Fire-Resistance of Styroferrocement Sandwich Panels

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ABSTRACT
This paper investigates the effect of fire on ferrocement sandwich panels. The experimental program consisted of fabricating and testing nine panels (400X400x30 mm in dimensions). The variables were type and number of mesh and Styrophoam content. A special arrangement was designed to create the effect of fire on panels. Test results showed that ferrocement panels have an endurance of fire when compared to control panels which may provide a desired protection to fire. In-spite-of wire mesh cracks, in plane cracks occurred when more volume fraction of mesh included. Whereas Styrophoam content affected the number of in-plane cracks. Plastic wire mesh had no significant effect on the wire mesh-induced cracks.
Keywords: Crack patterns, Fire-damage, Fire-resistance, Styroferrocement, sandwich panels.

INTRODUCTION
Ferrocement is a highly versatile form of reinforced concrete; it differs from conventional reinforced concrete by the arrangement and dispersal of reinforcing element. (1) Ferrocement consists of cement-sand mortar and steel wire mesh reinforcement with small diameters. Styroferrocement means adding Styrofoam layer at the middle of the ferrocement panels. Engineering properties of this construction unit were studied by researchers and well documented. Static and dynamic properties of high performance lightweight ferrocement sandwich panels were improved when the volume fraction of meshes increased.(2)
Husain et al, (3) also in a thermal analysis, showed increasing of thermal conductivity for ferrocement specimens used as a cover layer of light weight concrete sandwich panels.
Fire is one of the greatest risks to the structures which remain the aim of most research in the world. There are many works done for fire resistance and fire endurance of construction materials. Ferrocement as an important unit in constructions has no significant items in codes dealing with its behavior after exposure of fire. Ferrocement jackets found that they perform as confinement units in the improvement of the structural fire protection. (4, 5) The behavior of ferrocement content like steel, mortar and mesh, were studied by researchers at various temperature degrees. (6, 7, 8, 9) There are only few theoretical and experimental studies on the properties of the ferrocement panels exposed to fire.

The aim of this experimental work is to study the effect of direct fire on the confinement and resistance of ferrocement sandwich panels taking into consideration type and number of wire mesh and percentage of Styrophoams content. ASTM E119 (10) standard was used for the experimental program. To achieve that important standard, smoke and hot gas must not pass through cracks developed in the specimen. In this study, behavior and physical properties of sandwich ferrocement panels are investigated after exposure to fire.

Fire endurance: It is the measure of the elapsed time during which a material or assembly continues to exhibit fire resistance under specified conditions of test and performance. As applied to elements of buildings, fire endurance shall be measured by the methods and criteria defined by ASTM Methods E119 (Standard Methods of Fire Tests of Building Construction and Materials). (10)

Fire resistance: It is the fire protection behavior of a material or arrangement pattern. As a construction unit, fire resistance is measured by the ability to restrict a fire or to continue to conduct a special structural function or both. (11)

Fire rating: It is the time required, (in hours), for a construction unit in building to perform its special fire-resistance behavior. The desired fire rating for many construction units of building can be obtained from model codes. (11)

Panel preparation program

It consists of nine square ferrocement panels (400x400x30 mm in dimensions), divided into three series of ferrocement panels and each series consists of four groups except group **A** which consists of the main specimen as control for the others with no mesh and Styrophoam. Groups **B** and **C** are classified according to the number and wire mesh material and percentage of Styrophoam content (see table 1).

Table (1) Details of test specimens

Groups	Tile designation	Panels detail			Wire mesh details
		Galvanized mesh layers	Plastic mesh layers	Styrophoam content	
A Control	S1- 0.00%	----	----	0.00%	----
B	SP1- 0.00%	----	One	0.00%	Plastic type with large hexagonal openings
	SP1- 0.50%	----	One	0.50%	
	SP2- 0.00%	----	Two	0.00%	
	SP2- 0.50%	----	Two	0.50%	
C	SP1- 0.00%	One	----	0.00%	Galvanized type with large hexagonal openings
	SP1- 0.50%	One	----	0.50%	
	SP2- 0.00%	Two	----	0.00%	
	SP2- 0.50%	Two	----	0.50%	

