymer itself has excellent impact resistance. [28]

This behavior may be ascribed to the significant reduction in water content of the Ferro-cement slabs caused by inclusion of this type of admixture; the internal bond strength of Ferro-cement is dramatically increased leading to a significant increase in internal energy of concrete (impact resistance).For (2.4) m height falling mass, the maximum value of the number of blows to cause a first crack was 15 blow for specimen which reinforced with two layers of wire mesh while the maximum value for the number of blows to cause ultimate failure was 38 blow for specimen which reinforced with two layers of wire mesh, both values were by addition (10 %) polymer.

The percentage increase of number of blows to cause first crack were (33.33 %), (33.33 %) and (66.67 %), while the percentage increase in the impact resistance at ultimate failure were (28.57 %), (14.28 %) and (100 %) for unreinforced Ferro-cement slabs with wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete , the percentage increase of number of blows to cause a first crack were (33.33 %), (33.33 %) and (83.33 %), while the percentage increase in the impact resistance at ultimate failure were (0 %), (47.05 %) and (70.58 %) for reinforced Ferro-cement slabs with one layer of wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete ,and the percentage increase of number of blows to cause a first crack were (12.5 %), (50 %) and (87.5 %), while the percentage increase in the impact resistance at ultimate failure were (28.57 %), (57.14 %) and (80.95 %) for reinforced Ferro-cement slabs with two layers of wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete, Table (9). For (1.2) m height falling mass, the maximum value of the number of blows to cause a first crack was 21 blow for specimen which reinforced with two layers of wire mesh while the maximum value for the number of blows to cause ultimate failure was 53 blow for specimen which reinforced with two layers of wire mesh, both values were by addition (10 %) polymer.

The percentage increase of number of blows to cause first crack were (60 %), (60 %) and (120 %), while the percentage increase in the impact resistance at ultimate failure were

(11.11 %), (55.55 %) and (15.5 %) for unreinforced Ferro-cement slabs with wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete , the percentage increase of number of blows to cause first crack were (33.33 %), (44.44 %) and (88.88 %), while the percentage increase in the impact resistance at ultimate failure were (14.81 %), (51.85 %) and (74.07 %) for reinforced Ferro-cement slabs with one layer of wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete and the percentage increase of number of blows to cause first crack were (-20 %), (6.67 %) and (40 %), while the percentage increase in the impact resistance at ultimate failure were (11.11 %), (22.22 %) and (47.22 %) for reinforced Ferro-cement slabs with two layers of wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete, Table (10).

For (0.83) m height falling mass, the maximum value to the number of blows to cause a first crack was 27 blow for specimen which reinforced with two layers of wire mesh while the maximum value for the number of blows to cause ultimate failure was 102 blow for specimen which reinforced with two layers of wire mesh, both values were by addition (10 %) polymer.

The percentage increase of number of blows to cause first crack were (55.55 %), (88.88 %) and (88.88 %), while the percentage increase in the impact resistance at ultimate failure were (28.57 %), (66.67 %) and (123.81 %) for unreinforced Ferro-cement slabs with wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete , the percentage increase of number of blows to cause first crack were (-5.88 %), (23.53 %) and (35.29 %), while the percentage increase in the impact resistance at ultimate failure were (41.86 %), (72.09 %) and (79.06 %) for reinforced Ferro-cement slabs with one layer of wire mesh modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively when compared with reference concrete and the percentage increase of number of blows to cause first crack were (0 %), (9.09 %) and (22.72 %), while the percentage increase in the impact resistance at ultimate failure were (21.82 %), (67.27 %) and (85.45 %) for reinforced Ferro-cement slabs with two layers of wire mesh and modified with (P/C) ratios (3 %), (5 %) and (10 %) respectively compare with reference concrete, Table (11).

From the figures mentioned, it can be seen that the impact resistance represented by number of blows until failure decreases with the increasing in falling mass height. That might be due to an increase in strike force with an increase in falling mass height, and that means an increase in the absorbed energy by Ferro-cement slab body in each strike, and this leads to distribution of the total impact energy on the fewer number of blows until failure.

3.1.1. Behavior of ferro-Cement Specimens Under High Velocity Impact

High velocity impact test was done on (500 × 500 × 50 mm) slabs by shooting bullets of (7.62 mm) caliber having a striking velocity of (720 m/sec.) from a distance of (15 m). The results obtained from this test are presented in Table (12) and plotted in Fig.16 and Fig. 17. These figures illustrate the relationship between the (P/C) ratio for concrete specimens with and without wire mesh, with spalling and scabbing. From Table (12) and Fig.18, it can be seen that unreinforced specimens with wire mesh breaks into pieces and collapse then.

Results for polymer concrete specimens in general gave reduction in spalling area compared with reference mix and from same Table (12), it can be seen that the increase of the number of wire mesh layers increases the stability and prevent the collapse. Also it can be seen that the addition of polymer leads to decreasing the scabbing area when compared with reference mixes, in addition to that the slabs which reinforced with two layers of wire mesh gave the spalling area less than the slabs which reinforced with one layer of wire mesh. Generally, the spalling area at front face is less than the scabbing area at back face for all concrete slabs; this behavior might be attributed to the reflection of compressive wave from the front face to tensile wave in the back face of concrete specimens. (29) It can be seen also that, the area of scabbing decreases with the increase in damping for concrete specimens containing polymer and also due to the increase in bond strength and tensile strength of concrete slabs with an increase in (P/C) ratio. (17) From Fig.19 it can be seen that the number of cracks and the length of cracks decrease with the increase in (P/C) ratio. This behavior might be due to an increase in strength and bond action of the polymer structure within at the distance from the center of contact zone when the intensity of energy decreases.

