



## STUDY OF THE ELECTROCHEMICAL BEHAVIOR AND SURFACE INTERACTION OF AA6063 TYPE AL-MG-SI ALLOY BY SODIUM MOLYBDATE IN SIMULATED SEA WATER ENVIRONMENT

O. S. I. Fayomi<sup>1</sup>, M. Abdulwahab<sup>2</sup>, B. M. Durodola<sup>3</sup>, A. P.I. Popoola<sup>4</sup>, T.O. Joshua<sup>5</sup>, A. O. Alao<sup>6</sup>, O. O. Joseph<sup>7</sup> &  
O. A. Inegbenebor<sup>8</sup>

<sup>1,7,8</sup>Department of Mechanical Engineering, Covenant University, Ota, Nigeria

<sup>1,2,4</sup>Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Pretoria,  
South Africa

<sup>2</sup>Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria

<sup>3</sup>Department of Chemistry, Covenant University, Ota, Nigeria

<sup>5</sup>Department of Metallurgical Engineering, Kogi State Polytechnic, Itakpe Campus, Nigeria

<sup>6</sup>Department of Foundry Technology, Federal Polytechnic, Idah, Nigeria

### ABSTRACT

The potential of sodium molybdate on the corrosion of aluminium alloy AA6063 type was examined with the view to study the electrochemical and surface degradation for metal-inhibitor interface using gravimetric and electrochemical corrosion techniques in simulated seawater environment. The microstructures of as-corroded samples were also assessed for their surface morphology. The results show that corrosion rate decreased with an increase in the inhibitor concentration and exposure time. Equally, the inhibition efficiency increased with inhibitor addition with maximum efficiency obtained at 5g/v sodium molybdate addition. The adsorption of the molecules of the extract on the aluminium alloy surface obeyed the Langmuir adsorption isotherm. The potentiodynamic polarization results showed that sodium molybdate acted as mixed-type inhibitor.

**KEYWORDS:** Adsorption, Surface Interaction, Sodium Molybdate, Corrosion Rate

### INTRODUCTION

Aluminium alloys have found an intensive use in most industrial applications because of their delightful properties that they demonstrate. Its availability and high strength to weight ratio has indeed increased the usage of aluminium alloys in the world. Other desirable properties that these alloys reveal are low density, good workability and excellent thermal and electrical conductivity. Accordingly, alloys are increasingly used in aerospace and automobile industries for construction because of its light weight property [1-7]. However, this alloy shows poor performance in some service condition that required aggressive corrosion environment. Hence, methods for improving such drawback become important. In that direction, the use of inhibitor, has been identify by different authors as a means of reducing the corrosion rate of metals and alloys [8]. The uses of some inhibitors for the control of corrosion in different media have been reported [9, 10]. In the present study, an attempt was made to examine electrochemical behavior and surface interaction of AA6063 type Al-Mg-Si alloy by sodium molybdate in simulated seawater environment using gravimetric and potentiodynamic techniques.

## EXPERIMENTAL PROCEDURE

### Materials and Sample Preparation

Aluminium alloy AA6063 type with chemical composition shown in Table 1 was sectioned into 20 x 20 with a thickness of 3 mm was used as coupons for the corrosion study in simulated sea water containing 3.6% of NaCl with 100 ml of distilled water. Initially, the coupons were mechanically abraded with 220 down to 1000 grid sizes of emery papers, degreased with acetone and rinsed with distilled water before each experiment was conducted. The initial weight of each sample was taken and recorded. The sodium molybdate used was obtained from Technology Innovation Agency, Chemical Station, Ga-Rankuwa.

