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# DURABLE FERROCEMENT PANELS FOR USE IN SECONDARY ROOFING – AN EXPERIMENTAL STUDY

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

*[1]M.tech (by Research) Scholar, [2]M.Tech Student, [3]Professor, B.S. Abdur Rahman University, Chennai, (India)*

## ABSTRACT

*The present study investigates the performance of newly developed cement composites for manufacturing ferrocement panels for use in secondary roofing. The cement mortar mix adopted in the study is 1:2 and Sodium nitrite based mixed inhibitor was incorporated at 2% by weight of cement. The reinforcement used in the study are galvanized wire mesh and crimped wire mesh in the mid of the panel in two layers. The performance of inhibitor admixed cement mortar is compared with that of control mortar for studying the influence of inhibitor addition on basic cement properties, fresh mortar and hardened mortar properties. Durability of the inhibitor admixed mortar is assessed by conducting rapid chloride penetration test (RCPT), accelerated corrosion test (ACT) and chloride penetration test. The tests are conducted as per BIS / ASTM. The flexural behavior of inhibitor admixed ferrocement panels under four point loading is also assessed as per Indian standards. It is found that inhibitor incorporation did not significantly modify the basic properties of cement and fresh mortar. Whereas, significant increase in 28 day compressive strength of the order of 22% for inhibitor admixed mortar was observed. RCPT, ACT and chloride penetration test results also showed appreciably improved durability for inhibitor admixed mortar as compared to control mortar. Flexural strength results exhibit insignificant changes in the ultimate strength irrespective of inhibitor modification. It is concluded that addition of corrosion inhibitor in mortar appreciably increases the durability of ferrocement panels without affecting the strength and may be suggested for use in secondary roofing for enhanced thermal insulation.*

***Keywords: Ferrocement panels; corrosion inhibitor; crimped wire mesh, galvanized wire mesh; Accelerated corrosion test.***

## I. INTRODUCTION

India is home to an extraordinary variety of climatic regions with ambient temperature varying from 25 °C - 45 °C [1]. Air conditioning is the obvious solution generally resorted to for improving the thermal comfort and indoor air quality of the occupied space. But, besides being expensive and harmful to the environment, its efficiency is reduced due to heating up of the buildings. Though the whole building absorbs heat from the surrounding and dissipates it inside, the roof of buildings acts as the prime contributor and receives the maximum amount of radiant heat, consequently allowing large quantities of heat to enter the building envelope.

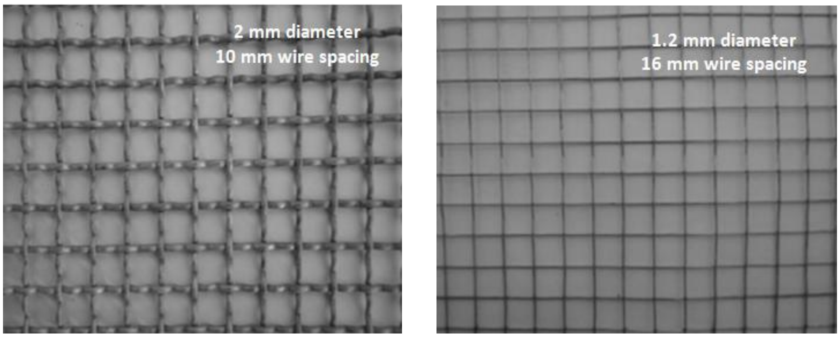
This results in the increase in temperature inside the buildings, higher air conditioning loads, increased running time of the compressors and thus, higher energy cost.

For roofs, both LEED (Leadership in Energy and Environmental Design)-India and GRIHA (Green Rating for Integrated Habitat) advocate over-deck insulation as against the conventional way of under-deck insulation. An over deck insulating material has to satisfy the dual requirement of acting as a thermal barrier and a waterproofing layer. A lot of methods have been used in India in the past namely mud phuska, brick bat coba, cool tiles, cool roof coatings etc. However, their durability is always a question. Need for frequent replacement cannot be catered to always as it involves a huge cost. The application of ferrocement as secondary roofing elements has been explored in the past [2]. However, steel corrosion, even in well-constructed concrete, can be active when chlorides continuously accumulate at the depth of the steel. Once corrosion initiates, corrosion may propagate rapidly. Subsequent corrosion of steel produces rust products, which have the volume of 3-8 times greater than an original metal. This generates the stress causing cracking and spalling of the concrete cover, which further accelerates corrosion. This may be a problem with ferrocement panels as they have a very low cover depth [3]. Recently sodium nitrite based corrosion inhibitor which also offers improved workability to cement concrete was developed [4]. This study focuses on the improving the durability of ferrocement panels for use in secondary roofing by mortar modification and studying its effect on the flexural behavior of the panels.

