Influence of Heating Envelope on Post-Fire Mechanical Properties of Ferrocement Jackets

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Abstract

The mechanical properties of ferrocement jackets were experimentally determined based on their flexural characteristics after exposure to fire. The main parameter investigated was a heating envelope consisting of short and long heating duration of 3 and 63 hours respectively and the maximum temperature for both cases was 1060°C. A sandwich-sample configuration was adopted to simulate the actual conditions of exposure to fire. Test results showed that using ferrocement jackets was a satisfactory solution for fire protection due to their post-fire strengths as compared with those of plain mortar for both heating envelopes. An increase in wire mesh content significantly improved the mechanical properties of ferrocement under normal conditions; however after fire exposure the amount of wire mesh was no longer significant, regardless of heating duration. Mortar covers had negligible influence on the mechanical properties of ferrocement jackets exposed to fire for both short and long durations of heating.

Keywords: Ferrocement; Fire-protection; Fire-damage; Post-Fire Strength; Toughness, Crack patterns

1. Introduction

Fire remains one of the most serious potential risks to most buildings and structures. Most structural materials which are weakened when exposed to high temperatures cause buildings to collapse. Therefore, the use of fire protection materials to reduce thermal damage of structural members is important and necessary. Many types of fire protection materials were developed to protect structural members. The main classes of materials used are cementitious, intumescent, fibrous and composite materials. Ferrocement is one of the cementitious composite materials, which is constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small sized wire mesh [1]. Since mortar is a good insulator and the reinforcing wire mesh could reduce surface spalling, using ferrocement jacketing for strengthening of structural components like reinforced concrete, prestressed concrete, or steel could enhance the fire resistance of the composite elements.

It was found that a ferrocement jacket which behaved as additional confinement caused enhancement of the structural fire performance [2-4]. The use of ferrocement as a fire protection material needs a full understanding of the effects of fire on this material. However, most previous research focused on the individual properties of ferrocement material; i.e. concrete, mortar and steel at high temperatures [5-11]. Several studies had been conducted on the effect of high temperatures on the mechanical behavior of discontinuous-fiber reinforced materials; i.e. steel and polypropylene fiber [12-15]. Nevertheless, there is still a lack of knowledge and experimental data on the behavior of ferrocement exposed to fire.

The purpose of this study is to investigate the influence of heating duration on mechanical properties of a ferrocement jacket which is obtained experimentally from the flexural strength and toughness of a ferrocement after exposure to fire.

The main parameter investigated was the heating envelope consisting of short and long heating durations and the maximum temperature for both cases was 1060°C. Two heating duration times namely 3 and 63 hours were used to investigate ferrocement specimens which had, different volume fractions and mortar coverings. The ferrocement specimens had a dimension of 200mm x 240mm x 25mm. Ordinary steel bar, having a diameter of 6 mm spaced at 100 mm center to center, was used as skeletal steel in the longitudinal and transverse direction. The longitudinal and transverse skeletal steel were welded together in the same plane; in other words, there was no overlapping of skeletal steel. Galvanized hexagonal steel wire meshes were used as mesh reinforcement, and the numbers of mesh layers were 2, 6 and 16 layers corresponding to the volume fraction of 0.54, 1.63 and 4.36 %, respectively. The wire mesh layers were so placed in such a way that the mesh opening was minimized. The mortar had a compressive strength of 57 MPa and was kept constant throughout. The mortar covering of ferrocement were 1.5, 2.0 and 2.5 mm. The control series consisted of one layer of skeletal steel, six layers of wire mesh, and a mortar covering of 1.5 mm. In case of short heating duration, a sandwich-sample configuration of ferrocement, which consists of a 3-mm air gap and edge insulation, was subjected to high temperature which reached a maximum of 1060°C within 3 hours in an electrical furnace. In the case of long heating duration, ferrocement specimens were carried from the standard test method for steady-state heat flux measurement and thermal transmission properties by means of a guarded-hot-plate apparatus in accordance with ASTM C177 [16]. In this method two identical specimens were sandwiched between the hot and cold plates. A thermocouple (type K) was used to record the temperatures. After being left to cool down in the furnace, ferrocement specimens were tested for their mechanical properties by flexural strength tests with center-point loading [17]. The flexural strength and toughness of ferrocement under normal conditions and after exposure to the 3 and 63 hours fire duration were compared.

