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Strength, Durability and Thermal Performance of Ferrocement Panels for Use in Secondary Roofing

Mohamed Iburahim M [1], Dyana Joseline [2] and Haji Sheik Mohammed M.S.[3]

[1]M.Tech. (By Research) Scholar, [2]M.Tech. Student, [3]Professor,

[1,2,3] Department of Civil Engineering, B. S. Abdur Rahman University,
Grand Southern Trunk Road, Vandalur, Chennai–600048, Tamilnadu, India.

[1]Orcid Id:0000-0002-8497-4421, [3]Orcid Id:0000-0001-6485-533X

Abstract

The present study investigates the performance of ferrocement panels for use as secondary roofing units in tropical climatic conditions. The meshes used in the study are crimped wire mesh and galvanized wire mesh. The mix ratio adopted is 1:2 and sodium nitrite based corrosion inhibitor is added at 2% by weight of cement. The influence of inhibitor addition on fresh and hardened mortar properties was studied as per Indian standards. Tests such as chloride penetration test, rapid chloride penetration (RCPT) and accelerated corrosion test (ACT) were conducted to assess the durability properties of inhibitor admixed mortar. Flexural strength test on ferrocement panels was conducted as per Indian standards under four point loading and the variables considered are type of mesh, number of mesh layers and type of mortar mix. Thermal performance of ferrocement panels in laboratory and field conditions was also studied. It is found that inhibitor addition in mortar did not significantly alter the basic properties of cement, marginally reduces water cement ratio and appreciably increases the compressive strength. Ferrocement panels with two mesh layers offered increased load carrying capacity and energy absorption irrespective of type of mortar mix. Durability test results revealed enhanced performance of inhibitor admixed mortar. Field thermal performance test results exhibit 25% improved thermal comfort and laboratory test exhibits 15^0C temperature reduction for ferrocement secondary roofing. It can be concluded that ferrocement panel as secondary roofing is a viable option to provide effective thermal insulation to buildings.

Keywords: Ferrocement panels; secondary roofing; corrosion inhibitor; crimped wire mesh, galvanized wire mesh; thermal insulation

INTRODUCTION

India is a home to an extraordinary variety of climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayan north. Ambient temperature varies from 25°C - 45°C. Analysis of climatic data, for the period 1901-2009, by Indian Meteorological Department, reports that annual mean temperature for the country as a whole has risen by 0.56°C and will continue to rise [1]. Humans need thermally comfortable environments for the revival of energy after the day's work. Air temperature is the main criterion and the most important environmental factor affecting human comfort [2]. A building roof is the horizontal skin through which a manmade indoor space and outdoor space interact and it receives the highest amount of solar radiation [3]. The comfort band of room temperature is 26˚C – 32.5 ˚C and the relative humidity ranges between 17% - 78% from a field study in Hyderabad, India [4]. A healthy and energy efficient indoor environment can be achieved by means of passive thermal protection methods [4] [5] [6]. Installation of secondary roofs is one of the passive methods of insulating the building against intense heat. The thermal damping capacity of still air is found to be almost equal to that of other insulators such as vermiculite, thermocole and celcrete [7].

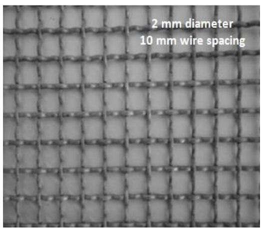
Ferrocement is an attractive material for secondary roofing that is necessary to provide heat insulation in buildings and it possesses better resistance to thermally induced stresses as compared to other alternatives such as cellular concrete and hollow block [8] [9]. As the roof system is subjected to a wide range of exposure conditions throughout the year, the structural integrity and durability of the insulation material significantly affects the long term performance and the need for replacement. A thermally efficient roof may not be a durable one and a strong material may not be a good insulator. Moisture intrusion to insulation can drastically reduce the roof system's thermal resistance and ultimately lead to premature failure [10]. There is a need to develop durable ferrocement panels for use in secondary roofing. Recently sodium nitrite based corrosion inhibitor which also offers improved workability to cement mortar / concrete was developed [11]. Quality of cement concrete / mortar has a direct effect on chloride ingress and corrosion [12]. Hence the performance of cement mortar admixed with inhibitor needs to be ascertained and correlated to the possibility for chloride ingress and subsequent corrosion. The flexural behaviour and crack development pattern of ferrocement panels are also an indication of the functionality of the panels as secondary roofing elements during the service life.

This study focuses on the experimental investigation of strength, durability and thermal performance of ferrocement panels for application as secondary roofing elements in the Indian climatic conditions.

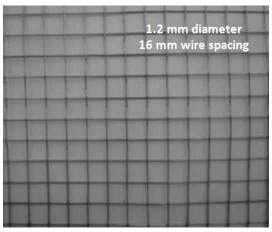
EXPERIMENTAL INVESTIGATION

Materials

Commercially available Portland pozzolana cement (PPC) conforming to BIS 1489-1991 [13] was used in the study. Well graded locally available river sand of nominal size less than 2.36 mm, conforming to Zone 2 and potable water were used for preparing mortar specimens. The types of mortar mixes used in this study include plain cement mortar and inhibitor admixed mortar with mix ratio 1:2 (Cement : Sand). Sodium nitrite based mixed inhibitor is used in the study [11] . The colour of the inhibitor is dark brown with a density of 1.36 kg/l and pH of 11.55. In the experimental study, inhibitor was added at 2% by weight of cement. The water cement ratio of the mortar mixes were determined based on ASTM C 1437-2007 [14]. The inhibitor was found to contribute positively to the workability of the mix. The flow was fixed as 85 ± 3 % based on the ease of mixing. For this flow, the water cement ratio was found to be 0.45 for plain cement mortar and 0.42 for inhibitor admixed mortar. Square crimped wire mesh of 2 mm wire diameter and 10mm wire spacing; and galvanized steel mesh of 1.2 mm wire diameter and 16mm wire spacing were used. Figure 1 shows the view of the mesh reinforcements used in the study.



