PERFORMANCE OF FERROCEMENT SLABS AT ELEVATED TEMPERATURE

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ABSTRACT

Ferrocement is an excellent construction material due to its mechanical properties, ease of construction, and economical aspects. It also had excellent tensile strength, fire resistance, lightness, and resistance to cracking. The primary goal of this work is to investigate the thermogravimetric analysis, surface performance, and flexural properties of ferrocement slabs at elevated temperatures. Three types of samples were used: 1.25% reinforcement (Mesh Opening 12.5 mm), 2.5% reinforcement (Mesh Opening 12.5 mm), and 1.25% reinforcement (Mesh Opening 33.25 mm). The mix proportion was 1(Cement):2 (Fine Aggregate) by volume. The water-to-cement ratio (w/c) was 0.45. A poly sheet was placed over the floor, and the wooden plank was used to make a mold with dimensions of (650× 450× 50 mm). The desired mesh layers were tied with 24-gauge galvanized steel wires and then placed inside the molds. The slabs were heated up to 500°C in a furnace. In the thermogravimetric analysis, the ferrocement slabs with a lower percentage of reinforcement lost more weight than the slabs with a higher percentage of reinforcement. In terms of flexure performance, the controlled samples had better flexure performance than the heated samples. Of the heated samples, those that had a higher percentage of reinforcement had better flexure strength than the samples that had a lower percentage of reinforcement. However, with the increase in temperature, the difference in flexural strength between higher and lower percentages of reinforcement was minimized and nearly similar at very high temperatures. In terms of surface cracking, a lower percentage of reinforcement of small mesh openings generated higher cracking areas than the other types. Also, samples with a higher percentage of reinforcement and samples with a lower percentage of reinforcement of large mesh openings showed nearly similar kinds of performance.

Keywords: *Ferrocement, fire resistance, thermogravimetric analysis, flexural properties, surface performance.*

1. INTRODUCTION

Ferrocement is a type of reinforced concrete that differs from conventional reinforced or prestressed concrete primarily in the distribution and arrangement of the reinforcing elements. It is made up of closely spaced, multiple layers of mesh or fine rods that are completely embedded. Ferrocement is a type of cementitious composite material which is made of hydraulic cement mortar reinforced by continuous, closely spaced layers of relatively small-sized wire mesh(Naaman, 2000). The mechanical qualities of ferrocement are determined by factors such as cement type and dose, wire mesh strength and geometry, aggregate, and the number of wire mesh layers. The ductility, cracking, and robustness of ferrocement are likewise affected by these variables (Rashid et al., 2019). In ferrocement, the close spacing of wire mesh layers promotes ductility and leads to crack resistance. As a result, ferrocement is suggested to use in housing and rural energy(Al-Rifaie & Azad, 2013; E. H. Fahmy et al., 1999; E. Fahmy & Shaheen, 1994; Ibrahim, 2011a; Milon et al., 2013).

For the majority of buildings and structures, fire is one of the biggest possible threats(Chan et al., 1996). Nonetheless, the majority of earlier studies concentrated on the room-temperature and thermal characteristics of ferrocement components; such as steel, concrete, and mortar.(Frattolillo et al., 2005). Prior studies have demonstrated that mortar has a lower thermal conductivity than regular concrete, despite the fact that thermal conductivity values varied widely(Khan, 2002; Kim et al., 2003; Xu & Chung, 2000).But the distribution of skeletal steel and wire mesh in ferrocement can alter its thermal properties, influenced by factors like mineral characteristics, pore structure, cracking, chemical composition, moisture, and temperature (Greepala & Nimityongskul, 2007, 2009; Wang et al., 2005).