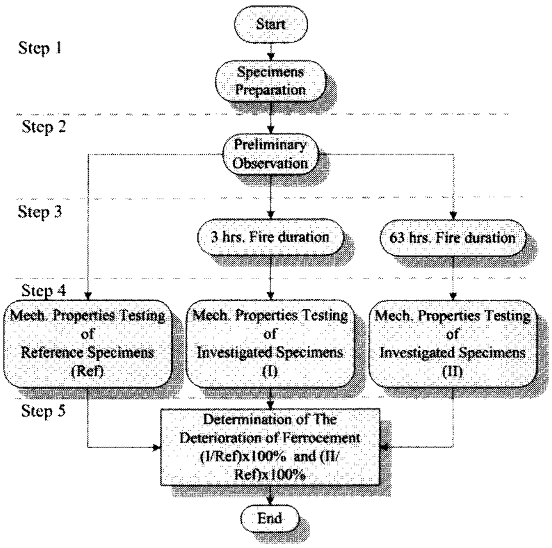


Fig. 1 Flow chart of the experimental processes

2. Experimental Program

In this study, the effects of the volume fraction of wire mesh and mortar covering on the post-fire mechanical properties of ferrocement were investigated. The experimental study was carried out in five steps: specimen preparation, preliminary observation, fire exposure, tests on flexural strength and toughness, and determination of the deterioration of ferrocement as shown in Fig. 1. Altogether seven series of ferrocement specimens were produced and divided into three groups; namely, Group A, B and C. Group A was tested in order to observe the performance under fire of plain mortar, steel reinforced mortar and ferrocement while Group B was tested to investigate the influence of wire mesh tested by varying the volume fraction of wire mesh from 0, 0.54, 1.63 and 4.36% which were equivalent to 0, 2, 6 and 16 layers of hexagonal wire mesh respectively. Finally Group C was tested to study the effect of the mortar covering of 1.5, 2.0 and 2.5 mm. Series 3, which was be used as the control series for all groups, consisted of skeletal steel and had volume fraction of wire mesh and mortar covering of 1.63% and 1.5 mm, respectively. The details of the specimen series and their groups are summarized and shown in Table 1. For each series, 11 identical ferrocement specimens were cast of which 3 specimens were tested without exposure to fire, 4 specimens were subjected to a temperature envelope where the temperature was gradually increased to a maximum of 1060°C within a duration of 3 hours and 4 specimens were subjected to the same maximum temperature for a duration of 63 hours. The mechanical properties were obtained by taking the average of these specimens.

2.1 Materials used

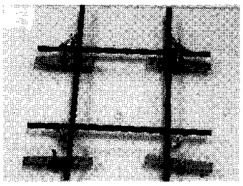
The ferrocement reinforcement cage consisted of skeletal steel and wire mesh. Ordinary steel bar having a diameter of 6 mm spaced at 100 mm center to center was used as skeletal steel in the longitudinal and transverse directions. The volume fraction of skeletal steel was 2.14%. Galvanized hexagonal wire mesh, which had a wire diameter of 0.78 mm, mesh opening of 19 mm and weight per unit area of 0.535 kg/m^2, was use as mesh reinforcement. The positions of the mesh layers were controlled by using galvanized plate spacers, as shown in Fig. 2, in order to obtain accurate mortar covering. The ferrocement mortar consists of Ordinary Portland Cement (OPC) Type I and natural river sand passing sieve No.16 [18] mixed at a ratio of 1:2 by weight and the water-cement ratio is 0.48 by weight. After mixing, the mortar was cast in steel molds over the reinforcement cage and compacted using a vibrating table. The dimensions of all specimen were 200 x 240 x 25 mm. All ferrocement specimens were cured for a period of 7 days and subsequently the specimens were allowed to air-dry until the time of testing.

2.2 Preliminary observation

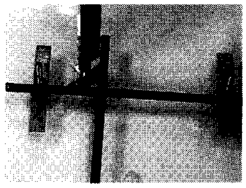
Before exposure to fire, all ferrocement specimens were weighed and observed by visual inspection and graphical details were recorded for comparison with ferrocement after exposure to fire.

2.3 Fire exposure

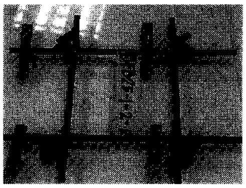
For the short heating duration test, a sandwich-sample configuration of ferrocement, which consisted of a 3-mm middle air gap and edge insulation, was put in the temperature controlled electrical furnace, as shown in Fig. 3 and Fig. 4. It should be noted that the temperature test is based on an ASTM standard. This study, as shown in Fig. 5, maintained the area under the curve to be equal [19] even though the two envelopes were not exactly identical due to the performance of the furnace used.