Table 9. *Number of Blows that Caused First Crack and Ultimate Failure of Various Concrete Slab Specimens for 2.4 m High Falling Mass*

No. of Blows	Number of Reinforcement Layers	(Polymer/Cement) %			
		0%	3%	5%	10%
Number of Blows to Cause a First Crack by Falling Mass	0	3	4	4	5
	1	6	8	8	11
	2	8	9	12	15
% Increase No. of Blows over Reference Mix	0	0	33.33	33.33	66.67
	1	0	33.33	33.33	83.33
	2	0	12.5	50	87.5
Energy (J) Cause a First Crack by Falling Mass	0	20.59	27.45	27.45	34.31
	1	41.17	54.9	54.9	75.48
	2	54.9	61.76	82.34	102.93

No. of Blows	Number of Reinforcement Layers	(Polymer/Cement) %			
		0%	3%	5%	10%
Number of Blows to Cause Ultimate Failure by Falling Mass	0	7	9	8	14
	1	17	17	25	29
	2	21	27	33	38
% Increase No. of Blows over Reference Mix	0	0	28.57	14.28	100
	1	0	0	47.05	70.58
	2	0	28.57	57.14	80.95

Table 10. *Number of Blows that Caused First Crack and Ultimate Failure of Various Concrete Slab Specimens For 1.2 m High Falling Mass*

No. of Blows	Number of Reinforcement Layers	(Polymer/Cement) %			
		0%	3%	5%	10%
Number of Blows to Cause a First Crack by Falling Mass	0	5	8	8	11
	1	9	12	13	17
	2	15	16	16	21
% Increase No. of Blows over Reference Mix	0	0	60	60	120
	1	0	33.33	44.44	88.88
	2	0	6.67	6.67	40
Energy (J) Cause a First Crack by Falling Mass	0	24.26	38.82	38.82	53.37
	1	43.67	58.23	63.08	82.49
	2	72.78	77.64	77.64	101.9
Number of Blows to Cause Ultimate Failure by Falling Mass	0	9	10	14	14
	1	27	31	41	47
	2	36	40	44	53
% Increase No. of Blows over Reference Mix	0	0	11.11	55.55	15.5
	1	0	14.81	51.85	74.07
	2	0	11.11	22.22	47.22

Table11. *Number of Blows That Caused First Crack and Ultimate Failure of Various Concrete Slab Specimens For 0.83 m High Falling Mass*

No. of Blows	Number of Reinforcement Layers	(Polymer/Cement) %			
		0%	3%	5%	10%
Number of Blows to cause a First Crack by Falling Mass	0	9	14	17	17
	1	17	16	21	23
	2	22	22	24	27
% Increase No. of Blows over Reference Mix	0	0	55.55	88.88	88.88
	1	0	-5.88	23.53	35.29
	2	0	0	9.09	22.72
Energy (J) Cause a First Crack by Falling Mass	0	36.32	56.5	68.6	68.6
	1	68.6	54.57	84.74	84.74
	2	88.78	88.78	96.85	109
Number of Blows to cause Ultimate Failure by Falling Mass	0	21	27	35	47
	1	43	61	74	77
	2	55	67	92	102
% increase No. of Blows over Reference Mix	0	0	28.57	66.67	123.81
	1	0	41. 86	72.09	79.06
	2	0	21.82	67.27	85.45

Table 12. *Results of High Velocity Impact Resistance of Tested Specimens at Age of (56) Days*

Mix.	No. Layers of Wire Mesh	(P/C) %	Condition of the Front Face	Condition of the Back Face
R1	0	0	Spalling Area (109.3) cm^2 + 4 Long Hair Cracks (Collapse).	Scabbing Area (226.86) cm^2 + 4 Long Hair Cracks (Collapse).
R2	1	0	Spalling Area (91.56) cm^2 + 3 Short Hair Cracks.	Scabbing Area (153.8) cm^2 + 1 Long Hair Cracks + 2 Short Hair Cracks.
R3	2	0	Spalling Area (75.4) cm^2 + 3 Short Hair Cracks.	Scabbing area (143.06) cm^2 + 6 short heir cracks.
FM1-3%	0	3	Spalling Area (94.98) cm^2 + 1 Long Crack (Collapse).	Scabbing Area (153.86) cm^2 +1 Long Crack (Collapse).
FM2-3%	1	3	Spalling Area (38.46) cm^2 + 1 Long Hair Crack.	Scabbing Area (122.65) cm^2 +1 Long Hair Crack.
FM3-3%	2	3	Spalling Area (44.15) cm^2 + 1 Long Hair Crack.	Scabbing Area (94.98) cm^2 +3 Short Hair Crack.
FM1-5%	0	5	Spalling Area (63.58) cm^2 + 1 Long Crack (Collapse).	Scabbing Area (70.84) cm^2 +1 Long Crack (Collapse).
FM2-5%	1	5	Spalling Area (56.71) cm^2 + 1 Long	Scabbing Area (78.5) cm^2 +1 Long Hair Crack.

