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ORIGINAL PAPER

Effect of Avogadro Oil as Corrosion Inhibitor of Thermally Pre-aged Al-Si-Mg Alloy in Sodium Chloride Solution

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Abstract The corrosion inhibition of thermally pre-aged Aluminium-Silicon-Magnesium (Al-Si-Mg) alloy in 3.5 % NaCl solution with natural Avogadro oil of varying concentrations has been studied using linear polarization techniques. From the results obtained, the corrosion rate decreased with an increase in Avogadro oil concentration. An inhibitor efficiency of 46.7, 58 and 71 % were obtained at 1.5, 3.0, 4.5 g/v Avogadro oil addition in a 3.5 % NaCl solution respectively for the conventional alloy. Results from the linear polarization technique indicate a higher potential value with an increase in the polarization resistance (R_p) and lower current density in the inhibited samples than the uninhibited Al-Si-Mg alloy as obtained from the Tafel plot extrapolation. There exist some levels of correlation in the inhibitor efficiency between the conventional and the thermally pre-aged Al-Si-Mg alloy/Avogadro oil in 3.5 % NaCl solution.

Keywords Avogadro oil · Inhibitor efficiency · Aluminium alloy · Eco-friendly · Corrosion rate

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1 Introduction

Cast Al-Si-Mg alloys have been widely used in the automotive and aircraft industries due to their good properties and high strength to weight ratio [1–8]. Some of their attractive properties are good extrudability, relative high strength, good corrosion resistance, excellent casting characteristics, light weight and acceptable cost [9–11]. Generally, aluminium has higher corrosion resistance because of its thin surface oxide film formation. Although, in an aggressive environment, mostly chloride and acidic, the protective films break down, however, the oxide coating is not totally removed but is thinned and regenerated by the oxidation of the underlying metal [12]. Corrosion inhibitors are needed to reduce the corrosion rates of metallic materials in these environments [13]. An inhibitor is usually added in small amount in order to slow down the rate of corrosion through the mechanism of adsorption [13]. Some chemical and synthetic corrosion inhibitors such as sodium benzoate that have been known to exhibit good corrosion resistance are not eco-friendly and create an environmental threat [12]. Therefore, efforts toward identifying any potential eco-friendly and less expensive corrosion inhibitors remain relevant and progressive. The growing interest among researchers for green inhibitors has remained a top research focus [12]. In that direction, plant extracts and oils have gained acceptance as corrosion inhibitors that are considered safe, eco-friendly, available and less expensive for most metals and alloys [14]. In our previous study [15], we considered the corrosion behavior of the pre-aged alloy in 3.5 % NaCl without the use of inhibitor. In this work, the potential of natural Avogadro oil as corrosion inhibitor for a thermally pre-aged Al-Si-Mg alloy in NaCl solution have been investigated.

Table 1 Chemical composition of the Al-Si-Mg alloy produced (wt %)

Al	Si	Mg	Fe	Cu	Mn	Zn	Ti	Na
92.14	7.0	0.3	0.08	0.03	0.03	0.03	0.03	0.01

2 Experimental Procedures

2.1 Materials and Sample Preparation

Al-Si-Mg alloy specimens of dimension 20 × 10 mm with chemical composition shown in Table 1 were used as coupons for the corrosion study in 3.5 % NaCl solution. Initially, the coupons were mechanically polished with emery papers down to 600 grid sizes. The samples were degreased in ethanol, dried, weighed and stored in a desiccator. A concentration of 3.5 % sodium chloride solution (NaCl) was prepared fresh as required for the experiment. Avogadro oil as inhibitor was used with NaCl salt solution. The Avogadro natural oil was obtained from Technology Innovation Agency, Chemical Station, Ga-Rankuwa, Tshwane University of Technology, Pretoria. The corrosion measurement was conducted at room temperature.

2.2 Pre-ageing Thermal Treatment of Al-Si-Mg Alloy

The alloy produced was machined to a standard corrosion coupon. The machined samples were solution heat treated at a temperature of 540 °C for 1 h in an electrical furnace and then rapidly quenched in warm water. The quenched samples were given double thermal ageing (DTAT) at a pre-ageing temperature of 90 °C for 3 h, and then finally aged at 180 °C for 2 h.