Group A was organized to observe behavior of the control panel when exposed to fire. Panels of group **B** consist of plastic mesh with large openings and Styrophoam while group panels **C** was arranged to study the effect of galvanized wire mesh with large openings and with Styrophoam 0.50% of mortar content. Both groups **B** and **C** were prepared to observe the effect of increasing wire mesh volume fraction from 0.0% to 8.15% and 16.3% which was equivalent to 0, 1 and 2 layers of wire mesh, respectively. The last two groups were also prepared to investigate the effect of inclusion of Styrophoam 0.50% of mortar content by weight.

Material and mix-design

Ordinary Portland cement according to the Iraqi standard 45 no. 5/1984 limits is used with well graded river sand of 2.36 mm maximum size according to I.O.S. 45/ 1984-Sand (12, 13). Locally available wire mesh of 0.7 mm wire diameter and plastic mesh were used. The mix proportion of 1:2 cement-sand mortars is used with water cement ratio of 0.50 by weight. Galvanized wire mesh of 0.70mm diameter and plastic mesh were used. Styrophoam grains available in local markets were used for intermediate layer of panels (see plate 1).

Mold preparation

The forms were designed to give clear dimension of 400mmX400mm tiles. They were made of 4 equal leg angles 50.8mm X 50.8mm in size see figure (1.a) which were fixed through bolt-net system so as to yield a portable form. Smooth face wooden rods of various thicknesses ranging from 23mm to 33mm were furnished in the molds to control tile thickness with a light gauge plate of 1mm thickness (see plate 2), such assembly formed the base of the molds.

Lamination Process and curing:

The tiles used consist of separate sequential layers of mortar made from cement-sand matrix followed by the foam grains dispersed to form a discrete thin layer, and then the required layers of wire meshes were furnished and covered with another discrete film of Styrophoam grains followed by a finishing layer of mortar. Firstly, the steel mould was placed on a table and oiled (see plate 3). After the first layer of mortar was cast, the prepared mesh layers were held in position and straightened by hand pulled and fixed to the sides of the mould by tightening wires (see plate 4). The panels were cast in two layers, and each layer was compacted by hand until no further air bubbles appeared on its surface (see plate 5). The specimens were demoulded after 24 hours and put into water for curing up to 28days (see Plate 6).

Plate 1: Galvanized hexagonal steel wire mesh.

Plate 2: Plastic wire mesh.

Plate (3): Specimen thickness control.

Plate (4): Furnishing and oiling light gauge base of the form.

Plate (5): Plastic mesh layout

Plate (6): Cast ferrocement panel.

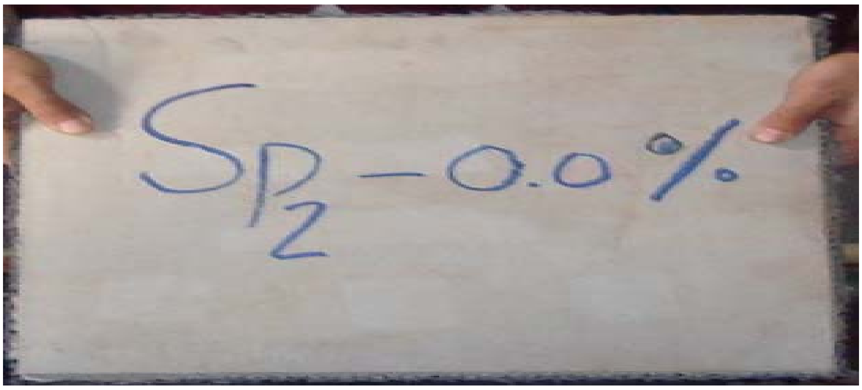


Plate (7): Prepared ferrocement panel to fire exposure.

