Electro Chemical and Mechanical Studies on Epoxy Coated Rebars in Marine Environment

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Abstract

Corrosion is a natural process, which converts refined metal to a more stable form such as its oxide, hydroxide, or sulfide. It is the gradual destruction of materials by chemical and electrochemical reaction with their environment. In order to prevent the corrosion of steel in concrete a number of protection techniques such as coatings to steel, coatings to concrete, cathodic protection, addition of super plasticizers, electrochemical removal of chloride, desalination, electrochemical re-alkalization and corrosion inhibiting admixtures is identified. Based on literature study rebar coating is found to be effective and economic. An experimental study was conducted to analyze the corrosion resistant property of Coal Tar Epoxy in marine environment. The rebars are subjected to chemical and electrochemical studies such as cathodic disbondment, accelerated corrosion and impressed voltage tests to analysis the effectiveness of coating. The mechanical properties of the coated rebars is analyzed by pull out test. The above test results indicated an appreciable adhesion and corrosion resistant property of Coal Tar Epoxy coating even under aqueous environment of 3.5% NaCl.

Keywords — *Corrosion, Coal Tar Epoxy, Electrochemical studies, Accelerated Corrosion, Cathodic Disbondment, Impressed Voltage.*

I. INTRODUCTION

Reinforcement of steel in concrete for taking tensional force is the one of the method widely used in this world. But the rusting and corrosion is the very big problem in steel when we use in marine environment. There are many techniques adopted to resist the rust and corrosion in steel.

Epoxy resin systems are made up of epoxy resin and curing agent. Epoxy coatings are formulated based upon the performance requirements for the end product. When properly catalysed and applied, epoxies produce a hard, chemical and solvent resistant finish. They are typically used on concrete and steel to give resistance to water, alkali and acids. Coal Tar Epoxy resin system is selected from the epoxy resins and its performance in 3.5% aqueous NaCl solution is studied.

In this research work Coal Tar Epoxy coating system is analyzed for its corrosion resistance property in reinforcing steel under marine environment. A comparative study is carried out between bare rebar and Coal Tar Epoxy coated rebars in terms of Electrochemical, chemical and mechanical studies is carried out. The electro chemical tests such as cathodic disbondment test, impressed voltage test and accelerated corrosion test is conducted to ensure the corrosion resistance of coated rebars. The mechanical study such as pull out test is to determine the ductile behavior of the Coal Tar Epoxy and adhesion of coating towards the rebar.

II. MATERIALS

Coal tar epoxy is made by the conversion of polyamide epoxy with a pitch of refined coal tar. This is a black surface protection polymer used on surfaces subjected to extreme corrosive environments. It is a blend of various epoxy resins and coal tar. It is commonly used to make high solids coatings or paints to provide moisture protection and also used on metal substrates and concrete in offshore, petroleum and industrial environments. The mixture is used in two-component parts.

The Coal Tar Epoxy resin is of two parts one is the resin and the other is co- reactant or hardener. The resin and its hardener is mixed in the proportion of 2:1 respectively. A TMT bar of 8mm, 10mm and 12mm diameters is adopted for testing. The coating is then applied over the rebars using brush and it is air cured for 2days. The coated rebars is then tested for its property analysis.

III. METHODS

A. Electrochemical Studies

1) Cathodic Disbondment Test:

Two identical rebars of 1cm diameter and 15 cm length is taken. The ends of the rebars was soldered with copper wire to serve as electrical contact point. The rebars were suspended vertically in a transparent non-conductive glass container. In this test, one rebar acts as anode and the other rebar acts as cathode with an aqueous solution of 7% sodium chloride as electrolyte. D.C power supply with a controlled voltage of 2V is continuously supplied for a period of 60min. the cathodic disbondment test setup is shown in fig, 1. The passage of current for every 5min interval is noted. The rebars are visually observed for any blisters, delamination and coating failure. This process is repeated for bare rebars.

Fig. 1 Cathodic Disbondment Test Setup

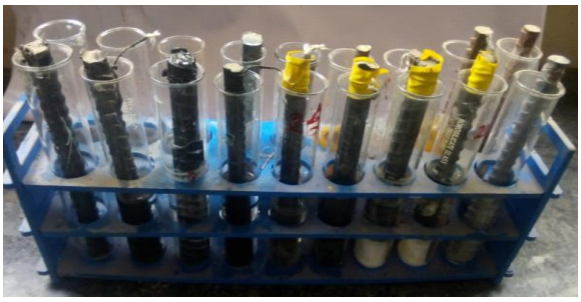

Fig. 2 Chemical Resistance Test

*2) **Accelerated Corrosion Test*:**

Coated rebar of 15cm length act as anode and the stainless steel metal acts as cathode. The ends of the electrodes is soldered with copper wire for electrical contact. The electrodes was suspended vertically in a transparent non-conductive glass container. A D.C power supply, with a controlled voltage of 12V is applied between the anode and the cathode. The electrolytic solution here is 3.5% of NaCl. The behaviour of coated rebar is observed for a period of 24hours.

