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Performance of ferrocement panels in different environments

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Abstract

To exploit the potential of ferrocement as a construction material, a proper understanding of material behaviour under different environmental conditions is essential. The main objective of this investigation is to study the performance of ferrocement panels under normal, moderate, and hostile environments. These conditions were created using potable and saline water for mixing and curing. Fly ash, a waste material, was also used as partial replacement of cement. The ferrocement slab panels cast with varying number of woven and hexagonal mesh layers were tested under flexure. Compressive and tensile strength of control specimens and load-carrying capacity of the panels under flexure with and without fly ash were investigated. Addition of fly ash in different environments affects the flexural strength of panel for both woven and hexagonal wire fabric. Scanned images of specimens provide an insight into the texture for virgin and distressed states.

Keywords: Processing, curing; Microstructure characterization, SEM; Properties, durability; Composition, fly ash; Application, composite

1. Introduction

Any structure or component thereof, made to serve a purpose, must be capable of taking the entire expected load throughout its life span without any damage. Ferrocement can be made to last for many years, but this depends on many factors such as mortar composition, corrosion of reinforcement, permeability, and construction practice. The effect of partial replacement of cement with fly ash in the ferrocement panels was investigated by Arif et al. [1]. No significant drop in the flexural strength of the panels using fly ash was observed up to 20% partial replacement of cement.

Several researchers have investigated the durability and performance of ferrocement structures. Killoh et al. [2] concluded from their studies that chloride induced corrosion of steel can be effectively improved by the use of mineral admixtures in concrete such as fly ash, blast furnace slag, and silica fume. Torri and Kawamura [3] have suggested that mineral admixtures such as fly ash, blast furnace slag, and silica fume help the formation of finer and discontinuous pore structures as a consequence of pozzolanic reaction. The successful application of ferrocement boats and roofing element is an indication that ferrocement is relatively resistant to the ingress of water.

Xiong and Singh [4] conducted studies on flexural behaviour of ferrocement in sulfuric acid environments with pH equal to 5.5, while Ramesht and Nedwell [5] studied durability aspects of ferrocement in flexure using different volume fraction and types of arrangement of mesh. Ramesht [6] evaluated the effects of corrosion on the properties and flexural behaviour of ferrocement by testing two series of specimens. It was concluded that the presence of NaCl and temperature increases the brittleness of mortar, reduces the number of cracks, and increases the crack width. Vickridge et al. [7] investigated high-durability ferrocement made with mortar mixes containing three different types of mineral admixture (silica fume, ground granulated, blast furnace slag, and pulverized fly ash) as a protecting system to prevent the penetration of chlorides into mortar. It was concluded that blending of plain cements with silica fume, fly ash, and slag significantly improved the corrosion resistance performance. Vickridge and Ranjbar [8] investigated the effect of aggressive environment on the flexural performance of ferrocement. The results revealed that specimens with low water-to-cement (w/c) ratio exhibited less corrosion damage than those made with high w/c ratio.

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The present study investigates the effect of moderate and hostile environment due to the presence of NaCl in the mortar matrix. Ferrocement panels using modified mortar matrix, prepared and cured under different environments, were tested in flexure. The results were compared with specimens under normal environment.

2. Experimental programme

The experimental programme was designed to check the flexural behaviour of ferrocement panels. For this purpose, a total of 72 ferrocement slab panels of size 750 × 600 mm with two and three layers of woven and hexagonal wire mesh, with three replication each were tested in one-way flexure. The load was applied incrementally up to failure and, for each increment of load, the deflection was measured. For all the slab panels with percentage of fly ash as 0% and 20% and under varying condition of casting and curing (NCC = normal casting and curing: normal environment; NCS = normal casting and saline curing: moderate environment; and SCC = saline casting and curing: hostile environment), the first crack load, ultimate load and deflection at first crack load, and at ultimate load were observed. The crack pattern and failure mechanism were also studied. Micro level examination of test specimens was done using scanning electron microscope both for virgin and distressed states of specimens.

3. Materials

3.1. Cement

Ordinary Portland cement (43 grade) was used in mix. The physical properties of cement were determined in the laboratory as per IS: 269-1989 [9] and are given in Table 1.

Table 1
Properties of cement

Properties	Values
consistency (%)	29
initial setting time (min)	35
final setting time (min)	510

3.2. Fly ash

Fly ash was procured from National Thermal Power Corporation (NTPC) Dadri (UP), India. Properties of fly ash are given in Table 2.