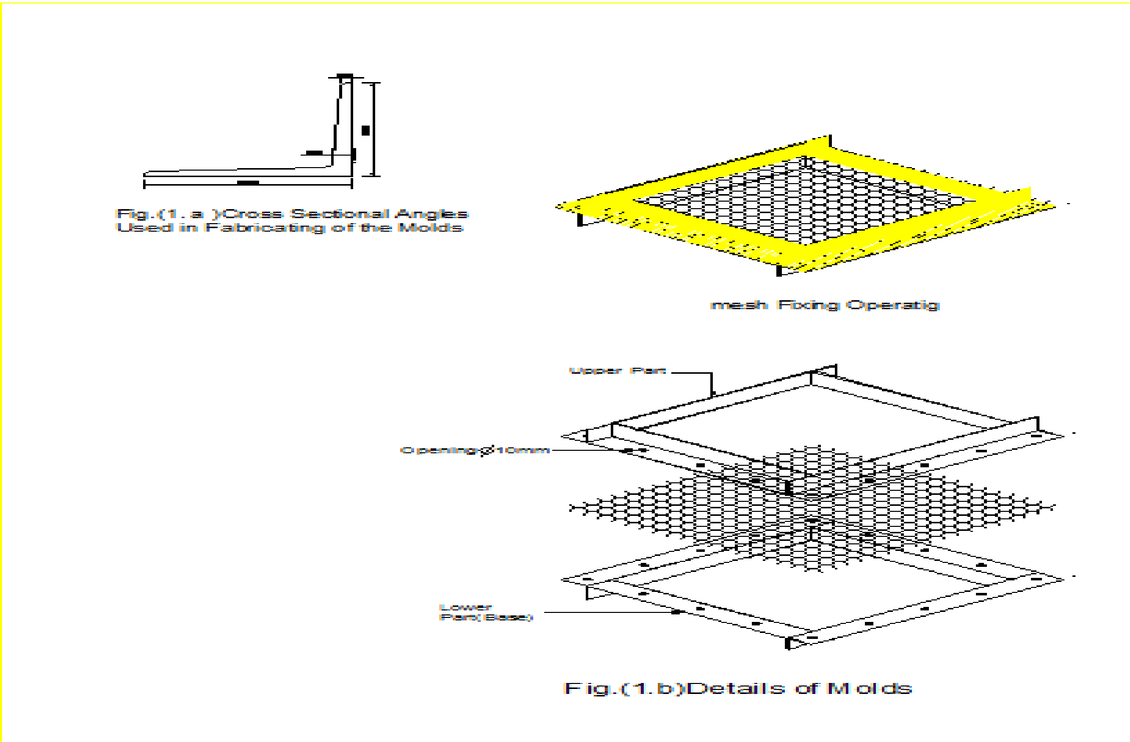


Figure.(1) Details of Molds

Fire exposure process

Each panel was tested for fire resistance by placing it in a prepared chamber which was built according to ASTM E119. The fuel used for fire was liquid gas (see figure 2).

Figure (2): The chamber for fire test

After 28 days of curing for the panels, the process of firing started by exposing the panels to fire inside the mentioned chamber.

Four thermocouples were placed at the unexposed surface of the sandwich panel to monitor the temperature readings at the different points on the surface of the panel by digital thermometers outside the chamber, and one for controlling the temperature of the chamber.

The time-temperature envelope pattern followed is as shown in figure ٣, which corresponds to ASTM E119 firing process.

After being exposed to fire for 3 hours, the panels were left to cool down to room temperature in the furnace before the visual inspection.

Visual inspection and deterioration of ferrocement panels

The results of fire exposure on the behavior of sandwich panels were recorded, such as occurrence of cracks, change in color and shape, spalling and failure patterns. Types of failure according to visual inspection were depth and width of cracks, also spalling of the matrix. The sandwich panels exposed to fire had enough cracks for passing smoke or hot gas through, were assumed to be completely damaged.

Results and Discussions

Figure ٤ and table 3, shows type of cracks, failure mode and changing in color of panels after exposure to fire. If number and type of cracks are not sufficient for smoke or hot gasses pass through, the panel considered to be within ASTM E119 criterion. (10,11) In this research, three types of failure modes were observed; cracks due to wire mesh, in-plane-matrix cracks and spalling of matrix.