**Table 1: Chemical Composition of the Aluminium Alloy Used (wt%)**

Element	Al	Si	Mn	Mg	Sr	Bi	Ca	Na	Fe	Ti	P,Cr, Zr,Cu ,Zn	B,Ni, Ag, Co
Composition	99.01	0.157	0.025	0.5	0.0001	0.0024	0.0012	0.001	0.281	0.0046	0.01	0.004

### Gravimetric and Potentiodynamic Polarization Measurement

The corrosion measurement was conducted in simulated sea water containing 3.6g with 100 ml of distilled water for 48-240 h at 30 °C in a static aerated solution. In each measurement, the cleaned aluminium alloy coupon was weighed and suspended with the aid of glass rod and hook in a beaker containing 100 ml NaCl solution with and without addition of different concentrations of sodium molybdate. The weight loss was taken as the difference between the weight at a given time and the initial weight of the test coupon determined using digital weighing balance. The sample weights were measured in milligrams to four decimal places and were used to calculate the corrosion rate (CR) and percentage inhibition efficiency (%IE).

$$\text{Corrosion rate} = \frac{534W}{DAT} \quad (1)$$

Where W is the weight loss, D the density of the steel in g/cm<sup>3</sup>, A is cross sectional area in cm<sup>2</sup> and T is the time in hour. Inhibition efficiency (% IE) was obtained by:

$$\text{IE} = \frac{CR^0 - CR^1}{CR^0} \times 100 \quad (2)$$

Where CR<sup>0</sup> and CR<sup>1</sup> are the corrosion rates in the absence and presence of inhibitor respectively.

The electrochemical measurement was made using a three-electrode cell assembly in a NaCl static solution at 30°C. The aluminium alloy was the working electrode, platinum electrode was used as a counter electrode and Ag/AgCl used as reference electrode. Before recording the polarization curves, the solution was de-aerated for 10 min and the working electrode was maintained at its corrosion potential for 30 min until a steady state was obtained. The inhibitor efficiency was calculated according to equation (3);

$$\text{IE}(\%) = \frac{i_{\text{cor}} - i_{\text{corr}}}{i_{\text{cor}}} \times 100\% \quad (3)$$

### Surface Analysis of the Coupons

The test coupons in the as-corroded condition were dried and the surface morphology was examined using an optical microscope with or without the sodium molybdate using magnification of x200.

## RESULTS AND DISCUSSIONS

### Gravimetric and Potentiodynamic Polarization Studies

The result from gravimetric technique shows that corrosion rate of aluminium in the environment decrease at 5 and 10g/v of sodium molybdate addition. Conversely, the corrosion rate increased at 2g/v sodium molybdate for all exposure time (Table 2 and Figure 1). This might be attributed to the fact that the concentration is the sodium molybdate low, hence not enough to create a passive site during the reaction process. Considering addition of 5g/v of sodium molybdate, at various exposure times, corrosion rate decreased/completely eliminated, with optimum percentage inhibitor efficiency (% IE) in the gravimetric study. In the potentiodynamic study (Table 3), potentiodynamic polarization-corrosion rate (PP-cr), potentiodynamic polarization-corrosion density (PP-I<sub>corr</sub>), and linear polarization resistance (Ipr) were used as an assessment for evaluation of corrosion resistance of aluminium in the studied condition. Figure 2 indicates the polarization curves for the alloy with or without the sodium molybdate in NaCl solution at 30°C. Accordingly, the enhanced environment showed a significant decrease in the corrosion rate and current density with addition of sodium molybdate inhibitor at all concentrations. While the corrosion potential (E<sub>corr</sub>) and polarization resistance (R<sub>p</sub>) increases with inhibitor concentrations. This is in agreement with reported study [11].

