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Influence of Voids Ratio on Impact Behavior of Circular Ferrocement Slabs

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Abstract

The objective of using materials is to fully utilize the properties of these materials in order to obtain the best performance of the structure. The merits of material are based on many factors like, workability, structural strength, durability and low cost. Ferrocement is an excellent construction system. This paper studies the behavior of ferrocement circular slabs under impact load. The experimental program include testing four sime fixed supported ferrocement circular slabs of 800mm diameter and 50mm thickness. The Influence of the use of styropor voids was investigated in different ratios (24% and 48%) and a number of wire mesh layers four and six layers. Impact load test results revealed that increasing number of wire mesh from 4 to 6 led to an increase in the impact energy for first crack by (41.991% ,37.62%) respectively when using voids ratio by (24% and 48%) respectively and impact energy for full perforation by (21.7% and 9.94%) respectively when using voids ratio by (24% and 48%) respectively. Ferrocement circular slabs are used in construction fields such as roofs, tanks, manholes, etc.

Keywords: Ferrocement; Circular Slabs; Impact Load; Voided slabs; Composite; Panel.

1. Introduction

Recently sandwich panels have gained much attention as an effective structural form in the building and construction industry. Sandwich panels have been used in the aerospace industry for many years and these are also being used as load bearing members in naval structures [1]. Sandwich panels offer high strength-to-weight ratio causing substantial reduction in the self-weight of the structures. The self-weight of the element with high density (weight) itself accounts for a major portion of the total load of the structure. Thus reduction in the self-weight of the structures by adopting an appropriate approach results in the reduction of element cross-section, size of foundation, cost and also the damages due to earthquake because the earthquake forces that will influence the buildings and other structures are proportional to the mass of the structure [2]. The use of sandwich panels with cores of lightweight concrete is spreading due to their manufacturing efficiency that leads to the industrialization of the building system [3]. Sandwich panels typically consist of two thin, high strength and density outside face sheets known as skin separated by a thick layer made of low strength and density material called as core [4]. Ferrocement laminated composite is also proved to be an effective material to produce skins of sandwich panels [5–9]. Ferrocement can be define as a type of thinning wall reinforced concrete usually comprised hydraulic mortar reinforced with closely spaced layers of continuous and relatively small wire mesh [10]. Ferrocement has a stiffness, punching shear, and a best impact resistance than reinforced concrete, because two dimensional strengthening of the wire mesh. So, before fall is subject to high deflections. It is durable, economic cost, lightweight, weather resistance, and its versatility for comparing with the reinforced concrete [11]. Circular slabs are generally used as base slabs for columns or cover slabs for circular storage tanks. The slab at failure will develop

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circumferential and radial cracks.

Jagannathan A, 2008 [12] Studied 20 ferrocement slabs of dimensions (250 × 250 ×25) mm under impact load. The investigated variables include the polymer mesh and steel wire mesh which were used at different locations of the specimens. It is concluded that the polymer mesh reinforced ferrocement samples absorbed about 50% of the impact energy. It would be absorbed by using steel welded wire mesh. The lower impact energy absorption can be referred to poor bonding between the polymer mesh and the matrix of the ferrocement. Noticed crack patterns were observed in ferrocement samples and it was in dependent of the type of reinforcement (polymer mesh or steel welded wire mesh).

Shaheen et al., (2013) [13] Studied 20 ferrocement slab specimens with dimensions of (500×500×25) mm under impact loads. The studied variables were the skeletal steel bars, metal meshes with steel bars and metal meshes. Weight of dropping ball was 1.15 kg and height of drop was 1.12 m at the center of slab. It is found that the increasing of the number of the wire mesh layers increased energy at first cracking and energy at full perforation. It was used steel meshes and steel bars for achieving higher energy compared with using steel bars only. This could be referred to the influence of welded and expanded steel meshes on dominant developed cracks. The increasing of the expanded steel mesh layers and a number of the steel bars delaying the appearance of the first crack which could result from increasing the specific surface area of wire steel meshes which leading to higher bond area.