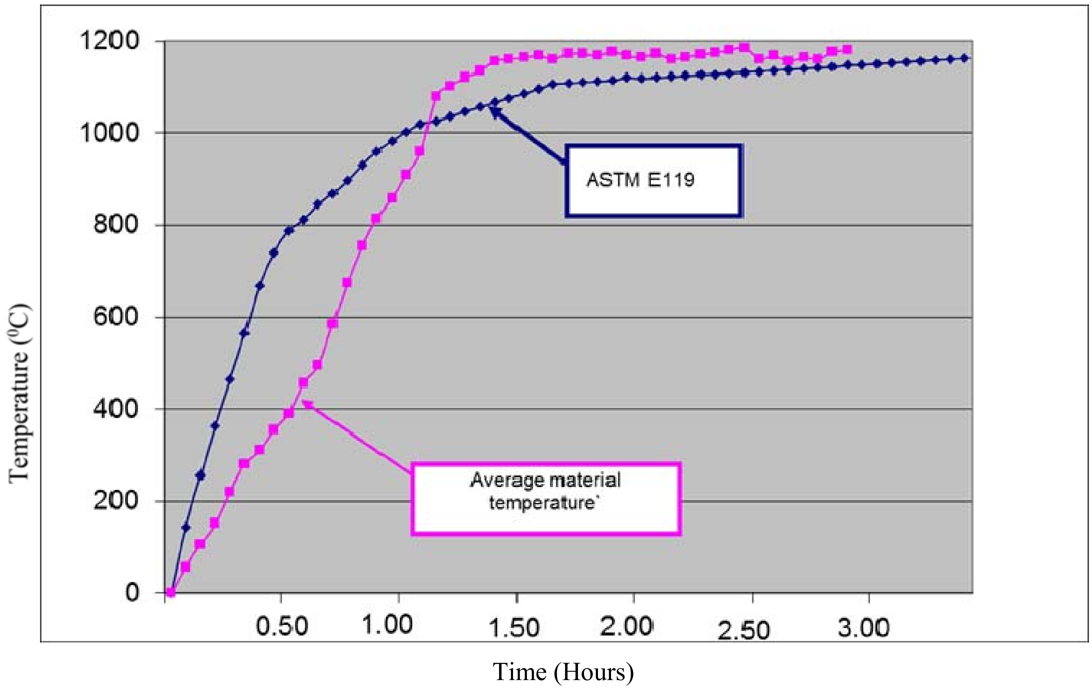


Figure 3: Time-temperature relationship

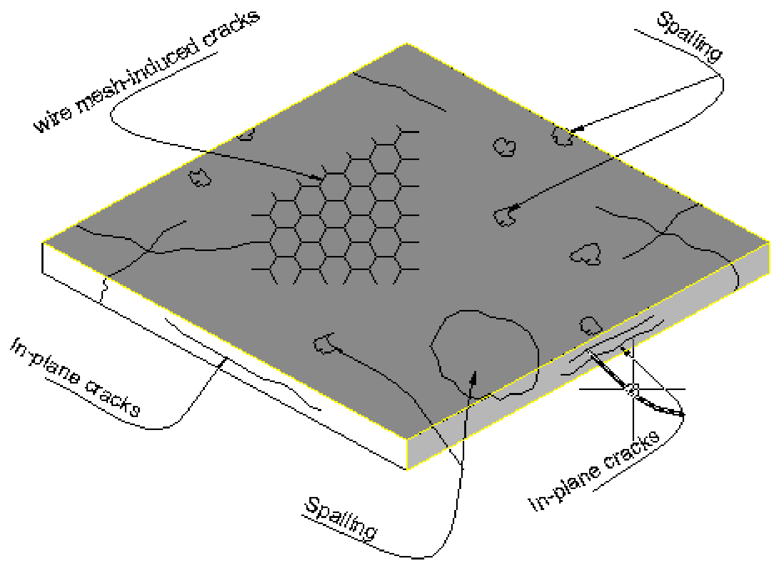


Figure 4: crack patterns of ferrocement panels exposed to fire.

