STUDY OF ELECTROCHEMICAL OXIDATION BEHAVIOUR OF HIGH BUILD EPOXY, COLD APPLIED POLY DEFINED TAPE AND POLYURETHANE COATING SYSTEM IN SALINE ENVIRONMENT

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ABSTRACT

This thesis proposes a methodology for predicting the corrosion behaviour of uncoated steel & different polymer coated steel samples (High Build Epoxy, Cold Applied Poly Defined Tape and Polyurethane) in Tap and Saline water. Corrosion properties were measured by Gamry Instrument. The \( I_{\text{CORR}} \) & \( E_{\text{CORR}} \) values are calculated by using Gamry Echem Software. The experimental measurement value used the Linear Polarization and Tafel Extrapolation curve techniques for determining the corrosion rate. Comparison of corrosion resistance among the coated samples reveal a few interesting observations. High Build Epoxy coated sample shows better corrosion resistance than the other different coated sample in different environment. From LPR test \( R_p \) values were also obtained. Higher \( R_p \) values indicate good coating property.

**Keywords:** High Build Epoxy, Polyurethane, corrosion rate, polarization resistance, tafel curve.
1. INTRODUCTION

Marine exposure is one of the most severe environments in nature accelerating the corrosion process. Deicing salts and other chemicals facilitate the penetration of chlorides and increase the likelihood of corrosion. High temperatures, contaminated soils, industrial and polluted air are other factors that increase the rate of corrosion. Increasing the resistance of the concrete cover to the penetration of chlorides is the primary measure used in increasing the service life of marine structures [6]. The basic repair principle is to create a protective barrier around the steel, thus decreasing permeability, and preventing the penetration of unwanted elements through the concrete to the steel surface. Some of the techniques incorporating these ideas are high build epoxy coatings. Electrochemical methods such as cathodic protection are also used to reduce corrosion damage. Corrosion has increasingly become a structural problem the world over. Structures in and around marine environments and transportation structures exposed to deicing salts are especially at risk. Steel is extensively used in which the steel cannot be inspected visually. Corrosion of steel is an electrochemical process. This process is triggered when the surface of the reinforcing steel becomes depassivated, allowing the steel to be oxidized in the presence of water and oxygen.

Polymer coated, inorganic or organic materials have been used for years as a method of providing added strength and ductility to steel structures. In recent years, Polymer coating has been considered and implemented for corrosion protection [12, 13]. Corrosion due to chloride ingress is purportedly arrested by the prevention of further chloride contamination and penetration by the oxygen and water needed to continue a corrosion process that has begun or has caused damage [2, 3].

Many factors influence the durability of a steel structure. It is possible to greatly reduce the risk of corrosion by proper material selection and by implementing suitable design and maintenance principles. Stainless Steel is more resistant to chloride penetration and carbonation but has high cost of implement. Low permeability is crucial in defining durability [5]. It is important to protect the steel from rain and chemicals that might cause it to corrode before placement. A harsh environment will cause corrosion even in the highest quality steel. Alternating wet/dry cycles are very detrimental to steel structures. The formation of rust is the most tangible evidence of corrosion and causes many of the problems associated with corrosion damage in steel based structure [5, 8].

1.1 CORROSION PROTECTION PROVIDED BY VARIOUS COATING SYSTEMS

Coating systems have been used extensively in seismic retrofits and for structural maintenance. Many of the maintenance applications depend on the external wrap to prevent further chloride ingress and therefore halt the corrosion process inside the structure. The results of past research have raised questions regarding the effectiveness of Polymer wrap and jacket systems to prevent ongoing corrosion. The laboratory research involves repaired structures that have undergone some corrosion. The corrosion behaviour of previously unexposed (new) structures treated with an Polymer wrapping system has not been thoroughly evaluated and is an integral portion of the laboratory program described herein [12,13].

Much of today’s research to improve the durability of steel based structures focuses on the use of polymer coating in large-scale infrastructure projects. Polymer Coating exhibit
excellent corrosion resistance comparable to bare steel. Reduced maintenance and repair expenses justify their higher initial cost. This section will define key terms related to different type of coating and focus on different type of polymer coating as a protective barrier against corrosion.

