Structural Behavior of Ferrocement Panels Exposed to Fire

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Abstract

In this experimental investigation cement mortar panels reinforced with different type of meshes were subjected to impact load after exposure to fire. Five groups of sandwich ferrocement panels (400x400x30mm in dimensions) had been cast and exposed to firing temperature up to 700°C. Then the panels were tested using drop impact loading to measure the energy absorption of the specimens after firing. The variable parameters were type and number of mesh and styrofoam content. The results showed that the impact resistance of all groups of panels was significantly decreased when exposed to fire. Firing had little effect on strain energy for panels having a layer of styrofoam at the center. Different crack types and failure modes were observed due to the variety in number and type of meshes and percentage content of styrofoam. Numbers of blows were increased due to increase of number of mesh layers.

Keywords: Ferro cement, Firing, Impact, Styrofoam, Wire mesh.

1- Introduction

In many countries where housing deterioration due to environmental conditions is common, ferrocement has been established as environmental friendly low cost building technology. It possesses incomparable properties such as good strength/weight ratio, water proofing, improved toughness, fire resistance, light weight and speed in construction. ACI Code defined "ferrocement as a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials". Nowadays ferrocement construction technology is relatively common throughout the world. As a result of explosions close to buildings, structures may be subjected to fire and impact stresses. The damages affected by fire and impact stresses may be reduced by conducting various researches on response of building materials, especially structures consisting of ferrocement units. Various methods of test instrumentations have been used by researchers to estimate the impact stresses due to the lack of standard method for impact testing.

In general, impact resistance is measured by the amount of energy absorbed during the impact test loadings Nagan and Mohana (2014)(1), ACI Committee 549(2004)(2), and Eltehawy (2009)(3) Alwiset et.al. (2001)(4) conducted experimental program to study the properties of sandwich ferrocement panels under lateral load, whereas most of the researchers were using the drop-mass test to estimate the related response of ferrocement units. Sasiekalaa and Malathy (2012)(5) and Abdullah (2016)(6) concluded from their experimental studies that the increase in volume fraction of mesh reinforcement in ferrocement units increases the energy absorption of drop weight on the surface of the specimens. Murali et.al (2011)(7) carried out an experimental survey on ferrocement panels with different type of mesh and subjected to impact load. Their test results showed higher energy absorption in expanded metal mesh as they were capable of controlling propagation of cracks.

Thirumal (2012)(8) tested ferrocement plates (250mmX 250mmX25mm) consisting of galvanized steel mesh and synthetic polyofin fiber, the results showed that the increase of polyofin and volume fraction of meshes increases the absorption of energy. Fire resistance and thermal properties of ferrocement units have also been interested by investigators. Husain et.al. (2010)(9) and Greepala and Nimityongskul (2009)(10) conducted experimental investigations on reinforced concrete (RC) slabs reinforced with ferrocement plates. The results showed that the use of ferrocement as reinforcement in concrete slabs improved the fire resistance and crack propagation at (700°C) and reduced the heat transfer through. Based on the research data from the previous study performed by the authors, ferrocement panels have an endurance of fire when compared to control panels and may provide a desired protection against fire Kadir and Abdullah(2016) (11). Previous researches have focused on the mechanical properties of ferrocement, fire and impact resistance separately. There are no researches conducted to evaluate the properties of ferrocement panels subjected to impact load after exposure to fire.

2- Research Significance

The purpose of this experimental investigation is to study the behavior of sandwich ferrocement panels subjected to drop impact loading after being exposed to fire for 60minutes. Galvanized and plastic meshes have been used as reinforcement material to the cement paste. Styrofoam grains are dispersed randomly at the center between the two reinforced mortar layers of the panels. The conclusion of this experimental investigation may be used to enhance the impact resistance of structures consisting of ferrocement elements when subjected to explosion and fire stresses.

3- Experimental Program

The following variables are taken into account to study their effect on the impact properties of the panels after exposure to fire:

1- Types of mesh used.
2- The presence of styrofoam dispersed between layers of the mesh reinforcement.
3- Number of mesh layers used.