Nagan et al., (2014) [14] Investigated the strength of geopolymer mortar panels subjected to impact loading. In this research, the samples have dimensions of (230×230×25) mm with 2 layers of rectangular weld mesh, 4 layers of chicken mesh and combination of one layer of wire mesh and 4 layers of chicken wire mesh. Samples were tested under drop weight test. The results depicted that he addition of the over mesh reinforcement has increased the Irs of geopolymer ferrocement slabs by 4-28 times that of the reference0ferrocement mortar specimens. The combination of four layers of chicken mesh of geopolymer and one layer of weld mesh ferrocement samples showed the best performance in the impact loading test. Energy absorbed residual impact strength ratio (Irs) was noticed that the increase in Vf increased the impact energy absorption. The (Irs) also increase of geopolymer ferrocement than that of ferrocement samples

Aziz I., and Hadeel R., (2014) [15] studied the behavior of multilayer composite ferrocement slabs under impact load. The slabs include two ferrocement layers with an intermediate rubberized cement mortar layer. Different rubber ratios, different thickness of RCM layer, and shear connectors to connect the upper and lower reinforcement layers were used. The specimens were cast in 500 × 500 mm, with an overall thickness not exceeding 50 mm. Test results showed that increase in the rubberized cement mortar layer thickness, with an increase in the crumb rubber ratio, and using shear connectors; it increases impact energy to cause first a crack and then full perforation. The results also show that the rubberized cement mortar layer enhances the impact resistance of the ferrocement composite slab.

Elavarasan et al., (2016) [16] Studied twelve square ferrocement slab samples with dimensions of (350 × 350 × 25) mm subjected to impact load. The investigated variables include the galvanized iron mesh of rectangular grid openings and steel mesh with wire woven hexagonal openings. The testing program included impact load testing, projectile impact test using projectile (steel ball) of a diameter of 12.5 mm and impact load testing done after subjecting the slabs to heat in oven reaching a temperature of 110 degrees Celsius for 24 hours. It is concluded that the use of the ferrocement as a reinforcement to concrete slabs enhanced the perforation resistance and reduce the heat transfer through the thinner thickness of the steel mesh reinforced cement matrix. The basic idea behind this material is that concrete can undergo large strain in the neighborhood of the reinforcement and the magnitude of strain

Moda et al., (2016) [17] Investigated the influence of the mesh spacing and thickness of ferrocement slabs of size (300×300) mm which were subjected to low impact load test. A steel ball of weight 1236 gm dropped from height 150 mm, 350mm, and 500mm has been used in this work. There was a perfect linear correlation between the mesh spacing and impact strength of ferrocement samples against slab thickness. The first crack and ultimate crack impact strength of 40 mm specimen by 2.00 times and 1.84 times are used respectively against the 20 mm slab with the same mesh spacing. While the first crack and ultimate crack impact strength of 40 mm slab with 20 mm mesh spacing are 2.24 times and 3.70 times respectively against 50 mm mesh spacing with the same slab thickness. The mesh with higher content of reinforcement provides more contribution to the slab resistance as compared with the thickness

Subramani et al., (2016) [18] Studied eight ferrocement panels with dimensions of (600×400×15) mm and (600 ×600×25) mm under impact load. The main objective of this research was to investigate the behavior of ferrocement panels strengthened with waste plastic fibers of proportions of 5% and 15% usage in ferrocement slabs. Samples were tested under low velocity impact. From results noticed that more number of pvc coated wire mesh layer and waste plastic fibers increased the impact energy.

2. Experimental Work

2.1. Materials

Normal Portland cement was used for casting specimens during the experimental program, locally known (Mass). It conforms to the Iraqi Standard specification [19]. Table 1 and 2 show the chemical and physical properties of the cement used.

Fine Aggregate A locally available sand was used in this work (typical sand from Toz city at east of Tikrit was used as fine aggregate for casting specimen). it was passed from 2.36 mm sieve.

Styropor to create voids in the specimens, a high-density compressed styropor (density of styropor 20 Kg/m^3) panels were used in this study. The panels' size was (1000×2000) mm and 30 mm thickness, the styropor was cut into the circular shape and then cut into strips according to the dimensions required to create the voids.

Reinforcement the locally available welded wire mesh was used as a reinforcement. locally known as a chicken wire mesh. This is produced in shape of rolls of 1.25 m wide. The wire mesh was cut in a circular shape to fit the molds. The average diameter of grids is 0.68 mm and opening size is 13 mm distributed equally in two orthogonal directions, f_y = 389.4 MPa and f_u = 412.8 MPa .

