

## POTENTIODYNAMIC POLARIZATION STUDIES OF A HEAT TREATED AL-ZN-MG SACRIFICIAL ANODE

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**Abstract:** *The influence of heat treatment on the corrosion behavior of an Al- 5wt. % Zn-1 wt. % Mg sacrificial anode was investigated by electrochemical measurements and weight loss tests. The Al-Zn-Mg anodes were prepared by stir casting technique from high purity materials and subsequently solution heat treated at 450°C, 480°C and 500°C. The results obtained revealed that increasing heat treatment temperatures had a strong influence on the open circuit potential, corrosion rate, closed circuit potentials and weight loss. As the temperatures increased corrosion rates increased slightly and reduced from 0.069952 mm/yr to 0.03391 mm/yr while polarization resistance decreased slightly and then increased from 2136.11  $\Omega$  to 3770.26  $\Omega$ . From the galvanic coupling tests the closed circuit potentials were within  $0.957 \pm 0.00126$  V vs Ag/AgCl. The results indicate that heat treatment helped improved homogeneity in the matrix and uniform anodic dissolution.*

**Keywords:** *corrosion; heat treatment; anode*

### 1. Introduction

Oil and gas facilities are susceptible to corrosion damage because of the operating environment and the corrosive fluids that are constantly handled. Components are likely to fail under such conditions after a period in operation. A study by [1], revealed that over two million dollars was spent annually on corrosion related maintenance for oil platforms in Nigeria. This value would definitely run into billions of dollars when the cost from other production facilities are aggregated and inflation to date is taken into account. Sacrificial anodes are frequently applied to mitigate these huge corrosion related costs [2]. Aluminum over the decades has remained a choice material for sacrificial anodes in the protection of pipelines, storage tanks and platforms mainly due to its low density, large electrochemical equivalence, availability, thermal and electrical conductivity [3], low specific weight and reasonable cost due to its relatively high theoretical capacity of about 2980 Ahr/kg [4–7]. Several works on Al-Zn-Mg anodes have been reported considering varying Mg Contents [8,9], high strength properties, phase equilibriums, solidification [10] and precipitation of intermetallics [11]. When Mg is added to the melt, it will reduce grain size [12], and help improve anode activation [9,13–15]. This present paper seeks to highlight the influence of heat treatment temperatures on corrosion behavior of an Al-Zn-Mg alloy to be used as a sacrificial anode.

### 2. Materials and Methods

#### 2.1 Alloy Specimen and Test Solution

The aluminium anode (Al - 5wt% Zn - 1 wt% Mg) was produced from Pure aluminium, zinc and magnesium (>99.75%). The required amount of raw materials were weighed and melted in a gas furnace. The melt was vigorously agitated to allow for good mixing and reheating again before pouring into prepared sand moulds. The cast samples were machined, cut and solution treated at 450, 480 and 500°C for 1 hour in a muffle furnace followed by water quenching at room temperature.

#### 2.2 Electrochemical Measurements

All Electrochemical experiments were performed in a conventional three-electrode cell using a computer controlled VersaStat 4 potentiostat. A Silver/Silver Chloride (Ag/AgCl) and platinum were used as the reference and counter electrodes respectively. The aluminium anode samples used as working electrodes were cut into rectangular shapes with an exposed surface area of 1 cm<sup>2</sup>. The working electrodes were prepared by attaching insulated wires to the samples and covering them with epoxy resin such that only one face of each sample was exposed. The exposed surfaces were wet ground with emery paper, washed thoroughly with running tap water prior to testing. The test environment was in a seawater solution. Potentiodynamic scan was performed at  $\pm 250$  mV of the Open circuit Potential (OCP) (versus Ag/AgCl). The experimental plots were then used to obtain corrosion rate, Tafel constants and polarization resistance.

### 2.3 Closed Circuit Potential and Weight loss from Galvanic Coupling

The samples were coupled galvanically with a 1:10 area ratio (anode to cathode ratio) with mild steel used as cathode. The galvanic couples were immersed in natural seawater and the Closed Circuit potentials (CCP) were measured continuously for 144 hours. The weight of the anodes were measured before and after immersion and their weight loss determined. Parallel couples were set up and average values were taken. The chemical composition for the low carbon mild steel used for the test is shown in table 1.

