Reinforced Concrete Beams and Columns Retrofitted with Ferro-cement using Corrosion Inhibitor

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ABSTRACT

Ferrocement is one of the cement based composites used for retrofitting and rehabilitation among many applications. One of the foremost factors affecting the durability of ferrocement is the corrosion of wire meshes. This problem is magnified in corrosive environments. With the passage of time, the effective strength of the wires is reduced due to a reduction in diameter and deterioration of the bond between the matrix and the reinforcement. In the present study, an attempt has been made to improve the corrosion resistance of the metallic wire meshes used in ferrocement with corrosion inhibitors. Two corrosion inhibitors, viz. Calcium Nitrite and Tannic Acid, were used. Weight loss studies and potentio-dynamic polarization tests were conducted in saline water medium. Corrosion efficiency and corrosion rate were calculated. At a 1% dose, both the inhibitors, when applied in a slurry coated form, were found to be sufficiently effective in controlling the corrosion. The effect of these corrosion inhibitors on compressive strength of cement sand mortar was also observed.The high efficiency and low corrosion rate exhibited by both the inhibitors proves their potential in controlling the corrosion. The electrochemical tests also confirm these findings. Compressive strength test also suggest that these inhibitors do not have any significant adverse effect on the mechanical properties of mortar mix. Long term studies are needed to make final recommendations with regard to the dose of these inhibitors for the protection of steel wire mesh reinforcement in ferrocement. One of the foremost factors affecting the durability of ferrocement is the corrosion of wire meshes. This problem is magnified in corrosive environments. With the passage of time, the effective strength of the wires is reduced due to a reduction in diameter and deterioration of the bond between the matrix and the reinforcement. In the present study, an attempt has been made to improve the corrosion resistance of the metallic wire meshes used in ferrocement with corrosion inhibitors. Two corrosion inhibitors, viz. Calcium Nitrite and Tannic Acid, were used. Weight loss studies and potentio-dynamic polarization tests were conducted in saline water medium. Corrosion efficiency and corrosion rate were calculated. At a 1% dose, both the inhibitors, when applied in a slurry coated form, were found to be sufficiently effective in controlling the corrosion. The effect of these corrosion inhibitors on setting time of cement, pH, and compressive strength of cement sand mortar were also observed.

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1. Introduction

Reinforced concrete is a very versatile construction material. Properly designed concrete structures are both strong and durable. However, concrete structures are vulnerable to a number of factors that can cause deterioration. Deterioration can result in loss of strength and unsafe conditions. Therefore it is important to have an understanding of the vulnerabilities of concrete structures in order to help minimize long-term repair and maintenance costs.

Concrete deterioration typically occurs when the material is exposed to weather, water or chemicals over an extended period of time. When protected from these elements, as in the case of internal members of enclosed commercial and institutional buildings, reinforced concrete can be expected to perform for decades with very little maintenance. However, in many cases, concrete can be exposed to environments that promote deterioration. Long-term deterioration can occur at the embedded reinforcing steel as well as at the exposed concrete surface. The deterioration of reinforced cement concrete is due to the corrosion of the reinforcing steel has become a major problem. It has received worldwide attention and code of practices of different countries has suggested measures to control the steel corrosion but evidence of corrosion of steel in concrete continues to be reported in field situations. The corrosion of steel reinforcement in concrete structures leads to concrete fracture, loss of bond between steel and matrix and reduction in strength and ductility. As a result, safety, serviceability and durability of concrete structures are reduced. During the last few decades the corrosion problem in reinforced concrete has been extensively investigated by many researchers. Corrosion inhibitors are one of the most cost-effective solutions to rebar corrosion problem in concrete. Corrosion inhibiting admixtures fall into the specialty admixture category and are used to slow down corrosion of reinforcing steel in concrete. In order to protect metallic materials against corrosion, certain inorganic and organic products, called corrosion inhibitors, are added in small concentration to the aggressive medium. The addition of corrosion inhibitors to the mix, offers a viable corrosion protection measure There are generally three groups of inhibitors: anodic, cathodic and mixed inhibitors. Anodic inhibitors reduce the corrosion rate by reacting with the corrosion products and form a protective film. Cathodic inhibitors reduce the corrosion rate by reacting with the cathode sites (as an oxygen-barrier) on the steel. Passivating inhibitors like nitrites represent special types of anodic inhibitors and they are generally very effective if present in sufficient concentrations.

