ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

Influence of Mixture, Wire Mesh and Thickness on the Flexural Performance of Hybrid PVA Fibre Ferrocement Panels

Nadim Abushawashi[1], Vanissorn Vimonsatit[2]

PhD Candidate, Department of Civil Engineering, Curtin University of Technology, Perth, Australia

Lecturer, Department of Civil Engineering, Curtin University of Technology, Perth, Australia

ABSTRACT: This paper presents the results of an experimental investigation into the flexural performance of hybrid polyvinyl alcohol (PVA) fibre ferrocement (HFF) composites panels. The primary focus is on the influence of mixture matrix and wire mesh content in the panels which have different thicknesses. The effect of using fly ash and silica fume in the mixtures is investigated from the testing of 21 panels. Best performed mixes are then chosen to prepare additional 27 ferrocement panelswith varying thicknesses and wire mesh layers. The observation of deflection hardening, energy absorption, and flexural stress is significant in this experiment. The energy absorption at post cracking and the toughness indexes are calculated from the flexure test results, and are used for the evaluation of strength capacity of this type of cementitious composites.

KEYWORDS: Hybrid ferrocement, reinforcement content, thickness, flexural strength.

I. INTRODUCTION

The extraordinary cast in place thin cementitious construction materials with relatively high performance have stimulated the application of such materials in the construction world. Ferrocement is a type of thin shell reinforced mortar where usually hydraulic cement is reinforced with layers of continuous mesh. Mesh may be made of metallic material or other suitable materials [1]. The wire mesh content in a ferrocement panel has a significant impact on the structural strength performance [2]. Specific guide for wire mesh proprieties and the design of ferrocement are reported in the ACI Committee 549.

Ferrocement is known to be a durable construction material which can last for many years. The durability of this thin cementitious composite depends on numerous factors such as mortar composition, corrosion of reinforcement, permeability, and construction application [3]. Another way to improve ferrocement structural specifications is monitored thought the enhancement of mortar mixtures such as putting additives, and using fly ash as a partial replacement of cement[4]. The properties improvement of ferrocement has also been affected by the type and the ratio of reinforcement

II. BACKGROUND

Hybrid fibre or hybridization process of fibres in cementitious composites is achieved by combining different types of fibres, in structural and mechanical properties[5]. Mixtures of hybrid fibre with 1.5% to 2% volume fraction (V_f) with high volume fly ash shows high performance fibre reinforced cementitious composite (HPFRCC) behaviour. Generally the fibre has the effect in increasing the ductility, post-cracking strength, and energy absorption capacity.

Since, the mesh content is significantly affecting the performance of ferrocement used as structural elements subjected to binding moments[6]. It is clear that a specific wire mesh content, and type in a ferrocement panel has a substantial impact on the enhancement of its their ability of energy absorption, and its general strength performance [7, 8].

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

A study of PVA (poly-vinyl alcohol) mono discontinues fibre in ferrocement with only one layer of steel mesh, shows a better overall performance in term of cracking behaviour[9], yield and ultimate strengths than conventional ferrocement[10, 11]. Since, the effect of using two types of PVA fibre in ferrocement has been not studied intensively at this stage. The following study will focus on flexural performance by adjusting the mixture, wire mesh content, and specimen thickness of this hybrid composite.

III. EXPERIMENTAL PROGRAM AND MATERIAL MIXTURE

In this study an experimental program is set to investigate the effect of using different mixture water ratio and additives in the hybrid fibre ferrocement mortar on the flexural performance of ferrocement panels. Additives used are superplasticizers and silica fume. The effect of increasing fly ash contents from 25% to 50% on the flexure behaviour of hybrid PVA fibre composites is also evaluated. Other significant efforts are made on optimizing the wire steel mesh reinforcement content and panel thickness of the hybrid PVA fibre ferrocement which shows strain hardening and multiple cracking behaviours in bending by using two types of PVA fibre (poly-vinyl alcohol).