Table 2
Properties of fly ash

Properties	Values
Colour	light grey
Specific gravity	2.24
pH	7.42
% retained on 90 μm	47
% retained on 75 μm	68

3.3. Fine aggregate

Locally available sand was used for the investigation. Lumps of clay and other foreign matter were separated from the sand, and it was later washed with potable water and then air-dried. The fineness modulus of sand was obtained as 2.41.

3.4. Wire mesh

Woven and hexagonal galvanized steel wire meshes with average wire diameter of 0.502 and 0.40 mm, respectively, were used. Tension tests on wire mesh were carried out in the laboratory. The properties of wire mesh are as given in Table 3.

Table 3
Properties of wire mesh

Wire mesh type	Properties	Values
Woven mesh	average diameter	0.502 mm
	opening size	7.5 × 7.5 mm
	modulus of elasticity	0.9×10 N/mm^2
	yield strength in tension	350 N/mm^2
Hexagonal mesh	average diameter	0.40 mm
	dimension of repeating Y section	12.50 × 15.25 mm
	modulus of elasticity	0.85×10 N/mm^2
	yield strength in tension	305 N/mm^2

3.5. Mortar mix

Two mortar mixes 1.0:0.0:2.5 and 0.8:0.2:2.5 comprising of cement/fly ash/sand (fine aggregate) were used. Both potable and saline water (2.5% NaCl solution) have been used for mixing and curing of specimen. To achieve proper workability, the w/c ratio was kept as 0.40. Control specimens were cast to determine mortar crushing and tensile strength. The cubes and briquettes were tested after 28 days of curing. The compressive and tensile strength of the control specimens are given in Table 4.

4. Casting of panels

For the casting of the test panels, 6-mm-thick base sheet along with 6-mm-thick and 75-mm-wide water-resistant ply sheet strips at the sides of the specimen were used. Lubricating oil was applied on the base sheet and along the side sheet edges. The first layer of the side sheets was put in position and mortar was spread on the base sheet and compacted. The wire mesh layers were cut to size and laid on this 6-mm-thick mortar layer. The second layer of side

Table 4
Tests of mortar control specimens

Specimen designation	Mix used C/FA/S[a]	Compressive strength of cube tested at 28 days (MPa)	Tensile strength of briquette tested at 28 days (MPa)
CFAS00	1.0:0.0:2.5	20.50	2.41
CFAS20	0.8:0.2:2.5	26.20	2.90

[a] C = cement; FA = fly ash; S = sand.

sheets was put in position and then the mortar layer was spread and compacted on this wire mesh layer. This process was repeated until the required thickness was obtained. Metallic strips were used at all the four corners, and fastened by bolts with sufficient height to accommodate the specimen thickness to ease demoulding. The panels were demoulded after 24 h and cured under moist gunny bags for 28 days. The cured panels were air-dried for 4 days before the actual testing. The details of cast specimens are given in Table 5.

5. Testing of panels

Panels were tested under one-way flexure with its shorter sides (600 mm) resting on simple support and the longer sides free (650 mm clear span) leaving an overhang of 50 mm on each support (Fig. 1). Mechanical dial gauges mounted on magnetic base having least count of 0.01 mm were used to obtain deflection at various stages of loading. The dial gauges were used at the mid-span and the quarter-spans in both longitudinal and transverse directions. Loads were applied through a reaction frame using hydraulic jack of 100 kN. A proving ring of 50-kN capacity was used to measure the applied loads accurately. The load was uniformly distributed through a load tree at 16 points on the specimen. The panel under test is shown in Fig. 1. The first crack load, ultimate load, and deflection at various stages were recorded. For all the test specimens, three replications were used and an average value of deflection is reported in Table 6. Four tested panels are shown in Figs. 2–5.

