

Potentiodynamic Polarization of Brass, Stainless and Coated Mild Steel in 1M Sodium Chloride Solution

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Abstract. Enormous funds are spent on the protection of engineering components and structures annually as a result of corrosion. Degradation sets in, due to electrochemical reaction that takes place between materials and the environment leading to reduced performance. The associated downtime caused by replacement and maintenance of vessels, pipes, valves and other equipment necessitated seeking for techniques and method to efficiently combat corrosion. This study evaluated the potentiodynamic polarization of brass, Coated Mild Steel (CMS) and Stainless Steel (SS) in sodium chloride (NaCl). The samples (1 x 30 x 30 mm³) were used as working electrodes for Potentiodynamic Polarization Experiment (PPE). The samples were cleaned, and soaked in 1M NaCl solution. Open circuit potentials and current densities of the samples were obtained from PPE which were used to evaluate their corrosion rates. The pH of the media was recorded before and after each experiment. The results obtained using PPE in NaCl (in mm/y) were 0.209, 0.0053 and 0.0046; for brass, MSC and SS respectively. The pH of the medium was measured as 10.9. The results revealed that brass had highest corrosion rate in the medium. The least corrosion rate was obtained for Stainless Steel in 1M NaCl followed by Coated Mild Steel.

Introduction

Corrosion is the degradation of material resulting from exposure and interaction with the environment. It exists as part of our everyday life, in extreme situations catastrophic failures such as sudden collapse can result to damages when the load bearing capability of a structure is undermined. The usefulness of a metal for an engineering project is determined by its mechanical properties [1].

Corrosion damage can also result in life threatening situation which are not as dramatic as structural collapse such as contamination of beverages by corrosion product from storage tanks and piping, also possible toxic level of lead in drinking water supplies as a result of contamination by corrosion products from lead piping and tanks [2]. The problem is basically that the metals which we use in practical operations are unstable in the environment in which we wish to use them [3]. Nature gives us iron ore in the form of hematite (α -Fe₂O₃), which we reduce to metal. This metal on exposure to air and water is unstable and tends to go back to the oxide form which it comes [4].

Many studies have been conducted in attempts to investigate potentiodynamic polarization study of corrosion performance of painted mild steel, stainless steel, and brass in a selected media. Other researcher studied electrochemical behaviour of low carbon steel in aqueous solutions [5]. He concluded that the carbon contents of the steels used played a part in the corrosion process, especially in the acidic solutions. One hypothesis would be that the electrolytic cell arose between the ferrite phase and the iron carbide particles with the anode in the cell becoming the Fe₃C [6].

Electrochemical methods were used to study the corrosion inhibition of mild steel in H_2SO_4 solution in the presence of *Juniperus* plant at a temperature range of 30 to 60°C using chemical and electrochemical methods [7]. The *Juniperus* plant acts as an inhibitor in the acid environment. The inhibition efficiency increases with increase in inhibitor concentration but decreases with an increase in temperature. The inhibitive effect of the *Juniperus* plant could be attributed to the presence of some compound in the plant which is adsorbed on the surface of the mild steel. The *Juniperus* plant was found to conform to the Frumkin adsorption isotherm and Temkin adsorption isotherm at all the concentration levels and temperature studied.

Other researcher experimented on the corrosion of 304 stainless steel exposed to nitric acid - chloride environments [8]. He found that some solution chemistries promoted active corrosion upon immersion. He stated that corrosion in these solutions was autocatalytic, with the corrosion rate increasing exponentially with time and potential and found that the current densities was as large as 0.2 A/cm^2 . He however stated that the period of active corrosion terminated following spontaneous passivation, resulting in a corrosion rate decrease as large as 5 orders of magnitude. Furthermore, he stated that corrosion behaviour was strongly dependent on the solution volume to surface area ratio. That this phenomenon, coupled with other results, suggested that spontaneous passivation arises solely from solution chemistry, as opposed to changes in surface composition.

The linear polarization method is capable of measuring the corrosion rate of a system. It is achieved by shifting the corrosion potential typically 10 to 20mV towards more noble or more active. Both the potential and the current required to achieve this potential are recorded. The potential is stepped in increments (called over-potentials, typically 1mV) from one extreme to the other and each of these steps is recorded [9]. This research work therefore, examined the potentiodynamic polarization of brass, stainless and coated mild steel in 1 M NaCl solution.