The application of a surface coating or sealer is one repair method that is intended to create a barrier to the incoming contaminated water, thereby robbing corrosion of its reactants. Unfortunately, there is still some question about the reliability of waterproofing using these treatments. The use of corrosion inhibitors has gained interest as a means of corrosion protection. The use of coating is a widely used technique for corrosion prevention. The most common examples are high build epoxy-coating and galvanizing. Fusion-bonded epoxy is intended to prevent corrosive elements from reaching the steel surface. Concern arises when the epoxy layer is damaged during transport or installation. If kept intact, epoxy coatings are effective for corrosion prevention.

The Corrosion experiment is carried out with three different coating steel and with bare steel. The name of different coating is as following:

a) High build epoxy Coating.

b) Cold applied poly defined tape coating

c) Polyurethane Coating.

d) Uncoated mild steel.

This report represents an initial account of laboratory studies. The report will provide information on material selection and different coating system practices. The specimen variables chosen for analysis are defined, and a detailed monitoring program data collection is furnished. In addition to presenting laboratory work, a review of existing corrosion detection and repair methods is presented. In the following chapter, corrosion attack, different type of coating, and experimental method is described. The information will be helpful in identifying other engineering and government groups conducting re-search on coating or having completed successful infrastructure projects.
2. EXPERIMENTAL PROCEDURE

The mild steel and the coated steel samples were supplied from industry in a form of cold rolled, annealed condition. The sample is to be coated is properly polished. Then the sample is used as anode & graphite plate is used as cathode. Then several experiments are done by varying the current & potential [15].

Standard Corrosion Cell has been used to perform the electrochemical potentiodynamic polarization tests on standard flat metal specimens. Polarization experiments have been carried out as per ASTM ST72 using Gamry Potentiostat. The software used is Gamry Echem Analyst. First the potentiodynamic experiment is done with the as received sample with the scan rate of 1mV/sec and the \( I_{CORR} - E_{CORR} \) value is obtained by Tafel’s extrapolation and Linear Polarization Resistance method [14]. The experiment is done in tap and salt water solution. The experiment Set up of the polarization testing is shown in figures.

![Experiment Set up of the polarization testing](image)


2.1 TEST PROCEDURE

- A particular steel specimen was selected to be the working electrode.
- The tip of the working electrode was ground off, if it was a coated steel, to facilitate proper electrical connections.
- The tip was well polished.
- The working area (the portion of the steel sample to be exposed to the electrolyte) of the steel was cleaned and degreased.
- The surface area of the sample portion to be exposed was measured (in square cm).
- Polymer-Coated steel with Their Tips Polished to Ensure Good Electrical Contact during Polarization Resistance Test.

<table>
<thead>
<tr>
<th>Metal / Alloy</th>
<th>Density (g/cc)</th>
<th>Equivalent Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron/Steel</td>
<td>7.87</td>
<td>27.92</td>
</tr>
</tbody>
</table>

Table 2.1: Density and Equivalent Weight of iron / steel
3. RESULT

While all of the types of samples were immersed in the two different corrosive environments (Tap water and saline water), PR tests were carried out for mild steel, mild steel with high build epoxy coating, M.S. with cold applied poly defined tape coating and M.S. with polyurethane coating. The results are discussed below and shown in figure 3.1 to 3.16.

Tafel Extrapolation Curves (Tap Water)

![Figure: 3.1 Tafel curve for Mild Steel –tap water.](image1)

![Figure: 3.2 Tafel curve for high build epoxy Coating –tap water.](image2)

![Figure: 3.3 Tafel curve for Cold applied poly defined tape Coating –tap water.](image3)

![Figure: 3.4 Tafel curve for polyurethane Coating –tap water.](image4)

Tafel Extrapolation Curves (Sea Water)

![Figure: 3.5 Tafel curve for Mild Steel –Sea water.](image5)

![Figure: 3.6 Tafel curve for high build epoxy coating– Sea water.](image6)
Linear Polarization Curve (Tap Water)

The linear polarization method takes its name from the apparent linearity of polarization curves near their origin. This is the region of low applied current and subsequently low over voltages (voltages differing from the determined corrosion potential, $E_{corr}$). Note that the region of curve linearity is limited to points near the origin.

![Figure: 3.7 Tafel curve for cold applied poly defined tape Coating – Sea water.](image)

![Figure: 3.8 Tafel curve for polyurethane Coating – Sea water.](image)

![Figure: 3.9 LP curve (mild steel-tap water).](image)

![Figure: 3.10 LP curve (high build epoxy Coating -tap water).](image)

![Figure: 3.11 LP curve (cold applied poly defined tape Coating -tap water).](image)

![Figure: 3.12 LP curve (Polyurethane Coating -tap water).](image)
Linear Polarization Curve
(Sea Water)

4. DISCUSSION

The corrosion data of different coated samples were derived from figures 3.1 to 3.16 by using Gamry Echem software and Tafel Extrapolation method.