Superplasticizers hyperplast PC600 was used as a superplasticizer. The purpose of using this agent was to get concrete mix with high workability and high strength of concrete mix.

Cement mortar all the slab specimens have been cast by using a cement/aggregate ratio of 1:1.5, superplasticizers 1.5% from cement and water/cement ratio of 0.27 for mortar.

Table 1. Chemical Properties of Cement

Oxides composition	Content (%)	Limit of Iraqi specification No. 5/1984
CaO	60.1	-
Al_2O_3	4.06	8 % Max.
SiO_2	20.3	21 % Max.
Fe_2O_3	3.67	5 % Max.
MgO	2.03	5 % Max.
SO_3	2.02	2.8 % Max.
Loss on Ignition, (L.O.I)	2.95	4 % Max.
Insoluble material	1.17	1.5 % Max.
Lime Saturation Factor, (L.S.F)	0.9156	(0.66-1.02)

Table 2. Physical properties of cement

Physical Properties	Test Results	Limit of Iraqi specification No. 5/1984
Setting time (Vicat apparatus)		
Initial setting, (hrs : min)	1:30	Not less than 45 min
Final setting, (hrs : min)	7:10	Not more than 10 hrs
Compressive strength (MPa)		
For 3 day	34.2	15 MPa lower limit
For 7 day	36.15	23 MPa lower limit

2.2. Experimental Parameters and Specimen Testing

The main aim of this research is to investigating the effect of voids ratio and number of wire mesh layer on the structural behavior of ferrocement circular slabs subjected to impact loading. The influence of the use of styropor were studied for different ratios (24 and 48%), and the number of layers of wire mesh was varied from 4 to 6 layers. For this purpose, 4 circular slabs were casted and tested under impact loading. A series of slabs of diameter (800 mm) and thickness (50 mm), Figures 1 and 2 clarify the experimental work of this study.

