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Study on Flexural Behaviour of Ferrocement Slabs Reinforced with PVC-coated Weld Mesh

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***Abstract**— The authors of this experimental research work have made an attempt to experimentally investigate the ultimate flexural load of ferrocement slabs of size 700mm. X 200mm. X 15mm. (thickness) reinforced with PVC coated steel weld mesh, and compare the results with slabs using GI-coated steel weld mesh, by varying the number of layers from 1-3. Ordinary Portland Cement, locally available river sand and potable water have been used in preparation of cement mortar, and the sand-cement ratio of 2:1 and water-cement ratio of 0.43 have been used in accordance with ACI codes. The flexural strength of ferrocement slabs was determined on four-point loading using a specially fabricated flexure loading frame. The flexural load, maximum deflection, crack-pattern and crack-width of ferrocement slabs reinforced have been analysed using varying PVC and GI coated weld mesh layers (1-3). Increasing the number of mesh layers from 1-3 caused a substantial increase in flexural load as well as improvement in ductility behavior of ferrocement slabs. It was also found that the flexural load of slabs with PVC-coated weld mesh is 90% that of specimens reinforced with GI-coated weld mesh, and therefore, PVC-coated weld mesh can be effectively used in ferrocement slabs, as non-corrosive reinforcement.*

***Keywords**—Crack, Deflection, Ferrocement, Load, Non-corrosive Coating, Weld-Mesh*

I. INTRODUCTION

Ferrocement is an innovative construction technology which is widely adopted throughout the world. It is a type of thinly reinforced and light-weight cementitious composite constructed of hydraulic cement mortar with closely spaced layers of continuous and relatively small size wire/weld mesh [1], and cast to any shape due to its easy mouldability characteristics. Since the specific surface of reinforcement in ferrocement is one to two orders of magnitude higher than that of reinforced concrete, the larger bond forces are developed between the reinforcing mesh and cement matrices [1,2]. The close spacing of the weld meshes in rich cement sand mortar and the smaller spacing of weld mesh layers imparts ductility, and leads to a better crack arresting mechanism in ferrocement [3]. The applications of ferrocement are numerous including low-cost roofing/flooring on short spans [3,4] and repair and rehabilitation of old/deteriorated structures [5,6].

The success of ferrocement largely depends upon its durability aspects and corrosion problems of thin reinforcing wire/weld mesh. Therefore, in order to overcome the problem of corrosion and to ensure long-term performance, it is advisable to select and use reinforcing mesh that is either not susceptible to corrosion or which has a protective coating [7]. Rapid development in reinforcing meshes and matrix design requires continuous research to characterize the new material and improve the overall performance of ferrrocement [5]. Therefore, the present authors have proposed new reinforcing mesh material, namely “PVC coated steel weld mesh” in an attempt to eliminate the inherent deficiency of corrosion in ferrocement composites. The objective of this study is to determine the functional characteristics of using PVC coated steel weld mesh in ferrocement slabs through flexure load tests and by comparing the results with use of GI coated steel weld mesh reinforcement.

II. EXPERIMENTAL INVESTIGATION

This experimental research program was designed to evaluate the flexural behaviour of ferrocement slab sections. In this section, the properties of materials used, mix proportion and casting of specimens, and flexure loading tests carried out are presented.

A. Materials

Ordinary Portland Cement (OPC) is used as the main binder and the physical properties of cement used in this study are evaluated by standard tests, and conform to IS 12269-1989 [8]. Good quality river sand appropriate for ferrocement construction, which is free from silt and other impurities, and conforming to Zone-II of IS 383-1970 [9] and passing through IS Sieve 2.36 mm was used as fine aggregate. The ferrocement mortar was thus prepared by mixing sand and cement in the ratio of 2:1, and water-cement ratio of 0.43, in line with ACI recommendations [10]. Potable water was used for preparation and curing of specimens.