**Table 2: Corrosion Rate, Inhibition Efficiency (IE %), and Surface Coverage (Θ) for Aluminum in 3.6% Sodium Chloridesolution with and without Varying Concentration of Sodium Molybdate**

Exposure Time (hr)	Inhibitor Concentration(g/v)	Corrosion Rate (mm/yr)	Surface Coverage (Θ)	Inhibition Efficiency (%IE)
48	0	4.73148E-04	-	-
	2	6.75925E-04	0.428	-42.80
	5	0	1	100
	10	2.02777E-04	5.714	57.14
92	0	2.36574E-04	-	-
	2	3.37962E-04	5.714	-57.14
	5	0	1	100
	10	1.12654E-04	4.285	42.85
144	0	2.25308E-04	-	-
	2	3.37962E-04	0.5	-50
	5	0	1	100
	10	1.12654E-04	0.5	50
192	0	2.19675E-04	-	-
	2	3.37962E-04	5.384	-53.84
	5	0	1	100
	10	8.44900E-05	6.154	61.54
240	0	2.02777E-04	-	-
	2	2.70370E-04	3.333	-33.33
	5	0	1	100
	10	7.45510E-05	6.333	63.33
288	0	1.91512E-04	-	-
	2	2.25308E-04	1.765	-17.65
	5	0	1	100
	10	1.12654E-04	4.118	41.18

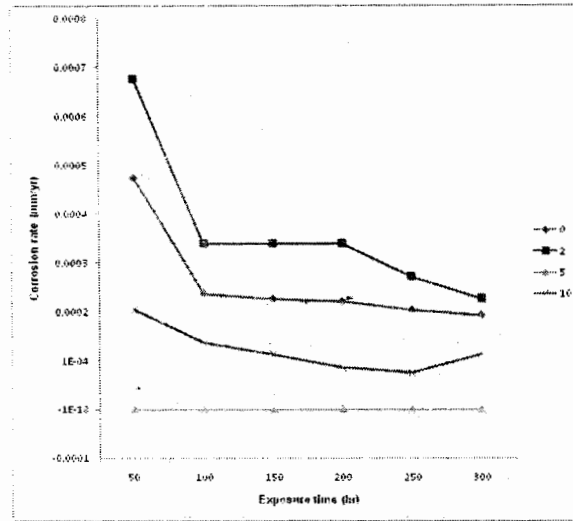


Figure 1: Variation of Corrosion Rate with Exposure Time of Aluminum in 3.6% Sodium Chloride Solution with and without Sodium Molybdate

The inhibited alloy in NaCl solution demonstrated a decrease in the corrosion rate from 0.16252 mm/yr to 0.14159, 0.07718 and 0.10347 mm/yr at 2, 5 and 10g/v sodium molybdate additions. Specifically, with polarization technique, the percentage efficiency of the inhibitor increased with increase in the concentration indicating an optimum of 52.51% improvement in the corrosion resistance at 5g/v sodium molybdate addition (Table 3). Similar results have been reported [11, 12]. While %IE decreased at lower concentration of 2g/v of sodium molybdate with a negative trends as compare with 5 and 10g/v sodium molybdate addition using the gravimetric technique.

Table 3: Electrochemical Corrosion Data Obtained for Aluminum in 3.6% Sodium Chloride Solution in Varying Concentrations of Sodium Molybdate at 30°C

Inhibition Conc.	E <sub>corr</sub> Obs (V)	i <sub>corr</sub> (A/cm <sup>2</sup> )	i <sub>corr</sub> (A)	CR (mm/yr)	R <sub>p</sub> (Ω)
10g/v	-1.2183	8.90E-06	8.90E-06	0.10347	530.76
5g/v	-1.1717	6.64E-06	6.64E-06	0.07718	702.95
2g/v	-1.2591	1.42E-05	1.42E-05	0.14159	362.43
control	-1.2699	1.20E-05	1.20E-05	0.16252	208.83