In preparing the ferrocement panels, general Portland cement, flyash, and silica fume were used. The locally available natural silica sand aggregates were clean and separated from all clay chunks and other external materials.

Flexible galvanized hexagon chicken mesh and a wire mesh diameter of 1.4 mm with wire spacing of 40 mm was used to reinforce the produced ferrocement slabs. PVA fibres were added as discontinues reinforcement to ferrocement. The different properties of these PVA fibres are as listed in Table 1. The total fibre content was 1.5% volume fraction (0.75% $V_f$from each type).

Table 1Poly vinyl alcohol fibre specifications

Fibre types	Diameter (d_f) µm	Length (L_f) mm	Aspect ratio (L_f/d_f)	Tensile strength MPa	Fibre flexural strength GPa	Fibre density gm/cm^3
PVA1	38	8	211	1400	30	1.3
PVA2	660	30	45	800	23	1.3

There were two experimental series in this study. The first was carried by testing 21 hybrid fibre ferrocement panels containing 4 wire mesh layers of different mixtures. In the second test series, additional 27 ferrocement panels with the size of 620 mm in length, 200 mm in width, and a variable thickness of 25, 30, and 40 mm, were made

The volume fraction of the steel wire mesh reinforcement (V*r*) has been calculated according to ACI 549 [12]. Table 2 summarizes the specimen identification and reinforcement information of the panels tested in the second series.

The mortar mix proportions and the corresponding compression strength of all mixes are as seen in Table 3. Based on the compressive strength results, all mixes with 0.25 fly ash ratio provided similar compressive strength compared to the control mix. Mix CL provided the highest compressive strength which was greater than C1 strength value. All mixes with 0.5 fly ash ratio showed low strength indicating that it would only be suitable when high strength was not required.

DOI: 10.15680/IJIRSET.2014.0309002

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

Table 2Specimen geometry and reinforcement

Specimen ID	Panel size (mm)	wire mesh layers	V_r (Steel mesh) (%)	PVA1 V_f(%)	PVA2 V_f(%)	Total fibre volume fraction (%)
CN40-6	620*200*40	6	1.00	0.75	0.75	1.5
CN40-4	620*200*40	4	0.67	0.75	0.75	1.5
CN40-3	620*200*40	3	0.50	0.75	0.75	1.5
CN40-2	620*200*40	2	0.33	0.75	0.75	1.5
CN30-4	620*200*30	4	0.89	0.75	0.75	1.5
CN30-3	620*200*30	3	0.67	0.75	0.75	1.5
CN30-2	620*200*30	2	0.45	0.75	0.75	1.5
CN25-3	620*200*25	3	0.80	0.75	0.75	1.5
CN25-2	620*200*25	2	0.53	0.75	0.75	1.5
CZ40-4	620*200*40	4	1.00	0.75	0.75	1.5
CM40-4	620*200*40	4	1.00	0.75	0.75	1.5
CL40-4	620*200*40	4	1.00	0.75	0.75	1.5

Table 3Mixture proportions and Compressive Strength

Mixture type	Binder		Sand	water	Silica fume	Superplasticiser	Compressive strength (MPa)
	Cement	Fly ash					
C1	1	-	1	0.45	-	-	51
CM	0.75	0.25	1	0.40	0.05	80 ml	47
CN	0.75	0.25	1	0.35	0.05	120 ml	53
CL	0.75	0.25	1	0.30	0.05	160 ml	58
CX	0.75	0.25	1	0.45	-	-	42
CY	0.75	0.25	1	0.45	0.05	-	46
CG	0.50	0.50	1	0.45	-	-	21
CZ	0.50	0.50	1	0.45	0.05	-	23

*All ratios are by weight.

The specimens were tested using the INSTRON testing machine. A four point loading fixture with a 580 mm loading span and a 200 mm constant bending moment zone was used.

