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# USE OF FERROCEMENT PANEL AS REINFORCED CONCRETE SLABS WITH LIGHTWEIGHT BLOCKS INFILL

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This paper is part of an experimental series to investigate the potential use of ferrocement panels as a permanent form of reinforced concrete slabs with lightweight blocks infill. The ferrocement panels used are engineered with polyvinyl alcohol (PVA) fiber to have a strain hardening which can be characterized as high-performance fiber-reinforced cementitious composite (HPFRCC), called Engineered Ferrocement (EF). In the experimental work, ferrocement control panels and hybrid ferrocement panels were tested for strength capacity and hard strain behavior through flexure, toughness, and multitrack forming. The results showed that by using the ideal fiber/wire mesh content, the hybrid ferrocement panels act as a strain-hardening cementitious material, and successfully increasing the flexure strength compared to the control-group ferrocement. The initial investigation indicates that hybrid PVA fiber ferrocement in tensile zones can be successfully used as permanent form.

*Keywords*: Engineered ferrocement, Hybrid polyvinyl alcohol (PVA) fiber, Hard straining, Lightweight composite.

## 1 INTRODUCTION

Ferrocement, a mesh reinforcement thin cementitious composite (ACI committee 549-R97 1997), has been commonly applied in several structural elements. It has been used in the construction of low-cost houses to resist earthquakes (Saleem and Ashraf 2008), for repairing and maintaining of damage structural elements caused from hurricanes (Adajar et al. 2006), for constructing water tanks (UNHCR 2006), and for a wide range of other important applications (Naaman 2000).

A variety of research has focused on methods to increase the strength capacity of ferrocement. Some of those studies modified the mortar mixture with a percentage of alternative binder such as fly ash, and additives like silica fume, to explore the effect of increased compression strength on the general performance of ferrocement (Masood et al. 2003, Ahmed et al. 2007, Bhikshma et al. 2011). Other investigation related to strength improvement have added fiber as an additional reinforcement to wire mesh (Debs and Naaman 1995, Wang et al. 2004). The use of hybrid fiber has led to the creation of high-performance material properties, such as high-performance=fiber cementitious composites, or HPFRCC) (Li 1993, Mobasher and Li 1996, Kim et al. 2012). These materials showed excellent ultra-ductility, high performance, and elimination of shrinkage cracking (Li et al. 2001, Zhang and Li 2002, Ahmed et al. 2003, Pereira et al. 2012).

In this study, two series of tests were conducted. In the first series, an experimental program investigated the effect of the interaction of hybrid polyvinyl alcohol fiber (PVA) reinforcement and wire mesh on thin cementitious composites. In the second series, appropriate mixtures of cementitious composites were selected to cast ferrocement panels. The purpose of this series was to investigate the potential of ferrocement panels to act as permanent form in the fabrication of reinforced concrete slabs with lightweight blocks infill.

## 2 MATERIALS AND EXPERIMENTS

### 2.1 Materials

The mix is designed for a Portland cement content of 400 kg/m3. The mortar mix proportions were equal for all specimens, with the ratio of 1:0.45:1 by weight of cement, water, and sand, respectively.

Two types of PVA fibers—short and long—were combined so that the shorter fibers were properly mixed with the longer ones (i.e., a hybrid). Flexible galvanized hexagon woven wire (i.e., chicken mesh) with a wire diameter of 1.4 mm and a square wire mesh of 1.24 mm were used. The ferrocement panels were 40 mm thick, and the concrete compression strength after 28 days was 30 MPa.

### 2.2 Sample Details

Materials were mixed in an adjusted mix sequence to allow for an equal distribution of the fiber according to Zhou et al. (2012). In the first series of tests, all casted panels were of dimensions 620 mm x 200 mm x 40 mm, reinforced with 4 different wire mesh layers (six, four, three, and two). Three different fiber volume fractions of the hybrid PVA fiber, namely 0.75% (FA), 1.00% (FB), and 1.50% (FC), were used in three different mixtures to study the effects of fiber content on strength.

In the second series, ferrocement panels with the dimensions of 1220 mm long x 1000 mm wide x 155 mm deep were cast to form composite slabs with lightweight blocks infill. Figure 1 shows a typical section of the composite slab with a ferrocement panel as a permanent form of the slab.