Mixed inhibitors both influence the anodic and cathodic reaction sites, by forming an adsorption film on the metal surface. In recent years, results of many investigations and review articles have been published on organic migrating corrosion inhibitor (MCI), which is mainly composed of an amino carboxylate or amino alcohol. The inhibitors are either admixtured or directly applied to the concrete surface and they act under bipolar mechanism and penetrate even dense concrete by virtue of their vapour pressure and affinity for IJRET: International Journal of Research in Engineering and Technology.

Ferrocement is the construction material consisting of wire meshes and cement mortar application of Ferrocement in constructions vast due to the low self-weight, lack of skilled

workers, etc. Retrofitting is the process of increasing the seismic resistance of damaged or weak structure by appropriate techniques. Retrofitting of earthquake damaged structure is done by repairing and strengthening the damaged portions of the structure and making it reusable.

Ferrocement used as retrofitting due to their easy availability, economy, durability and their property of being cast to any shape without needing significant formwork. In present work the square welded wire mesh (1.16mm diameter and grid 15mm×15mm) is use in the specimens to increase the compressive strength and providing 2-3 layers of ferrocement jacketing. We were cast the mortar cube and square welded wire mesh used in mortar cube. We tested the under compressive loading and got a result that compressive strength of square welded wire mesh mortar cube higher than the mortar cube.

Corrosion of steel in concrete structures plays a significant role in affecting the service life of the concrete structures. Various methods have been developed with the intent of preventing the corrosion and to enhance the service life. The methods include the coating to the concrete surface, the coating to the reinforcement, cathodic protection, electrochemical methods, alternative reinforcement, and corrosion inhibitors.

Among all the available techniques, the use of corrosion inhibitors is one of the most appropriate and efficient methods for corrosion protection of reinforced concrete structures due to the easy operation, low cost, and excellent corrosion resistance effect of Inhibitors which are added to the concrete in small concentrations are intended to delay and slow the onset of corrosion in reinforced concrete. Most of the inhibitors act by stabilizing the steel surface by forming the protective film, and some inhibitors react with concrete forming the complex thus reducing the permeability of the concrete. Corrosion inhibitors are generally used as admixtures in concrete for new construction, but they can also be utilized for repairs by admixed with concrete for patches, sprayed onto the surface of the concrete or applied by saturation treatment.

As per NACE international, “a corrosion inhibitor is a substance when added to an environment, either continuously or intermittently to prevent corrosion by forming a passive film on the metal.” In other processing industries, inhibitors are the first line of defence against corrosion.

Inhibitors slow down the corrosion process by:

increasing the anodic or cathodic polarization behaviour.

reducing the movement of ions of the metallic surface.

increasing the electrical resistance of the metallic surface.

Literature Review

- **Gurbir singh benipal, Kamal deep singh** (2015) conducted experiment on “Reinforced concrete beams retrofitted using ferrocement”.

- Reinforced concrete structural components are found to exhibit distress, even before their service period is over due to several causes. Such unserviceable structures require

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immediate attention, enquiry into the cause of distress and suitable remedial measures, so as to bring the structures back to their functional use again, strengthening and enhancement of the performance of such deficient structural elements in a structure is done.

- In this technique the plates of different material are bonded to the surface of structural member to increase its strength.
- The results show that the percent increase in load carrying capacity for beam retrofitted with ferrocement jackets with wire mesh at 0, 45, 60 degree angle with longitudinal axis of beam, varies from 45.87 to 52.29 percent. Also a considerable increase in energy absorption is observed for all orientations.

- **Sabih Akhtar** (2014) conducted study on "Performance of blended corrosion inhibitors for reinforced concrete".
- Concrete structures are vulnerable to a number of factors that can cause deterioration. Deterioration can result in loss of strength and unsafe conditions. Therefore it is important to have an understanding of the vulnerabilities of concrete structures in order to help minimize long term repair and maintenance costs.
- In the present investigation an attempt has been made to mix two commercially available corrosion inhibitors and evaluate its effect on setting time pH and commercial strength.

  An attempt has been made to investigate the behaviour of the blend of two corrosion inhibitors viz. Calcium Nitrate and Calcium Hypophosphite added in equal quantity. Physical properties tests of the cement and concrete in the presence of these inhibitors and potentio-dynamic polarization tests were conducted.
- Corrosion parameters have been estimated using potentio dynamic polarization test. It has been observed that the corrosion inhibitor does not have any adverse effect on physical properties of cement and cement concrete.
- The low corrosion current density exhibited by the inhibitor proves that potential in controlling corrosion initiation and propagation properties investigated viz setting time, pH and compressive strength tests clearly indicate that the addition of the blended inhibitors do not have any adverse effect. The low corrosion current density exhibited by the inhibitor proves their potential in controlling corrosion initiation and propagation.