Details of the tested panels are summarized in Table 1.

4- Materials

The properties of the materials used for casting the ferrocement panels are listed in Tables 2 to 5. The following paragraphs describe the materials used.

a- Cement

Ordinary Portland cement Type -1- produced by Tasluja factory in Suleimany city is used through the casting process of the panels. It is kept in sacks under airtight plastic covers to avoid prehydration due to humidity effect. The chemical composition of the cement is presented in Table 2 and cement physical properties are shown in Table 3. The results conform to the (Iraqi standard No. 5/1999 limits) (12)

b- Sand

The fine aggregate used in this investigation was brought from (local river) Darbandikhan region 80km south eastern of Sulaimani City. The grading and fineness moduli are shown in Table 4. The results conform to the (Iraqi standard No. 45/1999 limits) (13). The physical properties of sand are shown in Table 5.

c- Mesh

Galvanized wire mesh of (0.70mm) diameter with hexagonal openings about (5x7mm) and plastic mesh of (0.7mm) diameter with square openings about (5x5mm) is used. The meshes are tested directly for tension (14). The test is carried out on selected individual samples using Instron testing machine as shown in Figure 1. Results are automatically recorded by a plotter attached to the testing machine. The purpose of these tensile tests is to determine the stress-strain relationship of sample of the wire meshes. Figure 2 shows the stress-strain relationships for the tested wire meshes.

d- Styrofoam

Styrofoam is regarded as an organic material composed of Polyhydral and Polystyrene taken from Petroleum products. The raw material used in this investigation is taken from Al-Bahrany company-Baghdad. Its density ranged between 15 and 35 kg/m^3. The cells are obtained through expansion of molten plastic grains to about 20 times its volume (ASTM-C236) (15) and then cooled down under room temperature and carefully stored in special packages when dried.

5- Casting of Specimens

The tested panels dimensions are 400x400x30mm.The specimens consist of cement-sand paste (ratio 1:2), water-cement ratio 0.40 by weight. The cement and dry sand are mixed thoroughly then water is added to obtain a workable matrix. Special molds made of steel angles are used for casting process. The thickness of the matrix layers and smoothing lower surface of the panels are controlled by using wooden rods and 4mm thick glass. The lamination process started with placing first layer of prepared mortar into the mold, then the mesh layer is placed in the mold and Styrofoam grains dispersed to form a thin layer followed by the last matrix layer. A template was made and used according to ASTM (2002)(16) standard for hand compaction of each layer of the matrix. Special tools are used for straightening and smoothening the upper surface of the sandwich panels as shown in Figure 3.

6- Curing

After 24 hours from casting and demolding the specimens, they were put in a special water tank for curing up to 28 days.

7- Firing process of panels

The panels were exposed to fire in a special chamber assembled according to ASTM (E119) (17) for 60 minutes, as shown in Figure 4. Each panel was placed inside the chamber to be easily exposed to fire as shown. Five thermocouples were installed on the top surface of the panels for monitoring the side unexposed to fire; one of them at the center and the others at the four corners of the specimen. One thermocouple to measure the fire flame is placed close to the fire source. Digital thermometers connected to the thermocouples are used to measure the temperature. Every10 minutes temperatures are recorded up to 360˚C for the top surface of the ferrocement panels whereas the temperature of the flame reached 700˚C. The fire was turned off from the Liquid Propane gas source and the panels were left to cool down at room temperature. After cooling down the panels were inspected visually to investigate any significant changes before impact load testing.

8- Impact load process

A special steel frame was built for the purpose of dropping a load from the desired height on the simply supported panels. The ferrocement specimens were placed on the supports inside the impact frame and the steel ball left to hit vertically (by gravity) the surface of the panels as shown in Figure 5. All the sandwich ferrocement panels were tested after age of 28 days and compared to the control panels. According to ASTM (1709)(18),revision 16A,May 2016 and applied by UL(60950) and ECE (R21).The ball with 3.0 kg mass was dropped from the height of 1.30 m on the center of top surface of the panel and the cracks were recorded. As the procedure was repeated, it resulted in appearance of more new cracks, expanding surface cracks, spalling of mortar and split of the layers of the panels up to collapse or failure.