Materials and Method

Sample Material

The sample materials used for this research work are stainless steel, mild steel coated with red oxide and brass. The sample electrolytes are sodium chloride. The tool employed was a locally made potentiostat (NGP1). This potentiostat maintains an electrode potential within 1 mV of a pre-set value over a wide range of applied currents will be used. For the type and size of standard specimen supplied, the potentiostat has a potential range from -0.6 to 1.6 V and an anodic current output range from 1.0 to 10 μA . The potential-measuring circuit has a high input impedance on the order of 10^9 to $10^{10}\Omega$ to minimize current drawn from the system during measurements. Such circuits are provided with most potentiostats. It has sufficient sensitivity and accuracy to detect a change of 1.0 mV over a potential range between -0.6 and 1.6. It is capable of measuring a current accurately to within 1 % of the absolute value over a current range between 1.0 and 10A for Type 430 stainless steel (UNS S43000) specimen with a surface area of approximately 5 cm^2 . Other material includes: Beaker, Hand glove, Stirrers, Thermometer and pH meter

Chemical Composition of Metallic Materials

The CMS was Mild Steel coated with epoxy resin. The Mild Steel has percentage compositions as follows: Fe; 99,C;0.20, Mn;0.75,Cu;0.26,P;0.04,S;0.05 that of SS are Fe;67, Cr; 17.22, Mo;3.5. Ni; 9.0, Si; 1.0, P; 0.03, S; 0.02 while brass has Cu; 60, Zn; 37, Fe; 2, Sn;1. The corrosive medium was 1M NaCl.

Preparation of electrochemical cell

The basic electro-chemical cell involves a working electrode, reference electrode, counter electrode and solution media. Since the Working electrode (WE) is the electrode in an electrochemical system on which the reaction of interest is occurring.

The working electrodes are CMS, SS and Brass.

The reference electrode used is silver – silver chloride and the counter electrode used was carbon electrode. The entire electrode were then dipped into the different media for each experiment. This forms our electrochemical cell.

Determining the open circuit potential

The equilibrium potential assumed by the metal in the absence of electrical connections to the metal is called the Open Circuit Potential, E_{oc} . The terms E_{oc} (Open Circuit Potential) and E_{corr} (Corrosion Potential) are usually interchangeable, but E_{oc} is preferred. This is done by the use of a multimeter to measure the E_{oc} value for the given electrochemical cell at a measured pH value. It is very important to allow sufficient time for the E_{oc} to stabilize before beginning the electrochemical experiment. A stable E_{oc} is taken to indicate that the system being studied has reached "steady state", i.e., the various corrosion reactions have assumed a constant rate. Some corrosion reactions reach steady state in a few minutes, while others may need several hours. The value of either the anodic or cathodic current at E_{oc} is called the Corrosion Current. The value of either the anodic or cathodic current at E_{oc} is called the Corrosion Current. The measurements were repeated thrice and mean values taken.

Monitoring of the electrochemical cell using the potentiostat

The different electrodes were connected to potentiostat. This potentiostat was connected to a computer-controlled system. The corrosion monitoring was done in real time in which the reading values were determined from the computer Graphics User Interface (GUI) where a plot of voltage versus time and current versus time was shown. The different readings for the current and voltage were then exported to excel for further analysis.

Potential scan rate

This determines how slow or fast a potential window can be scanned, this is most important for experiments that requires high scan rates, the experiment was run at a scan rate of 20mV/s. This was done to ensure that the potentiostat would detect a quantitative amount of corrosion i.e. the potentiostat does not run too fast and also does not run too slow.

Procedure using Tafel analysis and determination of corrosion current

A Graph plot of Potential Versus logarithm of current was drawn using software application (Origin 6.0). Polynomial line of best fit which obeys the Butler-Volmer equation for the cathodic corrosion occurring were determined. The E_{oc} potential was also plotted on the graph. Using Tafel analysis, an extrapolation of the linear portion of the cathodic curve to the corrosion potential to indicate the corrosion current (I_{cor}) at which corrosion is occurring.