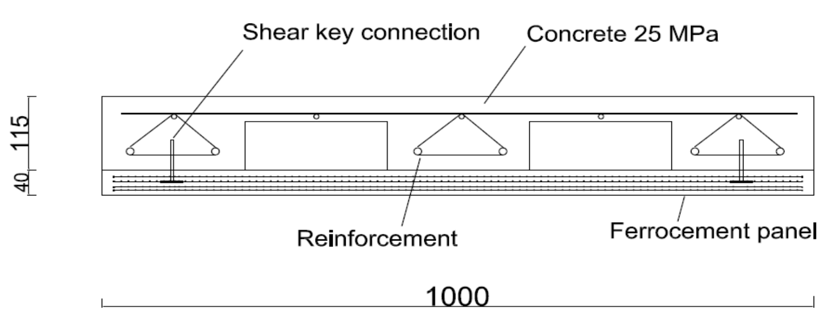


Figure 1. Ferrocement panel as permanent form of composite slab.

### 2.3 Test Procedure

In the first series of tests, a four-point bending test after 28 days, with a constant bending moment zone, was used to determine the flexure strength of the panels. An INSTRON testing machine was used with the applied load being under displacement control at a loading rate of 1 mm/min for all tested panels. The test results would be compared with the flexure test results of ferrocement and mono fiber reinforced ferrocement control panels.

In the second test series, four slabs were tested. Each slab was set up on two simple supports over a 1000 mm span, and was subjected to a single point representing a standard three-point bending test.

## 3 RESULTS AND DISCUSSION

According to the span arrangement and the load test setup in the first test series, the obtained load-deflection results and the equivalent elastic bending stress-deflection are as seen in Figure 2. The ultimate strength and the maximum strain of the ferrocement panel with 1.5% hybrid PVA fiber volume fraction exhibit all capacity values provided from testing all other specimens. The mono-fiber ferrocement with 1.5% fiber PVA content provides greater ultimate strength than the panels with 1.0% PVA fiber content and less fiber volume fraction; however, it shows a greater post-yield strain capacity than the EF 1.5% mono PVA fiber. It should be mentioned that all fiber-modified panels show an increase in the overall strength capacity compared to ferrocement.

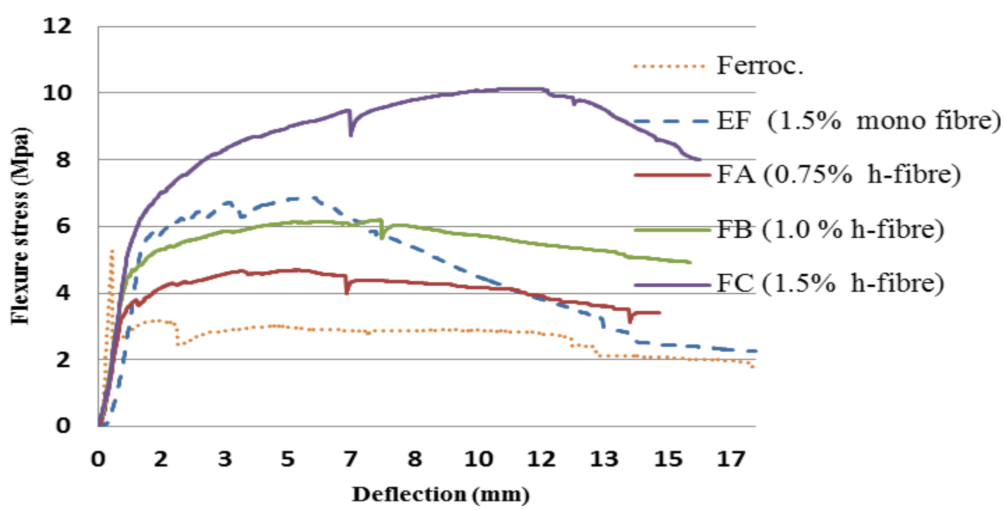


Figure 2. Strength of tested panels by different fiber volume proportions.

Naaman and Reinhardt (1995) pointed out that fiber-reinforced composites having toughness indices (i.e., the area under the load deflection curve up to a given deflection divided by the area under the same curve up to first cracking) I5 > 5, I10 > 10, and I20 > 20, and showing a multi-crack formation, behaved as quasi-strain-hardening or HPFRCC materials. In the present case, as seen in Figure 3, the toughness index results of the FC panels are I5 = 6.8 > 5, I10 = 12.3 > 10, and I20 = 27.2 > 20; therefore, these materials are considered to be HPFRCC.


Figure 3. Pictures of cracking in tested EF, and CF panels.