Table 5
Details of ferrocement panels

Mesh type	Slab panel designation	Panel thickness (mm)	Number of mesh layers	Mesh volume fraction	% fly ash	Mix proportion C/FA/S[a]
Woven	NCC 2WV 00 FA	18	2	0.0059	00	1.0:0.0:2.5
	NCC 2WV 20 FA	18	2	0.0059	20	0.8:0.2:2.5
	NCC 3WV 00 FA	24	3	0.0066	00	1.0:0.0:2.5
	NCC 3WV 20 FA	24	3	0.0066	20	0.8:0.2:2.5
	NCS 2WV 00 FA	18	2	0.0059	00	1.0:0.0:2.5
	NCS 2WV 20 FA	18	2	0.0059	20	0.8:0.2:2.5
	NCS 3WV 00 FA	24	3	0.0066	00	1.0:0.0:2.5
	NCS 3WV 20 FA	24	3	0.0066	20	0.8:0.2:2.5
	SCC 2WV 00 FA	18	2	0.0059	00	1.0:0.0:2.5
	SCC 2WV 20 FA	18	2	0.0059	20	0.8:0.2:2.5
	SCC 3WV 00 FA	24	3	0.0066	00	1.0:0.0:2.5
	SCC 3WV 20 FA	24	3	0.0066	20	0.8:0.2:2.5
Hexagonal	NCC 2HG 00 FA	18	2	0.0028	00	1.0:0.0:2.5
	NCC 2HG 20 FA	18	2	0.0028	20	0.8:0.2:2.5
	NCC 3HG 00 FA	24	3	0.0031	00	1.0:0.0:2.5
	NCC 3HG 20 FA	24	3	0.0031	20	0.8:0.2:2.5
	NCS 2HG 00 FA	18	2	0.0028	00	1.0:0.0:2.5
	NCS 2HG 20 FA	18	2	0.0028	20	0.0:0.2:2.5
	NCS 3HG 00 FA	24	3	0.0031	00	1.0:0.0:2.5
	NCS 3HG 20 FA	24	3	0.0031	20	0.8:0.2:2.5
	SCC 2HG 00 FA	18	2	0.0028	00	1.0:0.0:2.5
	SCC 2HG 20 FA	18	2	0.0028	20	0.8:0.2:2.5
	SCC 3HG 00 FA	24	3	0.0031	00	1.0:0.0:2.5
	SCC 3HG 20 FA	24	3	0.0031	20	0.8:0.2:2.5

Size of panel = 750 × 600 mm.
[a] C = cement; FA = fly ash; S = sand.

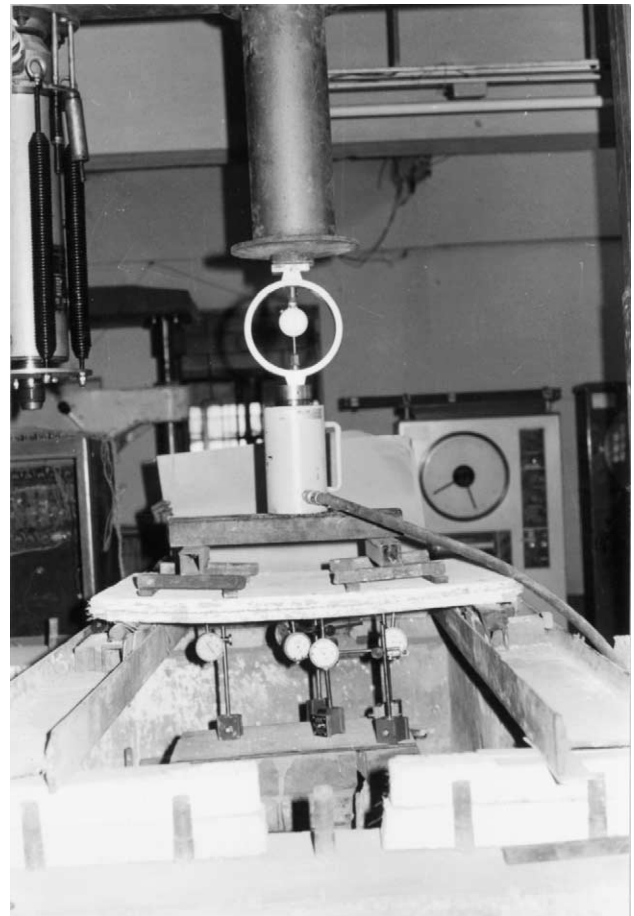

Fig. 1. Testing of ferrocement panels.