(Al-Rifaie et al., 2015)presented an investigation to study the effect of radiant heating on the strength of ferrocement specimens. The main parameters in this research were variation in temperature from 30 to 800°C, cement– sand mixture, the thickness of slab, and the number of layers of wire mesh. The behaviour of the specimens was observed by load deflection behaviour of the specimens. The first significant deterioration in compressive strength usually occurs between 200 and 250°C. Dehydration, or the loss of nonevaporable water or water of hydration, begins as the temperature approaches 250°C (Murtiadi, 2013).At 300°C, the strength reduction would be in the 15-40% range. At 550°C the compressive strength reduction would typically range from 55% to 70% of its original value (Greepala et al., 2008). Steel wire meshes offer numerous advantages over steel reinforcement, especially for structures with complex shapes and curvatures, because they are lighter, easier to handle, easier to cut, and easier to bend than steel reinforcement. The concrete beams incorporating permanent ferrocement forms, irrespective of the type of the steel mesh and number of layers in the ferrocement laminate, have a good strength, crack resistance, and energy absorption properties relative to conventional reinforced concrete beams of the same dimensions and total reinforcing steel content. The concrete beams incorporating ferrocement forms reinforced with expanded hexagonal steel mesh exhibited the highest first crack load and serviceability load followed by the beams reinforced with square welded steel mesh (Shaheen et al., 2009; Thanoon et al., 2005).An increase in wire mesh content significantly improved the mechanical properties of ferrocement under normal conditions, after fire exposure the content of wire mesh was no longer significant and higher volume fractions of wire mesh resulted in in-plane cracking. Mortar covers had negligible influence on the mechanical properties of ferrocement jackets under both normal and after fire exposures. However more visible fire damage occurred in ferrocement with thinner mortar cover(Greepala & Nimityongskul, 2008).Analysis and design of structures against blast loads had been extensively studied in previous researches(Li & Hao, 2014; Morrill & Karagozian, 2004).Closely spaced wire mesh reinforcement was examined by (Ibrahim, 2011b)for punching and flexural performance. In thin member the surface cracking is a visible sort of damage that has a major negative impact on a structure's mechanical and durability attributes. The use of image processing as a new tool to explore concrete qualities was widely adopted. This method will be used to determine the density of cracks in damaged concrete that has been exposed to high temperatures. Image processing software Fiji is used here to explore the areas of crack in ferrocement slabs.

Figure 1:Casing of ferrocement slab

In this study, the performance of ferrocement slabs at elevated temperature is investigated. The main parameters are the percentage reinforcement and opening of the mesh along with the variation in temperature. The flexural properties of the slabs are tested at normal temperature and at elevated temperatures and have undergone thermogravimetric testing. The basic raw materials, construction in any shape, and durability of ferrocement have all been found to be appealing. Ferrocement outperforms reinforced concrete in terms of modulus of rupture, tensile strength, and anti-cracking qualities. As the use of ferrocement in building construction becomes more common, so does the risk of being exposed to high temperatures during a fire. It is important to understand the strength and deformation properties of ferrocement structures in order to predict their response during and after high-temperature exposure.