Mix.	No. Layers of Wire Mesh	(P/C) %	Condition of the Front Face	Condition of the Back Face
FM3-5%	2	5	Hair Crack. Spalling Area (63.58) cm^2 + without Cracks.	Scabbing Area (68.8) cm^2 + without Cracks.
FM1-10%	0	10	Spalling Area (35.23) cm^2 + 1 Long Hair Crack.	Scabbing Area (73.86) cm^2 + 1 Long Hair Crack.
FM2-10%	1	10	Spalling Area (33.16) cm^2 + without Cracks.	Scabbing Area (63.58) cm^2 + without Cracks.
FM3-10%	2	10	Spalling Area (19.62) cm^2 + without Cracks.	Scabbing Area (44.15) cm^2 + without Cracks.

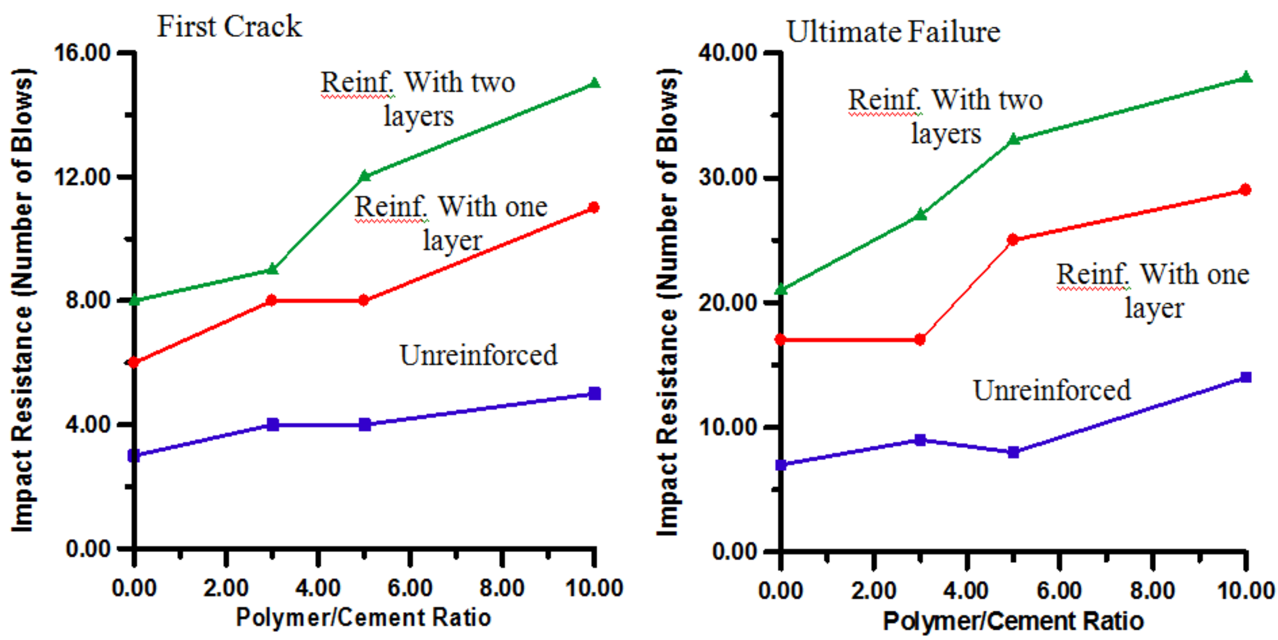

Fig. 4. *Relationship Between (P/C) Ratio and Number of Blows to Cause a First Crack and Ultimate Failure for 2.4 m High Falling Mass.*

