Study of the mechanical and corrosion resistance properties of ferrocement

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Abstract. Ferrocement is a lightweight, homogeneous and versatile structural material which is made as a composite of wire mesh and tightly wound skeletal steel impregnated with cement mortar. Ferrocement excels reinforced concrete system because of the minimal formwork and scaffolding requirement, possibility of casting elements on ground at site, fast erection and decrease in time of construction, and savings in the overall cost. Even though ferrocement has been used for various applications since 1800s, the technology is not properly standardized and unconventional local construction practices continue to prevail. Due to this and the poor workmanship, the durability of ferrocement structures has become an issue. Factors such as the corrosion of mesh and or the skeletal reinforcement, improper mix design etc. lead to deterioration of ferrocement structures. The major corrosion prevention methods used in reinforced concrete systems are application of coating to the steel such as epoxy or cement polymer composite (CPC) coatings and use of corrosion inhibitor in the cementitious matrix. The present study evaluates the possibility of adoption of these corrosion prevention strategies in ferrocement. The objective of the study is to analyse the flexural and corrosion resistance behaviour of four different types of ferrocement systems. The systems studied include ferrocement with normal welded mesh in normal cement mortar(WM); CPC coated weld mesh in normal cement mortar (CPC); normal weld mesh in cement mortar with corrosion inhibitor (WM CI); and CPC coated weld mesh in cement mortar with corrosion inhibitor (CPC CI). The corrosion analysis is done by using half cell potential measurements following ASTM C876-15 and flexural analysis by flexural strength test following IS 516: 1959. The results indicate that usage of both corrosion inhibitor and CPC coating can prominently increase the durability of ferrocement structures.

Keywords: Ferrocement, cement polymer composite coating, corrosion inhibitor, half cell potential test

1. Introduction
As per [1], “Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials”. The thickness of ferrocement sections vary from 10mm to 60mm. Metallic reinforcement used in ferrocement include woven or welded steel mesh, hexagonal twisted wire mesh and expanded metal mesh. The cover varies from 1.5mm to 5mm. It has superior cracking behaviour in tension [2] compared to conventional reinforced concrete. The
four construction methods recommended by [1] for the ferrocement construction are armature system, integral mould system, open mould system and closed mould system.

The durability of ferrocement is affected by three main factors. They are concrete cover, surface area of the reinforcement and usage of galvanized mesh [3]. Since the cover is small, it is quite easy for the aggressive species to enter into the matrix and cause corrosion. The corrosion in the reinforcement usually occurs through carbonation and chloride ingress. These situations can lead to breaking of passive film, thus initiating corrosion. The deterioration associated with the reinforcement corrosion can get worsen due to the presence of cracks. Therefore, in addition to the basic requirement of a well compacted cement matrix, design of ferrocement for serviceability conditions (for maximum crack width) is very much essential to ensure the durability of the ferrocement.

From the previous studies, it has been found that corrosion in the ferrocement can affect the structure by reducing its strength, thus affecting the load bearing capacity. [4] suggested that the corrosion can be reduced to a certain extent by using dense mortar with the help of flyash, silica fume and slag. Research by [5] also showed that the corrosion resistant nature can be improved upon by increasing the cover depth. [6] reported that introduction of corrosion inhibitor in the cement mortar matrix can reduce corrosion in ferrocement. However, not much studies have been found on the usage of anti corrosive coating to the rebar and its influence on the corrosion resistance behaviour of ferrocement. This paper presents a study on the flexural and corrosion resistance behaviour of different ferrocement systems, in which the efficiency of the use of corrosion inhibitor, and anti corrosion coatings are assessed.

2. The experimental programme
The four different ferrocement systems studied include ferrocement with normal welded mesh in normal cement mortar(WM); CPC coated weld mesh in normal cement mortar (CPC); normal weld mesh in cement mortar with corrosion inhibitor(WM CI); and CPC coated weld mesh in cement mortar with corrosion inhibitor (CPC CI).

2.1. Design of ferrocement system
The ferrocement was designed following the [1] and [7]. The design of ferrocement cross section is done similar to that of a reinforced concrete beam or column with different layers of steel by incorporating the design recommendations specified by the code. In order to get the trial section, guidelines are provided to fix mortar proportions. Accordingly, the sand/cement ratio as well as the water/cement ratio was fixed as 2.5 and 0.43.