2. METHODOLOGY

2.1 Material Properties

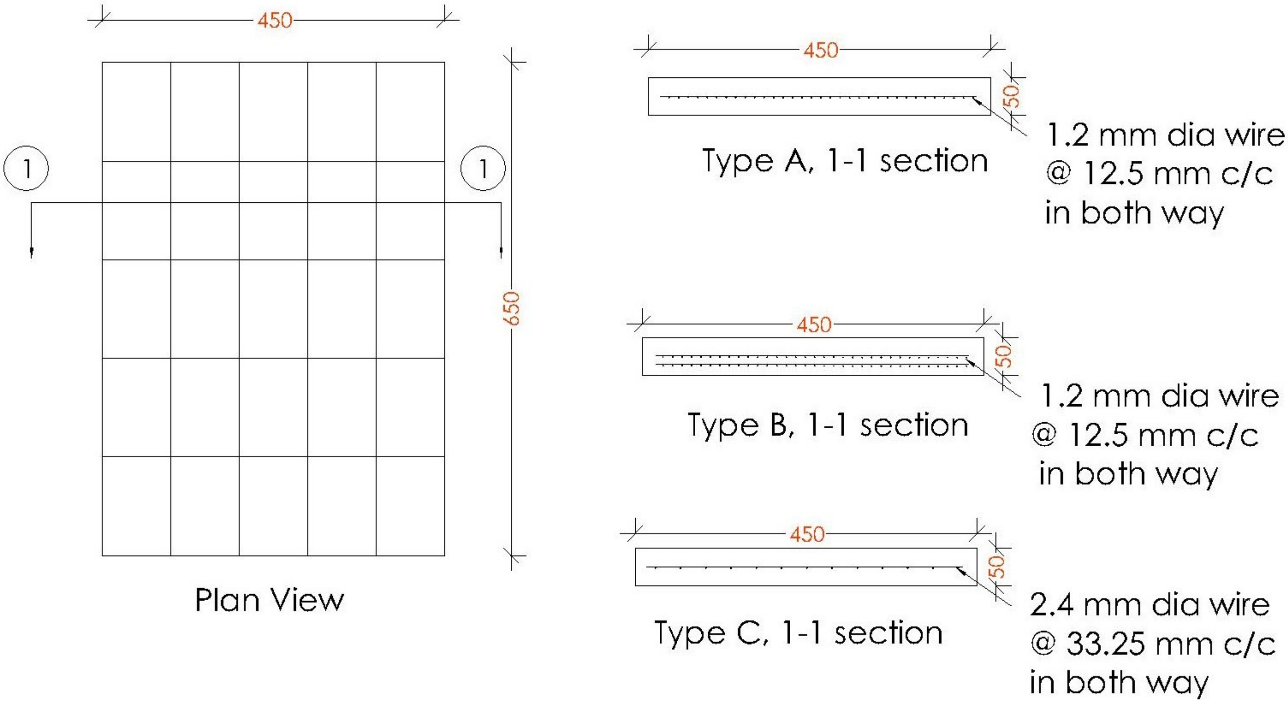
Portland Composite Cement (PCC) was used in this research. Available cement was collected from market and composition test was done. Oxide analysis result showed that the used cement has 30.8% SiO_2, 8.10% Al_2O_3, Fe_2O_3 is 5.72%. CaO was found 40.6% and SO_3 is 3.62%. Loss on ignition was observed 1.94%. River bed sand was used as fine aggregate in this research with fineness modulus of 2.

2.2 Fabrication Of Test Specimens

At first, the mesh were being cut in the size of (650× 450mm). Here, 3 types of samples were prepared.

Type A: 1.25% reinforcement (Mesh opening-12.5 mm).
Type B: 2.5% reinforcement (Mesh opening-12.5mm).
Type C: 1.25% reinforcement (Mesh opening-33.25mm).
The slab was 50mm (2 inch) thick. Here, the mix proportion was 1(Cement):2 (Fine Aggregate) by volume. The water-cement ratio(w/c) was 0.45.
After that, a poly sheet was placed over the floor and the wooden plank was used to make a mold having dimensions of (650 x 450 x 50 mm). The desired mesh layers were tied by 24-gauge galvanized steel wires and then placed inside the molds. To conform to the real picture, readily available wire mesh in the market was used. Fresh cement mortar mix was then poured into the wooden molds as shown in Fig 1. Compaction was done manually to produce a void-free member and finally, the surface was leveled and smoothened by steel trowels. All slabs were cured by ponding for 28 days after 20 hours of casting. Along with the slabs, a total of nine (50x50x50 mm) mortar cubes were molded to know the actual mortar strength (Compressive) at different times of this test. Molded specimens were cured in the mold for 20 hours and then removed from their molds and immersed in the curing tank for 28 days.

Figure 2: Reinforcement details of the test specimens
Figure 3: Cross-section of the furnace