Table 4.1 Corrosion data of the received sample (uncoated mild steel)

<table>
<thead>
<tr>
<th>Sample</th>
<th>$\beta_a$ mV (anodic tafel constant)</th>
<th>$\beta_c$ mV (cathodic tafel constant)</th>
<th>$R_p$ (k-ohm-cm$^2$)</th>
<th>$I_{corr} = \frac{\beta_a \beta_c}{2.3 R_p (\beta_a + \beta_c)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel in tap water</td>
<td>99.55</td>
<td>215.9</td>
<td>0.973</td>
<td>30.40 $\mu$A/cm$^2$</td>
</tr>
<tr>
<td>Mild steel in sea water</td>
<td>50.8</td>
<td>96.06</td>
<td>0.197</td>
<td>73.33 $\mu$A/cm$^2$</td>
</tr>
</tbody>
</table>
The corrosion properties of high build epoxy and were found to be far superior as reported in the literature. The corrosion properties of coated samples are much superior to the bare received sample. Among the coated sample high build epoxy has best corrosion resistance. Its \( E_{\text{CORR}} \) value is also much nobler.

From PR test we get the \( R_p \) value, which is known as polarization resistance. Using the Stern and Geary relationship, corrosion rates can be calculated from the polarization resistance \( (R_p) \) as per the relation \( I_{\text{corr}} = \frac{\beta_a \beta_b}{2.3 R_p (\beta_a + \beta_b)} \). Where \( K \) is a constant. However \( K \) also includes the Tafel slope values. Knowing Tafel slopes corrosion rates can be calculated. The stability of the coating depends on the \( R_p \) value. Higher the \( R_p \) higher is the stability. The \( R_p \) values of the samples are given in table 5.1. From this it can say that the coating of epoxy is far better than the other samples.

The corrosion graphs (between corrosion rate and polarization resistance versus salt concentration) for different coated samples were shown in figure 4.1 to 4.4 and which are

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**Table 4.2 Corrosion data & \( R_p \) of different coated samples in Tap water**

<table>
<thead>
<tr>
<th>NOMENCLATURE (sample in tap water)</th>
<th>( \beta_a ) mV (anodic tafel constant)</th>
<th>( \beta_c ) mV (cathodic tafel constant)</th>
<th>( R_p ) (k-ohm-cm(^2))</th>
<th>( I_{\text{corr}} = \frac{\beta_a \beta_b}{2.3 R_p (\beta_a + \beta_b)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>High build epoxy coating</td>
<td>49.33</td>
<td>135.1</td>
<td>680.96</td>
<td>23.07 nA/cm(^2)</td>
</tr>
<tr>
<td>Cold applied poly defined tape coating</td>
<td>170</td>
<td>105</td>
<td>150.36</td>
<td>187.09 nA/cm(^2)</td>
</tr>
<tr>
<td>Polyurethane coating</td>
<td>120</td>
<td>108</td>
<td>415.64</td>
<td>59.46 nA/cm(^2)</td>
</tr>
</tbody>
</table>

Corrosion rates of the cold applied poly defined tape coating sample in tap water were found to be on the higher sides, but corrosion rate of high build epoxy coating sample were found to be on the lower side of entire corrosive (Tap water) environment.

On the other hand similar effects were found for cold applied poly defined tape coating in saline water environment and as well as for high build epoxy coating in same environment. It is notice that the uncoated steel, when tested always shows the corrosion rate higher than the different type’s polymer coated samples in the environment i.e., tap & saline water.

**Table 4.3 Corrosion data & \( R_p \) of different coated samples in sea water**

<table>
<thead>
<tr>
<th>NOMENCLATURE (sample in sea water)</th>
<th>( \beta_a ) mV (anodic tafel constant)</th>
<th>( \beta_c ) mV (cathodic tafel constant)</th>
<th>( R_p ) (k-ohm-cm(^2))</th>
<th>( I_{\text{corr}} = \frac{\beta_a \beta_b}{2.3 R_p (\beta_a + \beta_b)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>High build epoxy coating</td>
<td>67.54</td>
<td>80.53</td>
<td>445.64</td>
<td>35.83 nA/cm(^2)</td>
</tr>
<tr>
<td>Cold applied poly defined tape coating</td>
<td>83.51</td>
<td>79.50</td>
<td>61.98</td>
<td>285.7 nA/cm(^2)</td>
</tr>
<tr>
<td>Polyurethane coating</td>
<td>96.69</td>
<td>68.21</td>
<td>305.15</td>
<td>66.98 nA/cm(^2)</td>
</tr>
</tbody>
</table>
derived from figures 3.1 to 3.16 by using Gamry Echem software and Tafel Extrapolation method.