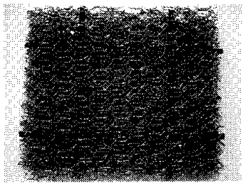
a) Position of skeletal steel



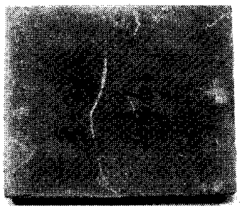
b) Position of galvanized plate spacer



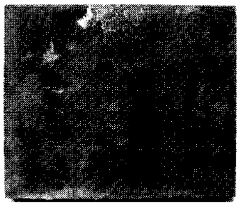
c) Skeletal steel with galvanized plate spacer before placing wire mesh



d) Installation of wire mesh

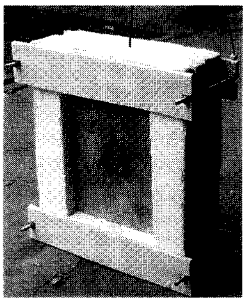


e) Finishing surface (to be subjected to fire)



f) Bottom surface

Fig. 2 Steps in the fabrication of ferrocement

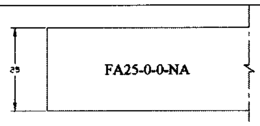
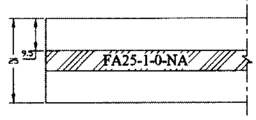
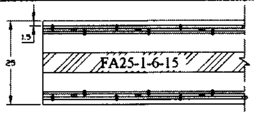
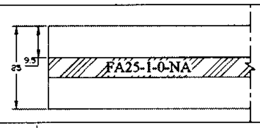
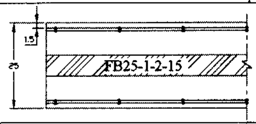
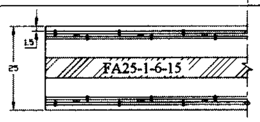
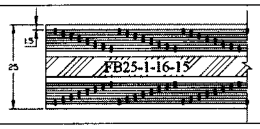
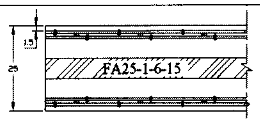
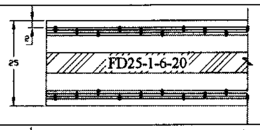
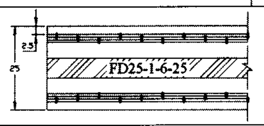


a) Photograph of sandwich-sample configuration of the ferrocement specimen

b) Thermocouple arrangement

Fig. 3 Photograph of specimen configuration and thermocouple arrangement

Table 1 Experimental program and details of test specimen

Series No.	Series Code	Mortar Covering (mm)	No. of Wire Mesh Layers	Volume Fraction %	Sectional Geometry
A. Control specimen					
1	FA25-0-0-NA	NA	0	0	 Plain Mortar
2	FA25-1-0-NA	NA	0	0	 Mortar + Skeletal Steel
3	FA25-1-6-15	1.5	6	1.63	
B.To study the effect of volume fraction of wire mesh					
2	FA25-1-0-NA	NA	0	0	
4	FB25-1-2-15	1.5	2	0.54	
3	FA25-1-6-15	1.5	6	1.63	
5	FB25-1-16-15	1.5	16	4.36	
C. To study the effect of mortar covering					
3	FA25-1-6-15	1.5	6	1.63	
6	FC25-1-6-20	2.0	6	1.63	
7	FC25-1-6-25	2.5	6	1.63	

For the long heating duration test, ferrocement specimens were carried from the standard test method for steady-state heat flux measurement and thermal transmission properties by means of the guarded-hot-plate apparatus in accordance with ASTM C177 [16]. In this method two identical specimens were sandwiched between the hot and cold plates as illustrated in Fig. 6. The sandwich-sample configuration was put into the electrical furnace in order to control ambient temperature. The temperature envelope was raised from room temperature to 200°C within an hour and then was maintained at 200°C for 12 hours. Subsequently the temperature envelope was raised to the next temperature levels of 400, 600, 800 and 1060°C respectively; at each level the ambient temperature was maintained constant for 12 hours for each interval, 30 minutes was required to rise the temperature to the required level as shown in Fig. 7.

A 60-mm thick ceramic fiber insulation edge was used to control the direction of the heat flow through the ferrocement specimen so that the heat transmission could be considered as a one-dimensional heat flow from the hot side to the cold side. The change in temperature during the test, which was measured by using thermocouple (type K) was recorded every 30 seconds by using a computerized data logger. There were three thermocouples installed at the exposed surface of the ferrocement specimen. Two thermocouples (T1) were used to monitor the temperature of exposed ferrocement surfaces, whereas one thermocouple (T3) was used to measure the temperature inside the furnace. Another thermocouple (T2), which was provided between the two specimens, was used to monitor the unexposed surface temperature. After fire exposure, the specimen were left to cool down to room temperature in the furnace before the tests for their physical and mechanical properties were conducted.