(a) Crimped steel mesh



(b) Galvanized steel mesh

Figure 1 : View of mesh reinforcements used in the study

Table 1: Consistency and setting time of cement

Type of cement paste	**Consistency (%)** BIS 4031:1988 Part 4 [15]	**Initial setting time (min.)**	**Final setting time (min.)**
		BIS 4031:1988, Part 5 [16]	
Plain cement paste	36	50	400
2% inhibitor admixed cement paste	32	35	230

The consistency, initial and final setting time of plain cement and cement admixed with 2% inhibitor were determined as per Indian standards [15] [16] and tabulated in Table 1. It was observed that the addition of inhibitor decreases the standard consistency by 11%, initial setting time by 30% and final setting time by 42%.

Compressive strength test

Compressive strength of control and inhibitor admixed mortar mixes was found as per BIS 516-1956 [17]. Cubes of size 100 mm x 100 mm x 100 mm were cast and tested for compressive strength at the age of 7, 14 and 28 days. In each category three specimens were cast and totally 18 specimens were subjected to compressive strength test. The test was conducted on a 3000 kN capacity digital compression testing machine. The maximum load at which the specimen failed was recorded and accordingly compressive strength was found.

Flexure test under four point loading

Flexural strength test was performed on ferrocement panels to study the effect of inhibitor admixed mortar, mesh type and number of layers on flexural performance. The mesh combinations employed in the study are single layer crimped wire mesh placed at the central zone; and a layer each of crimped wire mesh and galvanized wire mesh at one thirds of the thickness of the panel, with the crimped mesh at the bottom. The mortar mix ratio adopted was 1:2. Two types of mortar mixes were used namely plain Portland pozzolana cement (PPC) mortar and 2% inhibitor admixed PPC mortar at water cement ratio of 0.45 and 0.42 respectively.

Ferrocement slab panels of size 900 mm x 300 mm x 25 mm were cast with mesh embedded in cement mortar. Figure 2 shows the fabrication of ferrocement panel in progress. The designation of the specimens of various combination are as follows:

FCP_{1L} - Ferrocement panel made with single layer crimped wire mesh embedded in cement mortar

- FCP_{2L} - Ferrocement panel made with combination of crimped and galvanized wire mesh embedded in cement mortar
- FCI_{1L} - Ferrocement panel made with single layer crimped wire mesh embedded in inhibitor admixed cement mortar
- FCI_{2L} - Ferrocement panel made with combination of crimped and galvanized wire mesh embedded in inhibitor admixed cement mortar

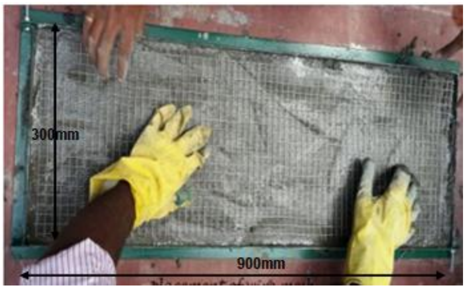


Figure 2: Fabrication of ferrocement panel

In each category, three slab panels were cast. The specimens were subjected to flexure test under four point loading as per BIS 516-1956 [17]. Figure 3 shows the schematic of flexure test setup and Figure 4 shows flexure test in progress.

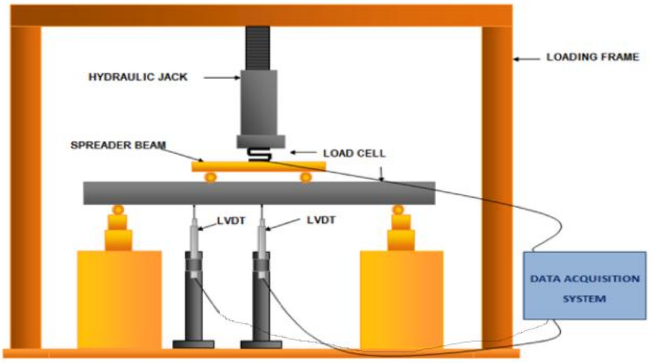
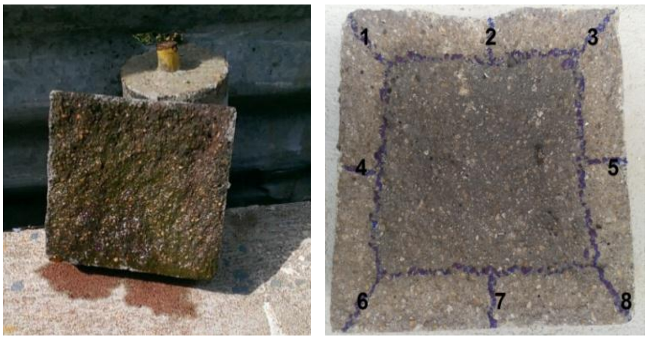