2.3 Electrochemical Corrosion Measurement

The potentiodynamic polarization was used to evaluate the corrosion rate of the Al-Si-Mg alloy in NaCl solution with Avogadro oil as inhibitor. All electrochemical measurements were obtained using an Autolab frequency response analyzer (FRA) coupled to a potentiostat and connected to a computer system as the source of data acquisition. A glass corrosion cell kit with a platinum counter electrode, saturated Ag/Ag reference electrode and Al-Si-Mg alloy sample as working electrode were used for the electrochemical study. The working electrode samples were positioned at the glass corrosion cell kit, leaving 1 cm^2 surfaces in contact with the solution. Polarization tests were carried out in 3.5 % NaCl solution with and without Avogadro oil in static solution using a potentiostat (Model: AuT71791 and PGSTAT 30) with a scan rate of 0.003 V/sec. From the Tafel corrosion analysis, the corrosion rate, potential and linear polarization resistances were obtained.

3 Results and Discussion

3.1 Results

Table 2 shows the linear polarization corrosion data for Al-Si-Mg alloy in 3.5 % NaCl static solution with and without Avogadro oil addition. Figure 1 illustrates the linear polarization curves for Al-Si-Mg alloy in 3.5 % NaCl static solution with and without Avogadro oil addition while Fig. 2 gives the comparism between inhibitor efficiencies and thermally treated Al-Si-Mg alloy for different concentrations obtained using potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion current (PP-Icorr) and linear polarization resistance (LPR) as criteria. Figure 3 shows Langmuir isotherms for the adsorption

Table 2 Linear polarization corrosion data for Al-Si-Mg alloy in 3.5 % NaCl static solution with and without Avogadro oil addition at room temperature

Samples	ba (V/dec)	bc (V/dec)	Ecorr, Calc (V)	Ecorr, Obs (V)	jcorr (A/cm^2)	icorr (A)	Corrosion rate (mm/year)	Polarization resistance (Ω)	E begin (V)	E end (V)
180/2h + 0.0Avo	0.052979	0.17701	−1.0426	−1.0166	3.49E-06	6.97E-06	0.032957	2539.4	−1.0727	−0.91156
180/2h + 1.5Avo	0.050268	0.1354	−1.125	−1.1056	1.86E-06	3.73E-06	0.017612	4272.2	−1.1459	−1.0361
180/2h + 3.0Avo	0.080537	0.15375	−0.86511	−0.83985	1.90E-06	3.79E-06	0.017935	6048.6	−0.87494	−0.74799
180/2h + 4.5Avo	0.11159	0.23682	−1.0697	−1.0409	1.88E-06	3.76E-06	0.017757	8767	−1.1093	−0.85785
90/3h + 0.0Avo	0.042124	0.17177	−1.1082	−1.0848	3.09E-06	6.18E-06	0.029225	2375.8	−1.1264	−0.98236
90/3h + 1.5Avo	0.064052	0.13327	−1.3241	−1.3045	3.35E-06	6.69E-06	0.03162	2808.1	−1.3266	−1.2363
90/3h + 3.0Avo	0.070627	0.1166	−1.092	−1.074	2.89E-06	5.78E-06	0.027338	3302.4	−1.1264	−1.0019
90/3h + 4.5Avo	0.058124	0.19357	−1.0292	−0.9995	2.55E-06	5.11E-06	0.02412	3802.4	−1.0556	−0.89203