Table 3: Sandwich panels failure modes after exposure to fire

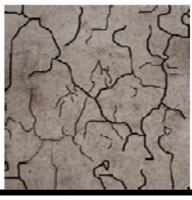
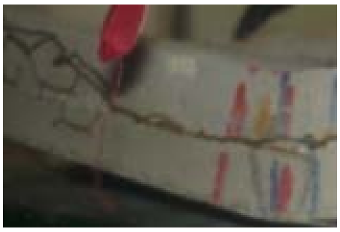
Type of panel	Failure mode of panels exposed to fire
1- Effect of type of the mesh	
S1-0.00%	
SP2-0.00%	
SS2-0.00%	
2-Effect of number of wire mesh content	
SP1-0.00%	
SP2-0.00%	
SS1-0.00%	
SS2-0.00%	

Table 3 Continued

Type of panel	Failure mode of panels exposed to fire
3-Effect of Styrophoam content	
SP1-0.50%	
SP2-0.50%	
SS1-0.50%	
SS2-0.50%	

Cracks due to wire mesh content

On the surface of the sandwich panels, cracks due to galvanized mesh content were observed looking like the shape of the hexagonal wire, especially where the mortar cover was thin. This type of cracks may be due to increasing the diameter of the wire mesh. However for panels with plastic mesh, there were no such significant wire mesh cracks.

In -plane cracks

Horizontal in-plane cracks on the sides of sandwich panels were observed. These cracks have parallel configuration with mesh layers, whereas the amount and intensity of cracks depend on the value of mesh content. This failure mode may be due to increasing the volume fraction of wire mesh as the area between wire mesh layers reduced. The shear bond failure will occur between matrix and mesh layers resulting delamination of wire mesh and matrix bond. (14)

Spalling of matrix

Pressure from evaporation of cement hydration causes breaking off matrix from the sandwich surface and producing spalling. When the shear strength between mesh layers and mortar is little, spalling may occur easier. The spalling may have occurred because of fast sudden discharge of vapor. This failure mode was seen on the sandwich surface of some panels whereas they did not occur on the others. Furthermore, the wire mesh content reduced the amount and size of spalling.

The color of the panel surface was found to be lighter after exposure to fire than before fire exposure, and the color change corresponded to the color change of concrete subjected to high temperature as reported by Georgali and Tsakiridis. (15)

Effect of number of wire meshes

Variety of failure modes and visible damage were observed due to increase of volume fraction of wire mesh content. Control sandwich panels have only vertical cracks at the sides of specimens. The width of this type of cracks was reduced by increasing layers of wire mesh. Whereas, in-plane and wire mesh cracks still occur. The number of in-plane cracks increased also by increasing mesh volume fraction. Spalling of matrix was observed when volume fraction increased to 16.30%.

For panels with plastic meshes, only few cracks due wire mesh and little in-plane cracks were observed in the sandwich panels and less than those occurred when the panels consist of galvanized mesh. This may be due to, at higher temperatures the plastic mesh melts, thus reducing the expansion of the mesh within the matrix causing less cracks.

In panels with 0.50% of Styrophoam, in spite of wire induced cracks, the number of in-plane cracks was increased due to the large deference between the thermal coefficient of mortar and Styrophoam materials, causing separation between the two materials and cracks occurred.

CONCLUSION

The influence of fire on the sandwich ferrocement panels with various types and numbers of wire mesh with Styrophoam content was experimentally studied and the followings were concluded:

1. Three types of failure modes were observed on the sandwich panels after firing process:
   a. Cracks due to wire mesh.
   b. In-plane mortar cracks.
   c. Mortar spalling.
2. Increasing the number of wire mesh increased the number and types of cracks.
3. Styrophoam content increased the number of in-plane cracks.
4. Wire induced cracks were visible for panels with galvanized steel wire mesh, whereas they were not significantly seen for panels with plastic wire mesh.

REFERENCES

[1]- ACI Committee 549, 2004 “State-of-the-Art Report on Ferrocement,” Report No.549R-1997, American Concrete Institute, MCP, Part VI.