9- Results and discussion

The weight of the ball was constant and dropped from a fixed height (1.30 m) for every impact test according to ASTM 1709. Table 6 summarize the drop test results of the panels (average of three test panels for each group), without firing and those after being exposed to fire flux 700˚C. The difference of temperature degree between leeward surface and backward surface was 340˚C. Number of blows which caused the first crack and failure are shown to indicate the first and final loads. The energy absorbed by the panels as the ball dropped on its surface after exposed to a limited duration of fire is shown in Figure 6. The ultimate strain energy of the panels (P1- 0.00, P1-0.50, P2- 0.50, S1- 0.00 and S2-0.50) were (2, 7, 10, 3, and 5) times that of the control panel, respectively as shown Table 6. The highest value of strain energy absorption is in sandwich ferrocement panel (P2-0.50) due to both high plastic mesh and percentage of styrofoam content. The increase of single plastic layer for the panels changed the first crack strain energy from 38.26N.m to 76.62N.m, whereas styrofoam content increased to 0.50%, the strain energy also increased to 267.82N.m.as summarized in Table 6. This increase may be due to the properties of plastic materials for both mesh and Styrofoam. The decrease of absorption energy was (25%, 47%, 40%, 60%, and 71%) for panels (P1- 0.00, P1-0.50, P2- 0.50, S1- 0.00 and S2-0.50) respectively, as compared to panels not exposed to fire as summarized in Table 6. As the panels were freely set on the steel frame, the number of blows was unexpectedly small may be due to more absorbed energy by the paste and mesh layers. Also the thermal stresses had effect on damaging the bond between the paste and mesh particles, leads to decreasing the number of blows. In-plane cracks, mesh-induced cracks, spalling and change in color were observed on the ferrocement panels after exposure to fire before carrying out the impact test. The effect of fire on the sandwich ferrocement panels with plastic wire mesh was more significant than those with steel meshes. The presence of both plastic mesh and percentage of Styrofoam together, had an important effect on increasing failure load and number of blows. The first crack of each panel appeared at the center of the panel at point of load contact and propagated on the surface towards the edges of the panels. Larger number and wider cracks were observed in the panels with plastic meshes and styrofoam compared to the panels with steel meshes. Impact dents happened on the upper surface of all panels and penetrated to the lower surface of the panels. Separation of the layers was observed at the failure load with split of some particles of upper and lower surfaces. Generally the results showed that the numbers of blows to cause cracking were increased with increasing the number of meshes, for those exposed to fire as well. All cracking modes are shown in Figure 7.

10- Conclusions

Based on the limited impact tests carried out in this investigation on sandwich ferrocement panels exposed to fire, the followings can be concluded:

1- The impact resistance of all ferrocement panels was decreased when exposed to fire in the range of 25% -75% compared to panels not exposed to fire due to reduced bond between the mortar particles and wire meshes.
2- Panels containing styrofoam layer had more impact resistance in the range of 40% to 70% compared to others without styrofoam grains, this is due to more energy absorption capacity of styrofoam materials.
3- In-plane cracks, mesh-induced cracks, spalling and change in color were observed on the ferrocement panels after exposure to fire before carrying out the impact test.
4- Different types of failure modes were observed due to non-homogeneity of the panels and variety of materials response to impact stresses.
5- Strain energy required to cause both first crack and failure were less for panels with plastic meshes without styrofoam grains compared to panels with steel meshes (50% and 35% for cracking and failure respectively); this may be due to melting of the plastic mesh material.
6- The effect of fire on the sandwich ferrocement panels with plastic wire mesh was more significant than those with steel meshes due to the difference of their behavior under fire.
7- Impact dents happened on the upper surface of all panels and penetrated to the lower surface of the panels at failure for panels with meshes whereas sudden failure occurred for panels without meshes.