In this study, PVC-coated steel weld mesh (represented as ‘P’ meshes throughout this paper) have been mainly used as the main reinforcement for ferrocement slabs. For the purpose of comparison, GI coated mesh (named as ‘G’ meshes throughout the paper) has also been used. Both these meshes are of 1 mm diameter, with mesh opening size of 12.5 X 12.5mm, and tensile strength and yield strength of 490 N/mm^2 and 392 N/mm^2 respectively for ‘P’ meshes and 588 N/mm^2

and 490 N/mm^2 for 'G' meshes respectively. The cube and cylinder compressive strength, which were tested at 28 days showed 33 N/mm^2 and 30.5 N/mm^2 respectively, and split tensile strength of 4.7 N/mm^2.

B. Casting of Test Specimens

The specimens of size 700mm x 200mm x 15mm (thickness) were cast for conducting the flexure tests, as shown in Fig.1. Aluminium moulds with open top and bottom was fabricated for casting the above specimens, and placed on thick plywood plank (free from undulations to get a good slab finish), after demoulding. The contact surfaces of the mould to the plywood bottom and sides were greased (oiled) before casting for easy demoulding of specimens. The cement mortar was properly mixed in a dry pan by adding required amount of water. For 15mm thick cementitious slabs with 1 layer mesh, the cement mortar is laid for 7 mm on the bottom of mould and well-compacted, and then single layer mesh is placed (at centre of slab) over the finished mortar, and the balance 7 mm mortar is laid with good compaction, and top surface finished. For 2 layer mesh, the cement mortar was laid for 3 mm cover area (using 3 mm glass spacer cover blocks), and the first layer of mesh was placed on the finished compacted cover mortar; and then, above the first mesh layer, 7 mm mortar was laid and properly finished; and next, second layer mesh has been placed, and finally the top cover area of 3 mm was spread above this second layer and top slab surface well-finished using straight edge. Similar process of laying for 3 layer mesh was done, except that the additional mesh layer has been placed in the centre of the slab. The specimens were demoulded after 24 hours and been transferred to the curing tank where they were allowed to cure for 28 days. After sufficient curing, ferrocement panels were removed from the water tank, surface dried and white washed at the top surface so as to have a clear picture of formation and propagation of cracks during flexure test.

Fig. 1 Typical Casting of Ferrocement Slabs with PVC-coated Mesh

C. Testing of Flexure Panels

A special flexure loading frame was exclusively fabricated for testing the slab panels and the details of the test set-up is shown in Fig. 2. In order to test the slabs on a four point loading (at 1/3rd span), over an effective span of 600 mm, the centre line of the panel, and the roller supports were marked and ferrocement panel was seated on the bottom rollers. Then these two roller supports were slowly raised by means of hydraulic jack till the panel touched the top roller support.

Loading was applied manually through a hydraulic jacking arrangement to cause upward deflection (see Fig.5) in order to facilitate easy measurement of deflection and crack width and also to study the crack pattern. The load was given through the jack in small increments and the mid-span deflection of the centre of the slab was recorded up to failure using an external LVDT. The proving ring readings and displacement values were observed simultaneously. The proving ring readings have been taken at every 5 division interval and the corresponding deformation values were observed in the displacement indicator. The loading was continued till the ultimate failure of the slab panels is reached, and the above measurements were taken at different load levels until final failure. The initial and final crack width was measured using a crack detection microscope. The ductility (deflection) of ferrocement composites using different reinforcing mesh types ('P' and 'G') and varying mesh layers has been studied at first crack and ultimate failure loads, and reported in Table I.

Fig. 2 Flexure Test Set-up

III. RESULTS AND DISCUSSION

A total of 18 specimens were tested in this investigation on four point loading tests (averaging three test specimens per category of 1, 2 and 3 layer ‘P’ and ‘G’ meshes) and the results of the experimental tests carried out are analysed including the flexural loads, deflection and crack width and given in Table I. It has to be noted that the identification of the specimens tested in this study are done using a combination of two or three sets of characters. The letter in the first set of characters refers to the type of matrix (PLAIN stands for Plain Cement Mortar, made of cement and sand, and no coarse aggregates), the letter in the second character refers to number of layers (SL stands for Single Layer, DL for Double Layer, and TL for Triple Layer), and P in brackets (P) indicates PVC-coated steel weld mesh.