IV. RESULTS AND DISCUSSION

4.1 The effect of mixture matrix.

The enhancement of flexural strength through the fibre-matrix leads to increase in terms of strain hardening and ultimate post crack stresses.The stress–deflection curves of the tested panels with different mixture proportions and wire mesh contents are as seen in Fig. 1. It is observed that the decrease in the water cement ratio, addition of silica fume, and the fly ash content can increase flexural and compressive strength value of the tested specimens.

Based on the obtained flexural behaviour, panel CL40-4 provides the highest ultimate flexure strength, which is consistent with the material cube strength. However, it must be noted that the CL mix was very stiff compared to all others used mixes in this test. On the other hand, the first peak stress and the ultimate strength of the CN40-4 specimen were greater than the strength results of other mixes. However, the post yield strain capacity shows a slight drop approximately 13% of the C1/40-4 control mixture. It should be noted though that this drop has no significant impact on the ductility. According to the overall performances of all the mixtures, CN40-4 has Comparing CX and CY with

ISSN: 2319-8753
International Journal of Innovative Research in Science, Engineering and Technology
(An ISO 3297: 2007 Certified Organization)
Vol. 3, Issue9, September 2014

the control mix C1, the use of 0.25 ratio of fly ash as cement replacement does not seem to have any influence on the elastic behaviour. On the other hand, adding silica fume to the mix shows a significant improvement in the flexural performance by reducing the deflection and increasing the strength at first crack. After the first crack, CX and CY panels appear to develop multiple cracking in a lower deflection range and achieve lower ultimate strength value than that of C1 panel.

Due to the high amount of fly ash in CG and CZ panels, a significant decreases in the flexure strength and strain capacity is observed. The stress at the first crack and the ultimate strength are the lowest, which were about 50% reduction in values when compared to other tested panels.

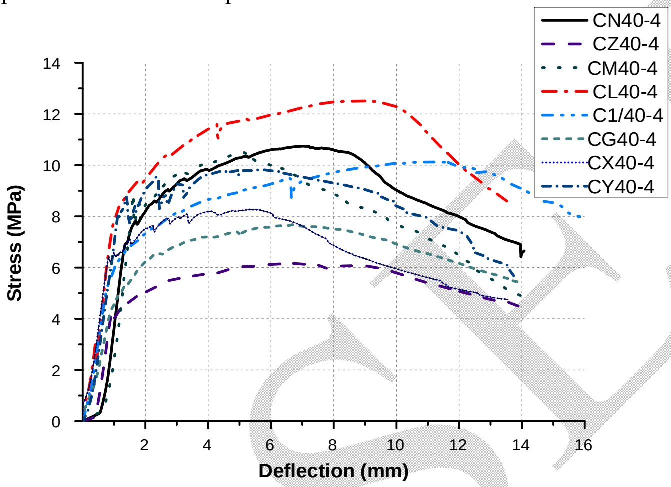


Fig.1 Stress – deflection curve of specimens with different water cement ratio and fly ash content

4.2 Influence of wire mesh content

The ultimate strengths of the tested panels are as seen in Fig. 2. Slabs with a thickness of 40 mm are found to decline with decreased numbers of wire mesh layers, except for the panels with 6 mesh layers. It is observed that the CN40 with 4 layers of wire mesh (0.67 % V_r) provides the optimal strength behaviour with the highest ultimate strength.

Similar stress-deflection behaviours are seen in specimens CN30 and CN25, reinforced with 3 layers wire mesh, respectively. The test results of CN30 specimens show that CN30 with 3 mesh layers performs better than the panels with 2 and 4 layers. These results, albeit having small differences, show that the optimum wire mesh content is not necessary the maximum volume fraction of the reinforcement. Remarkable stress values are observed in CN25-3 specimen, which exhibits 41% greater strength than the ultimate strength of CN25-2. This exceptional performance of CN25-3 indicates that it is possible to determine optimum thickness and wire mesh content of a hybrid fibre ferrocement panel.