### 3.1 The Effects of Wire-Mesh Content

Figure 4 shows the equivalent stress-deflection curves from the tested hybrid PVA fiber ferrocement panels with the variety of wire mesh layer numbers. The ultimate strengths are found to decline with decreased numbers of wire mesh layers. Panels with 6 mesh layers deliver acceptable results, but remain uneconomical, and provide less strength capacity compared to panels with 4 wire layers.

The panel with 4 layers of wire mesh (FC40-4) shows the optimal strength behavior with the highest ultimate strength, and an excellent first crack stress. From Figure 4 it can be seen that up to two wire mesh layers offer a supplementary increase in the post-yield strain capacity, and the ultimate strength is achieved. The results, although having small differences in the ultimate strength, show that the optimum wire mesh content is not necessary the maximum volume fraction of the reinforcement.

### 3.2 Ferrocement Panel as Permanent Form of Composite Slab

The adjusted content of hybrid PVA fiber and wire mesh in the mortar mixture were used to cast hybrid PVA ferrocement panels as a permanent form of reinforced concrete slab with lightweight blocks infill. Three slabs were casted and tested to compare the strength and behavior with a control composite slab.

The graph in Figure 5 illustrates the load-deflection results of four tested slabs. The control slab (S1) is only a reinforced concrete slab with AAC blocks infill. S2 is a composite slab with a ferrocement panel in the tensile zone without the addition of fiber. Slabs S3 and S4 consist of hybrid PVA ferrocement panels in the tensile zone of the hybrid composite slab. Additionally, it should be noted that shear keys were inserted in the four corners of these slabs (Figure 1), except in S4, which had two additional shear connecters in the middle strip of the slab.

As seen in Figure 5, the performances of the hybrid PVA ferrocement in the tensile zone exhibit the yield strain, and the ultimate load capacity of control and only ferrocement slab composite (S2). Due to the use of two different types of PVA fiber, an increase in ultimate load capacity of approximate 6.4%-9.8% has been achieved.

## 4 CONCLUSIONS

- Hybrid PVA fiber composites, as panels or as composite slabs, show generally greater ultimate strength and yield-strain capacity at the ultimate load than those of the control specimens.
- Remarkable strength results have been observed by using 4 wire mesh layers.
- The initial investigation results show that hybrid PVA fiber ferrocement in the tensile zone can be successfully used as permanent form.
- A slight improvement in the bending capacity of the specimens with hybrid PVA fiber ferrocement cover was observed, compared to concrete only and ferrocement cover only.

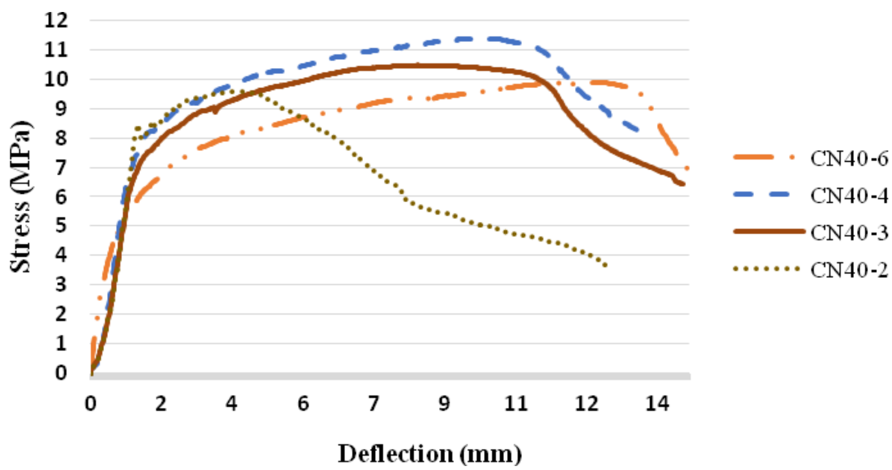


Figure 4. Load-deflection of hybrid PVA ferrocement panels by different wire mesh content.