## II. EXPERIMENTAL INVESTIGATION

### 2.1 Materials

Portland Pozzolana Cement (PPC) of 53 grade has been used in this experimental investigation. Locally available river sand sieved to a nominal size of 2.36 mm has been used in this study. Square crimped wire mesh of 2mm wire diameter, 10mm wire spacing and density 2.764 Kg/m$^2$ and galvanized steel mesh of 1.2mm wire diameter and 16mm wire spacing have been used. Figure 1 shows the view of the crimped and galvanized steel meshes used in the study. Sodium Nitrite based corrosion inhibitor, developed in the recent times is used. This inhibitor is a dark brown colored free flowing liquid of density 1.205kg/L.



(a) Crimped steel mesh (b) Galvanized steel mesh

**Figure 1. View of mesh reinforcements used in the study**

### 2.2 Mortar mix

Two types of mortar mixes have been used in this study namely plain cement mortar and 2% Sodium Nitrite based inhibitor admixed mortar. The cement to aggregate ratio was fixed as 1:2. The water cement ratios of the mortar mixes were determined based on ASTM C 1437[5]. 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.

The consistency (BIS 4031:1988 Part 4 [6]), initial and final setting time (BIS 4031:1988, Part 5 [7]) of plain cement and cement admixed with 2% inhibitor were determined as per Indian standards and tabulated in Table 1. It was observed that the addition of inhibitor decreases the standard consistency by 11% and the setting time by 30%.

**Table 1. Consistency and setting properties of cement**

| Type of cement paste | Consistency (%) | Initial setting time (min.) | Final setting time (min.) |
|---|---|---|---|
| **Plain cement paste** | 36 | 50 | 400 |
| **2% inhibitor admixed cement paste** | 32 | 35 | 230 |

## 2.3 Compressive strength test

For the determination of compressive strengths of the two mixes, cubes of size 100 mm x 100 mm x 100 mm were cast and tested for 7, 14 and 28 days compressive strength as per IS 516 [8]. In each category three specimens were cast and totally 18 specimens were subject to the compressive strength test. The test was conducted on a 3000 kN capacity digital compression testing machine. The compressive strength of the mortar specimens was found from the maximum load at which the specimen failed.

## 2.4 Flexure strength test

Flexural strength test was performed on ferrocement panels to study the effect of varying mortar mix. The mesh combination employed in the study includes 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 tension zone. The mortar mix ratio was fixed as 1:2. Two types of mortar mixes were used, namely plain Portland Pozzolana Cement (PPC) mortar and 2% inhibitor admixed PPC mortar, of water cement ratios 0.45 and 0.42 respectively. Ferrocement slab panels of size 900mm x 300mm x 25mm were cast with mesh embedded in cement mortar. In each category, three slab panels were cast. To clearly study the cracking behaviour, the slab panels were coated with a white cement-polymer mix prior to testing. The specimens were subjected to flexural strength test as per BIS 516 [8]. Figure 2 shows the schematic of the test set up for flexural strength test.

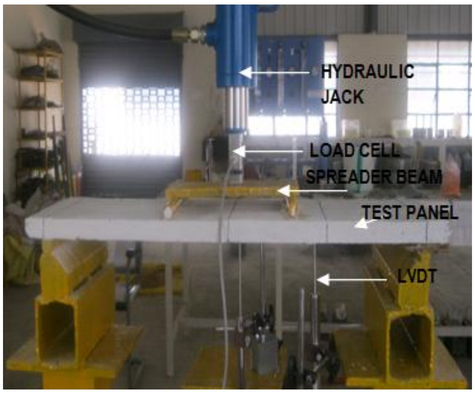


**Figure 2. Flexure test in progress**

The panel specimens were tested under four point loading through a hydraulic jack of 5 tonne capacity fitted to a loading frame, at a slow loading rate of 0.64mm/s. A spreader beam was used to distribute the load to two points. The centre to centre distances between supporting rollers were kept as 750mm leaving 75mm on either side. Two linearly variable displacement transducers (LVDT) were placed at the soffit; one at the midpoint and one at one fourth of the effective span. The load signals from the 2 tonne capacity load cell and the deflection signals from the LVDTs were fed into a data acquisition system to obtain the load displacement curves.