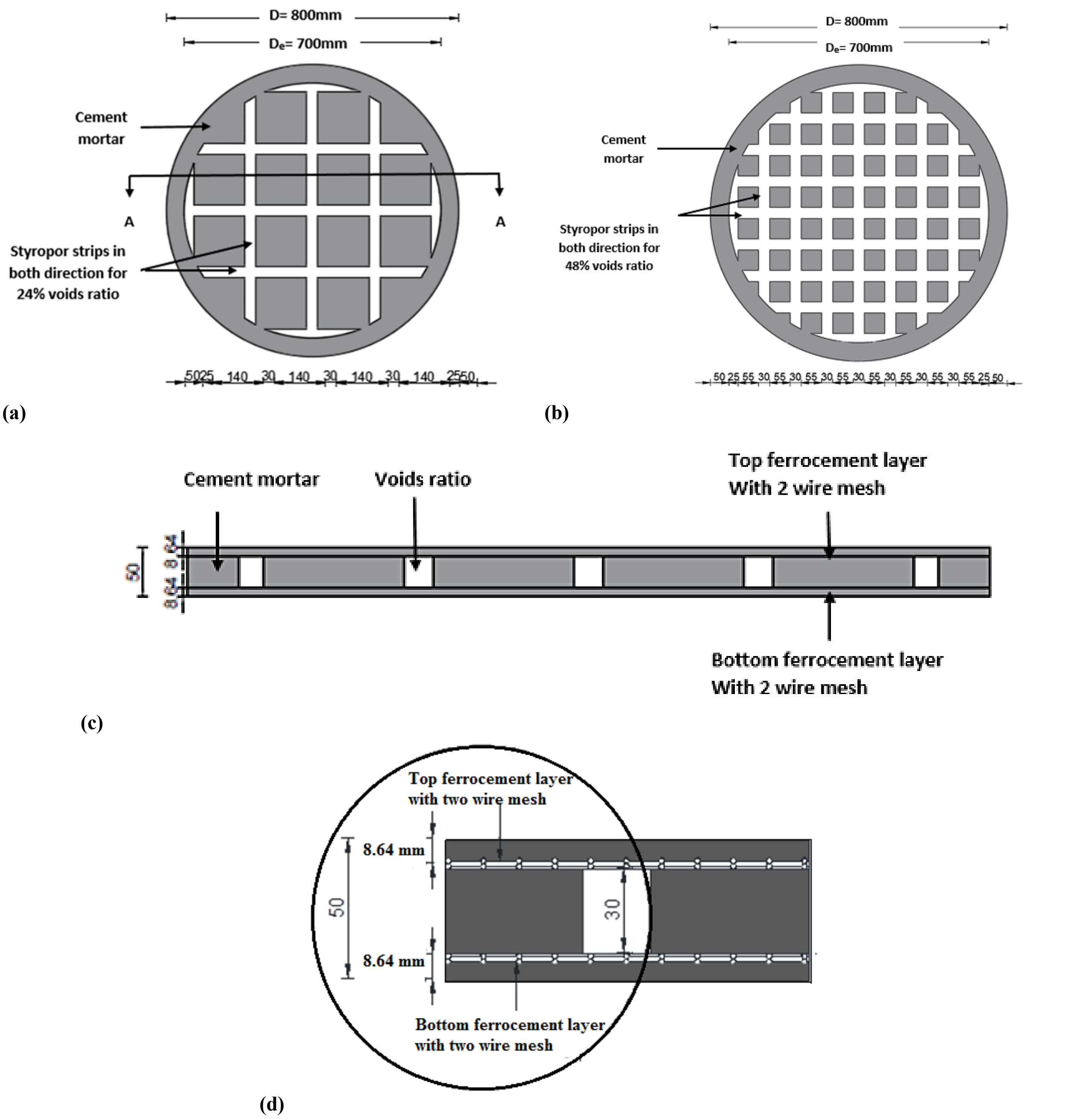
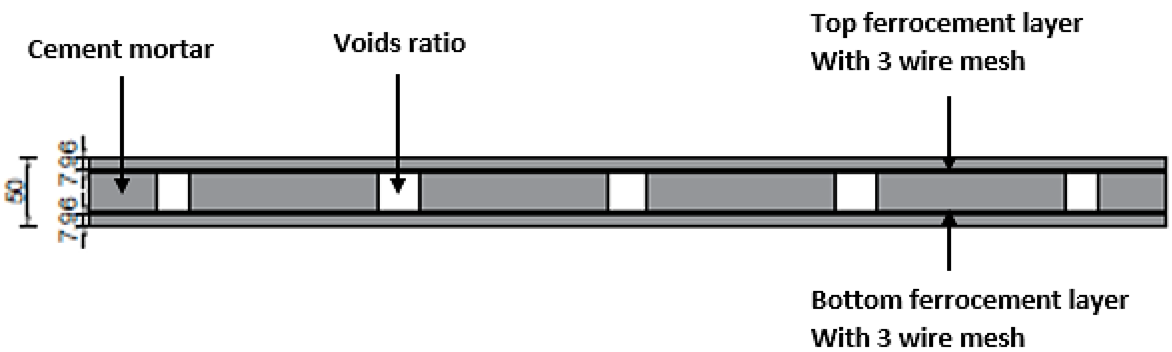
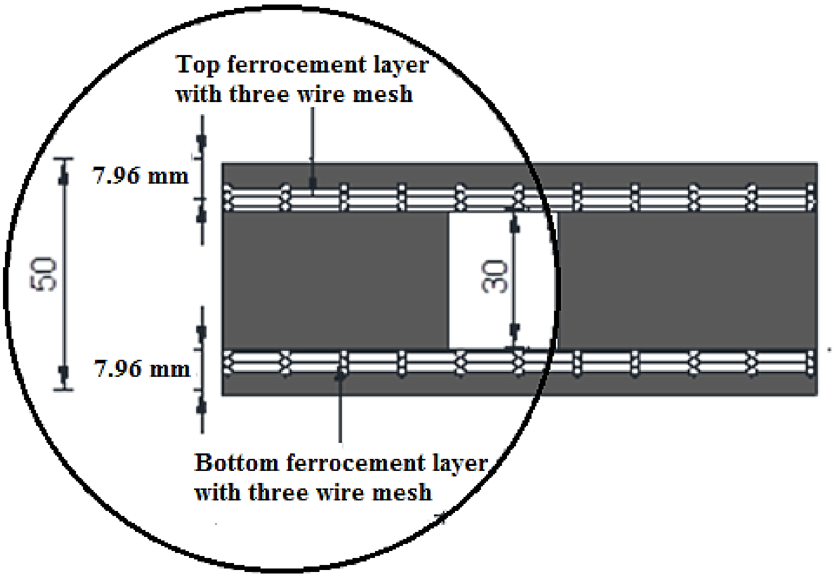