Figure 3: Schematic of flexure test setup

Figure 4: Flexure test in progress

Chloride ion penetration test

The ability of the inhibitor admixed mortar against chloride penetration under normal and sustained immersion conditions were assessed by conducting chloride ion penetration test [11]. 100 mm cubes were cast with and without inhibitor modification using PPC. In each category, three specimens were cast and totally six specimens were subjected to chloride ion penetration test. After 28 days of water curing, the specimens were dried, applied with polymer based water proofing coating on all the four sides leaving the top and bottom surfaces free and immersed in 3% sodium chloride solution for 20 days. Then the specimens were cut into two halves and sprayed with indicator solution containing 0.1% sodium fluorescein and 0.1N silver nitrate. The portion in which colour changes to white indicates chloride ion penetration and the remaining greenish area represents the unaffected area. The chloride penetration measurement location is fixed around the periphery of the cross section in eight measurement locations. The depth measurement was done using steel scale to the nearest millimeter. Figure 5 shows the view of specimens sprayed with indicator solution and the measurement locations in the chloride penetration test.



(a) Upon spraying (b) After drying

Figure 5: View of specimens in chloride ion penetration test

Accelerated corrosion test

The accelerated corrosion test was performed on miniature ferrocement panel specimens of size 150 mm x 150 mm x 25 mm with centrally embedded crimped wire mesh. The development of current with respect to time and time taken for cracking of specimen due to volumetric changes accompanying the formation of corrosion products [18][19] were observed. The reinforcing mesh in the panel acts as anode and a specially made perforated stainless steel hollow cylinder acts as cathode. The electrodes were immersed in 3% sodium chloride solution and the corrosion process was accelerated by applying a potential of 6V across the electrodes. Figure 6 shows the schematic of the test setup for accelerated corrosion test (ACT). Current development was monitored at regular intervals until the failure of specimens.

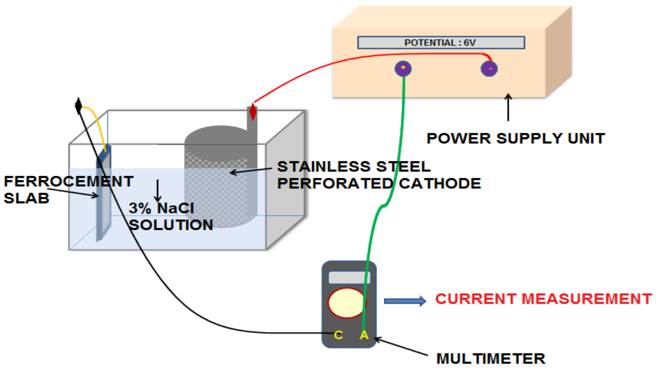


Figure 6: Schematic of the test set up for ACT

Rapid chloride penetration test

The resistance of inhibitor admixed mortar against chloride ingress under accelerated conditions was assessed by conducting rapid chloride penetration test (RCPT) as per ASTM C 1202-2012 [20]. Mortar specimens of 10 cm diameter and 5 cm thickness were used. Three control mortar specimens and three inhibitor admixed mortar specimens were subjected to RCPT. The test specimen was tightly placed between two cells. One cell contains 3% sodium chloride solution and the other contains 0.3N sodium hydroxide solution. The potential difference of 60V was impressed in between the cells. The current development at regular intervals was monitored up to 6 hours. The total charge passed in Coulombs at the end of the test period was also noted. Figure 7 shows the schematic of the RCPT setup.

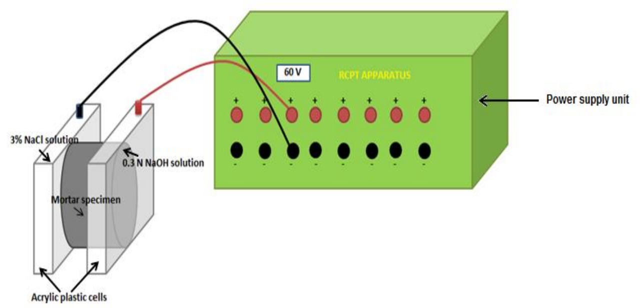


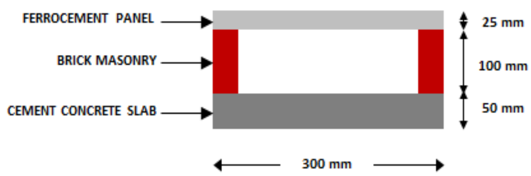
Figure 7: Schematic of rapid chloride penetration test (RCPT) setup

Laboratory thermal performance test

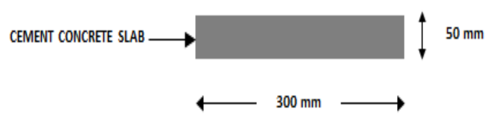
Slab specimens of size 300 mm x 300 mm were subjected to the laboratory thermal performance test. Figure 8 shows the details of the specimens used. The specimens were covered with an insulation material (thermocol) on the 4 sides leaving the top and bottom free to ensure one dimensional heat flow. Halogen lamps (1000 W) were used as source of heat. A lux meter was used to monitor the intensity of heat falling on top of the specimen. Thermocouples were fixed on the top and bottom surface of the specimens to capture the temperature at the desired locations. The signal from the thermocouples was fed to a data logger connected to a computer. The test was terminated after the temperature at the top and bottom reached steady state. Figure 9 shows the view of the laboratory thermal performance test in progress.