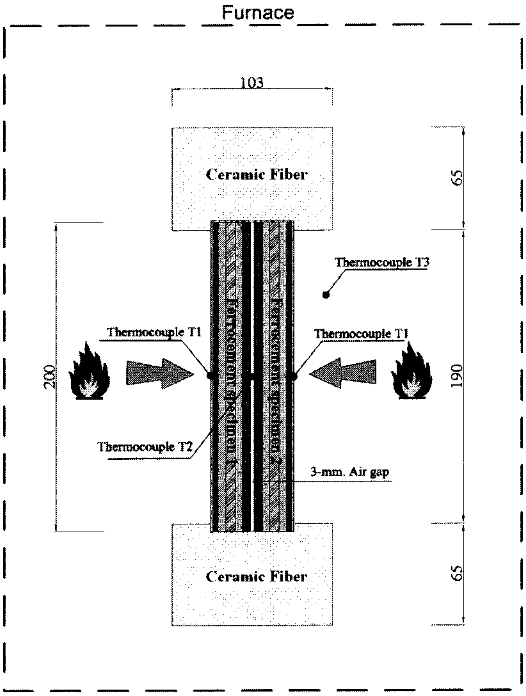


Fig. 4 Schematic diagram of ferrocement specimen based on sandwich-sample configuration, for short heating duration test

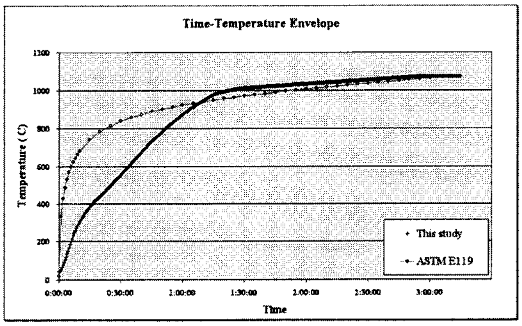


Fig. 5 Time-temperature envelope used in this study as compared with that of ASTM E119

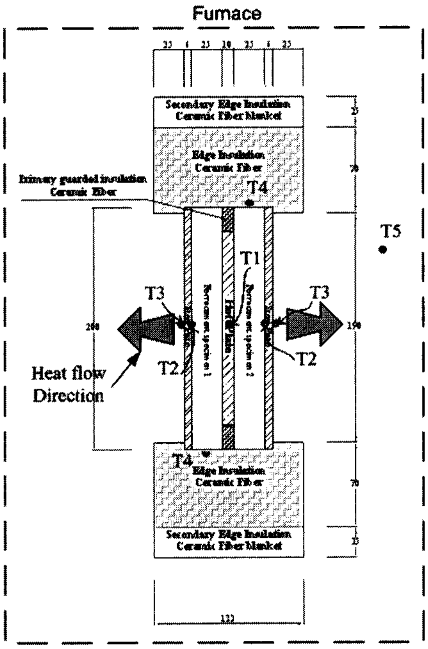


Fig. 6 Schematic diagram of ferrocement specimen based on sandwich-sample configuration, for long heating duration test

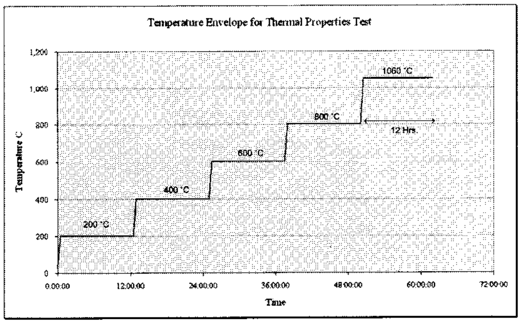


Fig. 7 Time-temperature envelope for long heating duration test

2.4 Mechanical properties tests

The mechanical properties of ferrocement before and after fire exposure, namely the flexural strength and toughness, were obtained by the flexural strength test with center-point loading in accordance with ASTM C293-02 [17]. The results are summarized and compared in order to determine the deterioration of ferrocement specimen.