2.3 Test Setup

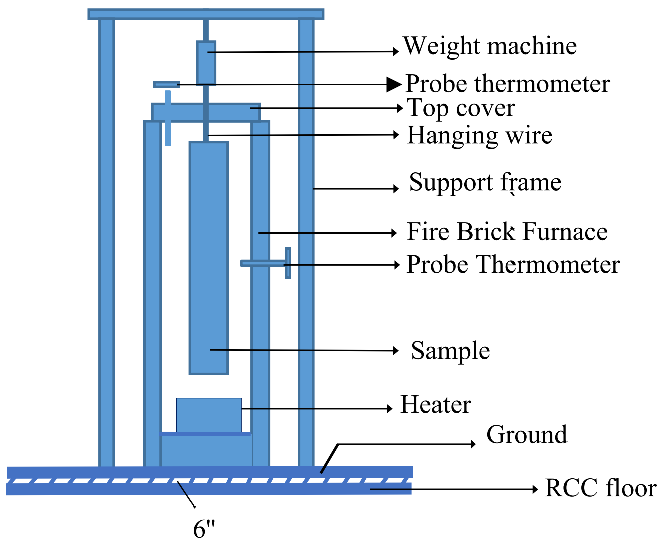


Figure 4:Time vs temperature

After curing of the specimen for 28 days, those are brought out from the specimen. A furnace was built for heating those specimens. The furnace was 24 inches in height, and 30 inches in width, and 6 inches in thickness. The furnace was built with fire brick and a brick unit joined by fire clay. After building the furnace it was filled with water for 7 days for the curing of the brick.

Three heaters are placed in the furnace for the elevation of the temperature. 3 heaters each was 3000 Watts, so in total 9000 Watts coil were used in the furnace. Slabs are hung into the furnace through an entrance in another wall, which is kept on the furnace's upper side. To keep the furnace entrance closed, bricks were laid on both sides of the wall. On the upper side of the hanging wall, a small gap was kept to allow heat to circulate. For preheating, heating was performed on the furnace for 24 hours at 100 °C and then at 200 °C for 6 hours. Then the furnace was cooled down to 40 °C. Then, the target sample was placed and another setup was prepared according to Figure 3**.**