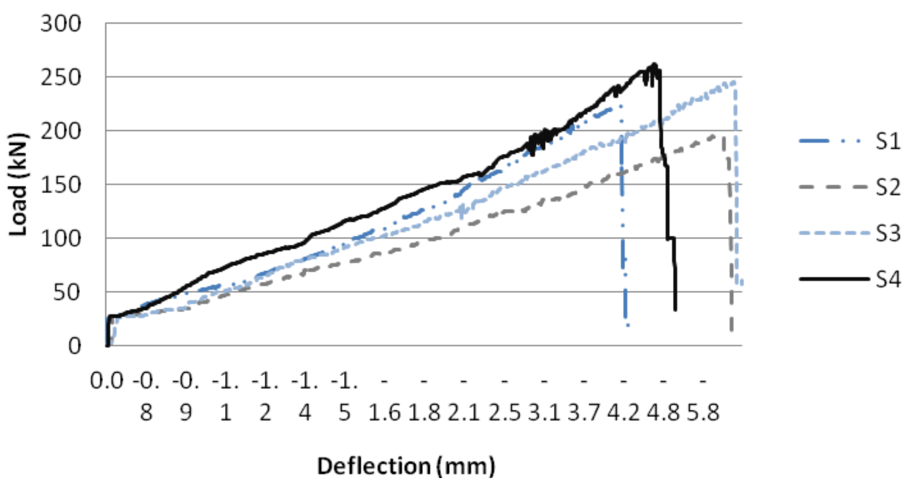


Figure 5. Load deflection of tested slabs.

## References

ACI Committee 549-R97, *State-of-the-Art Report on Ferrocement*, Detroit, Michigan, American Concrete Institute, 1997.

Adajar, J. C., Hogue, T., and Jordan, C., *Ferrocement for the Hurricane-Prone State of Florida*. Edinburgh, Scotland UK, 2006.

Ahmed, S. F. U., Maalej, M. and Paramasivam, P., Flexural responses of hybrid steel–polyethylene fiber reinforced cement composites containing high volume fly ash, *Construction and Building Materials* 21(5): 1088-1097, 2007.

Ahmed, S. F. U., Maalej, M., and Paramasivam, P., Strain-hardening behavior of hybrid fiber reinforced cement composites, *Ferrocement* 3(33): 172–182, 2003.

Bhikshma, V., Ravandekishore, and R. Srinivas, R., Durability of polymer and fly ash modified ferro cement elements, *Procedia Engineering* 14(0): 2642-2649, 2011.

Debs, M. K. E., and Naaman, A. E., Bending behavior of mortar reinforced with steel meshes and polymeric fibers, *Cement and Concrete Composites* 17 327-338, 1995.

Kim, D. J., Wille, K., Naaman, A. E., and El-Tawil, S., Strength dependent tensile behavior of strain hardening fiber reinforced concrete, *RILEM: High Performance Fiber Reinforced Cement Composites* 6, Springer (2) 3-10, 2012.

Li, V. C., From micromechanics to structural engineering – the design of cementitious composites for civil engineering applications, *Struct. Mechanics Earthquake Eng. JSCE* (10(2)): 37-48, 1993.

Li, V., Wang, C. S., and Wu, C. Tensile strain-hardening behavior of polyvinyl alcohol engineered cementitious composite (PVA-ECC), *ACI Materials Journal* 98(6): 463-472, 2001.

Masood, A., Arif, M., Akhtar, S., and Haquie, M., Performance of ferrocement panels in different environments, *Cement and Concrete Research* 33: 555-562, 2003.

Mobasher, B., and Li, Y. C., Mechanical properties of hybrid cement-based composites, *ACI Materials Journal* 93(3): 284-292, 1996.

Naaman, A. E., *Ferrocement And Laminated Cementitious Composites*, Techno Press 3000, 2000.

Naaman, A. E., and Reinhardt, H. W., Characterization of high performance fiber reinforced cement composites, *Proceedings of the second international RILEM workshop*, U.S.A, E and FN Spon, 1995.

Pereira, E. B., Fischer, G., and Barros, J. A. O., Effect of hybrid fiber reinforcement on the cracking process in fiber reinforced cementitious composites, *Cement and Concrete Composites* 34(10): 1114-1123, 2012.

Saleem, M. A. and Ashraf, M., Low Cost Earthquake Resistant Ferrocement Small House, *Engineering and Applied Science* 2: 59-64, 2008.

UNHCR, *Large Ferro-cement Water Tank*, Technical Support Section, 2006.

Wang, S., Naaman, A. E., and Li, V. C., Bending response of hybrid ferrocement plates with meshes and fiber, *Journal of Ferrocement* 34(1): 275-288, 2004.

Zhang, J., and Li, V. C., Monotonic and fatigue performance in bending of fiber-reinforced engineered cementitious composite in overlay system, *Cement and Concrete Research* 32: 415–423, 2002.

Zhou, J., Qian, S., Ye, G., Copuroglu, O, van Breugel, K. and Li, V. C., Improved fiber distribution and mechanical properties of engineered cementitious composites by adjusting the mixing sequence, *Cement and Concrete Composites* 34(3): 342-348, 2012.