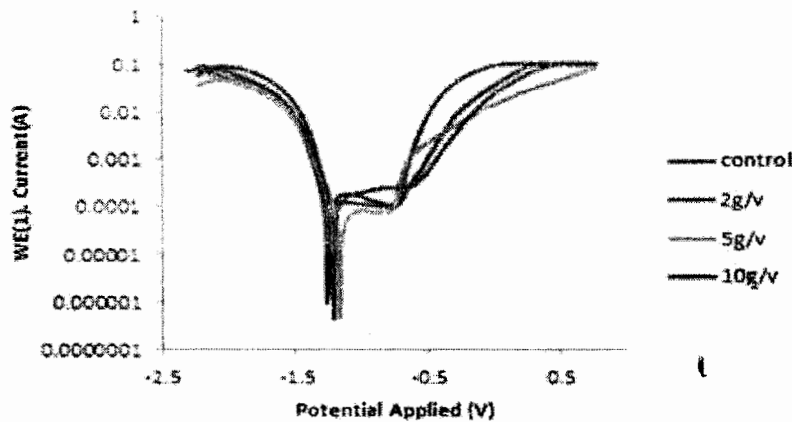


Figure 2: Linear Polarization of Aluminium in Sodium Molybdate-Sodium Chloride Solution at 30°C

1756

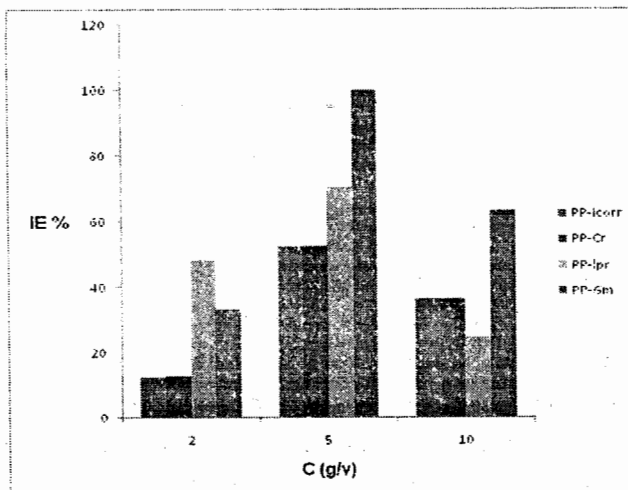


Figure 3: Comparative Chart of Inhibitor Efficiency (IE) for 3.6% Sodium Chloride Solution with Sodium Molybdate Concentration Obtained for Various Methods

**Inhibitor Efficiency and Adsorption Behavior**

The percentage inhibitor efficiency (% IE) of the aluminium in sodium molybdate-sodium chloride solution was computed using the equation reported elsewhere[13]. The variation in the % IE using gravimetric (Gm), potentiodynamic polarization-corrosion rate (PP-cr), potentiodynamic polarization-corrosion density (PP-I<sub>corr</sub>) and linear polarization resistance (LPR) are presented in Figure 3. This indicates that addition of sodium molybdate at various concentrations increased the %IE. This occurrence can be explain based on the fact that as the inhibitor concentration increases, there seems to be some degree of surface interaction between the alloy, NaCl and sodium molybdate which means the surface area covered by the inhibitor tends to increase resulting to a higher IE. The use of sodium molybdate as inhibitor can be said to exhibit a mixed-type corrosion inhibition due to the change in the anodic and cathodic region during the electrochemical analysis of the alloy in the studied condition. The trends have been previously reported [14]. Accordingly, there exist some level of correlation between gravimetric and potentiodynamic polarization method used for assessing the alloy. Equally, the adsorption mechanism has been shown with a relationship between C/θ against C indicated a linear trend at 30°C (Figure 4). From such mechanism, the variation of C/θ with C (g/v) was observed with regression coefficients estimated to be approximately unity and the mechanism of adsorption is believed to have obeyed Langmuir adsorption isotherms.