All tested specimens also show supplementary increases in the post yield strain capacity and the ultimate strength in relation to the steel reinforcement up to two layers. This behaviour is due to the effective reinforcement content of hybrid PVA fibre in addition to the wire mesh. It is substantial in strain hardening materials that the load, or from the stress- deflection curve, after reaching the first stress peak, the stresses increase until reaching the ultimate strength [13]. This behaviour of the material is due to the procedure of discontinuous reinforcement and the effect of fibre hybridization [14]. It is important to note that all tested specimens demonstrate strain hardening behaviours, and the variety of continuous reinforcement content and the specimen thickness have very little effect on the behaviour. Insensitivity to these parameters, while maintaining strain hardening behaviours, indicates a better prospect in the use of such hybrid ferrocement composites. Another important indicator of strain hardening behaviour is the multiple crack formation of flexure tested specimens [15], which is formed as seen in Fig. 3. It is observed that the small cracks close considerably after removal of load. Previous studies have shown that the usage of different length of fibre in a

DOI: 10.15680/IJIRSET.2014.0309002

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

cementitues composites increases the bridging stress-versus-crack relation, and that the activation of different fibres occurs at different scales of the material structure [16]. This explains the multiple cracks formation in all tested specimens, even by small amount of continuous reinforcement content like CN40-2 and especially in CN30-2.