### 2.5 Chloride ion penetration test

Chloride penetration is a cancerous but unavoidable phenomenon that reduces the alkalinity of mortar leading to corrosion of the embedded reinforcement. A high resistance to chloride penetration means that the mortar has less interconnected voids and that it is of good quality.

Cube specimens of size 100mm x 100mm x 100mm were cast for each mortar mix. The cured specimens were waterproofed with two coats of cement- polymer mixture and one coat of polymer on every side except the top and bottom leaving a time gap of three hours between the coats. The specimens were kept immersed in 3% Sodium Chloride solution for 20 days. The specimens were then split open with the help of the Universal Testing Machine. The split surfaces were then sprayed with an indicator solution comprising of 0.1 N Silver Nitrate and 0.1% Sodium Fluorescein, which is red-orange in color. The area unaffected by chloride is indicated by the change in color of the solution to green. Upon drying, the unaffected region gets darkened. The depth of penetration of chloride ion was thus identified for each specimen at 8 locations (as indicated in Figure 3).

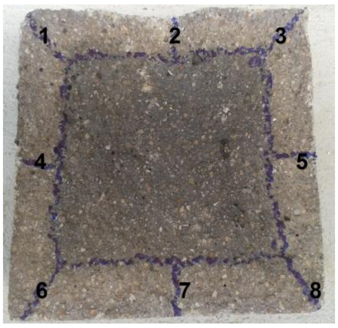


**Figure 3. View of indicator sprayed specimens for chloride ion penetration test**

### 2.6 Accelerated Corrosion Test

The accelerated corrosion test [9][10] was performed on miniature ferrocement panel specimens of size 150mm x 150mm x 25mm to determine the relationship between time and current development and also the time taken for cracking of specimen due to volumetric changes accompanying the formation of corrosion products. The mesh reinforcement in the panel acts as anode and a specially made perforated stainless steel hollow cylinder acts as the cathode. The electrodes were immersed in 3% Sodium Chloride solution. The corrosion process was accelerated by means of applying a potential of 6V across the electrodes. Figure 4 shows the view of ACT in progress. Current measurements were monitored at regular intervals until the failure of specimens.

Figure 4. View of ACT in progress

### 2.7 Rapid chloride penetration test

Rapid Chloride penetration test was performed as per ASTM C 1202 [11] to find the chloride penetrability of mortar matrix based on current measurement. Three mortar cylinders of size 100mm x 200mm were cast for each mix and 50mm slices were cut. The sliced specimens were placed between two plastic acrylic cells, clamped and sealed with silicone resin. The two cells were connected to the positive and negative terminals of a power supply source. The cell connected to the negative terminal was filled with 3.0% NaCl solution and the other cell was filled with 0.3 N NaOH solution. A potential of 60 V was applied across the two cells for a period of 6 hours and the current development was noted down every 30 minutes. Figure 5 shows the view of the test in progress.

(a) Specimen cell (b) Power source

Figure 5. View of rapid chloride penetration test (RCPT) in progress

## III. RESULTS AND DISCUSSION

### 3.1 Compressive strength test

Figure 6 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 at every stage of curing. An increase in 28 day compressive strength in the order of 22% was observed for inhibitor admixed mortar as compared to control mortar. The improvement in the compressive strength may be due to reduction of water cement ratio for the same degree of workability for inhibitor admixed mortar.

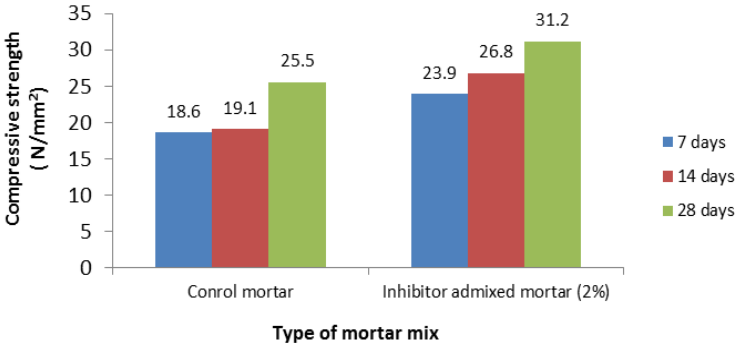


Figure 6. Comparison of compressive strength of control and inhibitor admixed mortar

