

# Estimation of Microbiologically Influenced Corrosion of Aluminium Alloy in Natural Aqueous Environment

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**Abstract:** This paper describes microbiologically influenced corrosion (MIC) behaviour of aluminium alloy (AA2024-T3) in natural aqueous environment. An optical microscopy is used to confirm the micro colony formation of rod and cocci bacterial species. The viable cell counts after one month are averaged  $1730 \times 10^7$  CFU/ml and the species *Pseudomonas* found dominant. The changes in chemical constituents of test solution including pH, dissolved oxygen and conductivity are also studied. Polarization study is also carried out to determine the shift in free corrosion potential of metallic structure due to biofilm formation. Corrosion rate is determined by finding the intersection point of  $E_{\text{corr}}$  and  $I_{\text{corr}}$  in the polarization curve. [Nature and Science. 2006;4(3):1-4].

**Keywords:** aluminum alloy (AA2024-T3); Microbiologically Influenced Corrosion (MIC); polarization study

## 1. Introduction

Aluminium is considered a reactive alloy (NACE, 1984). The good corrosion resistance of aluminium is due to the formation of a self-protecting, thin, invisible aluminium oxide film that forms immediately on the metal surface. The protective film is susceptible to corrosion by attack from halide ions such as chlorides. This susceptibility to localized corrosion appears to make aluminium alloys vulnerable to MIC. More reports are for AA2024-T3 alloy is used in aircraft or in underground fuel storage tanks, Little (1991), Wagner (1992), ASM (1985), Rosales (1980), Videla (1986). Contaminants in the fuel such as surfactants, water and water-soluble salts may contribute to bacterial growth. The two mechanisms for MIC of aluminium alloys have been documented: the production of water-soluble acids by bacteria and fungi, and the formation of differential aeration cells, Little (1991).

Microbial colonization of metal surfaces causes severe change in the ions concentration, pH, conductivity, and redox potential, altering the passive or active behaviour of the metallic substratum and its corrosion products, as well as the electrochemical variables. Micro organisms influence corrosion by changing the electrochemical conditions at the metal-solution interface. These changes may have different effects, ranging from the induction of localized corrosion to corrosion inhibition through a change in the rate of general corrosion (Beech 2004). A proper identity of bacteria by which corrosion may be exploited on metal surface and role of microbial contaminants in the specific environment as a useful tool to prevent frequent MIC effects (Videla 2005). In the last two decades, significant progress regarding

electrochemical interpretation of MIC has been achieved as a consequence of better understanding of MIC, Dexter (1991), Dickinson (1998), Shobhana (2005), Uhlig's (2000), Stoecker (2001). The usefulness of electrochemical techniques to assess MIC can be improved by documenting the presence of complex deposits of corrosion products, microbial metabolites, and EPS.

This paper describes assessment methods to elucidate microbial corrosion behaviour of aluminium alloy (AA2024-T3) in natural aqueous environment. The quantification includes determination of biomass, cell density and shift in free corrosion potential of metallic structure. Biomass is evaluated as a spectrophotometric analysis of carbohydrate and protein content. The bacterial colonies are expressed as colony-forming units per ml (CFU/ml). The bacterial species are identified up to genus level by employing morphological and biochemical characterization. The microbial corrosion effects on test material are also assessed by polarization study against a saturated calomel reference electrode (SCE).

## 2. Experimental

This work is carried out with aluminium alloy (AA2024-T3) test coupon having weight composition of 4.4 Cu, 0.6 Mn, 1.5 Mg and the rest of 93.5 Al. The specimen is polished using SiC emery papers up to 600 grades and degreased with acetone, washed with distilled water and dried. Biofilms are consented to grow on metal surfaces under laboratory conditions using 1% of glucose as nutrient to natural lake water. The contamination of water is avoided by adding 25 ml of fresh natural lake water after the same quantity of water is pipetted out from the

system for every five days. The chemical constituents of water sample, such as, water temperature, pH, conductivity and dissolved oxygen concentration are measured through out the experiment. All the experiments are carried out at constant atmospheric conditions. An UV-VIS spectrophotometer is used for carbohydrate and protein content analysis (M/s Shimadzu, Japan). Micro colony confirmation is done by an optical microscopy with CCD camera (M/s Shimadzu, Japan). Enumeration of viable cell can be counted by plate count technique using digital colony counter (M/s ELICO, India). The polarization studies are carried out using Potentiostat/Galvanostat (M/s Princeton, Model No. 362). All the chemicals used in this experiment, are purchased from M/s Fluka.