- **Han-seung lee, velu saraswati** (2017) conducted study on "corrosion inhibitors for reinforced concrete" .

- This chapter focuses on the type of inhibitors used in concrete, based upon their mode of action and the way of application.

- <u>Anodic (passivating) inhibitors</u>
  This type of inhibitors forms an insoluble protective film on anodic surfaces to passivate the steel. An anodic inhibitor shifts the potential to the passivation zone causing the formation of a thin passive film on the anodic sites, which increases the potential of the anode and decrease the corrosion in rate.

- Cathodic inhibitors slow down corrosion by reducing the rate of cathodic reactions in the corrosion environment. A cathodic inhibitor causes the formation of insoluble compounds precipitating on the cathodic sites in the form of a barrier film.

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- Mixed inhibitors
  Corrosion of steel in concrete structures is the primary concern when the structures are exposed to the coastal marine environment. The use of corrosion inhibitors can delay the onset of chloride-induced corrosion, prolong the time to initiation of corrosion, and thereby reduce the corrosion rate.
- The following conclusions were drawn:
  - The review focused only on the use of various types of inhibitors in concrete under laboratory and Field condition.
  - The corrosion inhibitors are effective in preventing reinforcement from corrosion within concrete structures.
  - Organic corrosion inhibitors were ineffective in preventing steel corrosion when their con-centrations were too low. The corrosion inhibitors can provide adequate protection for reinforcement only when the concentration of the inhibitor is higher than that of the chloride ions in the pore solution.
  - The surface-applied inhibitors can penetrate up to the depth of the embedded steel reinforcement; thus, adequate concentrations are necessary to provide corrosion protection.
  - Electrochemical injection of corrosion inhibitors (EICI) is found to be an effective corrosion mitigation technique for carbonated and chloride-contaminated reinforced concrete structure to improve the durability.

- **Amrul Kaish.A.B.M** [3] et al. (2013) conducted study on "Ferrocement Jacketing for Re strengthening of Square Reinforced Concrete Column under Concentric Compressive Load".

- This study focuses on the improvement of square jacketing technique in effective restrengthening of existing RC building column. Square jacketing technique can't effectively provide lateral confinement due to stress concentration and subsequent cracking at the corners. In order to overcome this problem, two different approaches are taken into account; i.e.

  - Strengthen all the corners, and
  - Reducing stress concentrations at corners. Three types of square jacketing techniques under these two approaches are considered in this study.

- Test results and crack pattern shows that, both approaches are effective to overcome the stress concentration problem of square jacketing. However, the first approach is practically more suitable than the second one.

Harilal pawar, sagar Chavan (2017)

- In present work welded wire mesh is used in the specimen to increase the compressive strength and providing 2-3 layers of Ferro cement jacketing. Three types of specimens were casted.
  1. Reinforced concrete beam
  2. Ferrocement jacket beam
  3. Cubes

Tests conducted were:

1. Compression test on concrete cubes and ferrocement cube using compression testing machine

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2. Flexural test were conducted on concrete beam without ferrocement jacketing and with ferrocement jacketing and the results were tabulated
3. By comparing the result of plain concrete beam and ferrocement beam for first crack load and ultimate load is increased by 1.25% and 1.28% respectively

Salwa M. Abdullah , B J al-sulyfani (2012)

- The goal of the present work is to experimentally investigate the behaviour of reinforced concrete column strengthened with carbon fiber reinforced polymer or ferrocement jackets subjected to combined axial load and moment.
- Initially seven columns were casted. One Un-strengthened column, three columns strengthened by ferrocement jacket, remaining three columns were strengthened by a carbon fiber. All seven columns were tested under combined axial load and bending moment. And the values were recorded
- The experimental results have shown that the average increase in failure loads of columns strengthened by ferrocement was about 31% while that for columns strengthened with CFRP is only 15%

MD daniyal, Akhtar S, Mumtaz ahmad quraishi (2015)

- This article reviews the studies undertaken to control corrosion in the ferrocement composites and thereby improving the durability of the composites.
- Only a few studies are reported which deal with the chemicals like chromium trioxide to address a particular problem of galvanic cell, a patented admixture and a polymer-modified coating to control the reinforcement corrosion. Christensen and Williamson suggested the use of chromium trioxide at the rate of 100-300 ppm by weight of water in preparing the mortar. Shirai and Ohama reported the performance of ferrocement with polymer-modified coating on reinforcement. And many more .