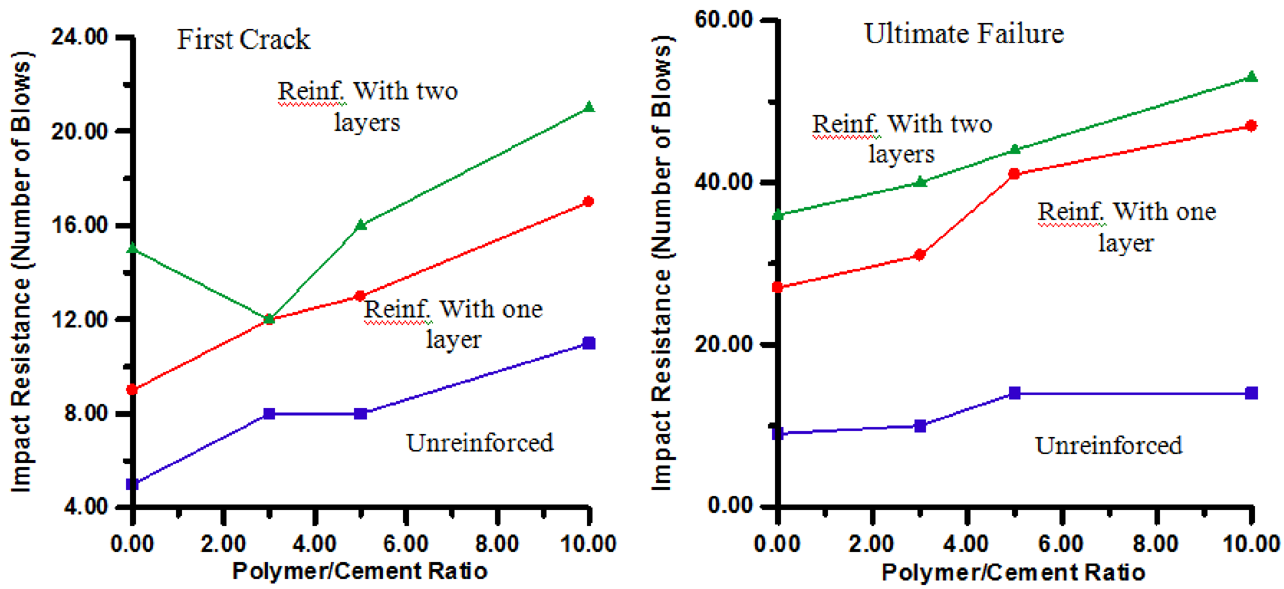

Fig. 5. *Relationship Between (P/C) Ratio and Number of Blows to Cause a First Crack and Ultimate Failure for 1.2 m High Falling Mass.*

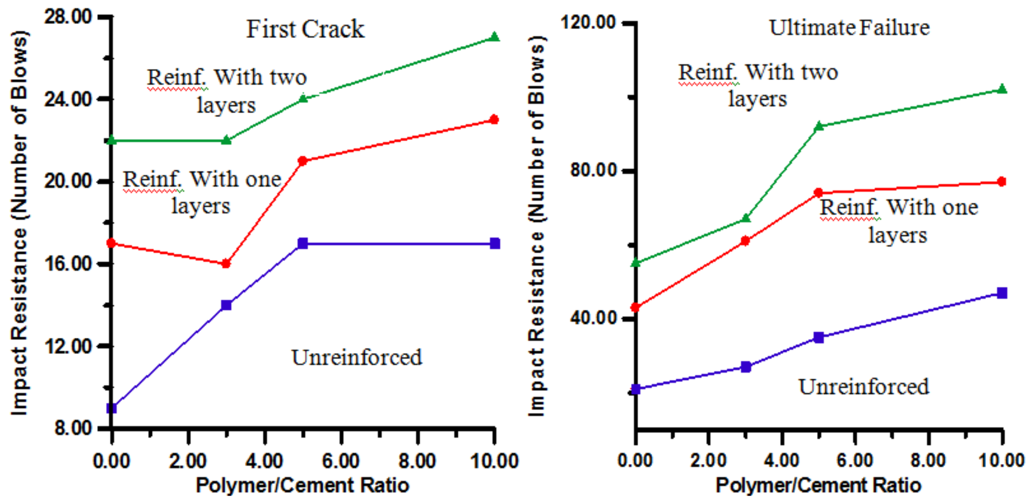

Fig. 6. *Relationship Between (P/C) Ratio and Number of Blows to Cause a First Crack and Ultimate Failure for 0.83 m High falling mass.*

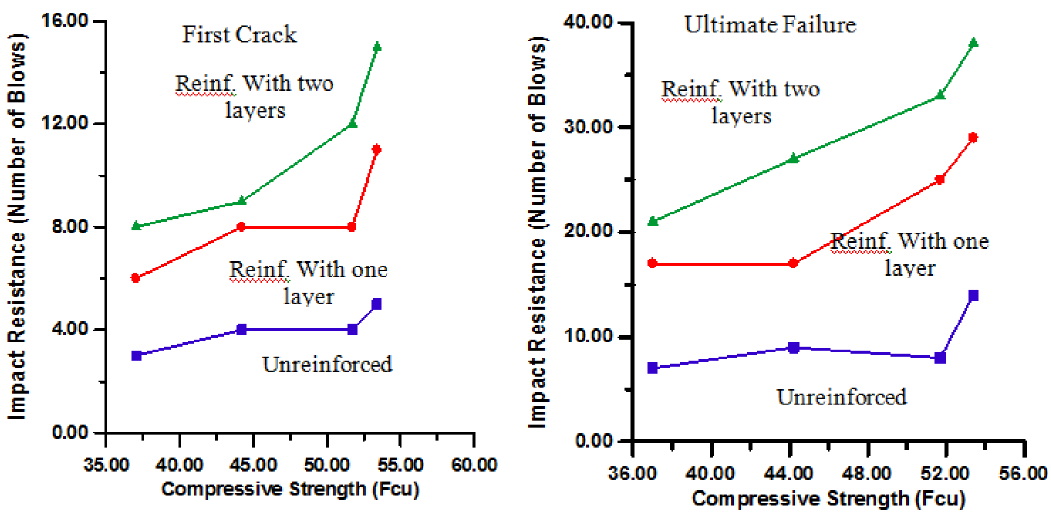

Fig.7. *Relationship Between Compressive Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 2.4 m High Falling Mass.*