Field thermal performance test

The experiments were carried out in Chennai, Tamil Nadu, 12.8757°N latitude and longitude 80.0834°E. The location is characterized by hot and humid weather. Two model buildings were constructed to study the influence of the addition of secondary roofing unit on the thermal insulation capacity. One model building was left with the roof unmodified and on the other, a ferrocement secondary roofing unit was installed with an air gap of 300 mm. The buildings under study are exactly identical in terms of their geometry, orientation, area and climate conditions. Figure 10 shows the view of the model buildings constructed for thermal study.



(a) Ferrocement secondary roofing unit



(b) Control specimen

Figure 8: Details of the specimens tested for thermal performance

Figure 9: View of laboratory thermal test in progress

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Figure 10: View of model buildings constructed for thermal study

For eliminating the boundary effects on the temperature measured, eight uniformly spaced locations were marked over the slab without discontinuity or joint. An infrared thermometer was used to measure the temperature at the top surface of roof slab / ferrocement panel exposed to sun and soffit of the roof slab at regular intervals throughout the day. Test data represents the observation made during April - May, 2015 in which the maximum and minimum temperatures recorded by the local meteorological station were 35.3ºC and 25.5ºC respectively.

RESULTS AND DISCUSSION

Compressive strength test

Figure 11 shows the comparison of compressive strength of control mortar and 2% inhibitor admixed mortar specimens made with PPC. It is observed that the compressive strength of the inhibitor admixed mortar is significantly higher than that of control mortar irrespective of the curing period. An increase in 28 day compressive strength of the order of 22% for inhibitor admixed mortar as compared to control mortar was observed. The improvement in the compressive strength may be due to reduction of water cement ratio in the order of 6.6% for the same degree of workability for inhibitor admixed mortar.

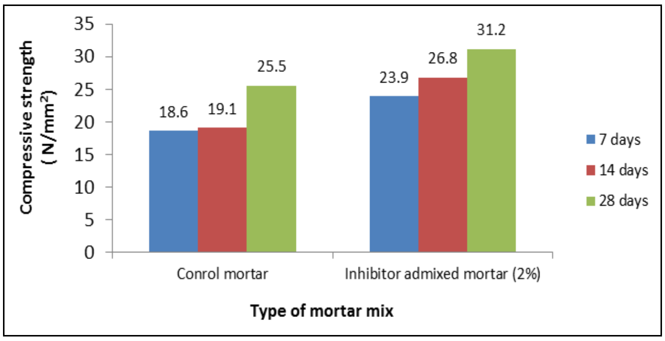


Figure 11: Comparison of compressive strength of control and inhibitor admixed mortar

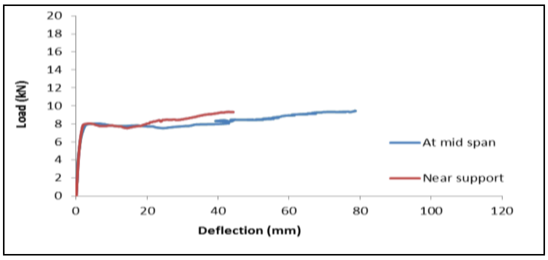
Flexure test under four point loading

Table 2 shows the observation on flexure test of ferrocement panels. It can be seen that ferrocement panels embedded with single crimped wire mesh in control mortar was observed with ultimate load of 8.6 kN which is similar to panels made with inhibitor admixed mortar. The ferrocement panels with two mesh layers made of control mortar and inhibitor admixed mortar were observed with ultimate load of 17.04 kN, and16.70 kN respectively. This also reveals a similar ultimate load values irrespective of type of mortar mix. As expected, ferrocement panels with two layers of mesh offered two fold increase in ultimate load as compared to ferrocement panels made with one layer of crimped wire mesh irrespective of type of mortar mix. Although inhibitor admixed mortar exhibits significant increase in compressive strength as compared to control mortar, it was not exhibited in the flexural strength development. It can be concluded that addition of inhibitor in cement mortar did not offer any negative influence on flexural strength development of ferrocement panels irrespective of type of mesh and number of layers used.

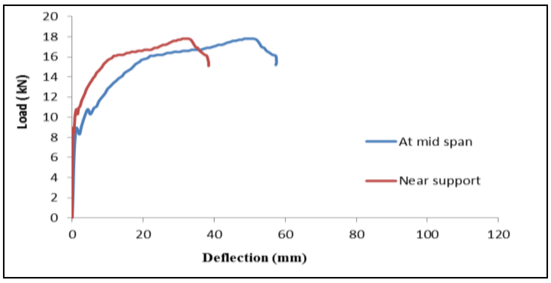
Table 2: Observation on flexural strength test

Specimen	Ultimate Load (kN)	Energy absorption capacity (kNm)	Failure region
FCP_{1L}	8.60	0.648	Middle one third
FCP_{2L}	17.04	0.768	Middle one third
FCI_{1L}	8.40	0.602	Middle one third
FCI_{2L}	16.70	0.790	Middle one third