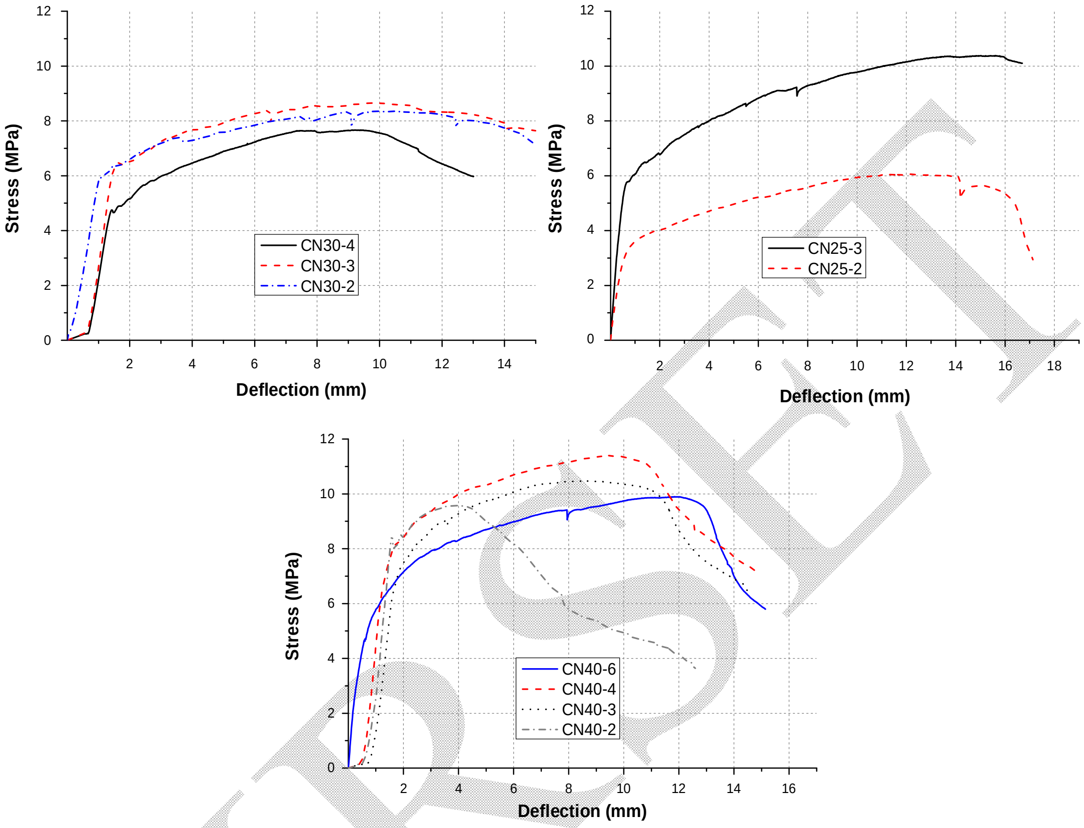


Fig. 2 Equivalent stress – deflection curves of different panel thicknesses

CN 25- 2

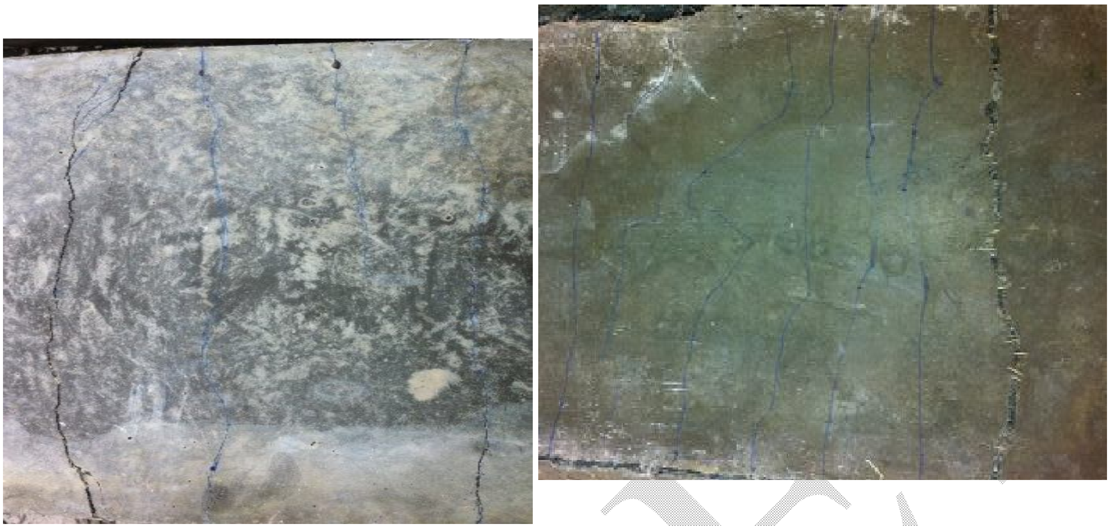
CN 30-3

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014



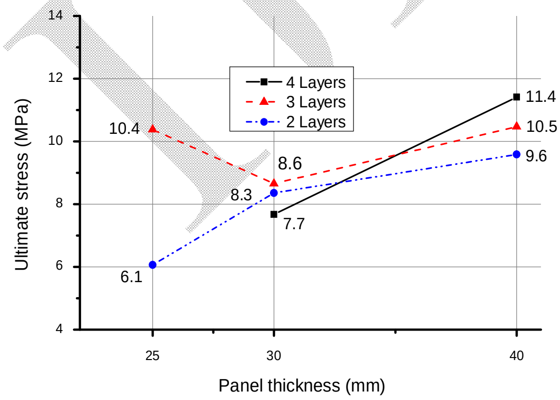
CN30-2 CN40-2

Fig. 3Cracking in tested hybrid PVA fibre reinforced ferrocement panels

4.3 Influence of specimen thickness

The mixture used to investigate the effect of the thickness is CN.Ultimate strength with the reinforcement content of 0.67% *Vr*(4 mesh layers) is exhibitingallother strengths. The use of 3 wire mesh layers in all the tested panel thicknesses also yields relatively high strength values. Equivalent stress results at ultimate loads of the tested panels,as seen in Fig. 4,show that the 25 mm thick panel with 3 mesh layers illustrates remarkable strength results compared to all tested 30 and 40 mm thick slabs. Understandable, this behaviour can be significant in term of considering the optimum weight reduction of these cementitious composites materials.