Table 1: Chemical Composition of Mild steel

Element	Fe	C	Si	Mn	P	S	Cr	Ni	Cu	Al	Co	Nb	Sn
% Composition	99.62	0.0231	0.0182	0.1047	0.0117	0.0125	0.0135	0.0436	0.0221	0.0154	0.002	0.001	0.007

## 3. Results and Discussion

### 3.1 Change in Open Circuit Potential (OCP) with time

Within the test period it was observed that the OCP for the samples fluctuated between -0.890 and -0.895 V for both heat treated and non-heat treated. This fluctuating behavior can possibly be attributed to simultaneous corrosion products formation and breakdown as suggested by [16]. The OCP gives information on how fast the samples reach their equilibrium states hence implying that heat treating will help achieve equilibrium faster.

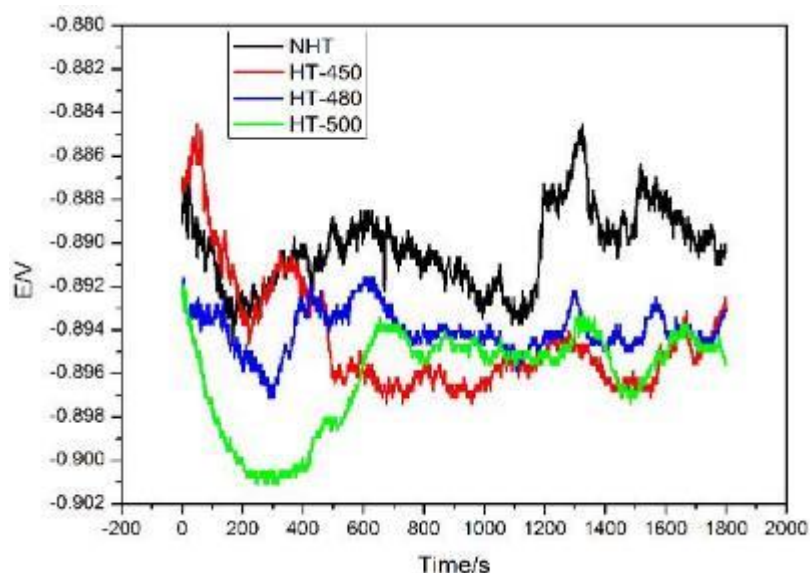


Figure 1: Open circuit potential for Al-Zn-Mg

### 3.2 Polarization Curves

Fig. 1 shows the Potentiodynamic polarization curves for the Non heat treated (NHT) and heat treated (HT) anode samples. The curves for NHT, HT-450°C and HT-480°C showed similar behavior implying that the electrode processes were not significantly modified by heat treating [17]. The current density ( $I_{corr}$ ) presented in table 2 was measured by extrapolating the anodic and cathodic Tafel lines at the corrosion potential ( $E_{corr}$ ). The maximum and minimum corrosion rates were 0.071619 mm/yr for HT-450°C and 0.03391 mm/yr for HT-500°C. All samples showed signs of active behaviour with no current plateaus which can be ascribed to the absence of any passive layers on the anode surface. This will significantly improve ionic – electron movement. The polarization resistance ( $R_p$ ) increased with heat treatment with a peak value of 3770.26  $\Omega$  for HT-500°C and minimum of 1808.18  $\Omega$  for the HT-450°C. These polarization results correlated with the low corrosion rates observed for the HT anodes. The low corrosion rates were significant to reducing self-corrosion of the anodes which have been mentioned by other researchers [18].