6. Results and discussions

A comparison of first crack load and ultimate load for the panels is given in the Table 6. The variation in the strength for the NCS and SCC environment with respect to NCC is also given in Table 6. The load deflection curves

Table 6
Comparison of loads and deflections for ferrocement panels

Slab panel designation	First crack load (kN)	Deflection at first crack load (mm)	Ultimate load (kN)	Deflection at ultimate load (mm)	Ratio of ultimate to first crack load	Ratio of deflection at ultimate load to deflection at first crack load	% variation in first crack load due to saline casting and curing	% variation in ultimate load due to saline casting and curing
NCC 2WV 00 FA	3.50	4.98	5.10	9.13	1.46	1.83	–	–
NCS 2WV 00 FA	3.00	3.91	4.25	6.53	1.42	1.67	− 14.25	− 16.67
SCC 2WV 00 FA	3.25	5.09	4.50	8.02	1.38	1.58	− 7.14	− 11.76
NCC 2WV 20 FA	3.25	5.32	4.50	10.40	1.38	1.95	–	–
NCS 2WV 20 FA	3.25	4.29	4.40	6.50	1.42	1.63	0.00	− 2.22
SCC 2WV 20 FA	3.50	4.68	4.50	6.25	1.29	1.54	7.69	0.00
NCC 3WV 00 FA	5.60	5.32	8.20	13.34	1.46	2.51	–	–
NCS 3WV 00 FA	4.55	5.38	6.65	8.81	1.46	1.63	− 18.75	− 18.90
SCC 3WV 00 FA	5.25	5.94	6.75	11.32	1.29	1.90	− 6.25	− 17.68
NCC 3WV 20 FA	4.90	5.30	7.35	12.51	1.50	2.36	–	–
NCS 3WV 20 FA	4.90	5.99	6.80	9.12	1.39	1.52	0.00	− 7.48
SCC 3WV 20 FA	3.50	9.40	7.00	12.46	1.27	1.33	12.24	− 4.76
NCC 2HG 00 FA	3.00	4.86	3.75	7.98	1.25	1.64	–	–
NCS 2HG 00 FA	2.50	3.70	3.00	5.26	1.20	1.42	− 16.67	− 20.00
SCC 2HG 00 FA	3.00	4.51	3.25	5.29	1.08	1.17	0.00	− 13.33
NCC 2HG 20 FA	2.75	5.61	3.50	6.62	1.27	1.18	–	–
NCS 2HG 20 FA	2.75	4.01	3.75	5.41	1.18	1.35	0.00	− 7.14
SCC 2HG 20 FA	3.00	4.20	3.50	5.88	1.16	1.40	9.09	0.00
NCC 3HG 00 FA	4.90	6.75	6.30	9.16	1.29	1.36	–	–
NCS 3HG 00 FA	3.50	3.86	4.25	5.55	1.12	1.44	− 28.86	− 32.54
SCC 3HG 00 FA	3.75	4.20	4.50	6.12	1.20	1.46	− 23.46	− 28.57
NCC 3HG 20 FA	4.55	8.10	5.25	9.72	1.15	1.20	–	–
NCS 3HG 20 FA	4.55	4.07	5.00	6.02	1.10	1.48	0.00	− 4.76
SCC 3HG 20 FA	4.80	5.95	5.25	6.50	1.09	1.46	5.49	0.00

for woven and hexagonal wire mesh are shown in Figs. 6–9. The load-carrying capacity is found to increase with increasing numbers of wire mesh layers. In NCC environment with 20% replacement of cement by fly ash, the load-carrying capacity of the panels under flexure decreases by 11.76% and 10.79% for two and three layers of woven wire mesh, respectively, as compared to panel without fly ash under same environment. However, there is an increase in the load-carrying capacity of panels with 20% fly ash for NCS and SCC environments. The increase is 3.53% and 2.26% for two and three layers of woven wire mesh, respectively, in NCS environment. For SCC environment, the increase is 2.22% and 3.70% for two and three layers of woven wire mesh, respectively. The above trend is also observed in the panels with hexagonal wire mesh. Due to presence of fly ash, the load-carrying

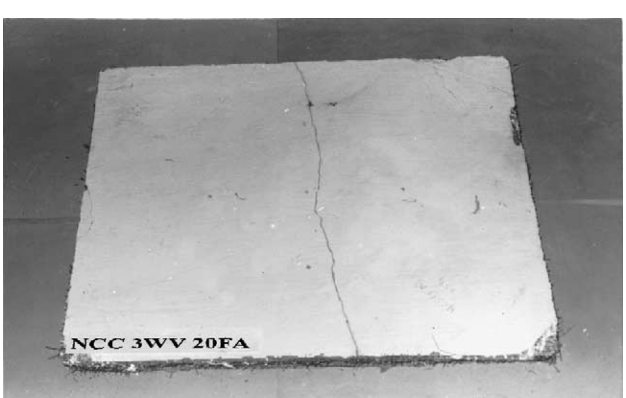

Fig. 2. Tested ferrocement panel in three layers of woven wire mesh with 20% fly ash under NCC environment.