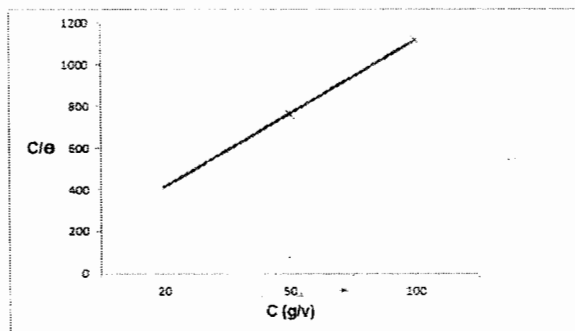


Figure 4: Langmuir Isotherm for the Adsorption of Sodium Molybdate Compounds on the Aluminum Surface in 3.6% Sodium Chloride Solution at 30°C

The microstructures of as-corroded aluminium alloy surfaces are shown in Figure 5(a-d). The un-inhibited aluminium alloy can be seen in Figure 5a. While inhibited sample in 3.5% NaCl solution with fair surface damage (Figure 5b-d). Generally there was degradation of all the samples in 3.5% NaCl solution with uninhibited sample indicating a more severe deterioration in the environment as a result of oxidation reaction and dissociation of the chlorides ion in the solution.

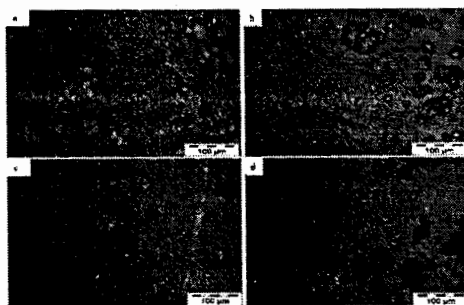


Figure 5: Optical Micrograph of (A) as-Corroded Uninhibited and Inhibited Aluminum in (B) 2g/V (c) 5g/v (d) 10g/v of Sodium Molybdate at 30°C (x200)

## CONCLUSIONS

- The addition sodium molybdate to aluminium-NaCl environment acted as an effective inhibitor within the experimental conditions by forming thin films of protective layer.
- Equally, the corrosion rate decreased with sodium molybdate additions, while the inhibition efficiency increases with concentration of the inhibitor.
- That the mixed-type corrosion inhibition exists and Langmuir adsorption isotherms were proposed for the aluminium alloy.
- The results obtained from all the methods employed are in good agreement with each other.

## ACKNOWLEDGEMENTS

The authors acknowledge the support from Surface Engineering Research Centre (SERC), Tshwane University of Technology and Technology Innovation Agency (TSC) Pretoria which helped to accomplish this work.

## REFERENCES

1. Alan, I. T., Paul, E. K., Alan, A.L., John, N.O., *JOM* 50<sup>th</sup> TMS (2007) 48.
2. Heller, D. K., William, G.F., Mathew, J. O., *Corr. Sci.* 52 (2010) 360.
3. Miao, W. F., Laughlin, D.E., *Scr. Mater.* 40(7) (1999) 873.
4. Madugu, I. A., Abdulwahab, M., *Nig. J. Res. Prod.* 10(2) (2007) 72.
5. Niranjani, V. L., Hari, K.K.C., Subramanya, S. V., *Mater. Sci. Eng.* A515 (2009) 169.
6. Westermann, I., Odd, S.H., Knut, M., Bjorn, H., *Mater. Sci. Eng.* A524 (2009) 151.
7. Zandar, J., Sandstrom, R., *Mater. Des.* 29 (2008) 1540.
8. Bregmann, J. I., *Corrosion Inhibitor*, Macmillan, New York, 1963.

9. Hackermann, N., The Theory and Practice of Corrosion and Its Control in Industry, Langmuir, 1987, 3, p 922-924
10. Giriciene, O., Rama, N. R., Gudaviciute, L., Martusiene, *Corrosion*, 67(2011)12.
11. Abdulwahab, M., Kasim, A., Fayomi, O. S. I., Asuke, F., Popoola, A. P. I., *J. Mater. Environ. Sci.* 3 (6) (2012) 1177.
12. Prabhu, D., Padmalatha, R., *J. Mater. Environ. Sci.* 4 (5) (2013) 732.
13. Halambek, J., Berkovic, K., Vorkapic-Furac, J., *Corr. Sci.* 52 (2010) 3978.
14. Rosliza, R., Nora'aini, A., Nik, W. B. W., *J. Appl. Electrochem.* 40 (2010) 833.

600