2.5 Deterioration of ferrocement after fire exposure

In order to determine the degree of deterioration of the ferrocement specimen, the post-fire mechanical properties, namely flexural strength and toughness, were calculated as a percentage of the reference properties (original properties). Toughness or the energy absorption capacity of ferrocement in bending was defined as the area under the load-mid-span deflection curve. In this study, toughness was calculated up to a mid-span deflection of 25 mm as shown in Fig. 8

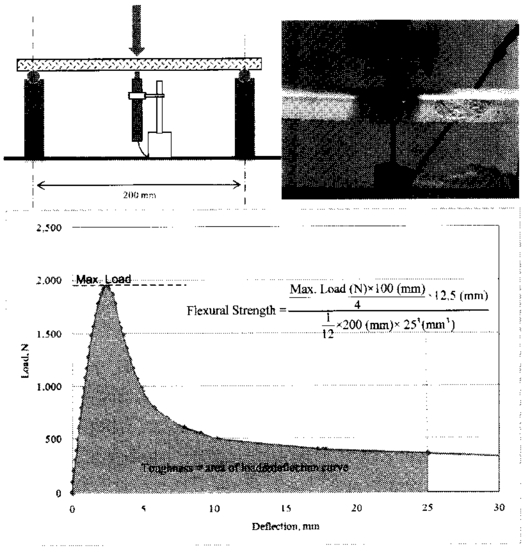


Fig. 8 Flexural test with center point loading and the determination of flexural strength and toughness

3. Experimental Results and Discussions

The percentage of residual flexural strength and toughness of post-fire ferrocement specimen which are determined from the average of 3 original specimen 3 and 4 post-fire specimens are summarized and shown in Table 2. Compared with the case without wire mesh, test results revealed that the incorporation of wire mesh not only improved the original mechanical properties (before exposure to fire) of ferrocement but also significantly enhanced post-fire mechanical properties for both durations of heating as shown in Table 2A and Fig. 9. The results also show that short heating duration resulted in more damage of ferrocement even though the same maximum temperature was applied. Besides being used as repairing and strengthening materials for reinforced concrete members, a ferrocement jackets was found to offer additional resistance against fire as evidenced in Fig. 9. In this figure the plain mortar, which represents the concrete cover, lost its flexural strength and toughness almost entirely, whereas for a ferrocement jacket, the remaining flexural strength and toughness were found to be approximately 18% and 21% of its original strength for short and long heating duration, respectively. The effects of volume fraction of wire mesh and mortar covering on the post-fire mechanical properties of ferrocement can be summarized as follows:-

- Volume fraction of wire mesh

The ferrocement specimen having a mortar covering of 1.5 mm (except for the case 0% volume fraction) was tested to investigate the influence of the volume fraction by varying the volume fraction of wire mesh from 0, 0.54, 1.63 and 4.36%, which were equivalent to 0, 2, 6 and 16 layers of hexagonal wire mesh, respectively, as given in Group B. Before exposure to fire, it is noted that an increase in wire mesh content significantly increased the flexural strength and toughness of ferrocement. However the post-fire flexural strength and toughness of ferrocement was barely dependent on the content of wire mesh as shown in Fig. 10a. Moreover it was found that in the case of short heating duration, the use of wire mesh content of 0.54% resulted in the highest relative mechanical properties (post-fire/original value) which are 25% and 21% for flexural strength and toughness, respectively, whereas in the case of long heating duration the highest relative mechanical properties occurred when the wire mesh content was 1.63%. It is of interest to note that the increase in volume fraction of wire mesh beyond 0.54 % and 1.63% resulted in a reduction of the relative mechanical properties of ferrocement for short and long heating duration, respectively, as shown in Fig. 9a. As a result, it can be seen that using high wire mesh content is not the right solution to improve the flexural strength and toughness of a post-fire ferrocement jacket, in other words the mechanical properties of a post-fire ferrocement jacket only slightly increased as the volume fraction of wire mesh is increased. Although ACI committee 549 [20] suggested minimum volume fraction of reinforcement to be 1.8% (not including skeletal steel in computing the resistance of bending member), in this study the use of 0.54% and 1.63% of wire mesh content could achieve the same level of residual mechanical properties as that having 1.8% of wire mesh content after exposure to short and long heating duration, respectively, as shown in Fig. 10a. This phenomenon can be explained by the fact that the core mortar is confined by layers of wire mesh. Kodur [2, 4] concluded that additional confinement in the core of high-strength concrete columns can enhance its fire performance. Although steel loses a lot of strength at high temperatures [21, 22], after cooling down, its strength is slightly lower than the original strength [6, 9]. Therefore, wire mesh consisting of galvanized steel has the ability to confine mortar in the ferrocement specimen, resulting in the enhancement of the post-fire mechanical properties. However for skeletal steel, although its post-fire strength is quite high, its position and spacing do not allow it to confine mortar; consequently, the addition of skeletal steel has less influence on the post-fire mechanical properties of ferrocement. Although an increase in the volume fraction of wire mesh causes a better degree of confinement in the core mortar, a higher volume fraction of wire mesh, say 4.36%, induces delamination of mortar and results in in-plane cracking.