The rate of temperature increasing in the furnace was shown in the Figure below-

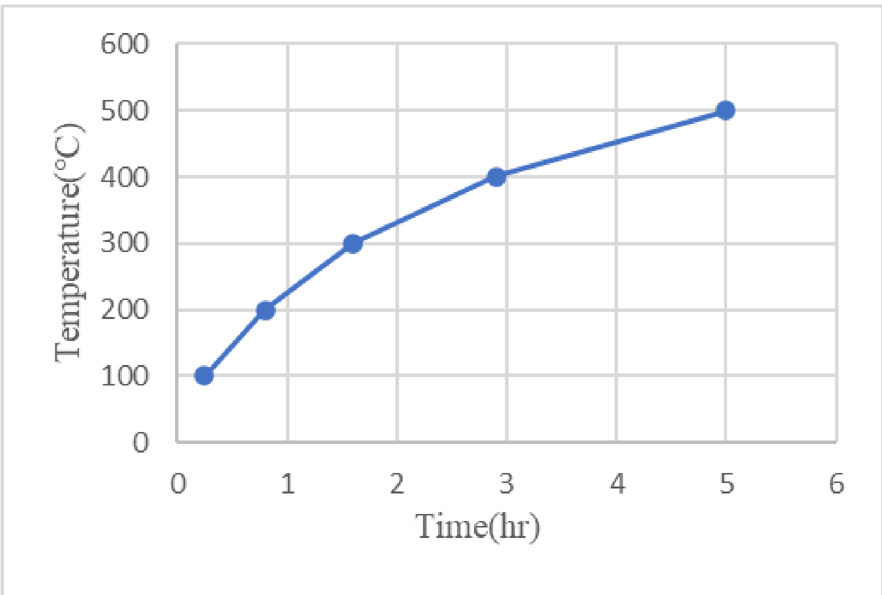


Figure 5: Setup for flexural test

2.4

Measuring Details

For the thermogravimetric analysis of the slab at elevated temperature, the weight of the hanging specimen was taken at 25°C intervals, and the temperature reading was taken manually from probe thermometer. One sample from each type was taken, and a small grid was drawn on it to check the surface performance of each panel of the slab. All the slabs are 650mm in length,450mm in width, and 50mm in thickness. There are two types of grid sizes. One type is (112.5x112.5mm) and another type of grid (125x112.5mm). These grids are drawn to take snaps to know the amount of the crack generated at each panel of the slab. These grids are numbered as 1,2,3 and so on. Before the testing day, the slab was cleaned, and a grid mark on the surface by a permanent marker, to achieve clear visibility and the position of cracks during testing. Slabs were kept out of the oven after they reached their desired temperature, and quenching was done right afterward, followed by photographs of the cracks. The cracks are then investigated using the Fiji software. Fiji image processing software was used to measure the area of the crack generated at the surface of the slab. In this software, the area of the crack can be calculated, and the length of the crack can also be measured. Then, the specimens were taken for the flexural test. The set-up was done according to ASTM-C78. In our setup, the distance from support to support was 550mm. The span length was divided into three equal divisions of 183.33 mm. Two dial gauges were used on both sides to have the deformation data.

3. RESULTS AND DISCUSSIONS

The properties which were tested in this research- thermogravimetric analysis, surface performance and flexural properties of ferrocement slabs at elevated temperature.

3.1 Thermogravimetric Analysis

Figure 7:Flexural strength vs temperature

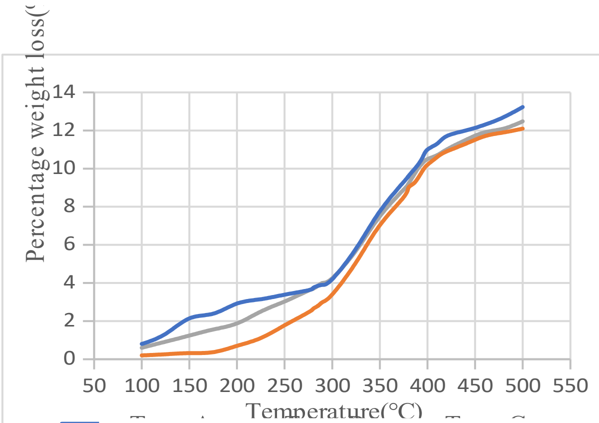
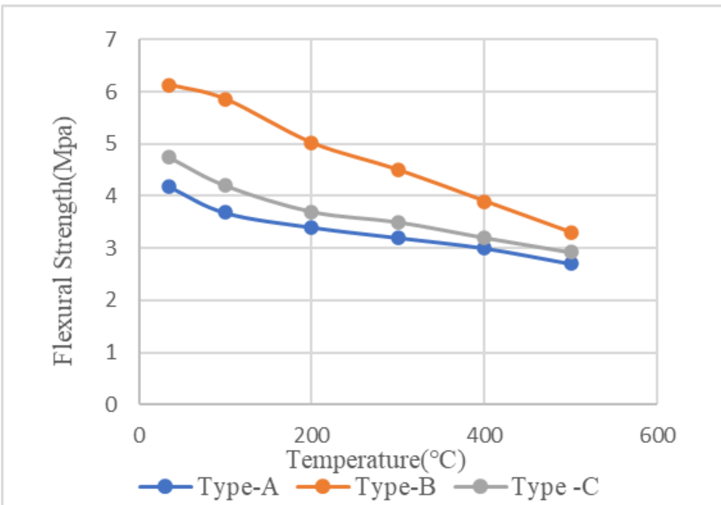


Figure 6: Percentage weight loss vs temperature

In this research, a total of nine specimens were used in the thermogravimetric test. A weight machine is used as the main equipment here. Specimens were hung by a weight machine into the furnace, and weights were automatically measured from the machine. Readings were taken at 25℃ intervals. The amount of the crack generated at the slab increases with the temperature. If the temperature increases, the amount of water inside the structure decreases as the water inside it vaporizes out. This is the reason behind the amount of weight loss increases with the temperature. From the Figure, it is clear that if the amount of the reinforcement increases, at the beginning the amount of weight loss varies but at 500℃ the amount of weight loss becomes nearly similar. At 300℃ there is a sharp rise in the amount of weight loss. Concrete loses its bond water at 300℃ and at that time the bond water gets vaporized and the amount of weight loss increases**.**