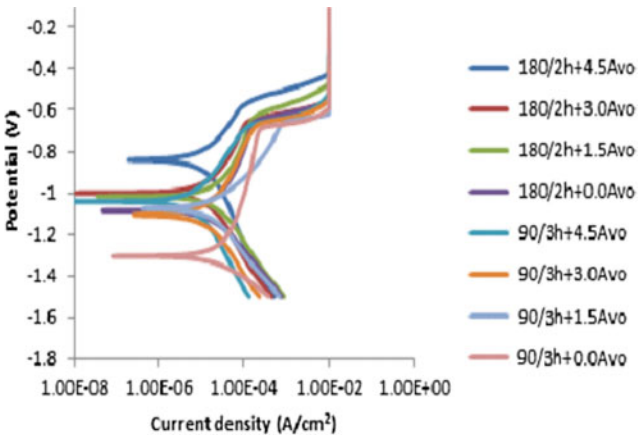


Fig. 1 Linear polarization curves for Al-Si-Mg alloy in 3.5 % NaCl static solution with and without Avogadro oil addition at room temperature

of Avogadro oil compounds on Al-Si-Mg alloy in 3.5 % NaCl static solution.

3.2 Discussion

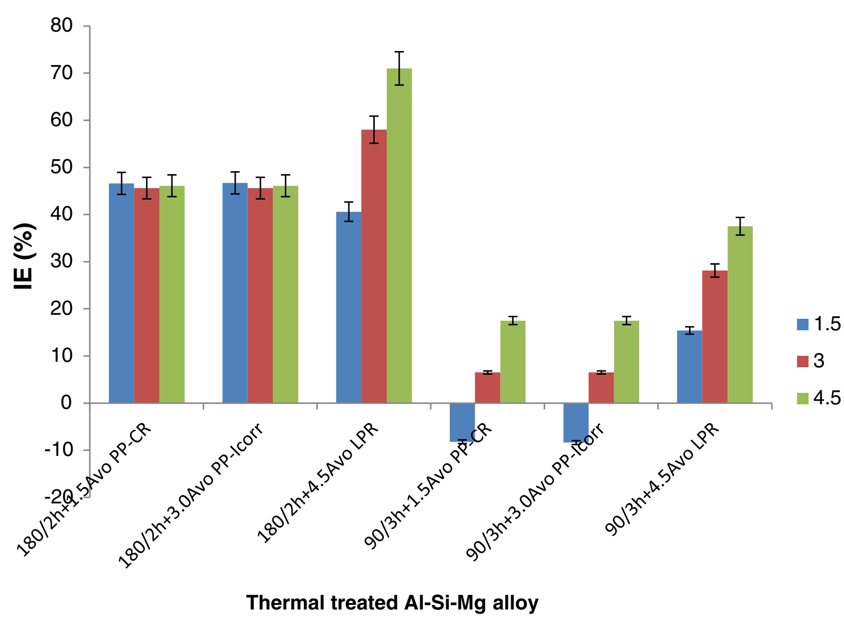
3.2.1 Potentiodynamic Polarization

In the polarization measurement (see Table 2), linear polarization resistance was used as the criterion for the electrochemical corrosion evaluation for Al-Si-Mg alloy in 3.5 % NaCl/Avogadro oil. In Fig. 1, the anodic and cathodic polarization curves for the Al-Si-Mg alloy in basic medium Avogadro oil and uninhibited conditions were shown. It can be seen that for samples that were given the conventional ageing treatment i.e 180 °C for 2 h, the current density decreased with an increase in inhibitor concentration and corrosion potential (Ecorr) increased for 1.5, 3.0 and 4.5 g/v Avogadro oil additions, respectively (Fig. 1). From the linear polarization resistance values, it shows that addition of the inhibitor resulted into an increase in the polarization resistance (Rp) of the Al-Si-Mg alloy from 2539.4Ω (uninhibited) to 8767Ω (inhibited) condition. The increase in Rp generally suggested an improvement in the corrosion resistance of the metal in the presence of the inhibitor. This shows that the metal is protected within the immersion time considered. Considering the electrochemical corrosion for the Al-Si-Mg alloy pre-aged at 90 °C for 3 h at 3.5 % NaCl-Avogadro oil (Fig. 1), a different trend in the corrosion resistance were observed with an increase in corrosion rate for 1.5 g/v addition of Avogadro oil and a decrease in corrosion rate with 3.0 and 4.5 g/v inhibitor addition as compared with the uninhibited condition. Since both the anodic and cathodic branches change with the addition of inhibitor concentrations, the natural Avogadro oil can be said to have acted as a mixed-type corrosion inhibitor within the studied environments.