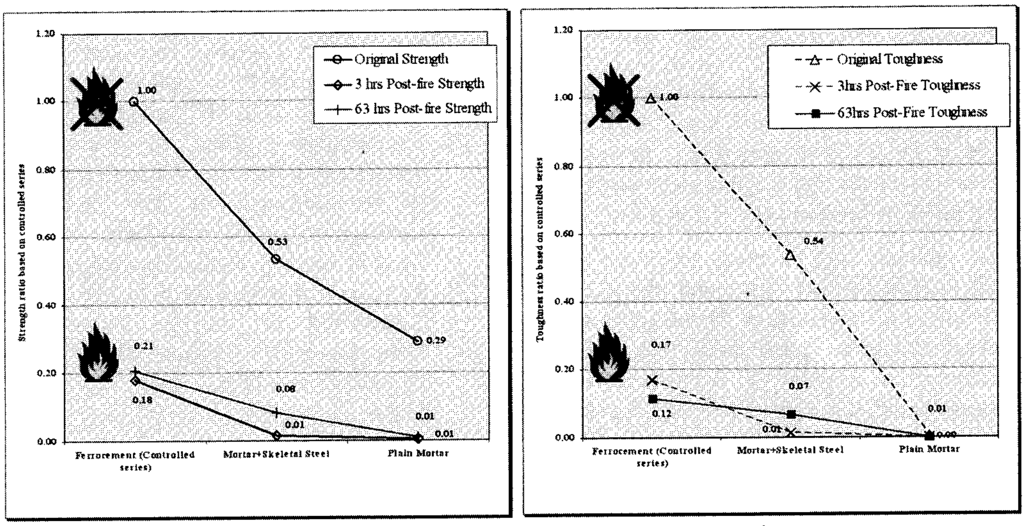
- Mortar covering

The ferrocement specimen consisting of 6 layers of wire mesh and corresponding to a volume fraction of 1.63% was tested to investigate the influence of the mortar coverings of 1.5, 2.0 and 2.5 mm as given in Group C. Before exposure to fire, the lower mortar covering exhibited higher flexural strength due to the fact that the lever arm of wire mesh layers was decreased as the mortar covering was increased, since all ferrocement specimens possessed identical thickness. After exposure to fire, the remaining flexural strength and toughness, which had value of approximately 18% of its original value, showed the same trend as that of unheated specimen regardless of heating duration as shown in Fig. 10b. However the difference in mechanical properties of ferrocement having different thicknesses of mortar covering was found to be insignificant. Therefore, it could be said that mortar covering had no significant influence on the flexural strength and toughness of a ferrocement jacket both before and after exposure to fire.