[2]- Husain M. H., Raouf A. Z. and Khalil I. W. 2009, "Properties of High Performance Lightweight Concrete Sandwich Panels Using Local Additives," Engineering and Technology Journal, Vol.27, No.3.
[3]- Husain M. H., Raouf A. Z. and Khalil I. W. 2010, "Thermal Analysis of High Performance Lightweight Concrete Sandwich Panels," Engineering and Technology Journal, Vol.28, No.21.
[4]- Greepala V. and Nimityoungskul P. (2009), "Influence of Heating Envelope on Structural Fire Integrity of Ferrocement Jackets," Kasetsart University Chalermphrakiat Sakonnakhon Province Campus, 59 Moolsakonnakhon-akhonphranom Rd., 47000 Thailand.
[5]- Kodur VKR (1999), "Fire performance of high-strength concrete structural members," Constr Technol Update 31:1–4
[6]- Outinen J, Makelainen P (2002), "High-temperature strength of structural steel and residual strength after cooling down," In: Proceedings of the international colloquium on stability and ductility of steel structures, Budapest, Hungary, pp 753–760.
[7]- Phan LT, Carino NJ (2002), "Effects of test conditions and mixture proportions on behaviour of high-strength concrete exposed to high temperatures,". ACI Mater J 99(1):54–56
[8]- Outinen J, Kaitila O, Makelainen P (2001), "High-temperature testing of structural steel and modelling of structures at fire temperatures," In: Laboratory of steel structures publications Espoo
[9]- Naaman, AE. (2000). "Ferrocement and Laminated Cementitious Composites," Ann Arbor, Michigan, USA: Techno Press.
[10]- ASTM, American Society for Testing and Material (2004), "Standard Test Methods for Fire Tests of Building Construction and Materials, ASTM E119-00," Annual Book of ASTM Standards. West Conshohocken, PA. United States.
[11]- Building Construction Information from the concrete and masonry Industries, (2011) "Analytical Methods of Determining Fire Endurance of Concrete and Masonry Members-Model Code Approved Procedures," No.13 OF A SERIES. Printed in USA.
[12]- (I.O.S. 5/ 1984) المواصفة القياسية العراقية رقم (٥) لسنة ١٩٨٤
للسمنت البورتلاندي
[13]- (I.O.S. 45/ 1984) Sand المواصفة القياسية العراقية رقم (٤٥) لسنة ١٩٨٤
(ركام المصادر الطبيعية المستعملة في الخرسانة)
[14]- Radin Sumadi and Mahyuddin Ramil, (2008), "Development of Lightweight Ferrocement Sandwich Panels for Modular Housing and Industrialized Building System," Salihuddin Research Vote No. Construction Industry Development Baord, CIDB,and Research Management Centre, RMC of University Teknologi Malaysia.
[15]-Georgali B, Tsakiridis PE (2005), "Microstructure of fire-damaged Concrete,"A case study. Cement Concrete Comp 27:255–259
[16]- Pankaj; Mohammed Arif; and Surendra K. Kaushik 2002,"Mechanical Behavior of Ferrocement Composites: Numerical Simulation," Pankaj; Mohammed Arif; and Surendra K. Kaushik, M. 10.1061/ (ASCE) 0899-561() 14:2(156).
[17]- Takiguchi, K. and Abdullah (2000), "Experimental Investigations on Ferrocement as an Alternative Material to Strengthen Reinforced Concrete Columns," Journal of Ferrocement. 30(2): 177-190.
[18]- Naaman, A.E. (2001). "Ferrocement and Thin Fiber Reinforced Cement Composites,"Looking Back, Looking Ahead. Journal of Ferrocement. 31(4): 267-280.
[19]- Rajamane, N.P. Ramachandarmurthy, D.S and Ravi, S. (2003), "Application of Ferrocement and Polymeric Materials for Repair of Corrosion Damaged Hyperboloid Overhead Water Tank Structure,"Journal of Ferrocement. 33(1): 43-54.
[20]- Abdullah K.A. (2001), "Strength and Thermal Properties of Sytoferrocement Sandwich Roof Tiles," M Sc. Thesis, University of Suleimani, college of Engineering.