3.2.2 Inhibitor Efficiency and Adsorption Behavior

The percentage inhibitor efficiency (% IE) of the Al-Si-Mg alloy-Avogadro oil in NaCl solution was computed using the equation reported [12]. The computed data for the IE using potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion density (PP-Icorr), and linear polarization resistance (LPR) are presented in Fig. 2 for NaCl/Avogadro oil. From the results, it showed that % IE of the Avogadro oil increases with an increase in the inhibitor concentrations. The reason being that, as the inhibitor concentration increases, the surface area covered

Fig. 2 Comparism between inhibitor efficiencies and thermally treated Al-Si-Mg alloy for different concentrations obtained using potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion current (PP-Icorr) and linear polarization resistance (LPR) as criteria



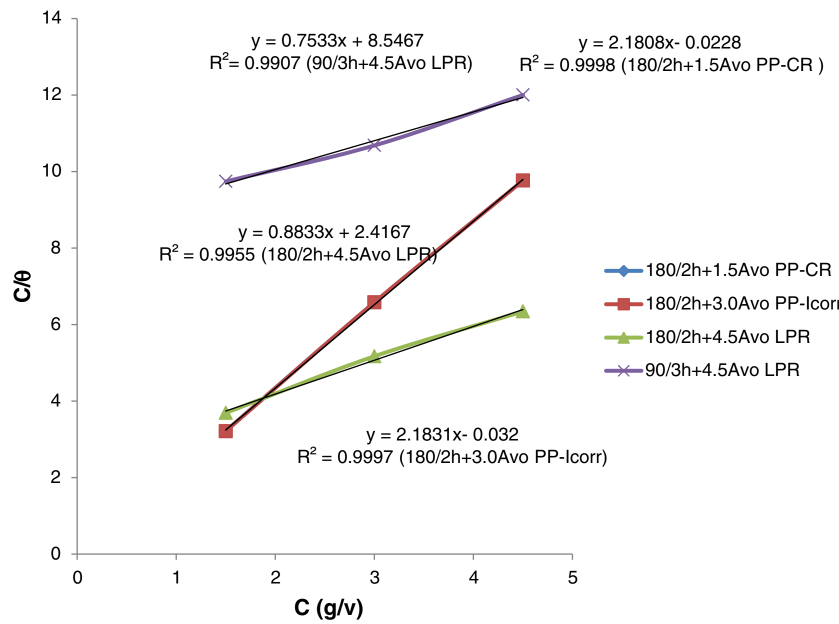


Fig. 3 Langmuir isotherms for the adsorption of Avogadro oil compounds on Al-Si-Mg alloy in 3.5 % NaCl static solution at room temperature

by this inhibitor increased. Hence, IE was enhanced significantly. It can be seen that the alloy with conventional thermal treatment demonstrated better corrosion resistance than those pre-aged prior to thermal treatment. From this behaviour, coupled with simultaneous change in the anodic and cathodic region during the electrochemical measurement Avogadro oil can be said to exhibit a mixed-type corrosion inhibition. This occurrence agrees with previous reports [12, 14].

The adsorption mechanism was shown from the variation between C/θ with C indicating linearity at room temperature for the environment (Fig. 3). The correction factors (R2) are approximately unity; PP-CR (0.9998), PP-Icorr (0.9997), LPR (0.9955), then, the adsorption behaviour is believed to have obeyed the Langmuir adsorption isotherm.

4 Conclusions

1. Avogadro oil has been found to be a good corrosion inhibitor for a thermally pre-aged Al-Si-Mg alloy in NaCl solution at room temperature.
2. The %IE and corrosion resistance of the thermally pre-aged Al-Si-Mg alloy increased with inhibitor concentrations with higher IE in the conventionally treated alloy.
3. The best corrosion resistant alloy was found with those treated at 180 °C/2 h in 1.5 g/v Avogadro oil addition.
4. The adsorption behavior of the Avogadro oil in basic media for Al-Si-Mg alloy can be said to have obeyed Langmuir adsorption isotherms and the oil acted as a mixed-type inhibitor.

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