Figure 1. Specimen details; (a) circular ferrocement slab 24% voids ratio of styropor; (b) circular ferrocement slab 48% voids ratio of styropor; (c) slab details and arrangements of 24% voids ratio and steel reinforcement; (d) cross section A-A for slab 24% voids ratio and 4 layer of wire mesh



(a)



(b)

Figure 2. Specimen details; (a) slab details and arrangements of 24% voids ratio and steel reinforcement; (b) cross section A-A for slab 24% voids ratio and 6 layer of wire mesh

2.2.1. Casting and Curing the Specimens

The research program consists of the following steps:

- All structural materials used in this research such as cement, fine aggregate, superplasticizers and wire mesh were tested according to standard specification.
- Layers of wire mesh were cut on circular shape to fit the steel mould. Two or three layers of wire meshes were tied together by using binding wire. Then the layers of wire meshes and styropor were linked together by links of two or three layers of wire meshes from the bottom and two or three layers of wire meshes from the top.
- Preparing the molds and oiling them for easy removal of the specimen when the mould will be opened.
- The mortar was mixed in drum mixer of 0.01 m^3 capacity. The required material in mixture was weighed accurately. The interior surface of drum mixer were cleaned and moisted to decrease the water absorption. The cement and fine aggregate were mixed by using mixer about 2 minutes. Then water and hyperplast were added and mixed 3 minutes to get homogenous mixture. Thin layer of mortar were put in the base of the mould which does not exceed 7-8mm to work as a clear cover. The specimens were vibrated by using a vibrator for about 10 secs. Then, wire mesh and styropor layers were put above a layer of mortar and was vibrated for 15 second to reduce the air bubbles. Finally the face was towelled to be smooth, Figure 3.

(a) **(b)**

(c) (d)

Figure 3. Preparation and casting the specimens: (a) Mould preparation with thin layer of mortar; (b) and (c) Casting mortar after arrange the wire mesh and styropor at different ratios; (d) Finally the face was towelled to be smooth

2.3. Testing of Ferrocement Slab under Impact Load

The specimen has been tested under drop-weight to study the impact resistance of ferrocement slabs [20]. The steel loading frame was manufactured from box and (C–shape) section, which was welded on octal shape. In fact the steel shaft diameter 25 mm was welded on octal to provide semi fixed support to the slab over diameter of 750 mm. The main parts of the framework consists of a base to provide semi fixed support to the slab specimens over diameter of 750 mm. The support conditions for the test are shown in Figure 4. Further, the striker consists of spherical head with a mass of 1.53 kg.

3. Results and Discussions

3.1. Ferrocement Slabs Under Impact Loads

Toughness of a material clarifies the ability to absorb energy. It is mostly estimted by the impact test. The widely used test is a type of the drop-weight method, that can be utilized to evluate the relative performance of composites throughout determining the energy absorbed required to cause first crack and full perforation. In this test, the drop height was considered to be 1 m and the mass of the striker is 1.53 kg while the velocity of the striker is 4.429 m/sec. These values give (15 J) per blow.

The impact energy calculated by the following equation:

$$U = n.W.h \tag{1}$$

Where:

U: the impact energy in Joules (N.m)

n: number of blows

m: mass of the hammer in (kg)

W: weight of the hammer in (N)

h: the drop height in (m)

The impact energy for first crack and full perforation for circular ferrocement slabs is shown in Table 4. we find the impact energy for first crack and full perforation has increased by 41.991 and 37.62%, and 21.7 and 9.94% respectively, when using 6 wire mesh layers and voids by ratios of 24, 48%, respectively in slabs compared to the slab when using 4 wire mesh layers and voids by ratios of 24 and 48% respectively, are shown in Table 3, Figures 5 and 6.