- User friendly, easily available, non-patented and cost effective chemical corrosion inhibitor for ferrocement is need of the day. the dose of corrosion inhibitor and its effective application technique also need to be explored.

S S Sneha, Karthika Soman1, C Prajith (2020)

- The objective of the study is to analyse the flexural and corrosion resistance
  behavior 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).

- Four different ferrocement systems were casted as specified by the code.and the tests were conducted to assess the mechanical and

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durability properties of the different ferrocement systems are discussed below.

1.Flexural strength test of ferrocement by three point loading.

2.Corrosion test was assessed using half cell potential test.

- 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.. 2. The better corrosion resistant behaviour was exhibited by CPC CI specimens, followed by WM CI and CPC specimens.

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Methodology Immersion Test

For immersion test welded steel wire mesh is taken. A total of three exposure mediums were considered using artificial saline water (distilled water mixed with 4% nacl); both with and without corrosion inhibitors. Two corrosion inhibitors, namely calcium nitrite (type-i) and tannic acid (type-ii), were used. The dose of inhibitors was kept at 1, 3, and 5% and the specimens were exposed for 30, 60, and 90 days. Inhibitor-i is an inorganic inhibitor, whereas inhibitor-ii is an organic inhibitor. The inhibition mechanisms of the two types are different from each other. Mostly inorganic inhibitors inhibit corrosion by reacting with the first corrosion product to form a protective film, precluding further corrosion. Organic inhibitors are usually applied in the form of a coating, which by adsorbing onto the metal surface, provides a barrier to the corrosive environment. Hence, for the naked wire mesh specimens (N), type-i inhibitor was directly dissolved in the medium, whereas the type-ii inhibitor was applied as a film over the surface of the specimen. However, these inhibitors are intended to be used for the protection of the reinforcing steel in cementitious composite, for which the best and most economical application methodology is to apply the inhibitor onto the metal surface. So for slurry coated specimens (SC), both the inhibitors were mixed in cement slurry which was applied over the surface. Immersion tests were conducted as per the recommendations of ASTM G1–03 and ASTM G31–72 .

Visual Inspection

The spread of corrosion is usually non-uniform over the surface. It is always better to observe the extent of corrosion through visual inspection. With this objective, the extent of corrosion was observed in the specimens before cleaning it for the weight loss study.

Electro Chemical Test

After identifying the dose for sufficient protection against corrosion, the effectiveness

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was validated through potentio-dynamic electrochemical studies . Electrochemical System Model "Gill AC" was used for these experiments. The instrument had inbuilt software support to evaluate corrosion kinetic parameters. The experiments were carried out at a constant temperature of 28±2 °C. The corrosion kinematic parameters were obtained from the potentio-dynamic polarization tests.

Potentiodynamic polarization test:

Potentiodynamic polarization test is a electrochemical process. This is the test of corrosion inhibitor coated and uncoated stainless steel were conducted in NaCl solution .these tests were carried out on each sample to achieve a study state potential .the potential sweep was carried out and the tafel plots were created for each test for calculation of corrosion rates and tafel parameters. Through tafel parameters and corrosion rates better inhibitor is selected.

Compression Test

To investigate the effect of corrosion inhibitors on the compressive strength of mortar, the mortar cubes of size 70.6×70.6×70.6 mm were tested after 3, 7, 14, 28, and 90 days of curing as per the recommendations of IS: 4031(Part 6).

Procedure:

Place the prepared concrete mix in the steel cube mould for casting.

Once it sets, After 24 hours remove the concrete cube from the mould.

Keep the test specimens submerged underwater for stipulated time.

As mentioned the specimen must be kept in water for 7 or 14 or 28 days and for every 7 days the water is changed.

Ensure that concrete specimen must be well dried before placing it on the UTM.

Weight of samples is noted in order to proceed with testing and it must not be less than 8.1Kg.

Testing specimens are placed in the space between bearing surfaces.

Care must be taken to prevent the existence of any loose material or grit on the metal plates of machine or specimen block.

Universal testing Machine (UTM)

- The concrete cubes are placed on bearing plate and aligned properly with the center of thrust in the testing machine plates.
- The loading must be applied axially on specimen without any shock and increased at the rate of 140kg/sq cm/min. till the specimen collapse.
- Due to the constant application of load, the specimen starts cracking at a point & final breakdown of the specimen must be noted.

FORMULA USED:

Compressive strength of concrete = maximum load carried by specimen

Top surface area of specimen

Results and Discussion

The corrosion rate has been found to be lowest for Type-I inhibitor for all the two types of specimen. In slurry coated form, only 1% dose of

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both the inhibitors gives very high efficiency and a corresponding low corrosion rate. Hence, it can be fairly concluded that the 1% dose of both the inhibitors, if applied in cement slurry coated form, gives a sufficient degree of protection to the metallic fabric.