TABLE I **: FLEXURAL TEST RESULTS OF FERROCEMENT SLABS WITH ‘P’ AND ‘G’ MESHES**

Slab Identification	**Type / Layers of Meshes**	**First Crack Load (kN)**	**Ultimate Failure Load (kN)**	**Deflection (mm)**		**First Crack Width (mm)**	**Final Crack Width (mm)**
				At First Crack	**At Ultimate Failure**		
PLAIN SL (P)	Single Layer PVC-coated (‘P’) Weld Mesh	0.376	0.474	1.02	5.67	0.15	1.90
PLAIN DL (P)	Double Layer PVC-coated (‘P’) Weld Mesh	0.376	0.591	1.25	7.43	0.15	1.90
PLAIN TL (P)	Triple Layer PVC-coated (‘P’) Weld Mesh	0.430	0.806	1.48	11.99	0.10	1.70
PLAIN SL	Single Layer GI-coated (‘G’) Weld Mesh	0.430	0.484	0.82	6.72	0.15	1.80
PLAIN DL	Double Layer GI-coated (‘G’) Weld Mesh	0.430	0.645	0.97	8.96	0.10	1.60
PLAIN TL	Triple Layer GI-coated (‘G’) Weld Mesh	0.484	0.914	1.18	13.35	0.10	1.20

A. Flexure Loads

Initially, the load was applied, and the first crack was visibly seen to naked eyes, and the corresponding load at the time of formation of initial crack is what is described as the “first crack load”. With further increase in load, the tension face of the specimen had started cracking, which was followed by crushing of the compression face, and final major crack(s) at failure load was noticed at the top middle surface of the specimen, and the ultimate states of the specimens are defined as “ultimate failure load”.

From Table I, and Fig. 3 and Fig. 4, it can be seen that the first cracking load increases by 14.36% (i.e., from 0.376 kN to 0.430 kN) between 2 and 3 layer ‘P’ meshes, and similarly increases by about 12.56% (i.e., from 0.430kN to 0.484kN) between 2 and 3 layer ‘G’ meshes. For slabs using ‘P’ meshes, the ultimate loads were found to increase by about 24.68% (i.e., from 0.474 kN to 0.591 kN) when the mesh layers were increased from 1 to 2, and found higher by 36.38% (i.e., from 0.591 kN to 0.806 kN) when 2 layer mesh is increased to 3 layers. Increasing the number of weld mesh layers in slabs with ‘G’ meshes from 1 to 2 causes to increase the ultimate load by about 33.26% (i.e., from 0.484 kN to 0.645 kN) and for 2 to 3 layers, the load has increased by 41.70% (i.e., from 0.645 kN to 0.914 kN). It is seen in Fig. 3 and Fig. 4 that the load carrying capacity of the specimens at first crack and final specimen failure increases with increase in number of mesh layers. Thus, the optimum number of layers for ferrocement slabs with thickness of 15mm can be taken as three.

When the ultimate loads of slabs are compared layerwise between ‘P’ and ‘G’ meshes, 1 layer ‘P’ mesh is 98% of 1 layer ‘G’ mesh (0.474 kN to 0.484 kN), 2 layer ‘P’ mesh is 91% of 2 layer ‘G’ mesh (0.591 kN to 0.645 kN) and 3 layer ‘P’ mesh is about 87% of 3 layer ‘G’ mesh (0.806 kN to 0.914 kN) . This implies that PVC-coated steel weld mesh is as effective as GI coated weld mesh for use as reinforcement in ferrocement slabs.

When there is progressive loading of specimens for flexure from first crack to ultimate crack stages, an increase in flexural load (between these two stages) of 26% (i.e., from 0.376 kN to 0.474 kN) for slabs with 1 layer ‘P’ mesh and 12.56% (i.e., from 0.43 kN to 0.484 kN) for slabs with l layer ‘G’ meshes were noticed. But in slabs reinforced with 2 layers, the increment from first crack to ultimate loads is about 57% (0.376 kN to 0.591 kN) for ‘P’ mesh and 50% (i.e., from 0.430 kN to 0.645 kN) for ‘G’ mesh. As far as 3 layer is concerned, the increment is about 87% (0.430 kN to 0.806 kN) and 89% (i.e., from 0.484 kN to 0.914 kN) for ‘P’ and ‘G’ meshes respectively. As such, we can establish from this results that the incremental loading behaviour of slabs from first crack to specimen failure load is almost identical for 2 layer PVC and GI mesh. Also, similar result was found for slabs with 3 layers wherein the incremental loading of slabs from initial crack to failure load is the same for both PVC and GI mesh.