Fig. 3. Tested ferrocement panel in three layers of hexagonal wire mesh with 20% fly ash under NCS environment.

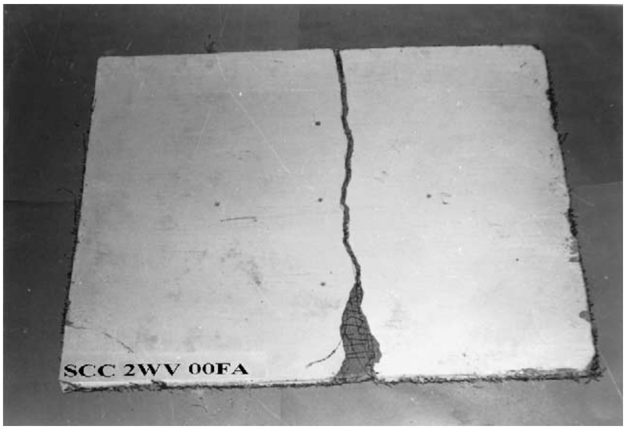

Fig. 4. Tested ferrocement panel in two layers of woven wire mesh with 0% fly ash under SCC environment.

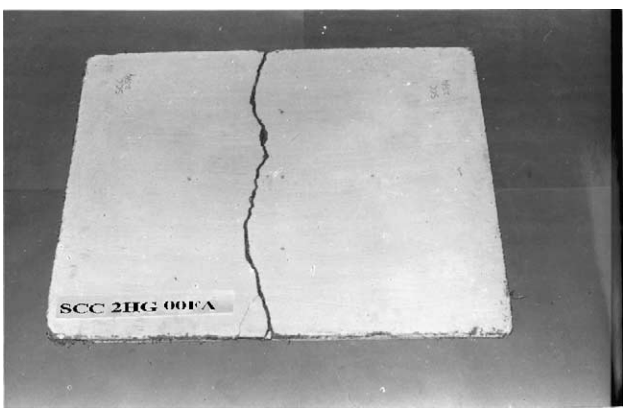

Fig. 5. Tested ferrocement panel in two layers of hexagonal wire mesh with 0% fly ash under SCC environment.

capacity increases in both NCS and SCC environment. There is a decrease in strength of panels with two and three layers of woven and hexagonal wire mesh in both NCS and SCC environment when compared to NCC for 20% fly ash content. But there is increase in strength of panels for both hexagonal and woven wire mesh in case of panels in SCC environment when compared to panels in NCS environment for 0% and 20% fly ash content, respectively. The variation in strength for the above two cases can be seen from Table 6.

Both first crack and ultimate load increases with increasing volume fraction of reinforcement. It is observed that volume fraction of reinforcement has a pronounced effect on ultimate load. In case of NCC panels, the specimens reach ultimate load level after sufficient warning; because of extended elastic range as compared to the specimens under NCS and SCC. The ratio of deflection at ultimate load to the deflection at first crack load is higher for panels with woven mesh in all the three environments.

In ferrocement panels with woven and hexagonal wire mesh, multiple cracks are formed. The cracks close considerably after removal of load. The flexural crack width in specimen with woven wire mesh is more as compared to specimen with hexagonal wire mesh. It is also observed that the crack width is more in case of SCC and NCS as compared to NCC panels.

Both woven and hexagonal wire mesh sustain corrosion. The failure of the panel is brittle in case of both NCS and SCC environments. It is further observed that the brittleness is more in case of hexagonal wire mesh panels as compared to panels with woven wire mesh. The scanned images indicate the presence of intragranular pores for cement mortar matrix without fly ash (Fig. 10). Fly ash particles along with the pores of the mortar matrix can be seen in the image obtained for mortar with fly ash (Fig. 11). The deterioration of wire mesh in saline environment at an age of 2 years as compared to wire in nonsaline environment is evident from the images shown in Figs. 12 and 13. A quantitative assessment reveals that there is considerable