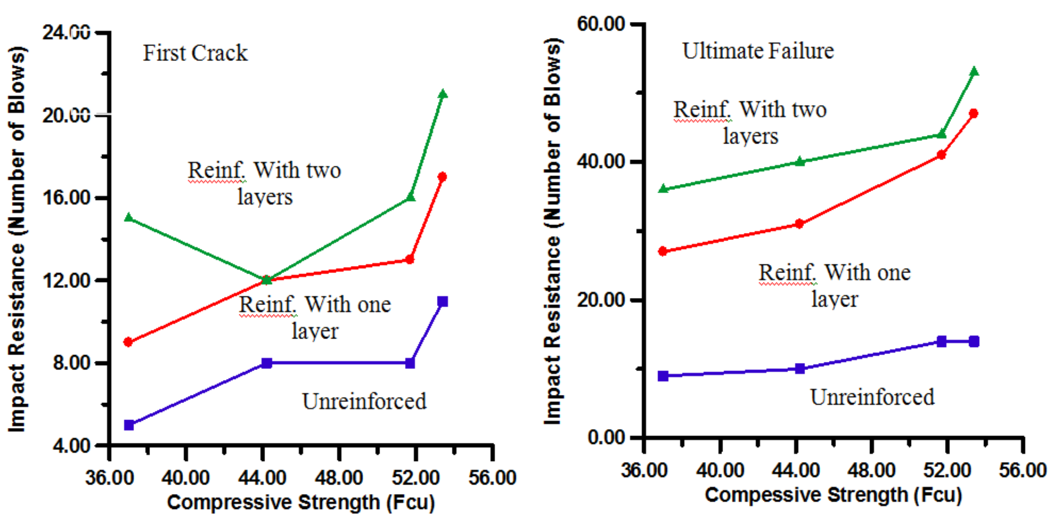

Fig. 8. *Relationship Between Compressive Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 1.2 m High Falling Mass.*

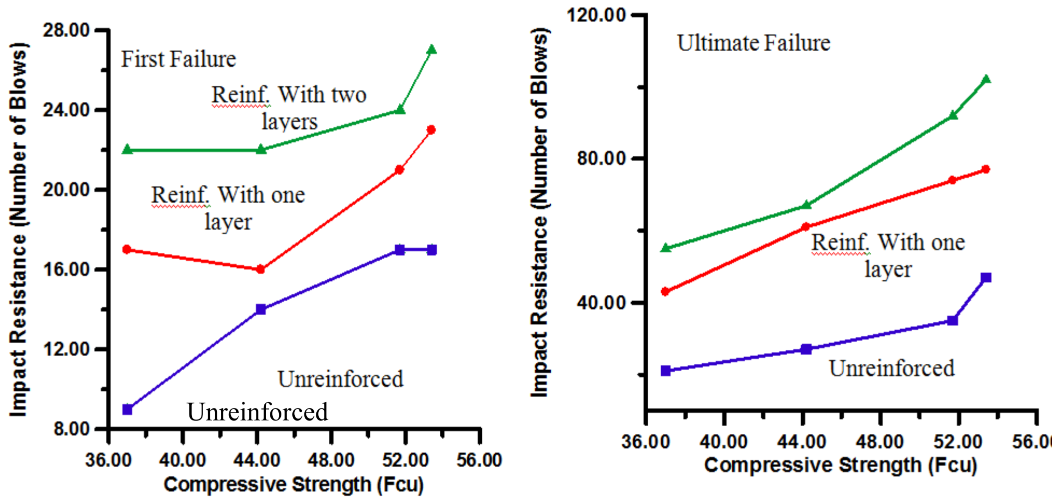

Fig. 9. *Relationship Between Compressive Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 0.83 m High Falling Mass.*

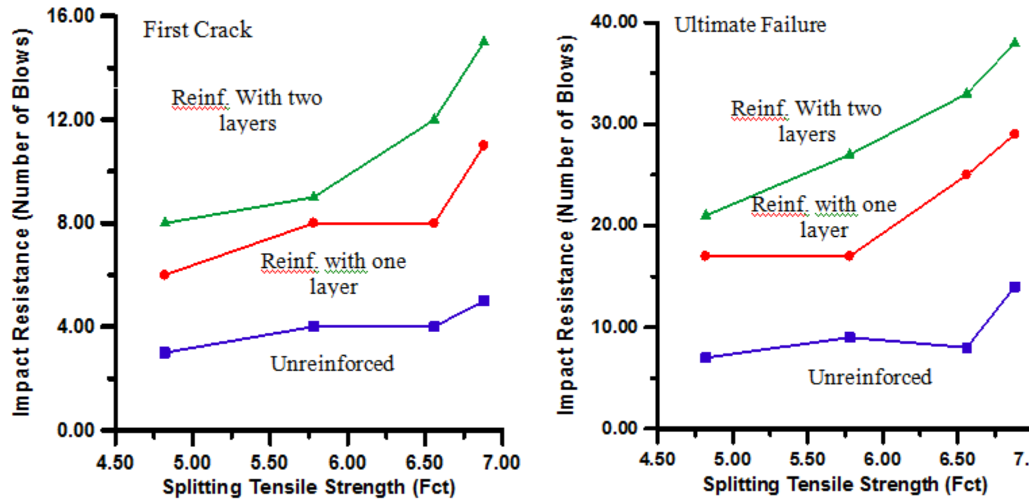

Fig. 10. *Relationship Between Splitting Tensile Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 2.4 m High Falling Mass.*