Table 2: Test results of mechanical properties of ferrocement

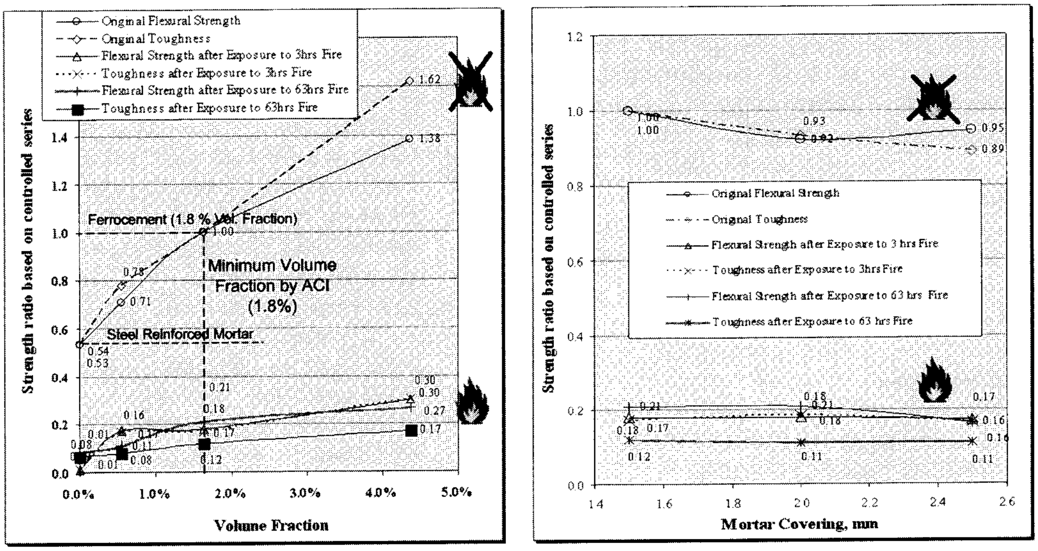
Series ID	Condition	Flexural Strength, MPa			*Toughness, N-m		
		Max	Min	Average	Max	Min	Average
A. Effect of reinforcement incorporation							
FA25-0-0-NA (Plain mortar)	Unheated	8.6	6.3	**7.5**	1.5	0.5	**1.00**
	After 3 hrs fire exposure	0.2	0.1	**0.2**	0.1	0.0	**0.06**
	After 63 hrs fire exposure	0.4	0.2	**0.3**	0.1	0.1	**0.09**
FA25-1-0-NA (Mortar + Skeletal steel)	Unheated	15.1	12.5	**13.8**	138	57	**98**
	After 3 hrs fire exposure	0.4	0.3	**0.4**	3	2	**2**
	After 63 hrs fire exposure	2.4	1.7	**2.1**	14	9	**12**
FA25-1-6-15	Unheated	26.1	25.6	**25.8**	194	170	**182**
	After 3 hrs fire exposure	5.6	4.0	**4.6**	41	25	**31**
	After 63 hrs fire exposure	6.6	4.4	**5.4**	27	16	**21**
B. Effect of the volume fraction of wire mesh							
FA25-1-0-NA (0 %)	Unheated	15.1	12.5	**13.8**	138	57	**98**
	After 3 hrs fire exposure	0.4	0.3	**0.4**	3	2	**2**
	After 63 hrs fire exposure	2.4	1.7	**2.1**	14	9	**12**
FB25-1-2-15 (0.54 %)	Unheated	19.0	17.7	**18.4**	147	136	**142**
	After 3 hrs fire exposure	5.1	3.7	**4.5**	36	24	**30**
	After 63 hrs fire exposure	3.4	2.4	**2.8**	18	11	**14**
FA25-1-6-15 (1.63 %)	Unheated	26.1	25.6	**25.8**	194	170	**182**
	After 3 hrs fire exposure	5.6	4.0	**4.6**	41	25	**31**
	After 63 hrs fire exposure	6.6	4.4	**5.4**	27	16	**21**
FB25-1-16-15 (4.36 %)	Unheated	35.8	35.5	**35.7**	303	287	**295**
	After 3 hrs fire exposure	8.0	7.5	**7.7**	55	55	**55**
	After 63 hrs fire exposure	7.8	5.8	**6.8**	37	26	**31**
C. Effect of the mortar covering							
FA25-1-6-15 (1.5mm)	Unheated	26.1	25.6	**25.8**	194	170	**182**
	After 3 hrs fire exposure	5.6	4.0	**4.6**	41	25	**31**
	After 63 hrs fire exposure	6.6	4.4	**5.4**	27	16	**21**
FC25-1-6-20 (2.0mm)	Unheated	26.5	22.1	**23.9**	189	158	**170**
	After 3 hrs fire exposure	4.8	4.2	**4.6**	38	24	**33**
	After 63 hrs fire exposure	6.6	4.0	**4.9**	24	13	**19**
FC25-1-6-25 (2.5mm)	Unheated	26.6	22.5	**24.5**	186	139	**162**
	After 3 hrs fire exposure	5.1	3.8	**4.4**	35	27	**30**
	After 63 hrs fire exposure	4.4	3.5	**4.0**	24	13	**18**

Note * Toughness at 25 mm mid-span deflection



a) Strength b) Toughness

Fig. 9 Influence of reinforcement on relative flexural strength and toughness of ferrocement before and after fire exposure



a) Volume fraction b) Mortar covering

Fig. 10 Influence of volume fraction and mortar covering on flexural strength and toughness of ferrocement before and after fire exposure

4. Conclusion

The influence of the duration of heating on post-fire mechanical properties, namely flexural strength and toughness including cracking patterns of ferrocement jackets, which had different volume faction of wire mesh and mortar covering, was experimentally investigated. The following conclusions can be drawn:

4.1 The post-fire mechanical properties of ferrocement subjected to a heating duration of 63 hours was more or less the same as that subjected to a heating duration of 3 hours provided that the maximum temperatures for both cases were the same. However, the degree of deterioration for long heating duration specimens was found to be slightly higher than that of short heating duration specimen.

4.2 Besides serving as strengthening materials, a ferrocement jacket was a satisfactory solution for fire protection due to its post-fire flexural strength and toughness as compared with those of plain mortar or concrete cover.