The average values of the energy absorption at the ultimate post cracking stress of hybrid fibre ferrocement specimens, each with 2, 3, and 4 layers, of different thicknesses are shown in Fig. 5. The low energy absorption values in 40 mm thick panels with 2 wire mesh layers can be explained due to inadequate reinforcement content of only 0.33 % V_r and a large cover limiting the free flow of the energy dissipation procedure. For specimens with 25 mm thickness, the post cracks have started at a very high energy level. This could be related to its better reinforcement content (0.80 % V_r) which supports the hybrid PVA fibre from first peak until the ultimate strength.



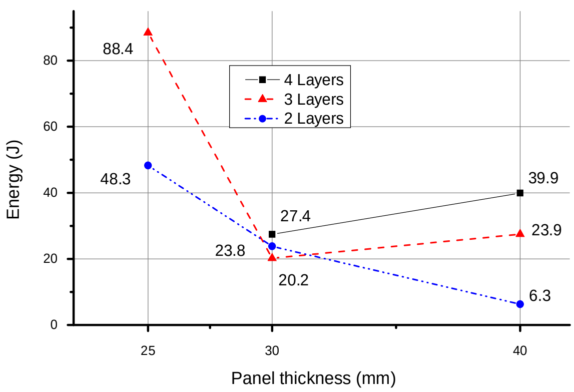


Fig.4Ultimate stressvs. panel thicknessFig. 5 Energy absorption vs. panel thickness

DOI: 10.15680/IJIRSET.2014.0309002

IJIRSET

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

According to Barr et al. [17, 18], toughness index can be used to measure the energy absorption of fibre reinforced cement composites. According to ASTM C1609[19] the toughness index is the area under the load deflection curve up to a given deflection divided by the area under the same curve up to first cracking deflection. Table 4 summarises the results of all the tested panels. The toughness results confirmall presented results related to the energy absorption at the post cracking points. Based on these results, it can be observed that increasing the reinforcement content from 0.67% to 0.80% $V_r$allows a larger area of load transfer and correspondingly increases the energy absorption level.

Table 4Strength summary of tested specimen

Panel designation ID	Specimen Weight (kg)	First crack Stress (MPa)	Deflection at first crack (mm)	Ultimate Strength (MPa)	Deflection at ultimate Stress (mm)	Ratio of ultimate to first crack load	Toughness (J)
CN25-3	6.62	5.48	0.57	10.38	15.62	1.89	15.8
CN25-2	6.60	3.16	0.63	6.06	12.13	1.92	11.6
CN30-4	7.39	4.75	0.87	7.67	8.67	1.61	9.8
CN30-3	7.33	6.38	1.02	8.66	9.40	1.36	6.9
CN30-2	7.10	5.94	1.08	8.36	10.60	1.41	6.4
CN40-6	11.18	4.61	0.57	9.89	11.83	2.15	15.4
CN40-4	11.12	6.19	1.18	11.41	9.47	1.84	11.9
CN40-3	10.96	6.16	0.92	10.47	7.68	1.70	11.4
CN40-2	10.87	8.51	1.12	9.59	3.42	1.13	7.3

V. CONCLUSION

Based on the results the following conclusions can be drawn:

- The addition fly ash (25%), silica fume, and Superplasticizersis found to be a significant factor to increase the workability (mixture flow), compression strength, and does not affect the flexure strength in a negative wayin HFF composites.
- The reinforcement optimization of wire mesh content leads to a general increase of flexural strength, tensile ductility, and energy dissipation of HFF composites.
- The thickness reduction with simultaneous adjustment of wire mesh content increases the strain hardening, toughness, and energy absorption levels particularly for thinner panels. This leads to a general weight reduction of the panel without affecting the strength capacities of the hybrid PVA fibre ferrocement composites.
- Remarkable strength and energy absorption results have been perceived by using a wire mesh volume fraction of 0.69 to 0.80% for different tested thicknesses.