*3) **Impressed Voltage Test:***

Impressed voltage test is carried out in an M20 grade concrete cylinder with an embedded rebar placed centrally during casting. The concrete cylinder measures 15cm in height and 5cm in diameter with an embedded reinforcement of 18cm long and 1cm dia. The concrete cylinder is cured for 7 days and it is prepared for testing. The rebar is soldered with copper wire for electrical contact at its ne end and it is connected to anode. An auxiliary stainless steel electrode is connected to cathode. The electrolyte is 3.5% of NaCl which is placed along with the electrolyte in a glass container. A constant potential of 12V is applied and it is observed until the crack in concrete specimen is initiated.

*4) **Chemical Resistance Test***

The chemical resistance of coating shall be evaluated by immersing coated and uncoated reinforcing bars in each of the following as shown in fig. 2

a) Distilled water,
b) A 3 M aqueous solution of $CaCl_2$.
c) A 3 M aqueous solution of NaOH, and
d) A solution saturated with Ca $(OH)_2$.

The coated and uncoated rebar of length 10cm and 1cm diameter adopted. The coated and uncoated rebars were partially immersed in each solution, so that they were in long term contact with both liquid and vapour phase. The minimum test time shall be 45 days. Every 24 hours, the surface condition of coated rebars was examined for appearance of blisters, disbondment from base metal or any coating defect throughout the test period.

B. Mechanical Study

*1) **Pull Out Test:***

The pull out test is carried out in a Universal testing machine (UTM) of 40ton capacity with reference to IS 2770 (Part I) – 1967. The test specimens consist of concrete cubes of size 150mm, with a single reinforcing bar of length 50cm and 10mm diameter is embedded vertically along a central axis in each specimen as shown in fig. 3. The bar project upward from the top face with a distance necessary to provide sufficient length of bar to extend through the bearing blocks and the support of the testing machine and to provide an adequate length to be gripped for application of load.

Fig. 3 Pull Out Test Setup

IV. RESULTS AND DISCUSSION

A. Electrochemical Test results

*1) **Cathodic Disbondment Test Result:***

The result of Cathodic Disbondment test is presented in table I. From the experimental results of cathodic disbondment test, it is noted that the uncoated rebar shows severe corrosion on anode rebar and evolution of hydrogen occurs on the cathode rebar as shown in fig. 4. The current gets increased with time. Coal tar epoxy coated rebar showed zero Amps current throughout the test period indicating its

resistive ability against the penetration of chloride ions which is clearly known from fig. 5.

Table I
Cathodic Disbondment Test result

Observation for a time period of 60min		
Coated Specimens		Uncoated Specimens
1	No rust formations on anode rebar.	Severe rusting was observed on anode rebar
2	No hydrogen evolutions on cathode rebar.	Hydrogen evolution occurred on cathode rebar.
3	Current is 0.0A throughout test period.	Increase in current throughout test period.

Fig. 4 Rust Formation in Uncoated Rebar

Fig. 5 No Rust Formation in Coal Tar Epoxy Coated Rebar

*2) **Accelerated Corrosion Test Result:***

Accelerated corrosion causes considerable weight loss in rebars due to the corrosion products. The corrosion rate of reinforcing steel was determined by measuring their weight loss. Fig. 6 clearly denotes that, as a result of accelerated corrosion there is certain amount of weight loss in uncoated rebar and negligible weight loss in coated rebar.