4.3 Even though an increase in wire mesh content significantly improved the flexural strength and toughness of ferrocement under normal condition, it was found that after fire exposure the amount of wire mesh is no longer correlated significant for these two mechanical properties. Using wire mesh content of only 0.54% in the case of short duration of heating and 1.63% in the case of long duration of heating could achieve the same level of residual strength as that having the minimum suggested wire mesh content of 1.8% given by ACI committee 549 [20].

4.4 For the range of mortar covering investigated, mortar covers had negligible influence on both the flexural strength and toughness of a ferrocement jacket under both normal and fire exposures.

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6. References

[1] Naaman, A.E., Ferrocement and Laminated Cementitious Composites, Techno Press 3000, Michigan, USA, 2000.

[2] Kodur, V.K.R., Cheng, F., Wang, T., and Sultan, M.A., Effect of Strength and Fiber Reinforcement on Fire Resistance of High-Strength Concrete Column, Journal of Structural Engineering, Vol. 129, No. 2, pp. 253-259, 2003.

[3] Kodur, V.K.R. Fire Resistance Evaluation of Large Scale Structural System. in Fire resistance Determination and Performance Prediction Research Needs Workshop: Proceedings: NISTIR 6890, 2002.

[4] Kodur, V.K.R., Fire Performance of High-Strength Concrete Structural Members, Construction Technology Update, Vol. 31, pp. 1-4, 1999.

[5] Akman, M.S., Building Damage and Repair Principles, Turkish Chamber of Civil Engineers, Istanbul, Turkey, 2000.

[6] Outinen, J. and Makelainen, P. 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, 2002.

[7] Phan, L.T. and Carino, N.J., Effects of Test Conditions and Mixture Proportions on Behaviour of High-Strength Concrete Exposed to High Temperatures, ACI Materials Journal, Vol. 99, No. 1, pp. 54-56, 2002.

[8] Outinen, J., Kaitila, O., and Makelainen, P., High-Temperature Testing of Structural Steel and Modelling of Structures at Fire Temperatures, in Laboratory of Steel Structures Publications: Espoo, 2001.

[9] Outinen, J. and Makelainen, P. Mechanical Properties of Structural Steel at Elevated Temperatures and After Cooling Down. in Proceedings of the Second International Workshop: Structures in Fire, SIF'02. New Zealand, 2002.

[10] Nabi, Y., Fevziye, A., and Leyla, D.O., Compressive Strength-Color Change Relation in Mortar at High Temperature, Cement and Concrete Research, Vol. 34, pp. 1803-1807, 2004.

[11] Consolasio, G., McVay, M., and Rish III, J., Mesurment and Prediction of Pore Pressures in Saturate Cement Mortar Subjected to Radiant Heating, ACI Materials Journal, Vol. 95, No. 5, pp. 525-536, 1998.

[12] Hannant, D.J., Fibre Cement and Fibre Concretes, John Wiley & Sons, 1978.

[13] Lennon, T. and Clayton, N. Fire Test on High Grade Concrete with Polypropylene Fibers. in Proceedings of Fifth International Symposium on Utilization of HSC/HPC. Stanford, Norway, 1999.

[14] Bentz, D.P., Fibers, Percolation and Spalling of High Performance Concrete, ACI Materials Journal, Vol. 97, No. 3, pp. 351-359, 2000.

[15] Kalifa, P., Chene, G., and Galle, C., High Temperature Behavior of HPC with Polypropylene Fibers-from Spalling to Microstructure, Cement and Concrete

Research, Vol. 31, No. 10, pp. 1487-1499, 2001.
[16] ASTM, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus, ASTM C 177-97, in Annual Book of ASTM Standards, American Society for Testing and Materials: West Conshohocken, United States., 2004.
[17] ASTM, Standard Test Methods for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading), ASTM C293-02, in Annual Book of ASTM Standards, American Society for Testing and Materials: West Conshohocken, United States, 2004.
[18] ASTM, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates, ASTM C136-95a, in Annual Book of ASTM Standards, American Society for Testing and Materials: West Conshohocken, United States, 2004.
[19] Buchanan, A.A., Structural Design for Fire Safety, John Wiley & Sons, West Sussex, England, 2001.
[20] ACI, State-of-the-Art Report on Ferrocement, in ACI Committee 549R-97, American Concrete Institute: USA, 1997.
[21] Harmathy, T.Z., Fire Safety Design and Concrete, Longman Scientific and Technical, UK, 1993.
[22] EC3, ENV 1993-1-2: General Rules Structural Fire Design, in Eurocode 3: Design of Steel Structures, European Committee for Standardization: Brussels, 1995.