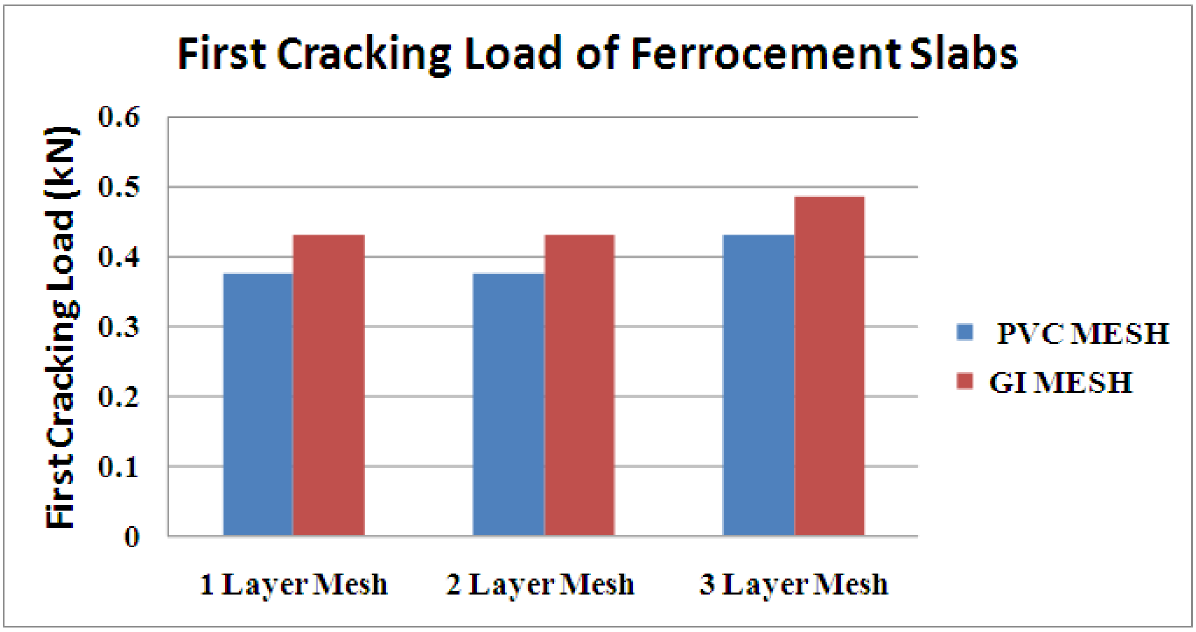

Fig. 3 First Crack Flexural Load of Ferrocement Slabs (15mm thick)

