

Comparison of Tafel Extrapolation and Linear Polarization Resistance Readings for TRC 8006 Aluminium Alloys in 3.5 wt. % NaCl Aqueous Solution

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Abstract

Corrosion behaviour of the twin-roll casting (TRC) 8006 Al alloys has been investigated as a function of foil thickness by two different polarization techniques; Tafel extrapolation and linear polarization resistance. Polarization curve changes depending on foil thickness for the TRC 8006 Al alloys have been achieved using both the polarization techniques, respectively. The measurements were performed using a three-electrode electrochemical cell system. Tafel slopes, polarization resistance, density of corrosion current, corrosion potential and corrosion rate values have been calculated based on the data collected from both method's outcomes and compared with those of each techniques used. For these two polarization curves, the corrosion rate values obtained for TRC 8006 Al alloy with a thickness of 180 μm is remarkably lower than the obtained results of TRC 8006 Al alloy with a thickness of 150 μm . This specifies that a decrease in foil thickness of the TRC 8006 Al alloys increased corrosion rate of the TRC 8006 Al alloys and thus the two techniques used in the present study to determine corrosion rate appears to be reliable methods for a long-term corrosion behaviour.

Keywords: Tafel extrapolation, Linear polarization resistance, TRC, 8006 Al Alloys, Corrosion rate

1. Introduction

There is a growing interest in the application of Al alloys in food, aviation and automotive industries for replacing poor corrosion resistance and heavier structural components usually fabricated with steel [1-3]. Accordingly, in order to satisfy this demand, various production techniques such as direct-chill casting (DC) and continuous casting for many Al alloys such as 3XXX, 4XXX and 8XXX have been successfully used to produce these group metals having remarkably enhanced corrosion resistance properties [4]. Recently, twin-roll casting (TRC) is one of the most interesting continuous casting methods to produce Al sheets and foils having better corrosion resistance by comparison with the Al alloys subjected to conventional production techniques for Al flat shapes. Among the various Al alloys already processed through TRC procedures, notable attention has been dedicated to 8006 Al alloys because of their excellent biocompatibility [5] and corrosion resistance properties [6].

Uniform or pitting corrosion in TRC 8006 Al alloys are mostly observed significant corrosion forms and their financial importance might have been considered [7]. Recently an attractive interest to determine corrosion rate using reliable techniques has been considered [8]. Although weight loss measurement is the most direct and reliable corrosion rate determination technique, it is currently used with time consuming and information limited features. Polarization techniques; Tafel extrapolation and linear polarization resistance (LPR) examine the specimens faster with more information, and can be used in field detection combined with other methods. They are quantitative and powerful tools for researching corrosion process and features [9].

In order to describe reliable detection and monitoring polarization methods to investigate long-term corrosion behaviour of the TRC 8006 Al alloys, the present work studied the discrepancies between Tafel extrapolation and linear polarization resistance results. The corrosion behaviour of the abovementioned Al alloys used in 3.5 wt. % NaCl aqueous solution conditions was analysed.

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2. Material and Methods

2.1. Materials preparation

Twin-roll casting (TRC) 8006 Al alloys with coupons of dimensions 15x15x0.15 mm and 15x15x0.18 mm used were subjected to two polarization techniques (Tafel extrapolation and linear polarization resistance) under 3.5 wt. % NaCl aqueous solution. The coupons were subsequently exposed to the sodium chloride solution using an epoxy resin uncovered with a hole for 1.5 mm in diameter. Table 1 shows the chemical compositions of Al alloy in wt. % which were measured using WAS Foundry master UV optic emission spectrometer, Oxford, UK. All the specimens were polished using 4000 grit SiC polishing papers and then put into ethanol and ultrasonically cleaned and subsequently rinsed with distilled water. The specimens were exposed to salty solutions, which is 3.5 wt. % NaCl, filled in a chest for electrochemical measurements. The solutions were prepared in BTU's laboratory and the fresh solutions were used in each experimental measurements under the indoor average temperature, 23 ± 5 °C. When a steady state status of coupons was obtained, corrosion rates of the specimens were measured using the two polarization techniques, respectively. The measurements were performed in triplicate and averaged for each specimen.

Table 1. Chemical compositions in wt. % of the TRC 8006 aluminium alloy used in this work

Specimen	Al	Si	Fe	Mn	Zn	Cr	Cu	Mg	Zr
TRC 8006	Balance	0,402	1,73	0,705	0,167	0,0039	0,0280	0,0001	0,0020