Corrosion rate analysis

According to literature, after determining the I_{cor} which is the corrosion current, it can be determined by subjecting it to the formula below [10]

$$CR(mpy) = \frac{k \times I_{cor} \times EW}{dA}$$

where

- $k_i = 3.272 \text{ m/(amp-cm-year)}$, E_w = equivalent weight, d = density
- A = Cross Sectional area of sample exposed to the medium, I_{cor} = Corrosion Current determine for data analysis

Results

The result obtained from PPE for CMS, SS in Sodium Chloride and Brass in Sodium Chloride are found in Tables 1 and 2. The current densities for above samples were obtained from the plots in Figures 4 to 6 below. CMS has low resistance to corrosion in Sodium Chloride medium as seen in Figure 4 below with the electrode Potential measured at -0.35V and corrosion current density as 0.186528555A/mm.

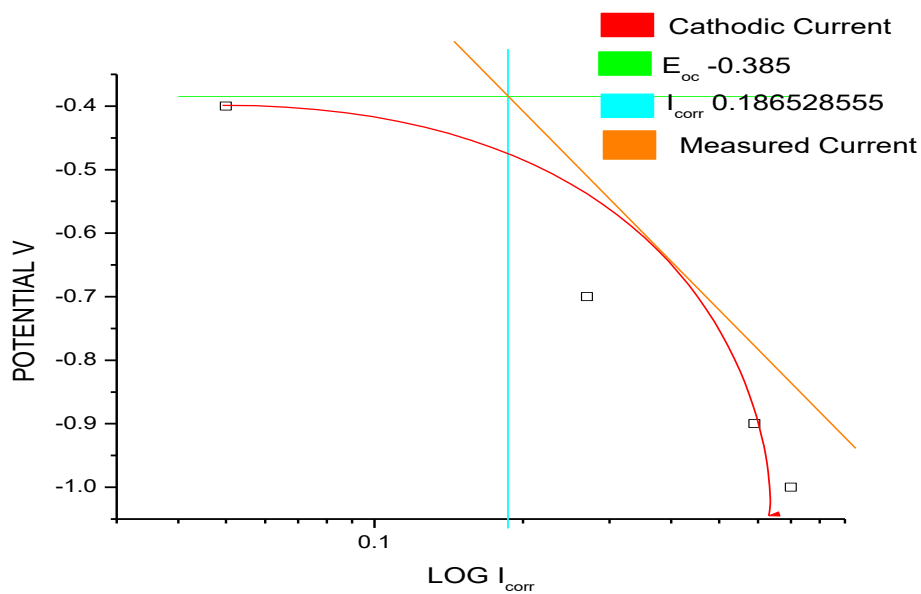


Figure 4: Polarization of Coated Mild Steel in NaCl

Stainless Steel in Sodium Chloride, the metal shows low resistance to corrosion in Sodium Chloride medium as seen in figure 5 with the electrode Potential measured at -0.18A and the corrosion current density as 0.157378974A/mm.