### 3.2 Flexural strength test

The observations of the flexural strength test are shown in Table 2. It is observed that there is no considerable influence of the addition of inhibitor on the flexural strength of the ferrocement panels. However, there seems to be an improvement in the failure pattern of the specimens upon inhibitor addition. Inhibitor admixed specimens failed with well distributed cracks in the middle third region and displayed significant deformation during loading. Figure 7 shows the crack patterns developed in the panels subjected to the flexural strength test. No spalling was observed in inhibitor admixed specimens during loading.

**Table 2. Observation on flexural strength test of panels**

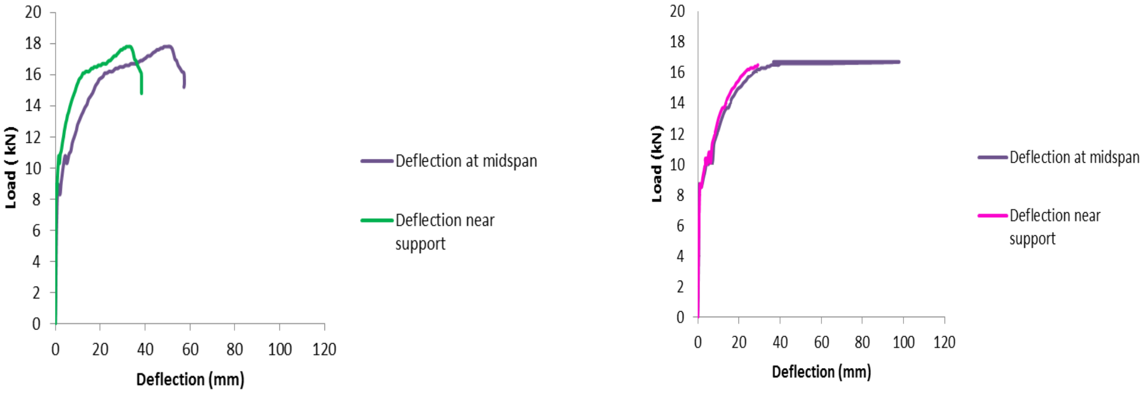
| Type of specimen | First crack load (kN) | Ultimate load (kN) | Physical observation |
|---|---|---|---|
| **Control mortar** | 11.709 | 17.04 | • Breaking of specimen after first crack load without forming crack patterns.<br>• No appreciable deformation of panel during loading |
| **Inhibitor admixed mortar** | 8.494 | 16.017 | • Well distributed patterned cracks in the middle 1/3rd region.<br>• Significant deformation of panel during loading |

(a) Control mortar

(b) Inhibitor admixed mortar

**Figure 7. View of crack patterns observed in the specimens**

Figure 8 illustrates the load deflection behavior obtained for each type of panel.



(a) Control mortar

(b) Inhibitor admixed mortar

**Figure 8. Load-deflection behavior of panel specimens**

Figure 8 shows that the load deflection behavior of panels with inhibitor admixed mortar is more pronounced than that of others (i.e) these panels showed good deformation even after yielding. The panels with control mortar failed comparatively sooner after the yield condition. The load- deflection behavior near the support was found to follow a pattern similar to the load- deflection behavior at the midspan.

### 3.3 Chloride ion Penetration Test

Table 3 shows the observation on chloride ion penetration test of mortar. It can be seen that the average chloride penetration depth in inhibitor admixed mortar is appreciably less as compared to control mortar.

**Table 3. Observation on chloride ion penetration test of mortar**

| S. No | Mortar mix | Chloride ion penetration depth (mm) |
|---|---|---|
| 1 | Control | 16.525 |
| 2 | Inhibitor admixed (2%) | 11.975 |

### 3.4 Accelerated Corrosion Test

The accelerated corrosion test was performed on the miniature panel specimens. Table 4 shows the observation on accelerated corrosion test with respect time taken for cracking of specimen due to the volumetric changes associated with formation of corrosion products when the potential applied across the electrodes was 6V.