The design process involves two steps, viz., calculation of the volume fraction of reinforcement (for the square shaped welded wire mesh) and calculation of design moment capacity. The volume fraction of the reinforcement depends on the shape, spacing, thickness of the section and diameter of the wire as well as the number of layers of the mesh used. As per [1], the thickness of section and number of layers of mesh was assumed to be 2.5cm and 1 respectively. The volume fraction of reinforcement was obtained as 1.939%. The design moment capacity calculation is done after fixing the spacing between the mesh layers and the depth of the reinforcing layer. Thereafter the distance from the external compression fibre to the neutral axis was fixed by trial and error process. Then the forces in each layer of mesh is calculated. The nominal moment capacity is found from tension or compression. The compressive force is found by incorporating the 28th day compressive strength of mortar. The design strength is calculated by incorporating the strength reduction factor from [8]. For the present section, the obtained design capacity was 0.167 kNm.

2.2. Materials used and the casting procedure adopted
The materials used in the study are as follows:

- Welded wire mesh with 2.8mm diameter wire and 1 inch × 1 inch opening
- Portland Pozzolano Cement(PPC)
- Sand passing through 1.18mm sieve
- Polypropylene fibres of 20mm length (to reduce shrinkage)
- Bipolar corrosion inhibitor
- Cement Polymer Composite Coating (CPC)

The material property evaluation of cement, sand, welded wire mesh and cement mortar were done as per [9], [10], [11], [1] and [12] respectively. Standard consistency test, initial setting time, final setting time and specific gravity test were carried out for the cement used. For the wire mesh used, tension test was carried out. The mortar was cast with a sand/cement ratio of 2.5 and water/cement ratio of 0.43. The compressive strength test of the mortar cubes was done and the 28th day compressive strength was found to be 42.7N/mm² which was greater than the limiting value as specified by [13]. For the preparation of ferrocement, the polypropylene fibres were added at a dosage of 1500g/m³ and the corrosion inhibitor at 4l/m³. The above dosage was fixed based on the recommendation from the manufacturer.

The casting procedure adopted is described below. The ferrocement sections for the current study were cast by an open mould system. The open mould system utilizes formwork on one side, above which wooden strips are placed to support the welded wire mesh. For the easy removal of the specimen, polyethylene sheet was used on the mould. A wooden strip of 1cm thickness was placed on the bottom of the mould to keep the mesh reinforcement in position. Mortar was filled in 3 layers and was hand compacted. After 24 hrs the wooden strips were removed and backfilled with mortar. A total of 20 specimens were cast, twelve for flexural test and eight for corrosion tests. Figure 1 shows the different stages of specimen casting.

The details of the tests conducted to assess the mechanical and durability properties of the different ferrocement systems are discussed below.

![Preparation of the mould](image1)
![Specimen with welded mesh](image2)
![Cast specimens for corrosion test](image3)

**Figure 1.** Different stages of specimen casting

### 2.3. Flexural strength test

Flexural strength test of ferrocement is carried out as per [1] and [14] by three-point loading. The specimen size for flexure test was taken as 50×10×2.5cm. The moment capacity of the specimens was calculated from the bending moment diagram using the load taken by each specimen and were compared with the design moment capacity obtained as 0.167kNm. Figure 2 shows the testing of ferrocement specimen for flexural strength determination.
2.4. Corrosion test
Corrosion in ferrocement was assessed using half cell potential test as per [15]. The specimen size was fixed as 30 x 30 x 2.5 cm. A total of eight specimens were cast for the corrosion test which include two each of the four types of specimen considered. Corrosion was induced in the specimen by ponding the specimen with 10% NaCl solution. A wet and dry cycle (5 days dry and 2 days wet) was adopted for accelerating the corrosion. Figure 3a shows the ponded specimens. The corrosion measurements were taken using half cell potential test, in addition to visual observation. Corrosion readings were taken at the end of each cycle using Cu/CuSO₄ electrode. A grid of 20 x 20 cm with grid lines at a spacing of 2 cm were drawn and the readings were taken at the intersection of the grid lines. The experimental set up is as shown in Figure 3b.

3. Results and discussion
The results obtained are discussed in the following sections.

3.1. Flexural Strength Test Results
Table 1 gives the flexural strength test results. From the table it can be inferred that only WM specimens showed moment capacity greater than the design strength (0.167kNm). The specimens with welded wire mesh showed the greatest moment capacity followed by WM CI and CPC specimens, and then by CPC CI specimens. The load taken by the corrosion inhibitor added specimen showed a decreasing trend. This is because the addition of corrosion inhibitor decreases the strength of the cementitious matrix. This was assessed by testing the mortar cubes.
Table 1. Flexural strength result