Table 3. Impact test results of ferrocement slab specimens

Specimen symbol	Thickness of slabs (mm)	Thickness of styropor (mm)	Number of wire mesh layer	Voids percentage %	Number of blows for first crack	Impact energy (J) for first crack	Number of blows for full perforation	Impact energy (J) for full perforation
CS 4, 24	50	30	4	24	231	3465	894	13410
CS 4, 48	50	30	4	48	202	3030	754	11310
CS 6, 24	50	30	6	24	328	4920	1088	16320
CS 6, 48	50	30	6	48	278	4170	829	12435

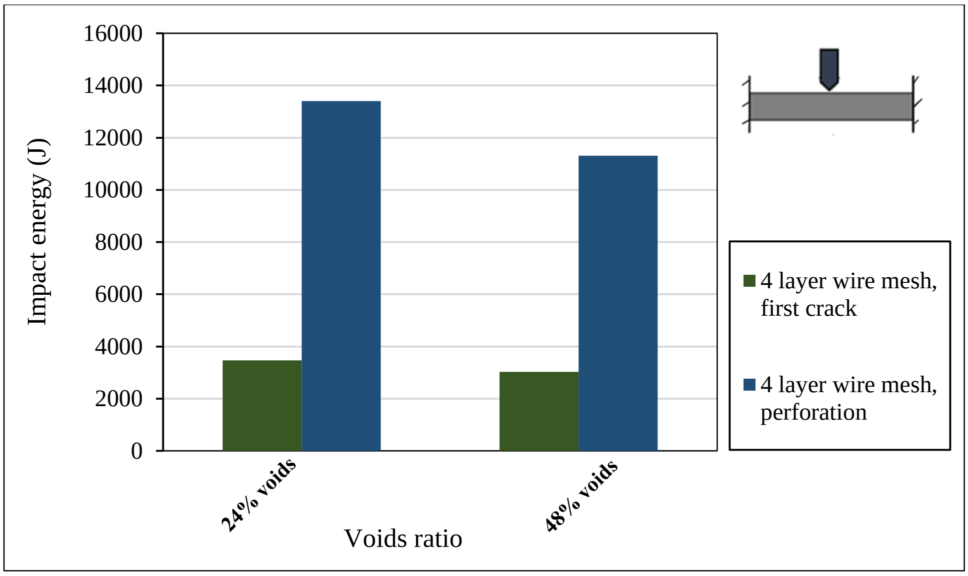


Figure 5. Effect of 24 and 48% voids ratio with wire mesh 4 layer on the absorbed energy at first crack and full perforation

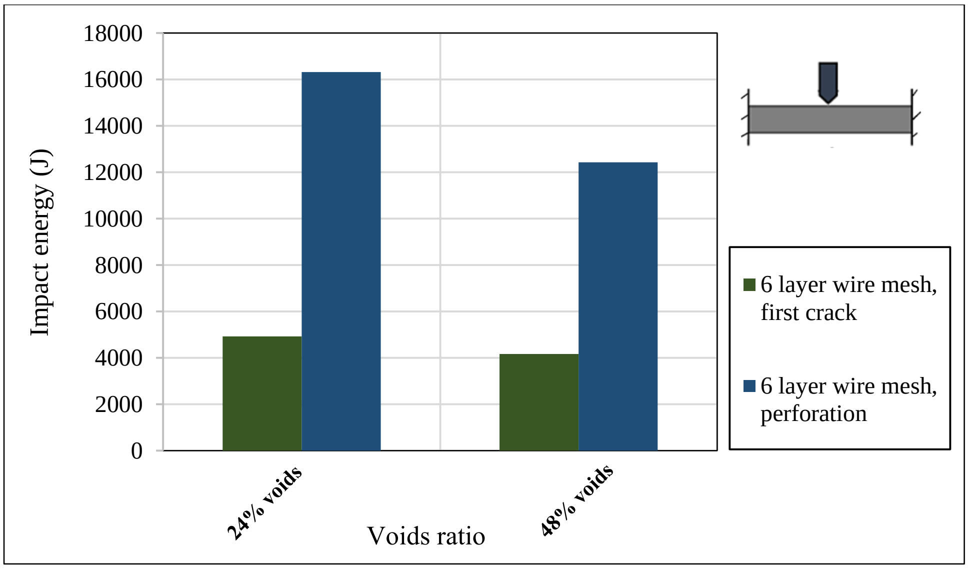


Figure 6. Effect of 24 and 48% voids ratio with wire mesh 6 layer on the absorbed energy at first crack and full perforation

For the same voids ratio and a larger number of wire mesh layers, it is observed that the impact energy for first crack and full perforation increases with the increasing of the number of wire mesh layers, because of the increased proportion of steel meshes in the samples. Results of the increment in volume fraction of the mesh in longitudinal and transverse directions of the specimens.