**Table 4. Observation on accelerated corrosion test on mortar**

| S. No | Mortar mix | Time for cracking (min) |
|---|---|---|
| 1 | Control | 307 |
| 2 | Inhibitor admixed (2%) | 356 |

It can be inferred from table 5 that the delay of cracking of about 50 minutes in inhibitor admixed mortar in comparison with control mortar may be due to the increased resistance offered by inhibitor admixed mortar to chloride penetration under a potential difference of 6V. Figure 9 shows the current development trend in the specimens with respect to time.

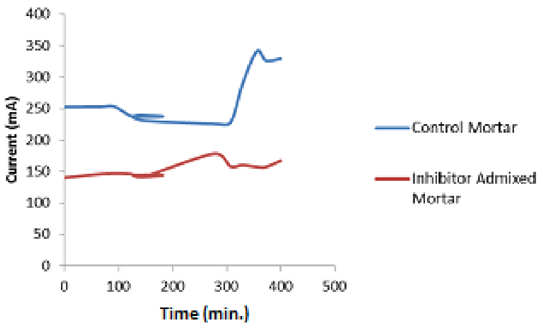


**Figure 9. Time versus current behavior of mortar subjected to Accelerated Corrosion Test**

It can be observed from Figure 9 that the current development was gradual and minimal in inhibitor admixed mortar as opposed to control mortar. While an increase in current of 30% was observed in control mortar specimen, inhibitor admixed specimen showed an increase of only about 20%. This indirectly indicates that the inhibitor admixed specimen offers high resistance to current development even in accelerated corrosion conditions and hence displays a better capability of corrosion resistance.

### 3.5 Rapid Chloride Penetration Test

Figure 10 shows the time versus current behavior of control mortar and inhibitor admixed mortar made of PPC. 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.

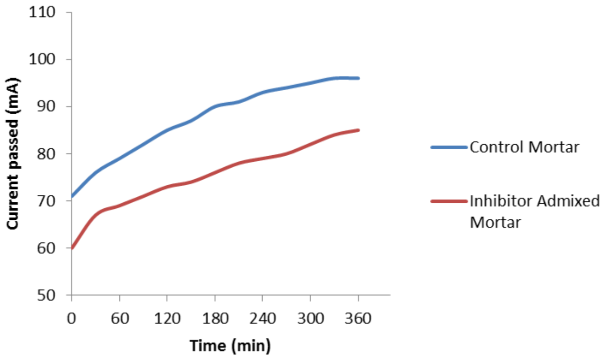


**Figure 10. Time versus current behavior of control and inhibitor admixed mortar**

Codal criteria for correlating the charge passed and the chloride penetrability is indicated in Table 5.

**Table 5. Chloride ion penetrability based on charge passed [11]**

| Charge Passed (Coulombs) | Chloride Ion Penetrability |
|---|---|
| >4000 | High |
| 2000-4000 | Moderate |
| 1000-2000 | Low |
| 100-1000 | Very Low |
| <100 | Negligible |

The charge passed through the mortars during the period of 6 hours was calculated as per code and is illustrated in Figure 11. It can be observed that at the end of the test period, the charge passage was found to be 16% less in inhibitor admixed mortar as compared to control mortar though they fall in the range of low chloride ion penetrability.

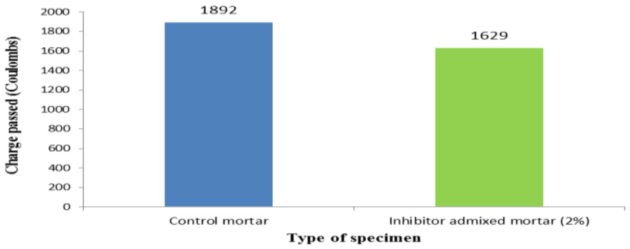


**Figure 11. Comparison of charge passage in control and inhibitor admixed mortar**

## IV. CONCLUSIONS

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

- Inhibitor modification in mortar did not significantly alter the basic properties of cement such as consistency, initial setting time and final setting time of cement.
- 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 reveal that the addition of inhibitor improves the cracking behavior of the panels.
- 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.
- A 16% reduction in current passage for inhibitor admixed mortar specimens was observed in the RCPT as compared to control mortar which reveals improved durability.
- It can be concluded that addition of inhibitor in the mortar mix will enhance the durability of ferrocement panels appreciably during service life making it more suitable for use in secondary roofing.

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