3.2 Flexural Behavior



After heating the specimens at elevated temperatures, their flexural behaviour was tested by the three-point loading method. A total of 18 specimens (6 in each type) were used in this test. In which,15 specimens were heated at elevated temperature and 3 specimens were at normal temperature. From the result, it was seen that flexural strength decreased with the increase in temperature. At higher temperatures, the internal energy of the materials is high. Because of that, the atoms of the material vibrate more vigorously with high thermal agitation. With these agitations are high the movement of dislocations (means ductility of material) becomes easy. It requires very little stress to tear the dislocations from their equilibrium positions. Therefore, the material exhibits low yield and ultimate strengths at high temperatures. Specimens of type A and C had less strength than type B. But with the increase in temperature, the gap between the lower and higher flexural strength was minimized and at 500℃ all the types had very little difference in terms of flexural strength. If the percentage loss of strength in ambient to 500℃ was analyzed, then it was seen that type B loses more percentage of strength than the other two types because of having less clear cover than the other types and this happened because of keeping the slab thickness uniform in all three types. The graph shows the change of flexural strength with the increasing temperature.

3.3 Stress Strain Curve and The Amount of Energy Stored

The Figure shows the stress-strain relationship of the three types of samples

The following table shows the energy stored in these three types. After plotting the graph of Stress vs strain, it is transferred to Excel, which makes an equation for the graph. And by integrating the

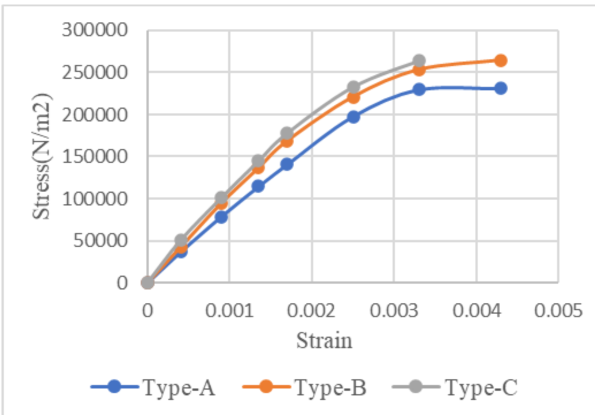


Figure 8:Stress vs strain of the tested samples

equation, the area under the graph is found, which means the energy stored in these samples.

Table 1:Type wise Variation of Energy stored at 500°C

	Energy Stored(J)
Type A	668
Type B	701
Type C	553

Here, it was seen that, type B had more energy stored than the other two types. Because, it sustained more load than the other ones before going to fracture. That's why, it deformed greater than the other types. That's why, when calculating the area of the stress-strain curve for determining the energy stored, it showed that type B stored more energy. It is also called the toughness of the material.

3.4 Surface Performance Of The Slab At Elevated Temperature

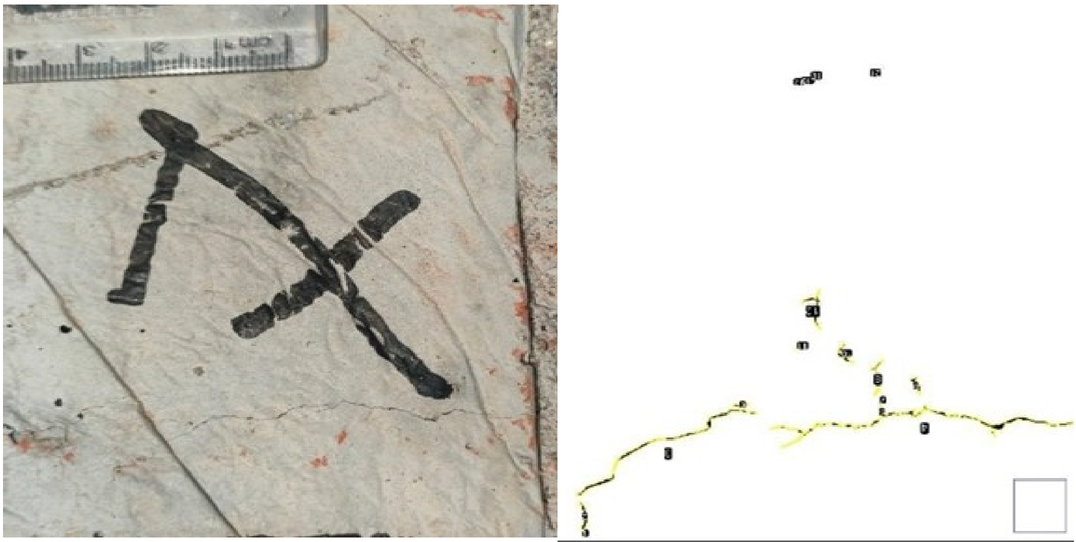
Table 2:Percentage of crack generated at the outer panel of ferrocement slab