3.2. Residual Impact Strength Ratio (Irs)

The "residual impact strength ratio" (Irs) is the ratio of energy absorbed in full perforation of sample to the energy absorbed at initiation of first crack , the (Irs) value given in Figure 7 [12].

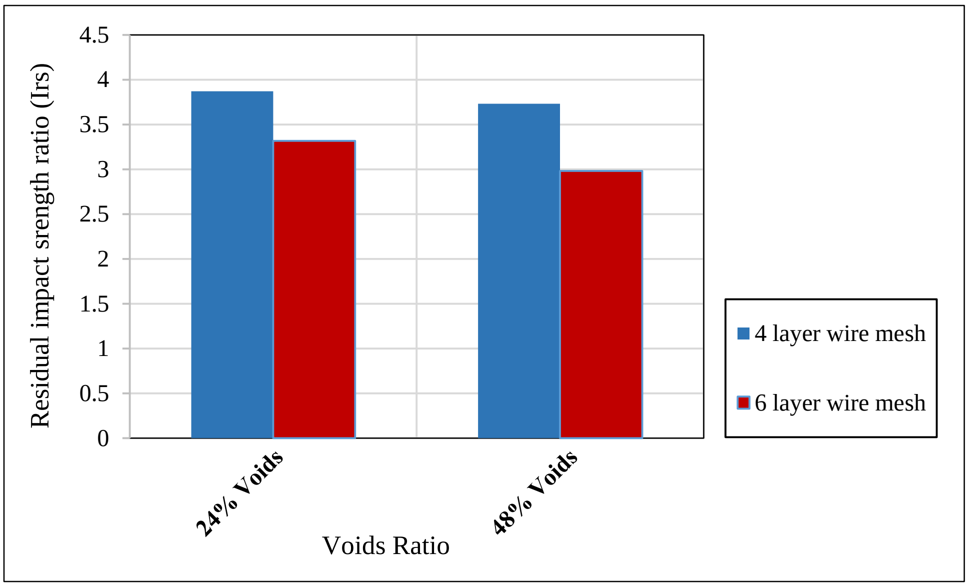


Figure 7. Effect of voids ratio and number of wire mesh on the slabs

3.3. Modes of Failure

The damage was mainly localized at the point of contact and only small fragments fell from the slabs, the crack pattern depended on the specific surface of mesh reinforcement and the impact energy. In general, the increase of specific surface of reinforcement tend to increase in number of cracks, however, the crack length and width decreased. With the increasing in number of blows, the crater depth increased and crack running from the point of contact towards edges and corners of the slab were generated. Characteristics of failures are shown in Figures 8 and 9.

Figure 8. Mode of failure of specimen; (a) with 4 wire mesh layer and 24% voids ratio, (b) with 6 wire mesh layer and 24% voids ratio

Figure 9. Mode of failure of specimen; (a) with 4 wire mesh layer and 48% voids ratio, (b) with 6 wire mesh layer and 48% voids ratio

4. Conclusions

The following conclusions can be drawn from this study:

- The impact energy for first crack and full perforation has increased by (41.991 and 37.62%) and (21.7 and 9.94%) respectively, when using 6 wire mesh layers and voids by ratios of (24 and 48%) respectively in slabs compared to the slab when using 4 wire mesh layers and voids by ratios of (24 and 48%) respectively.
- Increasing the voids ratio decrease in impact energy to cause first crack and full penetration.
- For the same voids ratio and increased number of mesh layers, it was observed that the impact energy increase with increasing the number of wire mesh layers, because of the increased proportion of steel meshes in the samples.
- For slab tested under impact load, the failure of specimen damage was local to the impact site, manifested by mortar spallation at the bottom face of the slab.
- The weight of ferrocement specimens has decreased by ratio of (12 and 24%) when used voids by ratio of (24 and 48%) respectively.

5. Acknowledgment

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6. Conflicts of Interest

The authors declare no conflict of interest.

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