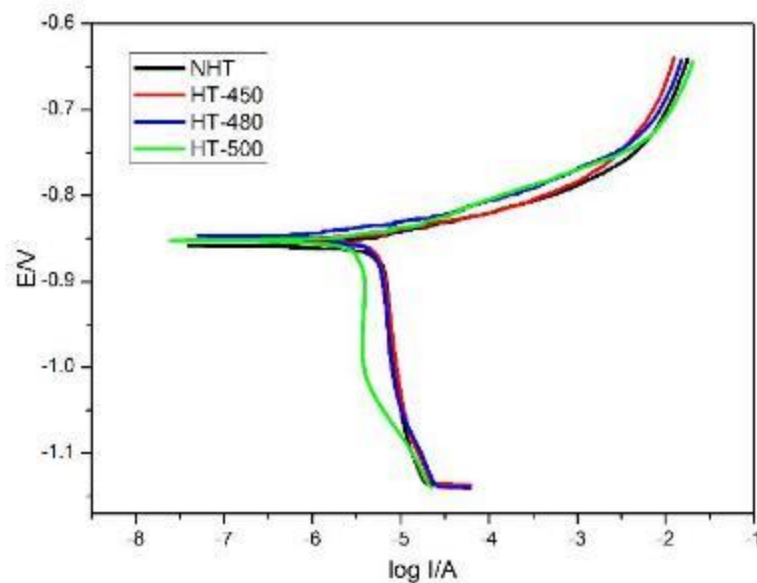


Figure 2: Tafel plots for Al-Zn-Mg anode

Table 2: Values from Extrapolated Tafel Plots

Al-Zn-Mg Sample	Corr. Rate (mm/y)	I corr (μA)	b c (V/dec)	ba (V/dec)	Rp (Ω)
Non Heat Treated (NHT)	0.069952	-6.024	0.8445	0.0306	2136.11
HT-450°C	0.071619	-6.167	0.9866	0.0263	1808.18
HT-480°C	0.067941	-5.850	1.2120	0.0406	2920.07
HT-500°C	0.033910	-2.920	0.7539	0.0262	3770.26

### 3.3 Effect of Heat treatment on CCP and Weight Loss

The CCP values for all samples tested ranged between 0.92 V and 0.97 V for the duration of measurement. The NHT had the highest CCP of 0.97 V after 144 hours of immersion. However it was observed that HT-450 °C produced constant CCP values after 144 hours of immersion implying possible uniform dissolution properties. No corrosion products were observed on the mild steel cathode for the duration of test implying the effectiveness of the test anodes. A white gelatinous precipitate observed in the test cells further confirmed this active dissolution of the anodes. The weight loss for all anode samples ranged between 0.025 g and 0.03 g. HT-450°C produced the highest weight loss of 0.0319 g followed by HT-500°C with 0.0312 g. The results obtained were in good agreement with those from polarization tests.

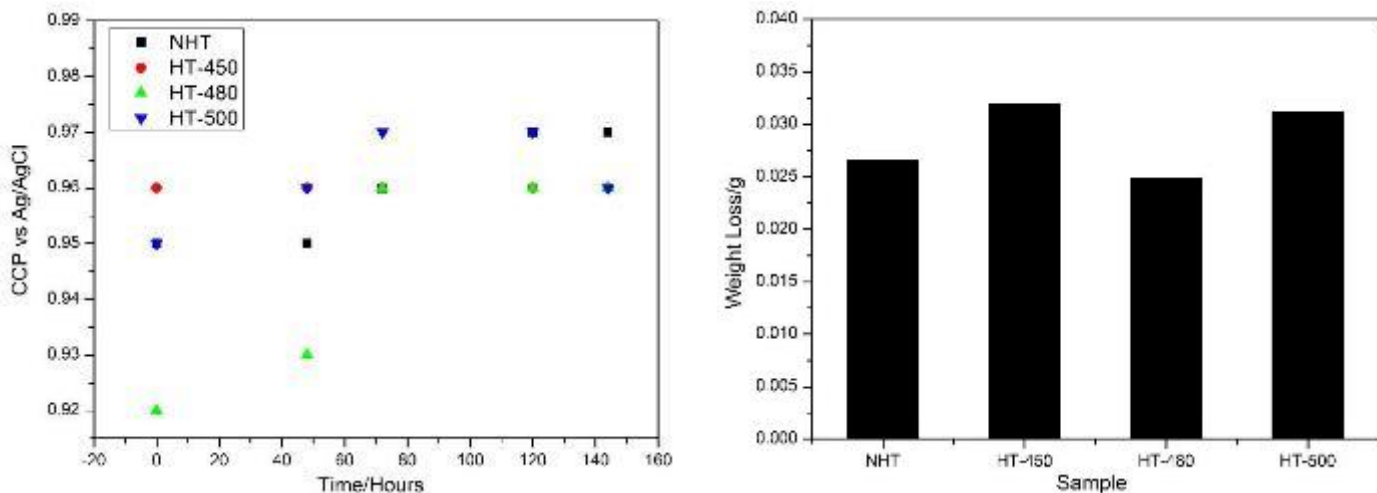


Figure 3: (a) Closed Circuit Potential (b) Weight Loss for Al-Zn-Mg

## Conclusions

The effect of heat treatment on an Al-Zn-Mg sacrificial anode was studied using Potentiodynamic polarization and weight loss measurements. The following conclusions can be made:

- Corrosion rates reduced with increasing heat treatment temperature
- Polarization resistance values increased as heat treatment temperatures increased.
- The Closed circuit potentials increased steadily during immersion which was an indication of active anodic dissolution.
- The weight loss increased as heat treatment temperatures were increased.
- Heat treatment proved useful in improving homogeneity in the matrix