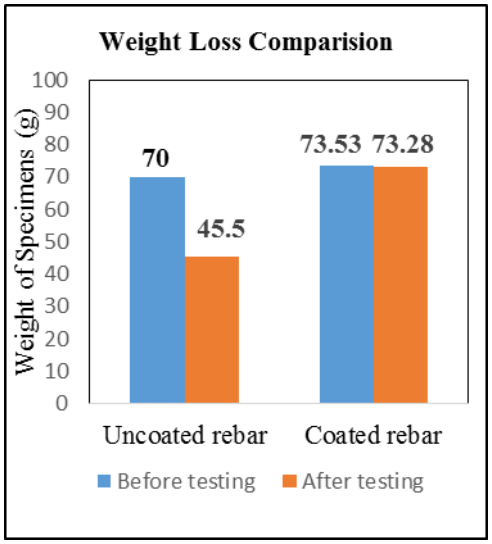

Fig. 6 Weight Loss Comparison

*3) **Impressed Voltage Test Result:***

Impressed voltage test specimens are broken and rebars are taken out from the concrete to determine its weight loss after the test period. When the voltage is impressed in concrete specimen only minimum weight loss has taken place in coated rebar whereas in uncoated rebar there is a heavy weight loss. Weight loss comparison chart in fig. 7 reveals that the coated rebars are far ahead than uncoated rebar where the weight loss is comparatively high. The rust particles oozes out from the concrete specimen at the earlier stage in case of bare rebar. The rust products are visible only after 46 days of testing in specimen containing coated rebar.

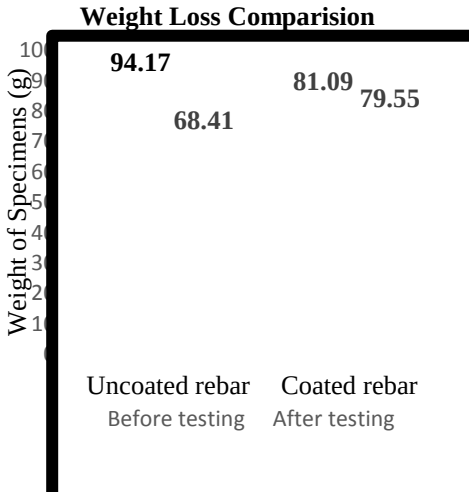

Fig. 7 Weight Loss Comparison

The diameter loss in coated and uncoated rebars are measured using vernier caliper and it is mapped. There is a severe diameter loss incase of uncoated rebar which is shown in fig. 8 whereas fig. 9 clearly indicates that there is no loss in diameter of coated rebars. Thus the corrosion mapping shows the corrosion resistance of coating

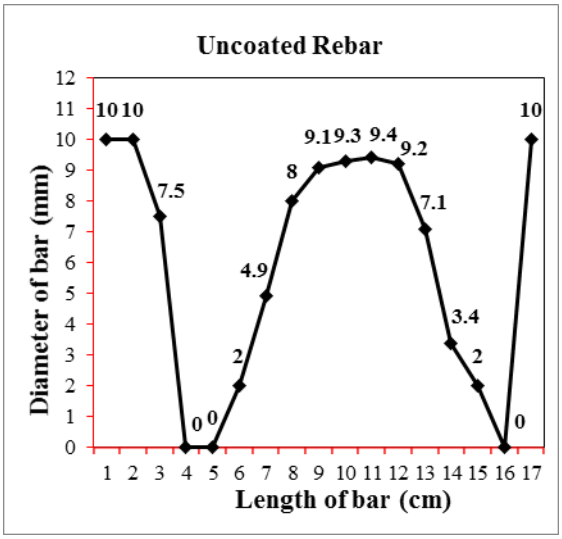

Fig. 8 Corrosion mapping in uncoated rebar

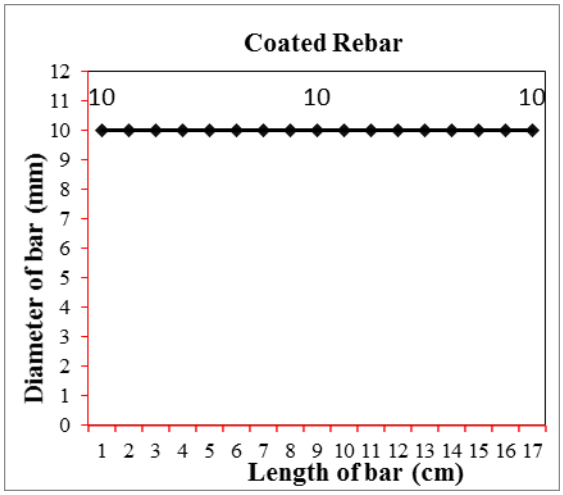

Fig. 9 Corrosion mapping in coated rebar

*4) **Chemical Resistance Test Result:***

The coating did not blister, soften and lose bond during the 45 days test period. Instead discoloration of coating took place which can be observed from fig. 10.