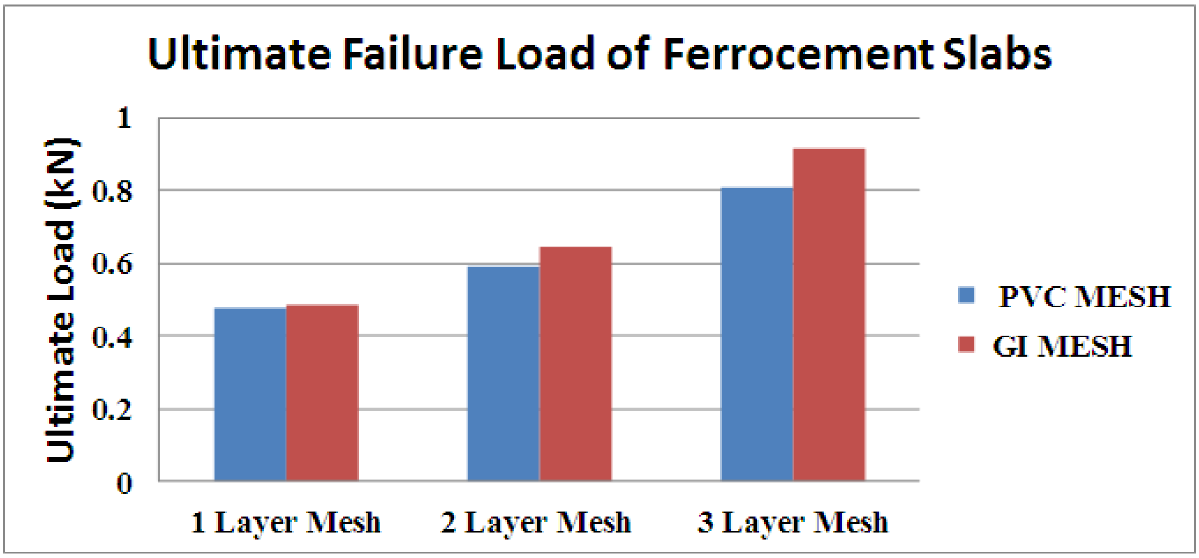

Fig. 4 Ultimate Flexural Load of Ferrocement Slabs (15mm thick)

B. Load Deflection Response

On flexural loading, the central deflection for ferrocement slabs 1,2 and 3 layer ‘P’ and ‘G’ meshes are given in Table I, and the typical ductile behaviour of ferrocement slabs from the experiments is given in Fig. 5. On analysing the graphs as depicted in Fig. 6 and Fig. 7, it was found that the deflection of slabs at first crack with 1, 2 and 3 layer ‘P’ mesh is higher than 1,2 and 3 layer ‘G’ mesh by 24.39% (0.82mm to 1.02 mm), 28.87% (0.97mm and 1.25 mm) and 25.42% (1.18 mm to 1.48 mm) respectively. But the deflection of slabs at ultimate failure with 1,2 and 3 layer ‘P’ mesh is found to be lower than 1,2 and 3 layer ‘G’ mesh by 18.52% (6.72 mm and 5.67 mm), 20.59% (8.96 mm and 7.43 mm) and 11.34% (13.35 mm and 11.99 mm) respectively.

Fig. 5 Ductility of Ferrocement Slabs

The deflection at ultimate failure for slabs increases with increase in number of meshes is shown in Table 1, and graphically represented for ‘P’ meshes in Fig. 6 and ‘G’ meshes in Fig. 7. When the number of layers is increased from 1 to 2, there is an increase in deflection at first crack of 22.55% (1.02 mm to 1.25mm) in slabs with ‘P’ mesh and 18.29% (0.82 mm to 0.97 mm) using ‘G’ mesh. Similarly, when mesh layers are increased from 2 to 3, there is an increase in deflection value at first crack by 18.4% (1.25 mm to 1.48 mm) and 21.65% (0.97 mm to 1.18 mm) for ‘P’ and ‘G’ meshes respectively. Also, the deflection at ultimate failure is increased by 31% (5.67 mm to 7.43 mm) and 33.33% (6.72 mm to 8.96 mm) for ‘P’ and 'G' meshes respectively, when the mesh layers are increased from 1 to 2; and increased by 61.37% (7.43 mm to 11.99 mm) and 49% (8.96 mm to 13.35 mm) for 'P' and 'G' meshes respectively, when the mesh layers are increased from 2 to 3.