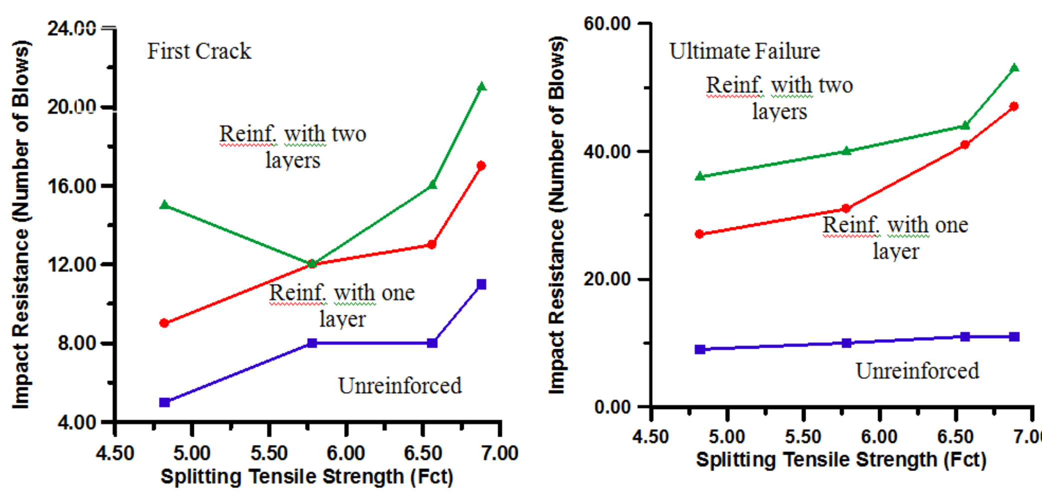

Fig. 11. *Relationship Between Splitting Tensile Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 1.2 m High Falling Mass*

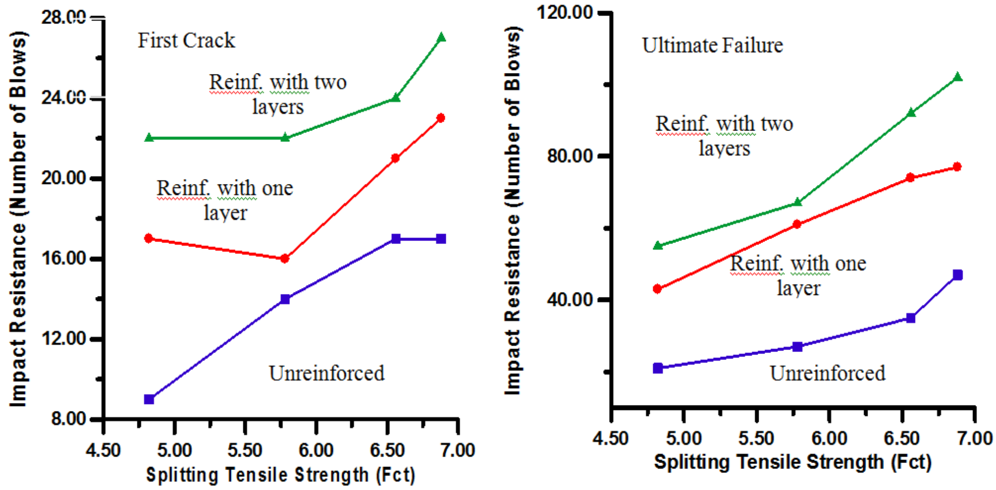

Fig. 12. *Relationship Between SplittingTensile Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 0.83 m High Falling Mass.*

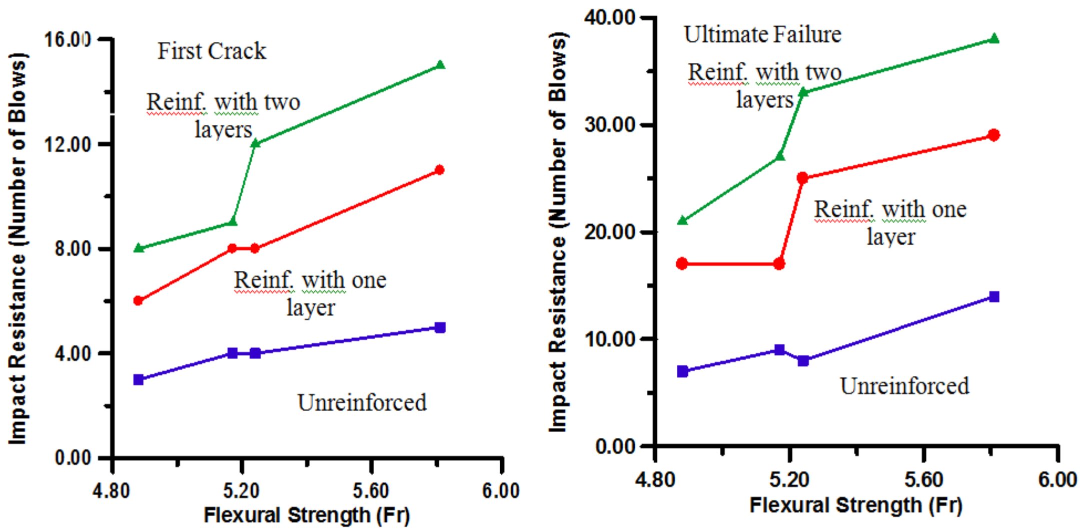

Fig. 13. *Relationship Between Flexural Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 2.4 m High Falling Mass*