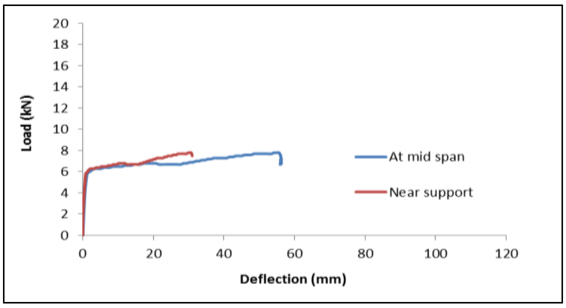
Figure 12a - 12d shows the load-deflection behaviour of ferrocement panels tested under four point loading in flexure. For the load increment, deflection was observed in the tension zone in locations one at the center of specimen (i.e., in the middle one third region) and another at 200mm from centre (i.e., in the left one third region near support) until failure of specimens. Load - deflection behaviour of ferrocement panels made with single layer crimped wire mesh exhibit significant increase in load for the small deflection during the test period until near peak load. Afterwards an almost flat region which implies large deflection for very small increment in load until failure of specimens is observed. This behaviour exists irrespective of type of mortar mix and deflection measurement locations and indirectly exhibits an inferior energy absorption capacity. In case of ferrocement panels with two layers of mesh, irrespective of type of mortar mix and measurement location, negligible deflection was observed upto 8.5 kN upon load increment. This is followed with almost a linear load-deflection behaviour until failure of specimens (at ultimate load) with an appreciable deflection of 40-45mm. This behaviour reveals a better energy absorption capacity interms of area under load-deflection curve for the ferrocement panels with two mesh layers. In all the tested specimens, load-deflection behaviour at observed locations followed a similar pattern in the initial linear region. The behaviour in the post linear region is also similar except that the deflection observed near support at ultimate load is comparatively less than that at mid span. It can be concluded that ferrocement panels made with a combination of crimped and galvanized wire mesh offered improved load carrying capacity and energy absorption as compared to ferrocement panels with one mesh layer, irrespective of type of mortar mix, which may be due to better composite action. There is an insignificant influence due to addition of inhibitor in cement mortar in terms of load carrying capaciety and energy absorption capacity of ferrocement panels in the tested categories.



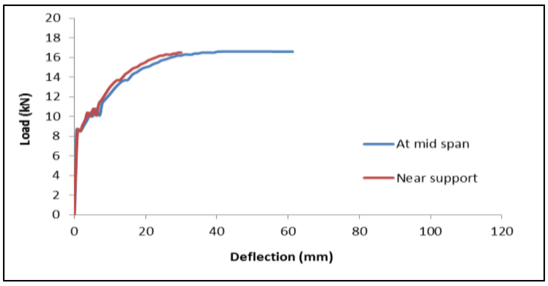
(a) FCP$_{1L}$



(b) FCP$_2$



(c) FCI$_{1L}$



(d) FCI$_{2L}$

Figure 12: Load-deflection behavior of ferrocement panel specimens

Figure 13a-13d shows the view of cracked ferrocement panels after the test. It can be visualized that major cracks were observed in all the tested specimens in the middle one third region. Ferrocement panels with two mesh layers made of inhibitor admixed mortar were noticed with systematic minor cracks in the middle one third region and a major crack in the centre which indicates a typical bending failure.

(a)FCP$_{1L}$

(b) FCP$_{2L}$

(c) FCI$_{1L}$

(d) FCI$_{2L}$

Figure 13: View of crack patterns observed in the specimens

Chloride ion penetration test

Figure 14 shows the chloride penetration behavior for control and inhibitor admixed mortar at various locations. The values indicated in various measurement locations are cumulative average of values obtained from six samples tested under similar conditions. It can be seen that the chloride penetration depth in inhibitor admixed mortar is appreciably less as compared to control mortar in all the measurement locations. The average chloride penetration in inhibitor admixed mortar was found to be 27.5% less than that of control mortar. This may be due to repulsion of entering chloride ions by nitrite ions present in the mortar matrix because of charge similarity in the normal acceleration conditions [11].

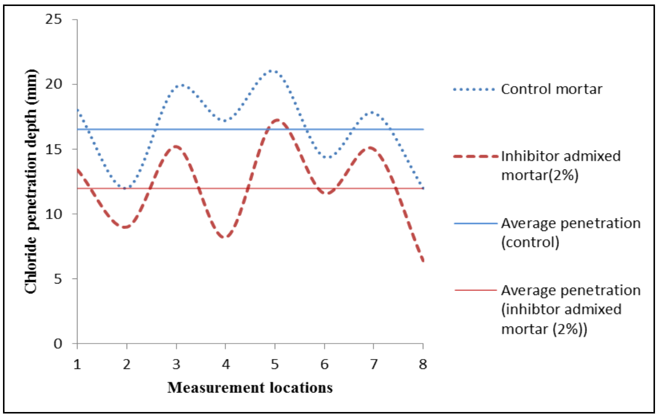


Figure 14: Chloride penetration behavior for control and inhibitor admixed mortar at various measurement locations

Accelerated corrosion test

Figure 15 shows the current development in the control and inhibitor admixed panel specimens with respect to time in the accelerated corrosion test. It can be seen that there is a steep but linear increase in current development for control ferrocement panels until cracking of specimens; and followed with insignificant increase in current values with respect to time during the remaining test period. In case of inhibitor admixed ferrocement panels, there is a gradual but small increase in current development with respect to time until failure of specimens. Post crack behaviour also shows gradual increase in current values over time in the tested duration. There is a fourfold reduction in current values for inhibitor admixed ferrocement panels as compared to control ferrocement panels in the failure region.