8- Separation of the layers was also observed at failure load for panels with styrofoam due to the effect of firing on decreasing the bond between sandwich layers.
9- Panels containing plastic meshes and styrofoam materials had more impact resistance in the range of 50% to 60% compared to panels with steel meshes
10. Generally the results showed that the numbers of blows to cause cracking were increased with increasing the number of meshes for panels not exposed to fire.

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السلوك الانشائي لألواح الفيروسمنت المعرضة للنار

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المستخلص :

تم في هذا البحث التجريبي تعريض مجموعة من الالواح الاسمنتية المقواة بانواع مختلفة من المشبك الى الحمل الصدمي بعد تعرضها الى النار. ولهذا الفرض تم صب خمس مجموعات من الواح الفيروسمنت بابعاد 400×400×30 ملم ، وعرضت لحرارة لهب النار بدرجة 700 ، وبعدها تم اختبار اللوحات باستخدام الاحمال الصدمية و تاثير التحميل على امتصاص الطاقة في تلك العينات بعد تعرضها الى النار.

تم اعتماد المتغيرات لانواع وعدد من المشبكات التي تحتوى على مادة الستايروفوم. اظهرت النتائج ان مقاومة جميع الالواح انخفضت بشكل ملحوظ عند تعرضها للنار. وكان تاثير النار قليل على الطاقة الكامنة للوحات المحتوية على مادة الستايروفوم. ولقد تم ملاحظة انواع مختلفة من التشققات وانماط الفشل بسبب تنوع عدد ونوع المشبكات والنسبة المئوية لمادة الستايروفوم. وتم زيادة عدد الضربات للحمل الصدمي بسبب زيادة عدد طبقات المشبك.

الكلمات المفتاحية : فيروسمنت ، لهيب النار ، الاحمال الصدمية ، ستايروفوم ، المشبك السلكي.

Table 1: Details of Specimens. (by researcher)

Groups	Sandwich panels detail			Wire mesh details
	Plastic mesh layers	**Galvanized mesh layers**	**% of Styrofoam by weight**	
C- 0.00 Control panel	----	----	0.00	----
P1- 0.00	1	----	0.00	Plastic type with square openings
P1- 0.50	1	----	0.50	
P2- 0.50	2	----	0.50	
S1- 0.00	----	1	0.00	Galvanized type with hexagonal openings
S2- 0.50	----	2	0.50	

Table 2: Chemical Composition of Cement. (by researcher)

No.	Chemical Composition	Tested Cement%	Iraqi Standard (5) (14) No.5 /1999 Limits,%
1	SiO_2	20.25	Nil
2	CaO	61.46	Nil
3	MgO	2.25	≤ 5.00
4	Fe_2O_3	2.85	Nil
5	AL_2O_3	4.17	Nil
6	SO_3	2.53	≤ 2.80
7	Loss on ignition	2.78	≤ 4.00
8	Insoluble residue	1.36	≤ 1.50
9	Lime Saturated Factor	0.86	0.66-1.02
10	C_3A	8.85	≥ 5.00
11	C_3S	41.63%	Nil
12	C_2S	27.42%	Nil
13	C_4AF	12.11%	Nil
14	K_2O	Nil	Nil
15	Na_2O	Nil	Nil

Table 3: Physical Properties of Cement. (by researcher)

No.	Property		Test Results	Iraqi Standard (5) (14) No.5 /1999 Limits,%
1	Initial Setting Time		89 min.	Greater than 45min.
2	Final Setting Time		256 min.	Not greater than 600min.
3	Fineness (Blaine), m^2/ kg		315	Greater than 230
4	Compressive Strength (MPa)	3days	17.5	Greater than 15
		7days	25.7	Greater than 23

Table 4: Sand properties. (by researcher)

Sieve size ASTM	Percent passing	Allowable passing	Percent retained (cumulative)
2.36mm	82.56	80-100	16.90
1.18mm	68.15	50-85	29.83
0.60mm	54.30	25-60	45.40
0.30mm	28.6	10-30	72.30
0.15mm	7.95	2-10	90.78
			∑ 255.21