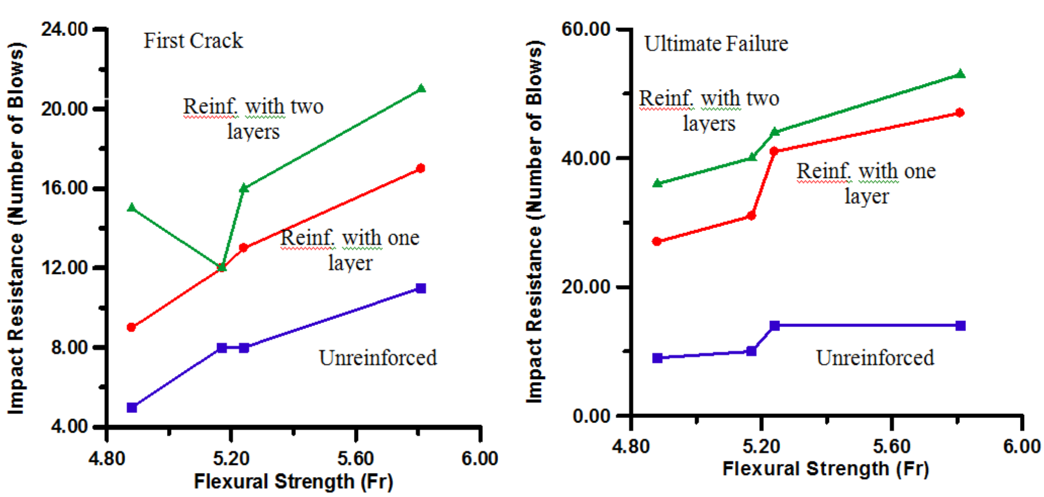

Fig. 14. *Relationship Between Flexural Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 1.2 m High Falling Mass.*

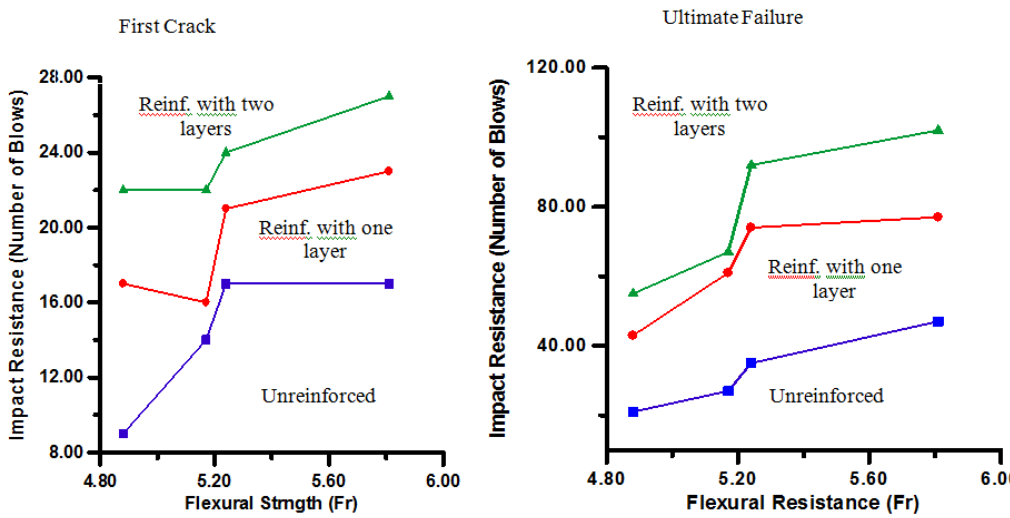

Fig. 15. *Relationship Between Flexural Strength and Impact Resistance for First Crack and Ultimate Failure for Ferrocement Specimens at (56) Days for 0.83 m High Falling Mass.*

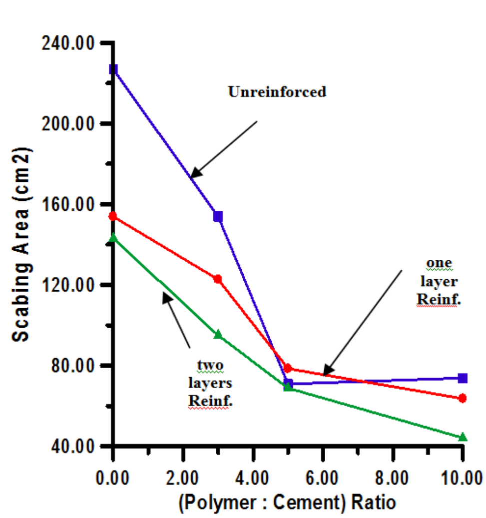

Fig. 16. *Relationship between (P/C) Ratio and Scabbing Area at High Velocity Impact Test for all Concrete Slabs at 56 Days.*

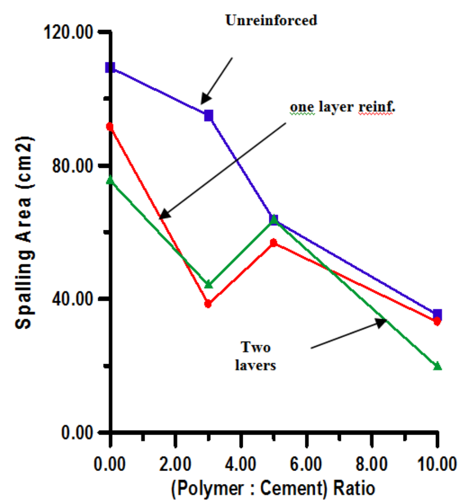

Fig.17. *Relationship between (P/C) Ratio and Spalling Area at High Velocity Impact Test for all Concrete Slabs at 56 Days.*

Fig. 18. *The Mode of Failure of Slabs under High Velocity Impact*

Fig. 18*. Continued*

4. Conclusion

ConclusionsFor Impact Tests

1- Low velocity impact resistance of polymer modified Ferro-cement slabs is greater than that of reference mix slabs.