Some of the specimens after 90 days of exposure have been shown in Figure. It has been observed that the blank specimens have very pronounced corrosion activity, especially around joints. In naked specimens inhibited with even a 1% dose of Type-I inhibitor, no signs of corrosion have been noticed. However, some isolated spots of corrosion that were too near the joints have been found in specimens inhibited with a 1% dose of Type-II inhibitor. In slurry coated specimens inhibited with either of the two inhibitors, corrosion was traceless. The visual observations are inline with the results obtained in a weight loss study.

however, in slurry coated form, only 1% dose of both the inhibitors gives very high efficiency and a corresponding low corrosion rate. Hence, it can be fairly concluded that the 1% dose of both the inhibitors, if applied in cement slurry coated form, gives a sufficient degree of protection to the metallic fabric. Some of the specimens after 90 days of exposure have been shown in Figure 5. It has been observed that the blank specimens have very pronounced corrosion activity, especially around joints. In naked specimens inhibited with even a 1% dose of Type-I inhibitor, no signs of corrosion have been noticed. However, some isolated spots of corrosion that were too near the joints have been found in specimens inhibited with a 1% dose of Type-II inhibitor. In slurry coated specimens inhibited with either of the two inhibitors, corrosion was traceless. The visual observations are inline with the results obtained in a weight loss study

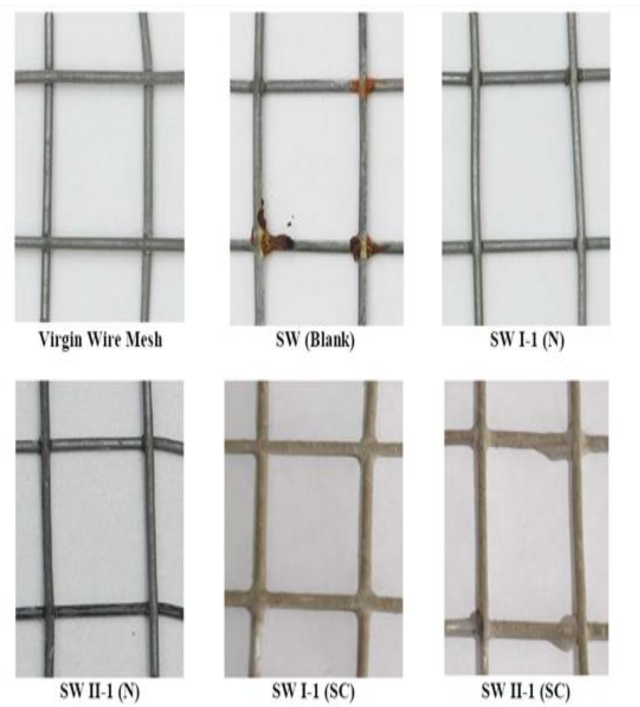

Table 3. Results of Potentio-Dynamic Study (Tafel Extrapolation)

OCP = ±200 mV; Sweep rate = 1 mV/sec

System	E_{corr} (mV)	b_a (mV)	b_c (mV)	I_{corr} (μA/cm²)	Efficiency (%)	Corrosion Rate (mpy)
Blank (Saline Water)	−609	54	164	94.86	---	43.28
1% Calcium Nitrite	−173	45	80	0.34	99.64	0.04
1% Tannic Acid	−611	59	238	0.58	99.39	3.92

Reasonably low corrosion current density and lower corrosion rates as compared to the blank specimen are clear indicators of the effectiveness of both the inhibitors at 1% dose of the inhibitors. These results validate the findings in a weight loss study. As these inhibitors may be mixed with the mortar, its effects on setting time

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of cement, pH of the mix, and the compressive strength of the mortar have also been investigated. The results of the setting time of the cement after adding 1% dose of the inhibitors are given in Table 4. It has been observed that both the inhibitors reduce the initial setting time. However, the values remain within the permissible limits of the codal provisions. Final setting time, however, remains very close to that of the Blank, thereby indicating no adverse effects.

Conclusion

The high efficiency and low corrosion rate exhibited by both the inhibitors proves their potential in controlling the corrosion. The electrochemical tests also confirm these findings. compressive strength test also suggest that these inhibitors do not have any significant adverse effect on the mechanical properties of mortar mix. Long term studies are needed to make final recommendations with regard to the dose of these inhibitors for the protection of steel wire mesh reinforcement in ferrocement.

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