Fineness modulus of sand used = 255.21/100= 2.55

Table 5: Physical properties of fine aggregate (sand). (by researcher)

Physical properties	Test results	Limit of Iraqi specification No.45/1984(13)
Percentage of Sulphate content	0.42	≤ 0.50%
Specific gravity	2.60	-------
Percentage of absorption	1.48	-------
Percentage of materials finer than 75µm	2.50	≤ 5%

Table 6: Average of drop test results. (by researcher)

Ferrocement Group	Number of blows without firing		Number of blows after firing		Strain energy without firing		Strain energy after firing	
	First crack	Failure	First crack	Failure	First crack N.m	Failure N.m	First crack N.m	Failure N.m
C- Control panel	--------	1	--------	1	--------	38.26	--------	38.26
P1- 0.00	3	8	1	2	114.78	306.08	38.26	76.52
P1- 0.50	3	15	2	7	114.78	573.90	76.52	267.82
P2- 0.50	5	25	3	10	191.30	956.50	114.78	382.60
S1- 0.00	2	5	2	3	76.52	191.30	76.52	114.78
S2- 0.50	3	7	4	5	114.78	267.82	153.04	191.30

Energy = number of blows X weight of the ball X height of drop
Where: weight and height are constant (3.0kg mass and 1.30m)respectively

Fig.1: Tensile testing machine (Instron) type used to test the wire mesh. (by researcher)

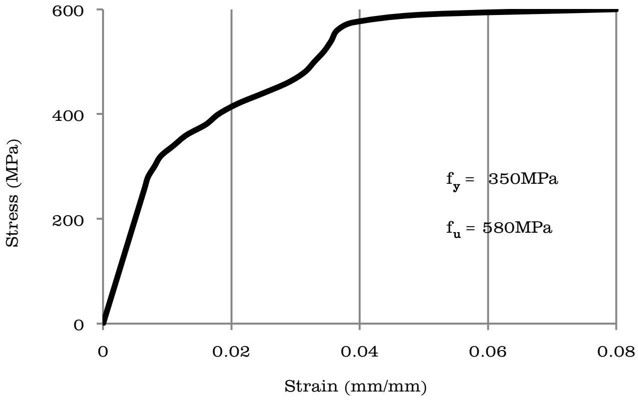


Figure-2- Stress – Strain diagram of wire mesh with square openings. (by researcher)

Fig. 3: **Casting facilities.** (by researcher)