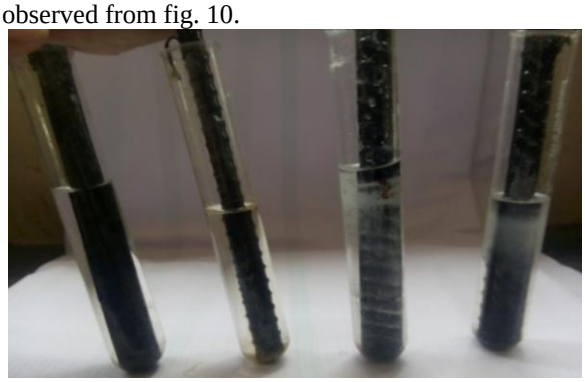

Fig. 10 Discolouration in Coated Rebars at the End of 45 Days Test Period

Fig. 11 shows the appearance of the test specimens at the end of 45 days test period which indicates the formation of rust on uncoated specimens. It is noted that there is nil corrosion in the specimens immersed in aqueous sodium hydroxide solution since it is alkaline in nature.

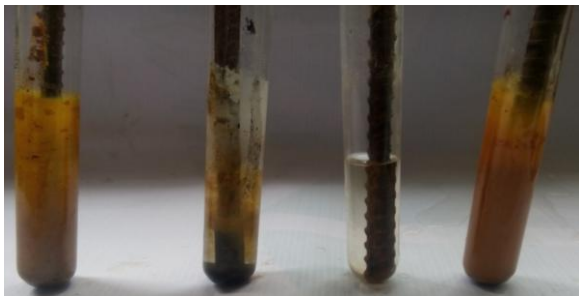

Fig. 11 Rust Formation In Uncoated Rebars at the End of 45 Days Test Period

The weight loss chart in fig. 12 indicates that there is maximum weight loss in various chemical compounds incase of uncoated rebars. Whereas in coated rebars there is negligable weight loss took place with the discolouration of the coating.

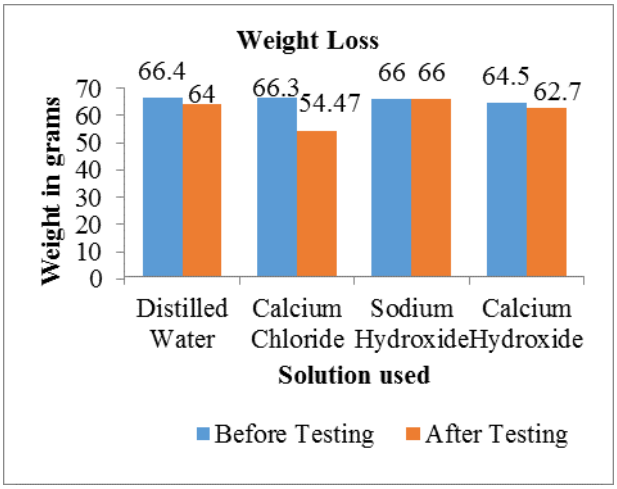

Fig. 10 Weight Loss Comparison Chart

B. Mechanical Studies

*1) **Pull – Out Test Result:***

Pull – out test is conducted on both coated and uncoated specimens where there is bond failure in both the cases. From table II it is clear that there is no much difference in bond stress between the comparative specimens. The bond strength is quite higher in case of coated specimens which give a positive approach regarding the adhesion between the coated rebar and the concrete.

Table II - Pull – Out test result

Specimen (Bar)	Applied load (p) (kN)	Surface area (mm^2) $A = \pi dl$	Bond strength (N/mm^2) (P/A)
Uncoated	54.50	4900	11.12
Coal tar Epoxy	56.20	4900	11.46

V. CONCLUSION

The adhesion and the corrosion resistance property of Coal tar epoxy is analysed by mechanical, electrochemical and chemical resistance studies. From the test results it is very clear that coating system showed appreciable corrosion protection properties.

Electrochemical studies such as cathodic disbondment test, accelerated corrosion test and impressed voltage test clearly indicates the excellent corrosion resistant and impermeable property of Coal tar epoxy coating against chloride attack. The chemical test results indicates that the coated rebars shows high chemical resistance without any corrosion products at the end of the test period. Pull out test is satisfactory in both coated and uncoated rebars embedded in concrete cubes. From the pull out test it found that the adhesion between the coated rebar and concrete is good.

Thus, various test results reveals the following factors regarding the efficiency of Coal Tar Epoxy coating which are good chemical and solvent resistance, good adhesion, excellent salt water resistance and resistance to cathodic disbondment, economical, hard, durable film, easy to apply with minimum surface preparation.

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