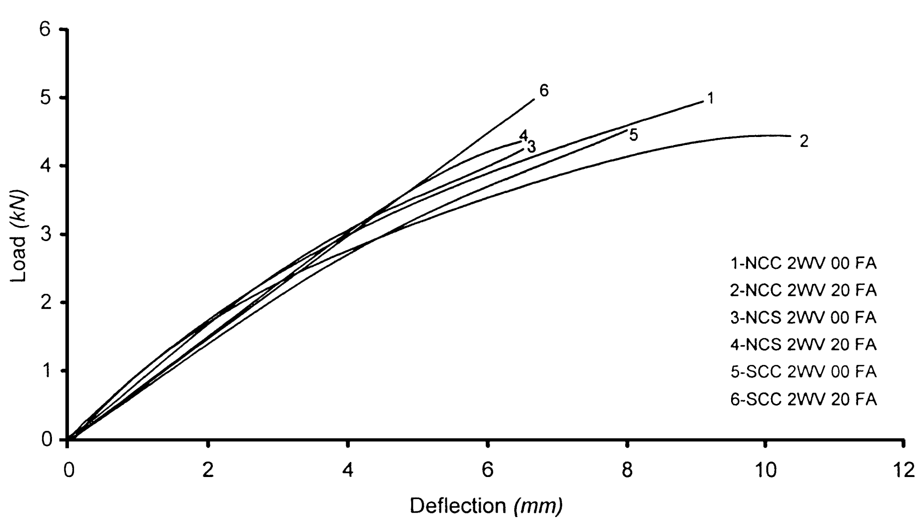

Fig. 6. Load deflection curves for panels in two layers of woven wire mesh and varying percentages of fly ash in different environments.

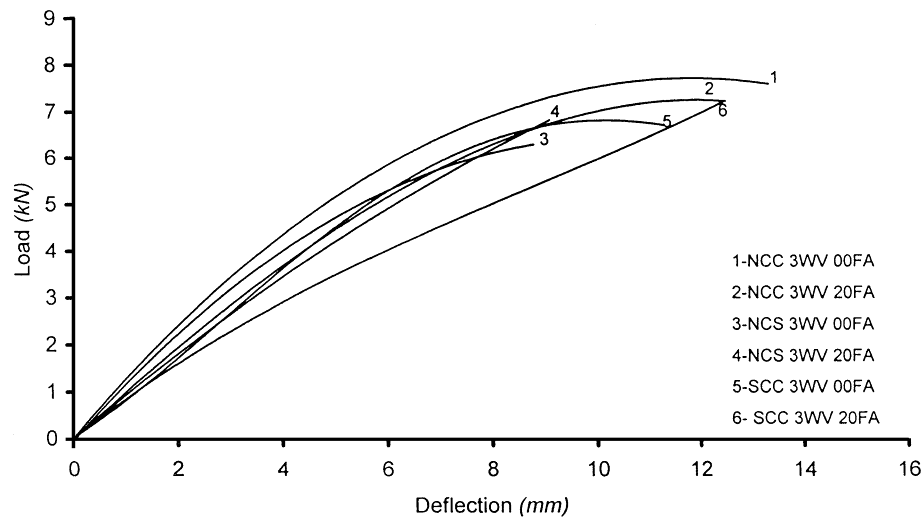

Fig. 7. Load deflection curves for panels in three layers of woven wire mesh and varying percentages of fly ash in different environments.

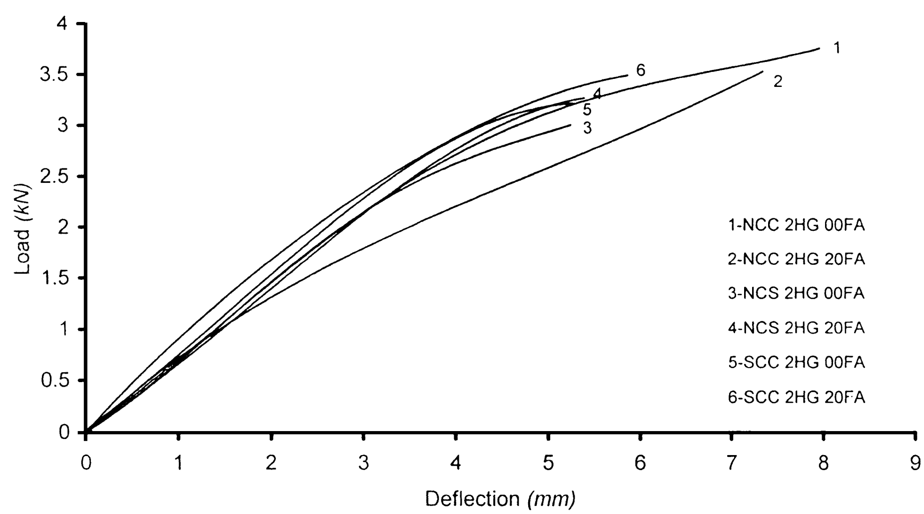

Fig. 8. Load deflection curves for panels in two layers of hexagonal wire mesh and varying percentages of fly ash in different environments.