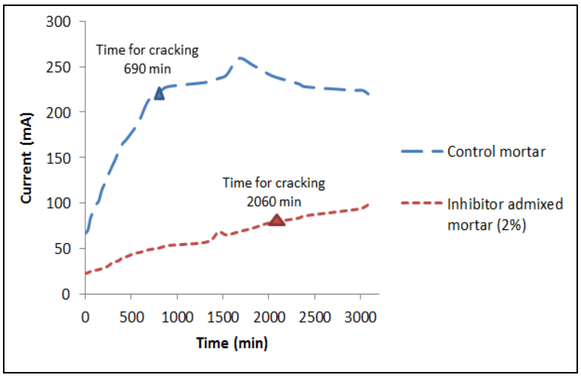


Figure 15: Time vs current behavior of control and inhibitor admixed ferrocement panels

The time for cracking of the ferrocement panels made with control mortar was 690 minutes. Whereas, ferrocement panels made with inhibitor admixed mortar offered 2060 minutes resistance against cracking. This threefold increase in the crack resistance time and four fold reduction in current development indicates that inhibitor addition in mortar at 2% by weight of cement offers significant resistance against chloride penetration in the highly accelerated corrosion conditions. This may be due to ability of nitrite ions in confronting chloride ions even in the accelerated corrosion conditions which is further assisted by the formation of passive layer on mesh reinforcement [11].

Rapid chloride penetration test

Figure 16 shows the time versus current passage behavior of control and inhibitor admixed mortar specimens made with PPC in RCPT test. A gradual increase in current passage was observed irrespective of type of mortar specimens in the test duration. However an appreciable reduction in the passage of current was observed for inhibitor admixed mortar as compared to control mortar throughout the test period. It can be inferred that inhibitor admixed mortar offers improved resistance to chloride ion penetration in the tested accelerated conditions.

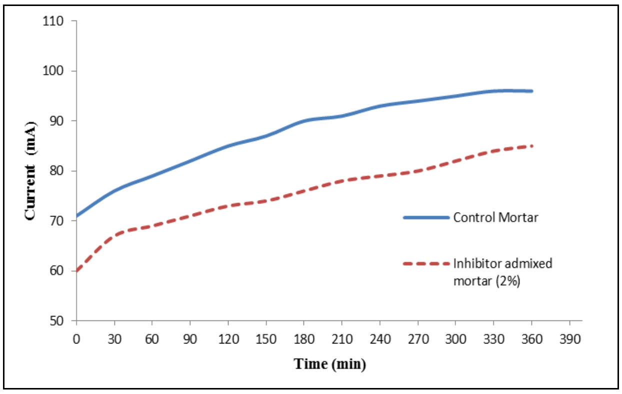


Figure 16: Time vs current behavior of control and inhibitor admixed mortar in RCPT

According to ASTM 1202 criteria [20], a passage of charge greater than 4000 coulombs is considered as high chloride penetration; 1000 - 4000 coulombs as normal; and less than 1000 coulombs as low penetration. Figure 17 illustrates the current developed at the end of test period. At the end of the test period, although the chloride ion penetrability was found to be low in both the types of mortar, the charge passage was found to be 16% less in inhibitor admixed mortar as compared to control mortar.

Laboratory thermal performance test

Figure 18 shows the time vs. temperature behavior of control slab and the ferrocement secondary roofing system. It can be seen that after 60 minutes duration, there is stabilization in temperature values at top and bottom surface of the test specimen under the influence of a constant source of heat. The maximum steady temperature at top surface and soffit of control slab is 43.26ºC and 42.69 ºC respectively. Whereas ferrocement secondary roofing system was observed with maximum steady temperature in top surface of ferrocement panel as 49.81ºC and at soffit of roof slab as 34.34ºC.

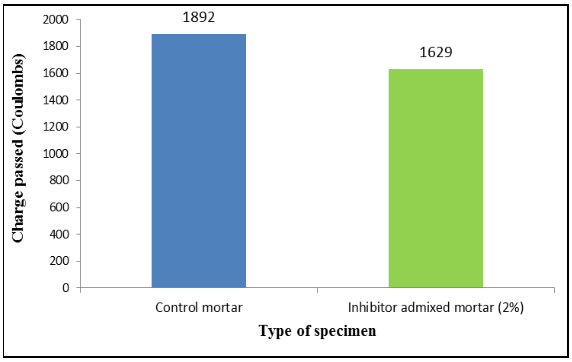
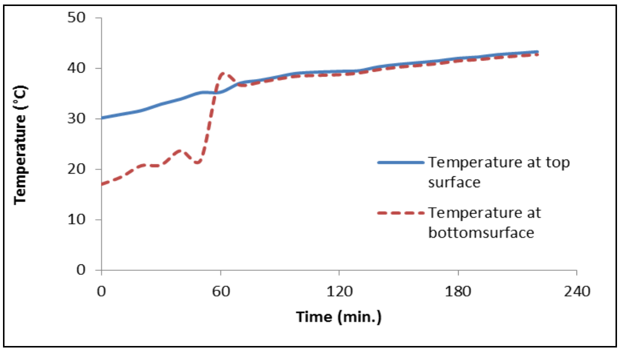
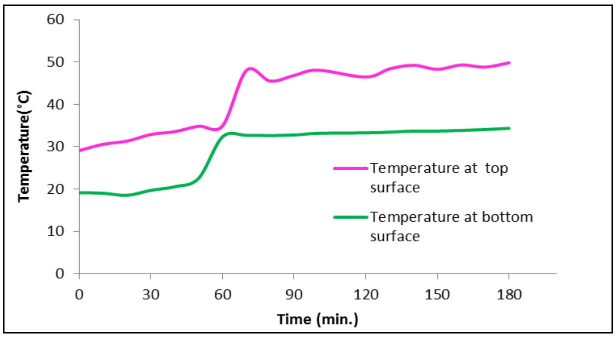


Figure 17: Comparison of charge passage for control and inhibitor admixed mortar in RCPT test