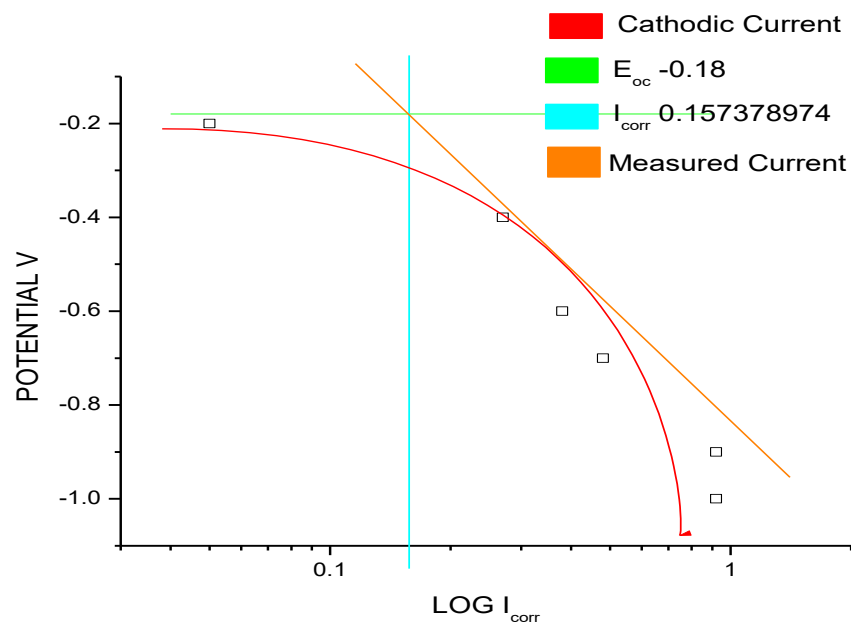


Figure 5: Polarization of Stainless Steel in NaCl

In the case of Brass in Sodium Chloride, the metal indicates active corrosion behaviour in Sodium Chloride medium as seen in figure 6 with the electrode Potential measured at -0.47 V and the corrosion current density as 7.92743575 A/mm as shown in the graph below.

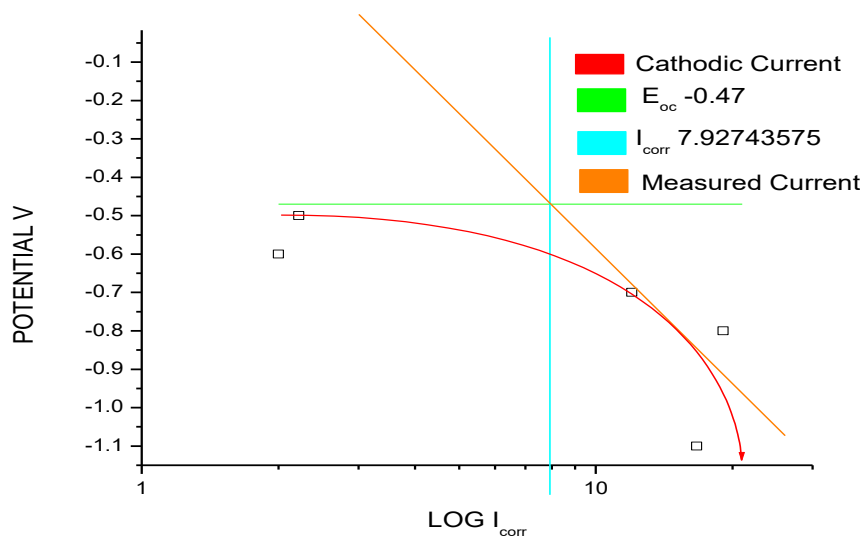


Figure 6: Polarization of Brass in NaCl

Table 1: Measured Value of Corrosion Current Hours

Sample	Medium	E_{oc} (V)
Coated Mild Steel	NaCl	-0.385
Stainless Steel	NaCl	-0.18
Brass	NaCl	-0.47

Table 2: Corrosion Rate of Brass, Coated Mild and Stainless Steels

Sample	Medium	Area(mm ²)	I _{corr} (A/mm ²)	CR(mm/y)
Coated Mid Steel	NaCl	460.08	0.186528555	0.0053214241
Stainless Steel	NaCl	395.76	0.157378974	0.0045991676
Brass	NaCl	463.3	7.92743575	0.2099469250

Discussion of Result

CMS had low corrosion rate in 1 M NaCl with a value of 0.0053214 mm/y. The protective film formed on the surface of the stainless Steel was able to passivate it from attack from the medium and low corrosion rate of 0.0045991 mm/y was got. However, brass had severe attack causing it to have highest corrosion rate of 0.2099469 mm/y in the medium. This might be due to de-zincification of brass in chloride environment. The result obtained conformed with findings of earlier researchers that used this method to study the corrosion behaviour of such metals in similar media [5,6,7 & 8].

Conclusion

Potentidynamic Polarization responses of coated mild steel in NaCl showed low corrosion rate which implies that the coating was able to protect the metal from the aggressive corrosion attack of Sodium Chloride. Low corrosion rate was obtained for Stainless steel in NaCl solution due to formation of protectie film formed on stainless steel. High corrosion rate was observed for Brass in Sodium Chloride.

Potentiodynamic method is a potent technique to study the electrochemical behaviour of metals in corroding medium.

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