Temperature (°C)	Area of crack generated (%)		
	Type-A	Type-B	Type-C
Ambient	0	0	0
100	0	0	0
200	0	0	0
300	0.25	0	0
400	0.37	0.20	0.24
500	0.43	0.29	0.32

From this table, it is clear that no cracks have been shown at 100°C and 200°C, and cracks have been generated at 300°C, 400°C, and 500°C. The amount of the crack was very low. For example, at 500 °C, the amount of crack generated is only 0.43% in type A, 0.29% in type B, and 0.32% in type C. Cracks were selected and the area of the cracks was calculated by FIJI software. The wire mesh diameter and mesh opening both were small in type A. As a result, cracks are generated mostly at the type A ferrocement slab. Because of having a higher percentage of reinforcement, type B generated lower cracks. Here, are the pictures of the cracks and amount of it in the FIJI software.

Figure 9:Crack generated in type-A at 500°C

Figure 11:Crack generated in type-C at 500°C



4. CONCLUSIONS

This study mainly looks at the behavior of ferrocement walls at elevated temperatures. That's why, thermogravimetric analysis, flexural strength, and surface performance tests were carried out. And compared the performance in elevated temperature with the ambient temperature. After analyzing and monitoring the result, the following conclusions are drawn:

- At higher temperatures, the percentage weight loss of slabs is higher than at lower temperatures, and ferrocement slabs with 1.25% reinforcement of mesh opening 12.5mm lost more weight than other slabs.
- Flexural strength decreases with the increase of temperature. 2.5% reinforcement of mesh opening 12.5mm shows higher strength than other slabs
- 1.25% reinforcement with a 12.5mm mesh opening generated more cracks than the other types.

So, a lower reinforcement ratio with less mesh opening shows weaker performance, and a higher reinforcement ratio shows better performance than the other types in terms of thermogravimetric analysis, flexural strength, and surface performance. Though at high temperatures, the performance was nearly similar.

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REFERENCES

Al-Rifaie, W. N., Al-Enezi, K. K., & Ahmed, W. K. (2015). Thermal response of a ferrocement cavity wall under direct fire. International Journal of Sustainable Building Technology and Urban Development, 6(4), 229–235. https://doi.org/10.1080/2093761X.2015.1116416

Al-Rifaie, W. N., & Azad, A. (2013). Experimental investigation on thin ferrocement dome structures. *International Journal of Engineering and Advanced Technology*, *3*(2), 373–377.

Chan, S. Y. N., Peng, G., & Chan, J. K. W. (1996). Comparison between high strength concrete and normal strength concrete subjected to high temperature. *Materials and Structures*, *29*, 616–619.

Fahmy, E. H., SHAHEEN, Y. B. I., & Korany, Y. S. (1999). Repairing reinforced concrete columns using ferrocement laminates. *Journal of Ferrocement*, *29*(2), 115–124.

Fahmy, E., & Shaheen, Y. (1994). Laminated ferrocement for strengthening and repairing of reinforced concrete beams. *Proceedings of the Annual Conference of the Canadian Society for Civil Engineering*, 475–483.

Frattolillo, A., Giovinco, G., Mascolo, M. C., & Vitale, A. (2005). Effects of hydrophobic treatment on thermophysical properties of lightweight mortars. *Experimental Thermal and Fluid Science*, *29*(6), 733–741.