2.2. Polarization techniques for determination of corrosion rates

Corrosion behaviour of the TRC 8006 Al alloys were examined by polarization techniques. Polarization measurements for determination of corrosion rates of the specimens were conducted with a CHI 608E potentiostat/galvanostat electrochemical cell system. The measurements were performed on a three-electrode electrochemical cell system in 3.5 wt. % NaCl aqueous solution. In the three-electrode electrochemical cell set up, the TRC 8006 Al alloy samples used as working electrode (WE), a graphite rod used as auxiliary electrode (AE) and a saturated calomel electrode (SCE) used as reference electrode. The schematic view of the three electrode electrochemical cell used in polarization measurements was demonstrated in Figure 1. TRC 8006 Al alloys were used as test samples with two different foil thickness. After a steady state occurred on the surface of the specimen, linear polarization resistance and Tafel extrapolation measurements were carried out at room temperature. The linear polarization resistance measurement were examined with a scan rate of 0.1 mV/s and the curves have -20 to +20 mV (vs. E_{corr}) potential range. The Tafel extrapolation measurements were performed with a scan rate of 5 mV/s and the curves formed from E_{corr} to cathode and E_{corr} to anode. Echem analyst software was used to assess the data collected from the polarization techniques performed. Polarization curves and the values derived from the curves for the TRC 8006 Al alloy specimen were obtained in triplicate and their averages were taken.

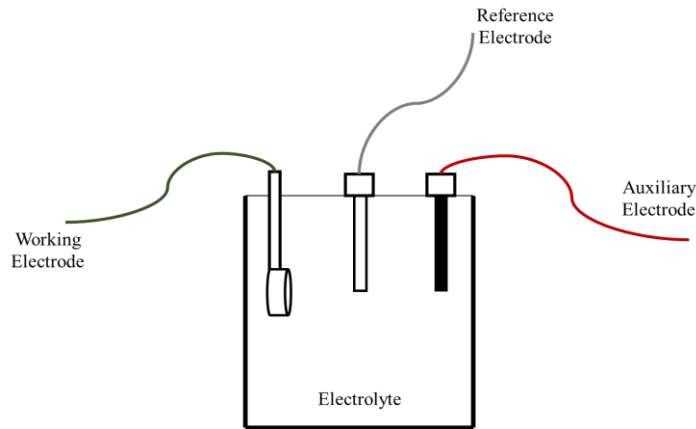


Figure 1. Schemes of electrochemical cell for the polarization techniques in 3.5 wt. % NaCl aqueous solution

3. Results and Discussion

3.1. Polarization curve behaviour

Due to the reliable and rapidly obtained results of electrochemical cell measurements, they are widely used to investigate corrosion properties of materials. Tafel extrapolation measurements are limitedly used since it has a destructive nature on sample surface. However, Tafel extrapolation has an invaluable role to assess corrosion characteristics of materials because the regions of the curve derived from the test provide us crucial information on corrosion behaviour of any materials. Tafel extrapolation method applied to the TRC 8006 Al alloys with two different foil thickness and the polarization curves obtained was depicted in Figure 2. As can be seen in Figure 2, less foil thickness of the TRC 8006 Al Alloy used leads to more positive value of the corrosion potential (E_{corr}) and changed slightly. The anodic portion shape of this curve and the anodic reaction mainly fluctuate and this specifies that the very thin aluminium oxide (Al_2O_3) layer causes an anodic process nominally (Figure 2). Generally, dissolution of active aluminium is the main anodic reaction. Moreover, the effect of the aluminium oxide layers on the shape of cathodic portion altered greatly. After the Tafel extrapolation measurements, the cathodic behaviours of both specimens showed different implementations, reducing of aluminium foil thickness results in an increase in the rate of cathodic reaction. Since cathodic process in 3.5 wt. % NaCl aqueous solution controlled the electrochemical measurement procedure for the TRC 8006 Al alloys, the growth of aluminium oxide layers which inferred variation of corrosion resistance between both specimens gives an increase in corrosion rate [10].

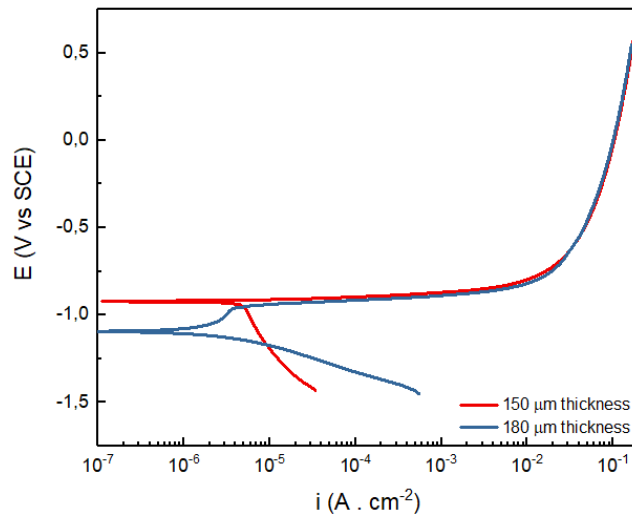


Figure 2. Tafel extrapolation curves of the TRC 8006 aluminium alloy for different foil thickness immersed in 3.5% NaCl solution

3.2. Comparison of corrosion rates for short-term exposure between Tafel extrapolation and linear polarization resistance results