VI. ACKNOWLEDGEMENT

This research was carried in the laboratories of the Civil Engineering Department at Curtin University. Assistance by the lab staff on the experimental work is greatly appreciated.

REFERENCES

1.ACI committee 549-R97, *State-of-the-Art Report on Ferrocement*. 1997, American Concrete Institute: Detroit, Michigan.
2.Paramasivam, P. and R. Sri Ravindrarajah, *Effect of Arrangements of Reinforcements on Mechanical Properties of Ferrocement.* ACI Structural Journal 1988.
3.Masood, A., et al., *Performance of ferrocement panels in different environments.* Cement and Concrete Research, 2003. **33**(4): p. 555-562.
4.Arif, M., et al., *Flexural behaviour of fly ash mortar ferrocement panels for low cost housing.* Journal of Ferrocement, 2001. **31**(2): p. 125-135.
5.Ravichandran, A., K. Suguna, and P.N. Ragunath, *Strength Modeling of High-Strength Concrete with Hybrid Fibre Reinforcement.* American Journal of Applied Sciences, 2009. **6**(2): p. 219-223.

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue9, September 2014

6.Hago, A.W., et al., *Ultimate and service behavior of ferrocement roof slab panels.* Construction and Building Materials, 2005. **19**(1): p. 31-37.
7.Hossain, Z., Rokonuzzaman, and S. Inoue, *Flexural Behavior Of Cement Composites Panels Reinforced With Different Types Of Meshes*, in *30 th Our World In Concrete & Structures*. 2005, Singapore Concrete Institute: Singapore.
8.Nanni, A. and R.F. Zollo, *Behavior of Ferrocement Reinforcement in Tension.* ACI Materials Journal, 1987: p. 273-277.
9.Wang, S., A.E. Naaman, and V.C. Li, *Bending Response Of Hybrid Ferrocement Plates With Meshes And Fiber.* Journal of ferrocement, 2004. **34**(1): p. 275-288.
10.El Debs, M.K. and A.E. Naaman, *Bending behavior of mortar reinforced with steel meshes and polymeric fibers.* Cement and Concrete Composites, 1995. **17**(4): p. 327-338.
11.Shannag, J.M. and T. Bin Ziyyad, *Flexural response of ferrocement with fibrous cementitious matrices.* Construction and Building Materials, 2007. **21**(6): p. 1198-1205.
12.ACI Committee 549-R93, *Guide for the Design, Construction, and Repair of Ferrocement*. 2009, ACI: Detroit, Michigan.
13.Naaman, A.E. *High Performance Fiber Reinforced Cement Composites: Classification And Applications*. in *CBM-CI International Workshop,*. 2007. Karachi, Pakistan.
14.Ahmed, S.F.U., Maalej M, Paramasivam P., *Strain-hardening behaviorof hybrid fiber reinforced cement composites.* Ferrocement, 2003. **3**(33): p. 172–82.
15.Naaman, A.E. and H.W. Reinhardt. *Characterization of high performance fiber reinforced cement composites*. in *Proceedings of the second international RILEM workshop*. 1995. U.S.A: E and FN Spon.
16.Li, V.C., S. Wang, and C. Wu, *Tensile Strain-Hardening Behavior of Polyvinyl Alcohol Engineered Cementitious Composite (PVA-ECC).* ACI Materials Journal, 2001. **98**(6): p. 463-472.
17.Barr, B.I.G., K. Liu, and R.C. Dowers, *A toughness index to measure the energy absorption of fibre reinforced concrete.* International Journal of Cement Composites and Lightweight Concrete, 1982. **4**(4): p. 221-227.
18.Barr, B., et al., *Toughness measurement — the need to think again.* Cement and Concrete Composites, 1996. **18**(4): p. 281-297.
19.ASTM, *Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)*, in *C1609/C1609M,*. 2012, ASTM.

DOI: 10.15680/IJIRSET.2014.0309002