| Specimen type                  | Trial No | Weight (kg) | Load (2w) (kN) | Moment capacity (kNm) | Average moment capacity (kNm) |
|-------------------------------|----------|-------------|----------------|-----------------------|-------------------------------|
| Welded Mesh (WM)              | 1        | 2.7         | 3              | 0.33                  |                               |
|                               | 2        | 2.582       | 3              | 0.33                  |                               |
|                               | 3        | 2.218       | 4              | 0.44                  | 0.183                         |
| CPC Coated Mesh (CPC)         | 1        | 2.517       | 2.5            | 0.275                 |                               |
|                               | 2        | 2.42        | 2.5            | 0.275                 |                               |
|                               | 3        | 2.49        | 3              | 0.33                  | 0.1467                        |
| Welded Mesh with Corrosion Inhibitor (WM CI) | 1        | 2.375       | 3              | 0.33                  |                               |
|                               | 2        | 2.532       | 2.5            | 0.275                 |                               |
|                               | 3        | 2.453       | 2.5            | 0.275                 | 0.1467                        |
| CPC Coated Mesh with Corrosion Inhibitor (CPC CI) | 1        | 2.592       | 2.5            | 0.275                 |                               |
|                               | 2        | 2.683       | 3              | 0.33                  |                               |
|                               | 3        | 2.291       | 2              | 0.22                  | 0.1375                        |

The obtained compressive strength in corrosion inhibitor added mortar cube is 12N/mm\(^2\) after 7 days and 20.533N/mm\(^2\) after 28 days of curing. The values were much less than the specified limits in [13]. The reason for reduction in CPC specimens is due to slippage of reinforcement caused by the presence of CPC coating. Decrease in the load carrying capacity of the mortar due to presence of CI ([16], [17]) and occurrence of slippage worsen the load carrying capacity of the CPC CI specimens. The percentage reduction in design strength of both CPC and WM CI specimens were 12% whereas it was 17.66% in the case of CPC specimens.

3.2. Corrosion Test Results

3.2.1 Half Cell Potential Test. Figure 4 shows the variation of electric potentials across the specimens. The specimens having electric potentials above 0.35V is considered to have 90 percent probability of corrosion whereas those having electric potential values below 0.35V is said to have uncertain or intermediate probability of corrosion.

Figure 4. Variation of corrosion across specimens
Those specimens with electric potential values less than 0.2V is said to have less than 10 percent corrosion. The specimens with electric potential values greater than 0.5V are considered to have severe corrosion. From the graph it can be inferred that the WM specimens showed values greater than 0.35V and also above 0.5V, which indicates that it has the highest corrosion probability among the four types of specimens. While comparing the specimens below 0.35V it can be seen that WM CI specimens showed greater probability of corrosion followed by CPC CI specimens.

3.2.2. Visual Observations  The corrosion was visually clear only from the specimens of welded mesh without corrosion inhibitor. The observation of patches of corrosion in welded mesh after 72 days is shown in the photographs given in Figure 5. WM specimen took 3 weeks to corrode whereas CPC specimen took 13 weeks to corrode. The CPC coating was worn off from CPC CI specimen.

![Figure 5. Marks of corrosion in WM specimen after 72 days](image)

After 14 weeks of inducing corrosion, mesh reinforcement was taken from all specimen and was examined. Pitting corrosion with diameter reduction was observed in WM specimen. The maximum diameter reduction for WM and CPC specimens were 39.3% and 4.5% respectively.

From the corrosion prevention strategies adopted, the CPC CI specimens showed better corrosion resistant behavior followed by WM CI specimens and CPC specimens. Thus, it was concluded that incorporating Corrosion Inhibitor as well as providing anti corrosive coatings can increase the useful life of ferrocement. Combining both methods can decrease the corrosion more predominantly.

4. Conclusion

The objective of the study was to analyse the mechanical properties and the corrosion resistant behaviour of the four ferrocement systems designed as per [1]. The effect of CPC coating and corrosion inhibitor on the flexural and corrosion resistance was studied.

The specific conclusions made from the study are as follows:
1. From the flexural strength results, the specimens with welded mesh showed more strength than the other types of specimens. Welded mesh specimens only satisfied the design strength and showed 9 percent increase from the design strength value. Thus, it can be concluded that provision of a corrosion prevention strategy can adversely affect the load carrying capacity of the ferrocement.
2. The better corrosion resistant behaviour was exhibited by CPC CI specimens, followed by WM CI and CPC specimens. Incorporating Corrosion Inhibitor as well as providing anti corrosive coatings can increase the useful life of ferrocement. Combining both methods can decrease the corrosion more predominantly.
3. By considering both strength and durability aspect, use of corrosion inhibitor is proved to be the better option as there is only little reduction in load carrying capacity while providing better corrosion resistance.

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