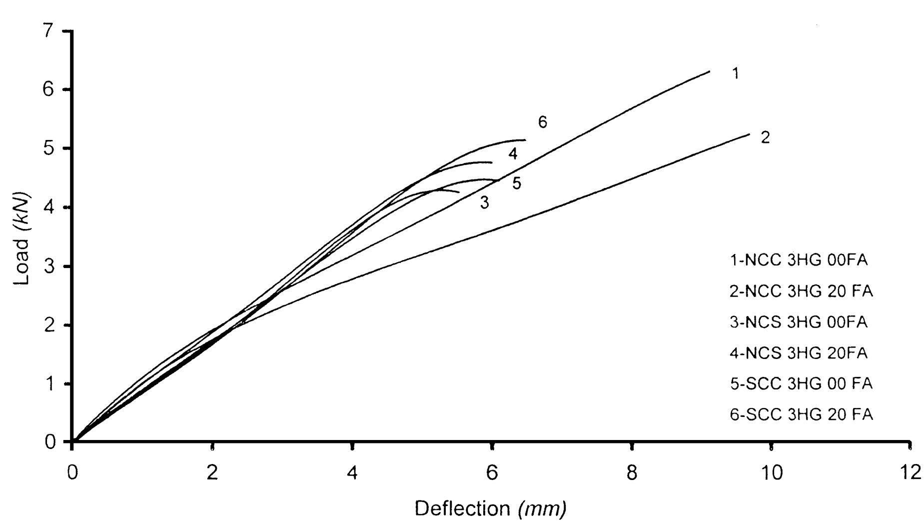

Fig. 9. Load deflection curves for panels in three layers of hexagonal wire mesh and varying percentages of fly ash in different environments.

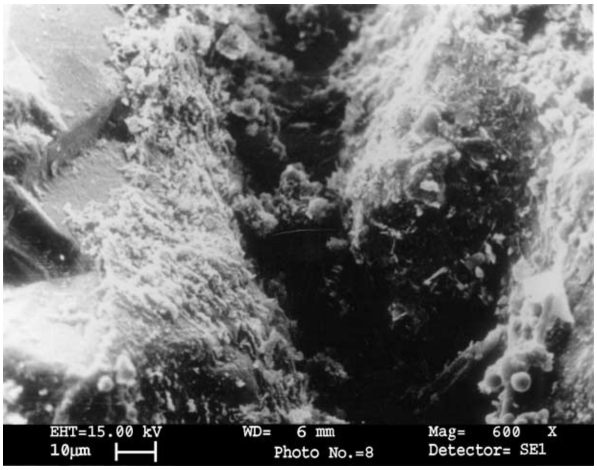

Fig. 10. Cement mortar matrix without fly ash.

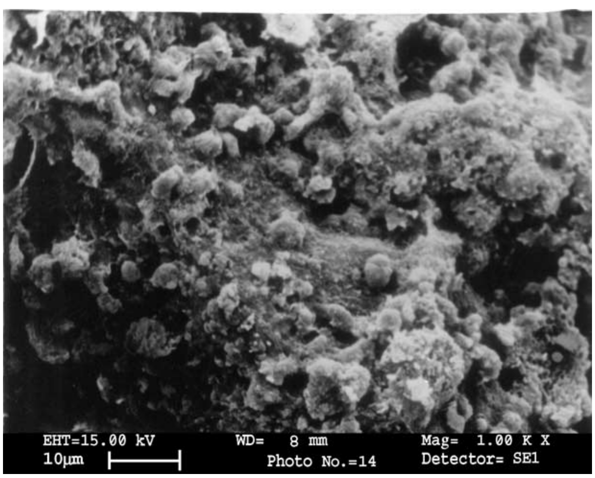

Fig. 11. Cement mortar matrix with fly ash.