(a) Control slab



(b) Ferrocement secondary roofing system

Figure 18: Time vs. temperature behavior of slab specimens

From Figure 18 (a), it can be seen that initially, a gradual rise in the temperature at top and bottom surface of the specimen was noted. At the end of 60 minutes, due to constant exposure to light source, the emanating heat travels from top surface through the dense concrete mass which facilitates faster movement and hence similar top and bottom surface temperature. Afterwards the temperature values observed at top and bottom surface of the specimen is similar until end of 200 minutes exposure period. This may be attributed to the moderate thickness of the concrete specimen and appreciably dense concrete without much air voids. In the ferrocement secondary roofing unit, marginal increase in temperature at top surface of ferrocement panels and insignificant increase in bottom temperature at soffit of roof slab was noted until a period of about 60 minutes. Then there is a linear increase in temperature in short time at both top surface and bottom surface of the tested specimen due to heat gain over a period of time. It may be inferred that initially, the ferrocement panels absorb the heat which resulted in marginal increase in temperature at top surface. Afterwards absorbed heat is partially transmitted to air gap which results in heating of terrace slab and subsequent increase in temperature at soffit of slab. Further exposure to heat source stabilizes the temperature at top surface of ferrocement panel and bottom surface of slab for the existing system. The stabilized temperature readings revealed that there is a 15^0C temperature reduction at the soffit of slab in the secondary roofing system due to provision of air gap as compared to unprotected slab. This exhibits 16 times superior performance for secondary roofing system as compared to unprotected slab.

Field thermal performance test

Field thermal performance test was conducted on model buildings during April- May 2015, which is considered to be hot climatic period in the study zone (i.e. Chennai, India). The average maximum and minimum temperature and relative humidity are 35.3°C, 25.5°C and 36% respectively. As variations in the temperatures were observed on different survey days, the exact temperature values are not used for analysis. The effectiveness of the addition of the secondary roof may therefore be judged based on the difference between the temperature on the roof surface and indoor, which gives better understanding of thermal insulation properties.

Figure 19 shows the time versus average temperature difference values in model buildings with unprotected control slab and slab provided with ferrocement panel secondary roofing. The observation was followed for 8 hours between 10 a.m. to 6 p.m. For control slab, it is found that temperature difference is only 4-5 degrees during peak sunny hours between 10 a.m. - 2.00 p.m. Afterwards similar temperature values were observed due to gradual cooling of top surface of slab exposed to breeze after 3 p.m. Whereas slab provided with ferrocement secondary roofing offers 15 degrees reduction in temperature to the inhabitants in the peak sunny hours. Afterwards temperature variation between top surface of ferrocement panel and soffit of roof slab was only marginal up to 5 p.m. followed with similar temperature values. This clearly indicates that ferrocement secondary roofing offers significant comfort to the inhabitants in the dry sunny hours of the day and results in enhanced energy conservation.

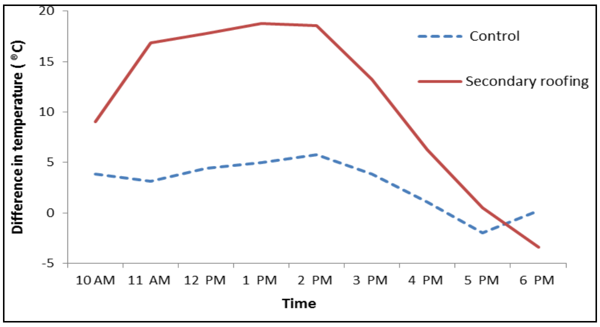


Figure 19: Time vs. average temperature difference values in model buildings

Figure 20 shows the comparison of average difference in temperature in control slab and secondary roofing unit during day time. It can be seen that temperature difference is in the range of 1-6°C during the tested time for control slab. In case of secondary roofing unit, significant reduction in temperature from top surface of ferrocement slab to soffit of roof slab of the order of 16-19°C was observed during peak sunny time of 11 a.m.- 2 p.m. Afterwards, a moderate reduction in temperature was observed until 4 p.m. Figure 21 shows the time vs. average bottom temperature observed at soffit of control slab and soffit of slab protected with secondary roofing. It can be seen that gradual increase in temperature up to 14°C at bottom surface of control slab from 10 a.m. to 2 p.m. followed by gradual reduction up to 6 p.m. Whereas, soffit of the control slab in secondary roofing system exhibits almost similar temperature values during the test period. An average difference in temperature of 10°C was observed throughout the test period which is a significant reduction.

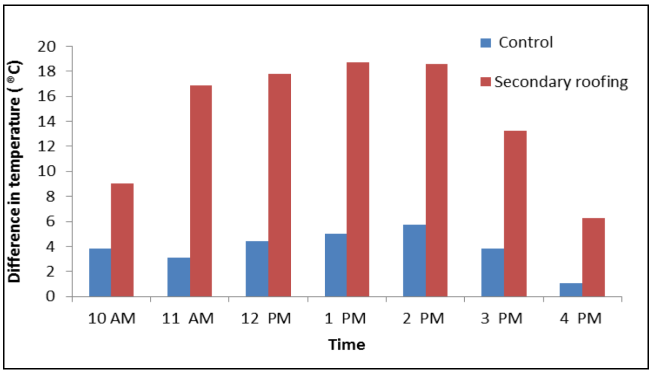


Figure 20: Comparison of difference in temperature in control and secondary roofing system