### 2.1. Biomass measurement

Biofilm samples for mass analysis are obtained from the outer surface of each metal at the end of experiments. Biomass data represents the average of ten measurements from the same sample. The biofilm samples from the respective metal are subjected for the analysis of carbohydrates and protein. The analysis of carbohydrates involves the treatment of samples with sulphuric acid to cause the hydrolysis of glycosidic linkages and to dehydrate the monosaccharide in order to allow the reaction with anthrone to yield blue-green coloured complex which is measured calorimetrically at 630 nm (Sadasivam, 1992). Bradford protein assay is based on the observation that the absorbance maximum for an acidic solution of Coomassie Brilliant Blue G-250 shifts from 465 nm to 595 nm when binding to protein occurs (Bradford, 1976). The metal biofilm samples are also subjected to determine the presence of sulphate reducing bacteria. The detection of sulphate reducing bacteria in biofilm samples can be performed using the method developed by the American Petroleum Institute (API, 1982).

### 2.3. Identification of bacteria

The biofilm samples are carefully scraped with a non-metallic spatula and are serially diluted. Then the samples are plated on nutrient agar medium to enumerate the heterotrophic bacteria (Murugesan, 1995). The bacterial colonies are expressed as colony-forming units per ml (CFU/ml). The most numerous similar colonies from all plates are identified through their morphological and biochemical characteristics (Staley, 1989).

### 2.4. Electrochemical study

The biofilm growth on metal surface can influence a change in free corrosion potential and also corrosion current. Corrosion potential and corrosion current of biofilm adhered aluminium alloy

is measured against a saturated calomel reference electrode (SCE). The working electrodes constitute test material of 1 cm<sup>2</sup> of test area. All the experiments are carried out at constant temperature with natural lake water as an electrolyte. The slope of the polarization curve can be used to characterize the degree to which any stage of anodic or cathodic processes is inhibited. The coordinates of this point define the free corrosion potential of the system, as well as total corrosion current ( $I_{\text{corr}} = I_{\text{anodic}} = I_{\text{cathodic}}$ ). The intersecting point of  $E_{\text{corr}}$  and  $I_{\text{corr}}$  in the polarization curve can be used to determine the corrosion rates through the Faradays law equation (1) (Pound, 1979).

$$\text{Corrosion Rate (CR)} = (I_{\text{corr}} * M) / zAF\rho \quad (1)$$

where CR is the corrosion rate (mm/yr),  $I_{\text{corr}}$  is the corrosion current (A), M is the molar mass of metal (g/mole), A is area of electrode (mm<sup>2</sup>), z is number of electrons transferred per metal atom, F is the Faraday's constant and  $\rho$  is the density of metal (g/mm<sup>3</sup>).

## 3. Results and discussion

### 3.1. Bacteria identification

The biofilm structures of all the three metal samples are confirmed on examination under a computer enhanced optical microscopy with CCD camera. The CCD image of dominant bacterial species *Pseudomonas* is shown in Figure 1.

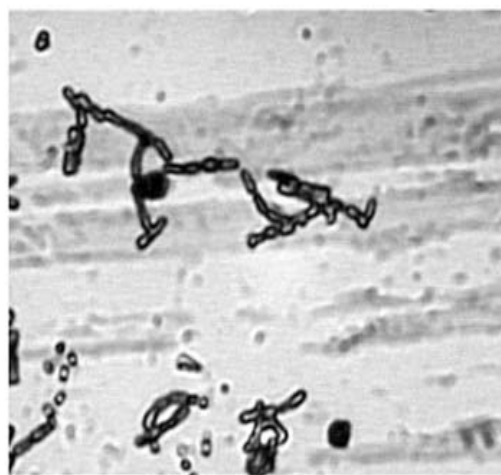


Figure 1. CCD camera image of dominant species *Pseudomonas*

A mixture of micro colony formation, including rod shaped bacteria and cocci are identified through microscopic analysis. The viable cell counts after one month are averaged 1730x10<sup>7</sup> CFU/ml. The biofilm sample is subjected to find out the presence of

Table 1. Analysis of chemical constituents of water

Test Coupon	Chemical Constituent					
	pH		TDS ( $\mu\text{S}$ )		Dissolved Oxygen (mg/L)	
	Initial	Final (Average)	Initial	Final (Average)	Initial	Final (Average)
AA2024-T3	8.6	8.1	840	910	1287.08	701.89

sulphate reducing bacteria. Based on the results of sulphate reducing bacteria determination, it is confirmed that the biofilm sample is not constituted with sulphate reducing bacteria. The changes in chemical constituents of water, such as pH, conductivity and dissolved oxygen after one month are averaged (Table 1).