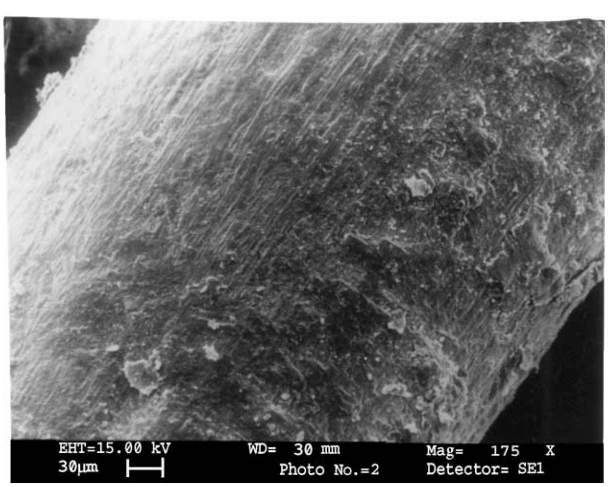

Fig. 12. Wire mesh fabric in nonsaline environment.

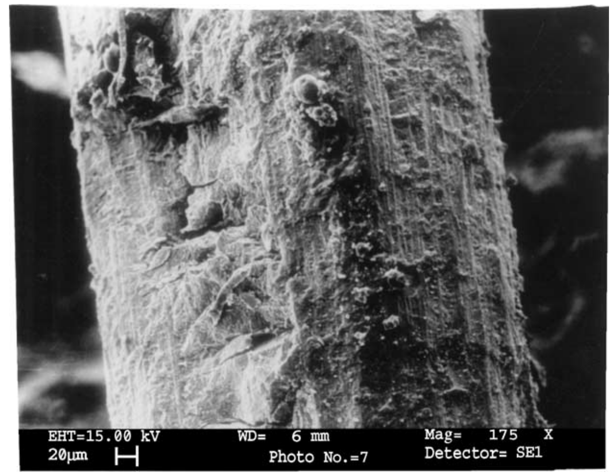

Fig. 13. Deterioration of wire mesh fabric in saline environment.

reduction in metal fabric diameter due to sustained exposure under hostile environment.

7. Conclusion

Addition of fly ash in different environments affects the load-carrying capacity under flexure for panel with both woven and hexagonal wire fabric. The strength of panel increases with fly ash dosage in saline casting and curing condition. There is considerable deterioration of the wire mesh fabric due to sustained exposure in saline casting and curing conditions. However, the strength of panels under saline casting and saline curing condition is more as compared to panels under normal casting and saline curing condition because of better pore structure minimizing the ingress of water, due to the presence of fly ash and the saline water during casting.

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References

[1] M. Arif, S. Akhtar, A. Masood, F. Basit, M. Garg, Flexural behaviour of fly ash mortar ferrocement panels for low cost housing, J. Ferrocement 31 (2) (2001) 125–135.

[2] D.G. Killoh, L.J. Parrot, R.G. Patel, Influence of curing at different relative humidities on the hydration and porosity of a Portland/fly ash cement paste, Proceedings of Third International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolonas in Concrete, Trondheim, ACI Spec. Publ. (114) (1989) 157–174.
[3] K. Torri, M. Kawamura, Chloride induced corrosion of steel reinforcement made with various mineral admixtures, Trans. Jpn. Concr. Inst. (12) (1990) 183–190.
[4] G.J. Xiong, G. Singh, Influence of cover thickness on the behaviour of ferrocement, J. Ferrocement 26 (3) (1996) 181–190.
[5] M.H. Ramesht, P.J. Nedwell, The influence of transverse wire on ultimate strength of ferrocement in flexure, J. Ferrocement 24 (l) (1994) 29–34.
[6] M.H. Ramesht, Effect of corrosion on flexural behaviour of ferrocement in a corrosive environment, J. Ferrocement 27 (l) (1995) 7–18.
[7] I.G. Vickridge, A.S. Nakassa, M. Turner, High durability ferrocement, Proceedings of 6th International Symposium on Ferrocement, University of Michigan, Ann Arbor, USA, 1998, pp. 297–312.
[8] I.G. Vickridge, M.M. Ranjbar, The effect of an aggressive environment on the flexural performance of ferrocement, Proceedings of 6th International Symposium on Ferrocement, University of Michigan, Ann Arbor, USA, 1998, pp. 313–328.
[9] IS 269-1989, Indian Standard Specification for Ordinary or Low Heat Portland Cement, Bureau of Indian Standards, New Delhi, 1989.