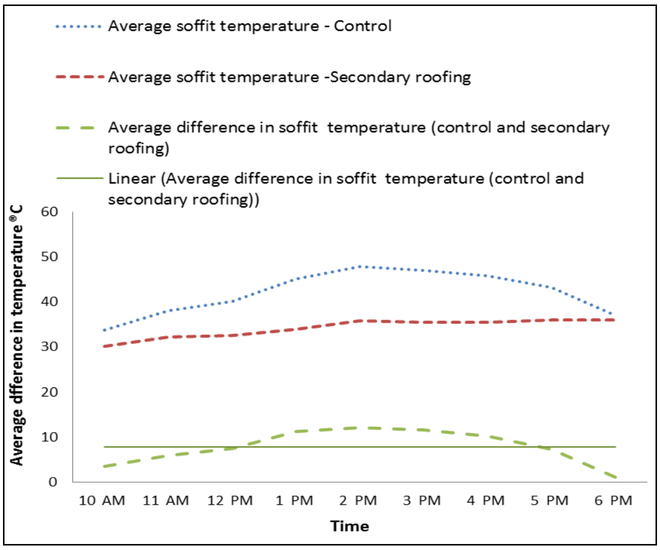


Figure 21: Average difference in temperature at soffit of slab in control and secondary roofing system

Figures 22 and 23 illustrate the 24 hour surface temperature variation in control building and building with secondary roofing system respectively. It can be seen that the peak temperature is attained by around 2.00 p.m. in both the model buildings. However, reversal of temperature (increased bottom surface temperature with respect to top surface) was observed to begin around 4:00 p.m. in control building and 5:00 p.m. in the building with secondary roofing. However the cooling of the soffit surface takes place earlier (12 a.m.) in control building compared to building with secondary roofing unit (2 a.m.). This may be due to the fact that the air gap, being a good insulator, slows down the cooling of the interior of the building due to external reduction in temperature and breeze. It can be inferred that the control roof slab heats up and cools down more rapidly than the slab provided with secondary roofing system.

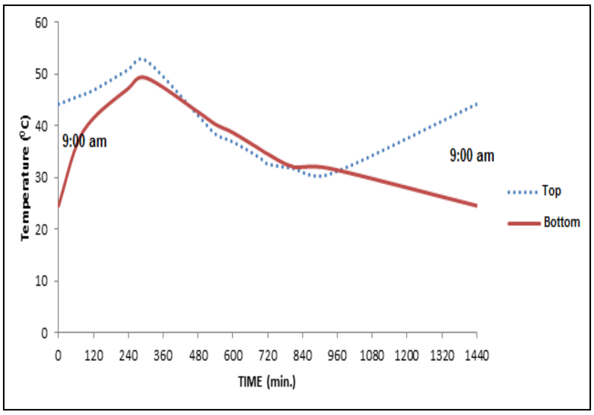


Figure 22: Hourly temperature variation in control building for 24 hour period

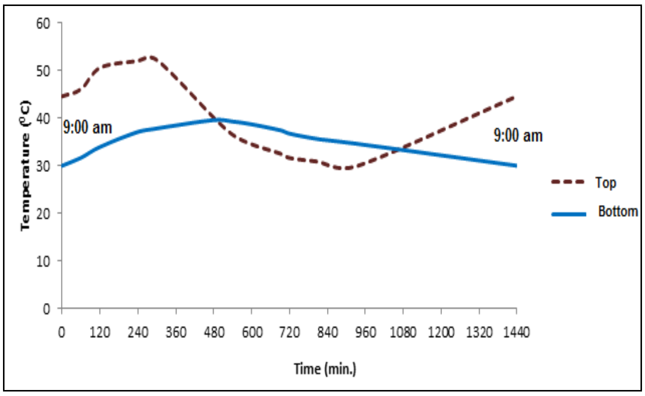


Figure 23: Hourly temperature variation in building with secondary roofing system for 24 hour period

CONCLUSIONS

Based on the experimental results obtained, the following conclusions are drawn.

- Inhibitor addition in mortar did not significantly alter the basic properties of cement such as consistency, initial setting time and final setting time.
- Addition of corrosion inhibitor in mortar marginally reduces the water-cement ratio of the order of 6% as compared to control mortar. There is a significant increase in 28 day compressive strength of the order of 22% for inhibitor admixed mortar as compared to control mortar.
- Flexure test results on ferrocement panels with two mesh layers indicate twofold increase in ultimate load carrying capacity and improved energy absorption as compared to ferrocement panels with one crimped mesh layer, irrespective of the type of mortar mix.
- Chloride ion penetration test results indicate a significant reduction in chloride penetration depth for inhibitor admixed mortar of the order of 27% as compared to control mortar.
- Improved resistance against accelerated corrosion attack was observed for inhibitor modified mortar specimens in the ACT test.
- RCPT result results suggest that control and inhibitor admixed mortar are under low chloride permeability. But there is 16% reduction in current passage for inhibitor admixed mortar specimens as compared to control mortar which reveals improved durability.
- Laboratory thermal performance test results on ferrocement secondary roofing system exhibit a significant reduction in temperature of the order of 15^0C in soffit of the slab when compared to incident temperature.
- Field thermal performance test results indicate a 25% improvement in thermal comfort in buildings with ferrocement secondary roofing unit as compared to buildings with bare roof when tested on a hot sunny day, during peak hours. However, roof protected with secondary roofing was found to cool down slower than flat roof at night.
- It can be concluded that ferrocement panel for use in secondary roofing is a viable option to provide effective thermal insulation to the flat roof slabs. Addition of inhibitor in the mortar mix will enhance the durability of ferrocement panels appreciably during service life.

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