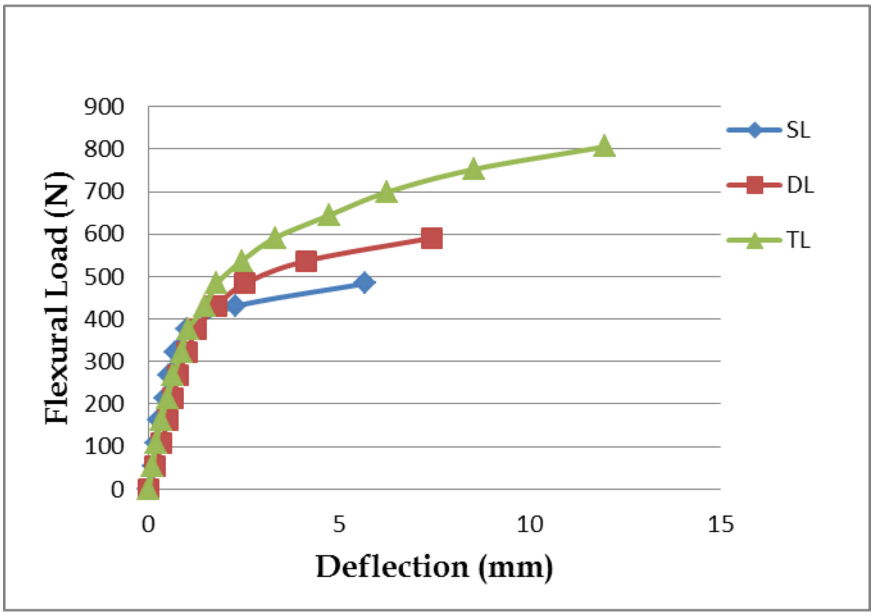

Fig. 6 Ultimate Flexural Load Vs. Deflection (at center) of Ferrocement Slabs with 'P' Mesh

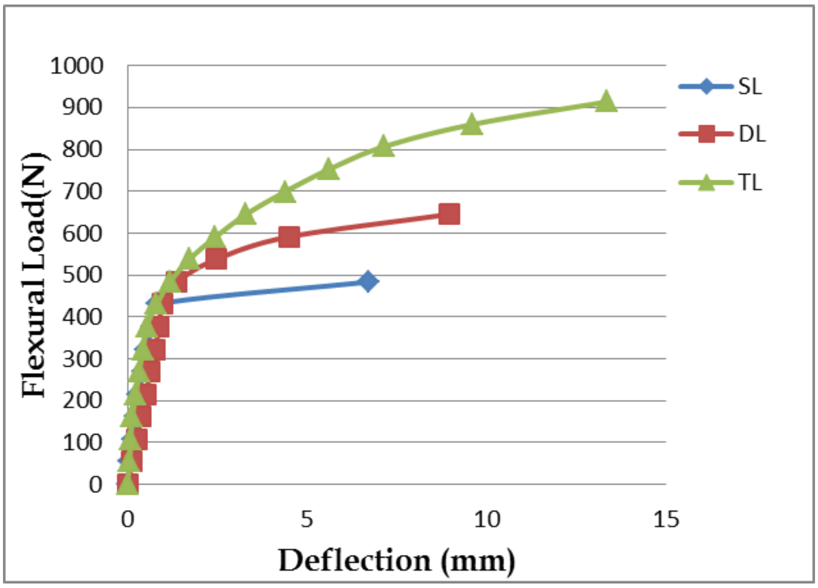

Fig. 7 Ultimate Flexural Load Vs. Deflection (at center) of Ferrocement Slabs with 'G' Mesh

From the above results, it can thus be inferred that the deflection of slabs varies depending on the types and number of layers of reinforcing mesh. It can be seen that the deflection at first crack of 'P' meshes is showing 25% more than 'G' meshes, for 1,2 and 3 layers.

Fig. 6 depicts the load-deflection relationships for cement composite elements reinforced with 3 layers of 'P' meshes under flexural loads. In 3 layer 'P' meshes, the initial linearity is seen upto 0.4 kN, and the curve in the non-linear zone is found to be parabolic in shape, for the flexural load between 0.4 and 0.8 kN. Whereas, in the case of 2 layer 'P' mesh, the load-deflection relationships can be considered as truly linear upto 0.37 kN, and shows horizontal line in the non-linear zone indicating increase in applied load, upto 0.59 kN. It can be found from Fig. 7 that the load deflection relationship for slabs with 3 Layer 'G' mesh shows almost linear relationship in the range of 0.48 KN of applied load, and at the upper limit, in the non-linear zone, the load varies between 0.48 kN and 0.9 kN and the load–deflection curve transforms in this loading area into a smooth flat parabolic shape, with the ultimate load reaching 0.9 kN. For 2 layer, the linearity is uptill 0.4 kN, with ultimate load touching close to about 0.65 kN.