Figure: 4.1 Corr. Rate and PR versus Salt Concentration for Mild Steel.

Figure: 4.2 Corr. Rate and PR versus Salt Concentration for high build epoxy Coating

Figure: 4.3 Corr. Rate and PR versus Salt Concentration for Cold applied poly defined tape Coating.

Figure: 4.4 Corr. Rates and PR versus Salt Concentration for Polyurethane Coating
5. COMPARISON OF ALL COATING SYSTEMS

A comparison of all the different type of polymer coating is given in Table 5.1 and Figure 5.1-5.4. It is evident that high build epoxy performed quite well (Figure 5.3 – 5.4) in all corrosive environments. It had extremely low corrosion rates and should be an excellent material in the form of a pure rebar or a clad bar (which would be more economical). Cold applied poly defined Tape had the highest corrosion rate its corrosion rate increased in the presence of salt.

Table 5.1 Comparison of different coating system.

<table>
<thead>
<tr>
<th>NOMENCLATURE</th>
<th>Corrosion Rate (mpy)</th>
<th>Polarization Resistance (k-ohm-cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Tap water</td>
<td>In Salt Water</td>
<td>In Tap water</td>
</tr>
<tr>
<td>Mild Steel</td>
<td>13.86</td>
<td>33.4</td>
</tr>
<tr>
<td>High build epoxy coating</td>
<td>0.0105</td>
<td>0.0163</td>
</tr>
<tr>
<td>Cold applied poly defined tape coating</td>
<td>0.0855</td>
<td>0.131</td>
</tr>
<tr>
<td>Polyurethane coating</td>
<td>0.0231</td>
<td>0.0260</td>
</tr>
</tbody>
</table>

Figure: 5.1 Comparison of Tafel curve of Various Coating – Tap Water.

Figure: 5.2 Comparison of Tafel curve of Various Coating – Sea Water.
However, in the presence of 3.5% NaCl, cold applied poly defined tape performed worse; this means that there is a greater chance of damage to cold applied poly defined Tape Coated steel. The high build epoxy Coating shows superior corrosion resistance in both the corrosive environment where as cold applied poly defined tape shows worse from all different coating systems.

In general, an open water mild steel corrosion rate of 1 MPY or below is considered excellent, 2-3 MPY is considered good, and a rate of 4 MPY is borderline acceptable. Corrosion rates at or exceeding 5 MPY warrant immediate investigation. Rates of 10 MPY and greater signal a serious threat to system safety, reliability, and building or plant operations.

Any corrosion rate above 15 MPY generally indicates a severe pitting condition, an under deposit or cell corrosion condition, or possibly MIC. In most cases, such high corrosion rates dramatically reduce service life, and strongly raise the probability of a premature failure. Corrosion rates above 25 MPY are not uncommon where under deposit corrosion and MIC are involved.

6. CONCLUSIONS

In this project, two types of testing approaches have been made to determine the corrosion evaluation of various coating systems. These include polarization resistance (PR) and tafel extrapolation tests. Corrosion tests were carried out for all different types of coating in Tap water and solution with 3.5% amounts of sodium chloride. These tests give valuable qualitative information on the nature of corrosion on polymer coating. Two cycles were completed at the time of writing this report. The following conclusions have been drawn:

- Mild steel showed considerable corrosion product formation at the solution-sample Interface in both the environment (Pitting Corrosion). However, no other coating showed corrosion product formation. As demonstrated high build epoxy performs excellently in all two corrosive environments. It has extremely low corrosion rates and high polarization resistance, should be an excellent and more economical material in the clad form.
• In the presence of 3.5% NaCl, cold applied poly defined tape performs worse. This means that there is a greater chance of damage to cold applied poly defined tape coated steel and has lower polarization resistance. The high build Epoxy Coating shows superior corrosion resistance in both the corrosive environment where as cold applied poly defined tape shows worse when compare to all three different coating.

7. REFERENCES