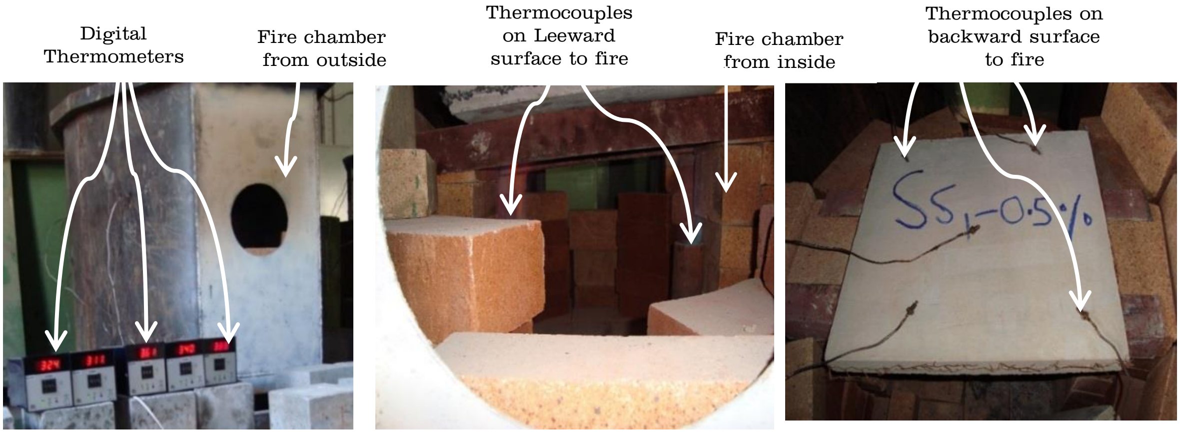
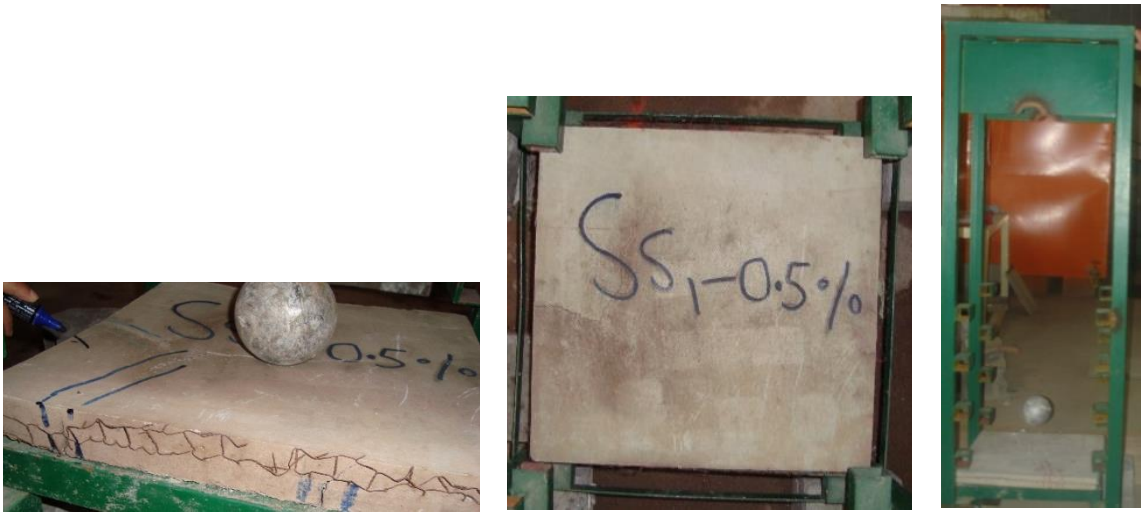


Fig. 4: Details of firing chamber. (by researcher)



a- Effect of drooping load

b- Place of panels inside the testing frame

c- Impact testing frame

Fig. 5: Details of impact test. (by researcher)

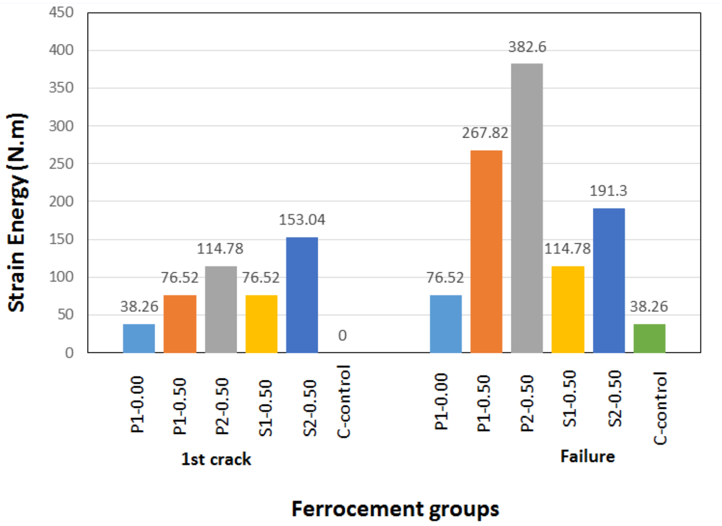


Fig. 6: Impact strength relationships. (by researcher)

a- S1-0.00

b- S2-0.50

c- P1-0.50

d- P2-0.50

e- P1-0.00

Fig.7: Cracks due to impact load for panels after firing. (by researcher)