Fig. 8 shows the crack patterns formed on ultimate failure of specimens. As load increases, the deflection also seem to increase accordingly and there has been a slow propagation of cracks during the transition period, i.e., from the first crack stage to ultimate failure stage, but the crack slowly widens up until it reaches the final phase of ultimate failure. The width of first crack ranges from 0.1 mm – 0.15 mm for all the specimens, which shows not much deviation among the slabs tested. Whereas, as the mesh layers are increased from 1 to 3, there is reduction in final crack width from 1.9 mm to 1.7 mm for ‘P’ meshes, and 1.8 mm to 1.2 mm for ‘G’ meshes. The increased final crack width in ‘P’ meshes, compared to ‘G’ meshes may be due to some bonding problems of PVC mesh with cementitious matrices.

Fig. 8 Typical Crack-Pattern of Ferrocement Slabs cast with GI and PVC coated Weld Mesh, on ultimate failure loads

IV. CONCLUSIONS

The following are the conclusions drawn from the above study:

1. The flexural loads at first crack and ultimate loads depend on number of reinforcing mesh layers used in ferrocement.
2. Increase in number of mesh layers also improves the ductile behaviour of ferrocement slabs.
3. The deflection of slabs at first crack using PVC-coated weld mesh is showing about 25% more ductile behaviour than slabs with GI coated weld mesh.
4. The progressive loading behavior from first crack to ultimate failure of ferrocement specimens reinforced with PVC-coated mesh is same as GI-coated mesh, especially in 2 and 3 layers. Also, the flexural load of slabs reinforced with PVC-coated mesh shows performance of 90% of GI-coated mesh. Since ferrocement slabs using PVC coated mesh reinforcement is corrosion-free and also capable of withstanding high flexural loads, this study recommends its effective use in roof slabs/terraces, repair and renovation works of open terraces and canal lining works.
5. The optimum number of mesh layers for 15 mm thick ferrocement slabs is 3 layers. Since further increase in number of meshes is not possible, this study suggests that in order to increase the flexural load capacity and ductility, as well as decrease the crack-width of ferrocement slabs, discontinuous fibers may be used as additional reinforcement; and this can be experimented in the future. Also, the slab thickness can be increased from 15 mm to 20 or 25 mm, and flexural studies conducted, and the results of load and deflection and crack patterns can be compared to this study.

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REFERENCES

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

[2]. P.B. Sakthivel and A. Jagannathan, "Fiber Reinforced Ferrocement – A Review Study", in *Proceedings of the 2nd International Conference on Advances in Mechanical, Manufacturing and Building Sciences (ICAMB-2012)*, held at VIT University, Vellore, India on January 09-11, 2012, p.1172-1177.

[3]. A. Kumar, "Ferrocement box sections-viable option for floors and roof of multi-storey buildings," *Asian Journal of Civil Engineering (Building and Housing)*, Vol. 6 No.6, p. 569–582, 2005.

[4]. S. Deepa Shri, R. Thenmozhi and M. Anitha, "Experimental Validation of a Theoretical Model for Flexural Capacity of Hybrid Ferrocement Slab", *European Journal of Scientific Research*, Vol.73 No.4, p.512-526, 2012.

[5]. S. Wang, A.E. Naaman. and V.C. Li., "Bending response of hybrid ferrocement plates with meshes and fibers," *Journal of Ferrocement.*, Vol. 34 No.1, p. 275-288, 2004.

[6]. H.M. Ibrahim, "Experimental investigation of ultimate capacity of wire mesh-reinforced cementitious slabs., *Construction and Building Materials*, Vol. 25, p. 251-259, 2011.

[7]. P.B. Sakthivel, A. Jagannathan and K. Nagamani, "Ferrocement Technology and Quality Improvisation Techniques – A Review*", in Proceedings of the 2nd International Conference on Current Trends in Technology (NUiCONE 2011),* held at NIRMA University, Ahmedabad, India on 08-10 December, 2011.

[8]. *IS:12269-1989, Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standards*, New Delhi, India.

[9]. *IS:383-1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standards*, New Delhi, India.

[10]. *ACI 549R-97, State of the Art Report on Ferrocement, reported by ACI Committee 549, Manual of Concrete Practice*, p.1-26.