Greepala, V., Greepala, V., Nimityongskul, P., Tanchaisawat, T., & Parichartpreecha, R. (2008). *Thermal conductivity of ferrocement*. https://www.researchgate.net/publication/286154293

Greepala, V., & Nimityongskul, P. (2007). Influence of heating envelope on post-fire mechanical properties of ferrocement jackets. *Science & Technology Asia*, 69–79.

Greepala, V., & Nimityongskul, P. (2008). Structural integrity of ferrocement panels exposed to fire. *Cement and Concrete Composites*, *30*(5), 419–430. https://doi.org/10.1016/j.cemconcomp.2007.08.007

Greepala, V., & Nimityongskul, P. (2009). Influence of heating envelope on structural fire integrity of ferrocement jackets. *Fire Technology*, *45*, 385–404.

Ibrahim, H. M. (2011a). Experimental investigation of ultimate capacity of wired mesh-reinforced cementitious slabs. *Construction and Building Materials*, *25*(1), 251–259. https://doi.org/10.1016/j.conbuildmat.2010.06.032

Ibrahim, H. M. (2011b). Experimental investigation of ultimate capacity of wired mesh-reinforced cementitious slabs. *Construction and Building Materials*, *25*(1), 251–259. https://doi.org/10.1016/j.conbuildmat.2010.06.032

Khan, M. I. (2002). Factors affecting the thermal properties of concrete and applicability of its prediction models. *Building and Environment*, *37*(6), 607–614.

Kim, K.-H., Jeon, S.-E., Kim, J.-K., & Yang, S. (2003). An experimental study on thermal conductivity of concrete. *Cement and Concrete Research*, *33*(3), 363–371.

Li, J., & Hao, H. (2014). Numerical study of concrete spall damage to blast loads. *International Journal of Impact Engineering*, *68*, 41–55. https://doi.org/10.1016/j.ijimpeng.2014.02.001

Milon, K. H., Rashid, M. H., & Zahangir, A. (2013). Effect of Saline Water on the Flexural Performance of Ferrocement Wall Panel. *International Journal of Advanced Structures and Geotechnical Engineering*, *2*, 95–100.

Morrill, K. B. , M. L. J. , C. J. E. , F. J. M., & Karagozian, J. (2004). *Blast Resistant Design and Retrofit of Reinforced Concrete Columns and Walls Related papers T he Use of Fiber Reinforced Polymers t o Mit igat e Nat ural and Man-Made Hazards Tonat iuh Rodriguez-Nikl Experiment al Performance of Concret e Columns wit h Composit e Jacket s under Blast Loading Blast Resistant Design and Retrofit of Reinforced Concrete Columns and Walls*.

Murtiadi, S. (2013). Review of Indonesian standard for concrete building subjected to fire. *Procedia Engineering*, *54*, 668–674. https://doi.org/10.1016/j.proeng.2013.03.061

Naaman, A. E. (2000). *Ferrocement and laminated cementitious composites* (Vol. 3000, Issue 1). Techno press Ann Arbor.

Rashid, M. H., Alam, Z., Mahmud, F., & Anita, M. S. (2019). Durability and Performance of Ferrocement Infill Wall Panel. *Civil Engineering Journal (Iran)*, *5*(6), 1205–1213. https://doi.org/10.28991/cej-2019-03091325

Shaheen, Y. B. I., Etman, Z. A., & Ramadan, A. G. (2009). *Pre-and Post-Fire Strength Assessment of Ferrocement beams*. www.crl.issres.net

Thanoon, W. A., Jaafar, M. S., Kadir, M. R. A., & Noorzaei, J. (2005). Repair and structural performance of initially cracked reinforced concrete slabs. *Construction and Building Materials*, *19*(8), 595–603.

Wang, K.-S., Tseng, C.-J., Chiou, J., & Shih, M.-H. (2005). The thermal conductivity mechanism of sewage sludge ash lightweight materials. *Cement and Concrete Research*, *35*(4), 803–809.

Xu, Y., & Chung, D. D. L. (2000). Effect of sand addition on the specific heat and thermal conductivity of cement. *Cement and Concrete Research*, *30*(1), 59–61.