## References

- [1] O.O. Akinyemi, C.N. Nwaukocho, a O. Asedanya, Evaluation of Corrosion Cost of Crude Oil Processing Industry, *J. Eng. Sci. Technol.* 7 (2012) 517–528.
- [2] I. Gurrappa, Cathodic protection of cooling water systems and selection of appropriate materials, *J. Mater. Process. Technol.* 166 (2005) 256–267.
- [3] M. Pourgharibshahi, M. Meratian, Corrosion morphology of aluminium sacrificial anodes, *Mater. Corros.* 65 (2014) 1188–1193. doi:10.1002/maco.201307173.
- [4] O.O. Oluwole, N. Idusuyi, Aluminium Anode Activation Research – A Review, *Int. J. Sci. Technol.* 2 (2012) 561–566.
- [5] S.M.A. Shibli, V.S. Gireesh, Activation of aluminium alloy sacrificial anodes by selenium, *Corros. Sci.* 47 (2005) 2091–2097.
- [6] S.A. Attanasio, J.N. Murray, R.A. Hays, others, Non-Uniform Electrochemical Behavior of Indium-Activated Aluminum Alloy Anodes, in: *Corros.* 96, 1996.
- [7] A. Venugopal, V.S. Raja, AC impedance study on the activation mechanism of aluminium by indium and zinc in 3.5% NaCl medium, *Corros. Sci.* 39 (1997) 2053–2065.
- [8] R. Orozco, J. Genesca, J. Juarez-Islas, Effect of Mg Content on the Performance of Al-Zn-Mg Sacrificial Anodes, *J. Mater. Eng. Perform.* 16 (2007) 229–235. doi:10.1007/s11665-007-9037-z.
- [9] A. Muazu, Y.S. Aliyu, M. Abdulwahab, A.P. Idowu Popoola, Sacrificial anode stability and polarization potential variation in a ternary Al-xZn-xMg alloy in a seawater-marine environment, *J. Mar. Sci. Appl.* 15 (2016) 208–213. doi:10.1007/s11804-016-1356-8.
- [10] C. Gonzalez, J. Genesca, O. Alvarez, J.A. Juarez-Islas, Solidification of chill-cast Al-Zn-Mg alloys to be used as sacrificial anodes, *Metall. Mater. Trans. A.* 34 (2003) 2991–2997. doi:10.1007/s11661-003-0198-6.
- [11] A. Barbucci, A. Sacconec, I. Universita, J.F.K. Genova, C. Fisica, C. Generale, Activation of aluminium anodes by the presence of intermetallic compounds, 42 (1997) 2369–2380.
- [12] Y. Yi, J. Huo, W. Wang, Electrochemical Properties of Al-based Solid Solutions Alloyed by Element Mg, Ga, Zn and Mn under the Guide of First Principles, *Fuel Cells.* 17 (2017) 723–729. doi:10.1002/fuce.201600092.
- [13] H. Moghanni-Bavil-Olyaei, J. Arjomandi, M. Hosseini, Effects of gallium and lead on the electrochemical behavior of Al-Mg-Sn-Ga-Pb as anode of high rate discharge battery, *J. Alloys Compd.* 695 (2017) 2637–2644. doi:https://doi.org/10.1016/j.jallcom.2016.11.176.
- [14] S. Tokuda, I. Muto, Y. Sugawara, M. Takahashi, M. Matsumoto, N. Hara, Micro-electrochemical investigation on the role of Mg in sacrificial corrosion protection of 55mass%Al-Zn-Mg coated steel, *Corros. Sci.* 129 (2017) 126–135. doi:https://doi.org/10.1016/j.corosci.2017.07.020.
- [15] J. Li, K. Wan, Q. Jiang, H. Sun, Y. Li, B. Hou, L. Zhu, M. Liu, Corrosion and Discharge Behaviors of Mg-Al-Zn and Mg-Al-Zn-In Alloys as Anode Materials, *Metals (Basel).* 6 (2016).
- [16] K.K. Alaneme, T.M. Adewale, P.A. Olubambi, Corrosion and wear behaviour of Al-Mg-Si alloy matrix hybrid composites reinforced with rice husk ash and silicon carbide, *J. Mater. Res. Technol.* 3 (2014) 9–16.
- [17] V.J. S.Lameche-Djeghaba, A. Benchettara, F. Kellou, Electrochemical Behaviour of Pure Aluminium and Al – 5 % Zn Alloy in 3 % NaCl Solution, *Arab. J. Sci. Eng.* (2014) 113–122. doi:10.1007/s13369-013-0876-7.
- [18] S.M.A. Shibli, V.S. Gireesh, S. George, Surface catalysis based on ruthenium dioxide for effective activation of aluminium sacrificial anodes, *Corros. Sci.* 46 (2004) 819–830.