### 3.2. Corrosion assessment by polarization experiment

The test coupon exposed to natural lake water is subjected to polarization experiments. The potentiodynamic polarization curve of aluminium alloy immersed in natural lake water is shown in Figure 2.

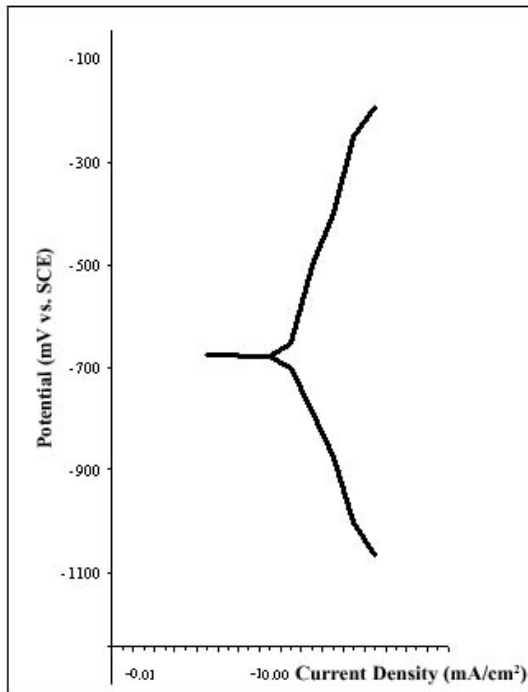


Figure 2. Polarization curve

The  $E_{\text{corr}}$  value achieved is typical for this experimental procedure with the aluminium alloy having a potential of -675 mV relative to SCE. The corrosion current density is the measure of corrosion activity. From the polarization curves, the corrosion current density ( $I_{\text{corr}}$ ) is determined by Tafel extrapolation method. Passive behaviour is not prevalent for test sample after one month period, but exhibited Tafel behaviour, indicating the surface is under polarization control. The obtained anodic current density is probably a result of the decreasing surface aluminium oxide film on the sample surface. The intersecting point of open circuit potential and corrosion current can be used to determine the microbial corrosion rate of aluminium alloy (AA2024-T3). The corrosion rate of aluminium alloy after one month immersed in natural lake water is estimated 0.01 mm/year. The table 2 summarizes the obtained results for this experimental procedure. It should be noted that the experiment is carried out with constant laboratory conditions in 1% glucose nutrient to natural lake water.

Table 2. Assessment of microbial corrosion behaviour of aluminium alloy

Test Coupon	Biomass (mg/ml)		Cell Count (CFU/ml)	Dominant Species	$E_{\text{corr}}$ (mV vs. Ag/AgCl)	$I_{\text{corr}}$ ( $\text{mA}/\text{cm}^2$ ) $\times 10^{-3}$	Corrosion Rate (mm/year)
	Carbohydrate	Protein					
AA2024-T3	0.3935	0.1914	$1730 \times 10^7$	<i>Pseudomonas</i>	-675	4.2	0.01

#### 4. Conclusion

Microbial corrosion behaviour of aluminium alloy (AA2024-T3) is evaluated through simple assessment techniques. Microscope with CCD camera is used to confirm the presence of micro organism on the surface of aluminium sample. Bacterial viable cell counts are averaged  $1730 \times 10^7$  CFU/ml after one month period and the species *Pseudomonas* found dominant in biofilm metal sample. Biomass is estimated as a spectrophotometric analysis of carbohydrate and protein content. The chemical constituents of natural lake water are continuously evaluated during the test period. The measurement of corrosion potential and corrosion current is successfully used to estimate the microbial corrosion of aluminium alloy through graphical method. The estimated corrosion rate offers the conclusion that the aluminium alloy (AA2024-T3) is the ideal alloy for long term condensation.

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