For 2.4 m High Falling Mass:

The maximum number of blows in low velocity impact resistance to cause first crack is:

- 5 blows for (P/C=10%) unreinforced Ferro-cement slab with wire mesh.
- 11 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 15 blows for (P/C=10%) reinforced Ferro-cement slab with two layers of wire mesh.
- The maximum increase in low velocity impact resistance to cause ultimate failure is:
- blows for (P/C=10%) unreinforced Ferro-cement slab with wire mesh.
- 29 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 38 blows for (P/C=10%) reinforced Ferro-cement slab with two layers of wire mesh.

For 1.2 m High Falling Mass:

The maximum increase in low velocity impact resistance to cause first crack is:

- 11 blows for (P/C=10%) unreinforced Ferro-cement slab with wire mesh.
- 17 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 21 blows for (P/C=10%) reinforced Ferro-cement slab with two layers of wire mesh.

The maximum increase in low velocity impact resistance to cause ultimate failure is:

- blows for (P/C=5%) unreinforced Ferro-cement slab with wire mesh.
- 47 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 53 blows for (P/C=10%) reinforced Ferro-cement

slab with two layers of wire mesh.

For 0.83m High Falling Mass:

The maximum increase in low velocity impact resistance to cause first crack is:

- 17 blows for (P/C=5%) and (P/C=10%) unreinforced Ferro-cement slab with wire mesh.
- 23 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 27 blows for (P/C=10%) reinforced Ferro-cement slab with two layers of wire mesh.

The maximum increase in low velocity impact resistance to cause ultimate failure is:

- 47 blows for (P/C=10%) unreinforced Ferro-cement slab with wire mesh.
- 77 blows for (P/C=10%) reinforced Ferro-cement slab with one layer of wire mesh.
- 102 blows for (47.22 = 10%) reinforced Ferro-cement slab with two layers of wire mesh.

2- Features of high-velocity impact resistance of polymer modified Ferro-cement slabs can be stated as follows:

- Reduction in spalling area compared with reference mix.
- Adding of SBR polymer resulted in prevention of the appearance of cracks.
- Scabbing area was decreased in comparison with reference mix when adding SBR polymer ranged between 109.3 cm^2 to 35.23 cm^2 for unreinforced slab concrete, from 91.56 cm^2 to 33.16 cm^2 for Ferro-cement slab reinforced with one layer of wire mesh, and from 75.4 cm^2 to 19.62 cm^2 for Ferro-cement slab reinforced with two layers of wire mesh.

3- Adding of SBR polymer and increasing number of layers of reinforcement caused significant reduction in the number of fragmentations flying out of the back face of specimens.

Mode of Failure under Low Velocity Impact :

For slabs used in low velocity impact tests, the latex modified Ferro-cement slabs failed with number of blows more when compared with reference mix and the crack started from center of top face and propagated on length and width of specimens, and specimens was fractured into separate pieces (ultimate failure) with number of blows more than that in first crack stage.

For impact test in which the height of falling mass equals (2.4) m, that un reinforced slabs with wire mesh reach to the ultimate failure with number of blows near than number of blows to cause a first crack . For low velocity impact tests with falling mass failure of unmodified concrete was more brittle than that latex of modified Ferro-cement slabs. The slabs made of references mixes reach the first crack and ultimate failure at number of blows less than that of the slabs made of polymer modified concrete.

Behavior of Ferro-Cement specimens under High Velocity Impact :

These figures illustrate the relationship between the (P/C) ratio for concrete specimens with and without wire mesh, with spalling and scabbing. and Plates , it can be seen thatunreinforced specimens with wire mesh breaks into pieces and collapse then. Results for polymer concrete specimens in general gave reduction in spalling area compared with reference mix , it can be seen that the increase of the number of wire mesh layers increases the stability and prevent the collapse.

Also it can be seen that the addition of polymer leads to decreasing the scabbing area when compared with reference mixes, in addition to that the slabs which reinforced with two layers of wire mesh gave the spalling area less than the slabs which reinforced with one layer of wire mesh.

Generally, the spalling area at front face is less than the scabbing area at back face for all concrete slabs; this behavior might be attributed to the reflection of compressive wave from the front face to tensile wave in the back face of concrete specimens. It can be seen also that, the area of scabbing decreases with the increase in damping for concrete specimens containing polymer and also due to the increase in bond strength and tensile strength of concrete slabs with an increase in (P/C) ratio.

From Plates, it can be seen that the number of cracks and the length of cracks decrease with the increase in (P/C) ratio. This behavior might be due to an increase in strength and bond action of the polymer structure within at the distance from the center of contact zone when the intensity of energy decreases.

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