An alternative polarization technique used to determine corrosion rate of the TRC 8006 Al alloy was linear polarization resistance method (LPR). As the resultant polarization curves obtained are almost accurate after the steady state condition obtained, this method is a non-destructive, quick and reliable to estimate corrosion characteristics of metals. Hence, this method was widely used in order to investigate the corrosion behaviour of aluminium sheets and foils [11, 12]. The resultant LPR curves of the TRC 8006 Al alloys with different foil thickness in 3.5 wt. % NaCl aqueous solution were represented in Figure 3. The resultant E_{corr} reading of the TRC 8006 Al alloy with a thickness of 150 μm shifted from a positive value and the E_{corr} value of the TRC 8006 Al alloy with a thickness of 180 μm shifted from a negative value and LPR curves got non-linearity progressively (Figure 3). This causes from the tenacious aluminium oxide layer which is stacking on the surface of the TRC 8006 Al alloys. Thus, the fitted zone was chosen from the linear region (-10 to +10 mV vs. E_{corr}) in order to determine the corrosion rate of both specimens.

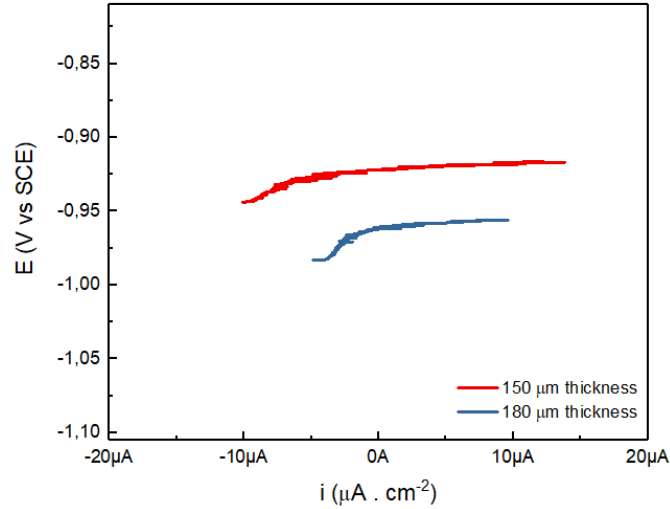


Figure 3. Linear polarization resistance curves of the TRC 8006 aluminium alloy for different foil thickness immersed in 3.5% NaCl solution

Linear polarization Tafel slopes (β_a and β_b), corrosion current (I_{corr}), corrosion potential (E_{corr}) and the polarization resistance (R_p) values were represented in Table 2 as a function of different foil thickness of the TRC 8006 Al alloys. It was observed that the results could be divided into three parts: R_p sharply decreased when the thickness of the TRC 8006 Al alloy went down, it changed remarkably. According to the Stern-Geary equation [13]:

$$i_{corr} = \frac{B}{R_p} \quad (1)$$

$$B = \left[\left| \left(\frac{\partial \ln I_a}{\partial (\Delta E)} \right)_{\Delta E=0} \right| + \left| \left(\frac{\partial \ln I_c}{\partial (\Delta E)} \right)_{\Delta E=0} \right| \right]^{-1} \quad (2)$$

Where I_a and I_c are anodic and cathodic current density separately in A, ΔE is potential difference and its unit is voltage, V. B could be manipulated as a function of corrosion behaviour and it is not always a constant. By using Stern-Geary equation, the corrosion rate was calculated from the LPR curves for all specimens. The anodic Tafel slopes (β_a) of the curves obtained changed remarkably when a reduction in foil thickness of the TRC 8006 Al alloy, but the cathodic Tafel slopes (β_c) of the curves increased in the present work Table 2. Furthermore, B value does not change from a decrease in foil thickness and the corrosion rate and thus an accurate value of B could not be estimated simply.

The values of i_{corr} , estimated by substituting B into Stern's formula, were compared to the results determined by Tafel extrapolation measurement in Table 2. Table 2 also shows corrosion loss as a function of foil thickness which was obtained by integration after Faraday transformation. The variation of instantaneous corrosion rate occurs with decreasing thickness of TRC 8006 specimens. With a decrease in thickness of TRC 8006 specimens, both corrosion loss and instantaneous corrosion rate by Tafel extrapolation and LPR measurements had the same variations and similar increase in values. There is no doubt that the corrosion rate determined by both polarization techniques are credible and the results obtained have similar trend in values which confirms both techniques could be used alternatively corrosion rate determination methods to assess corrosion behaviour of TRC 8006 aluminium alloys.

Table 2. Linear polarization Tafel slopes, density of corrosion current, potential corrosion rate and polarization resistance values obtained from the polarization techniques performed in this experimental work

	Tafel Extrapolation		Linear Polarization	
	150 μm Thickness	180 μm Thickness	150 μm Thickness	180 μm Thickness
β_a (mV/dec)	40	10^{15}	120	120
β_c (mV/dec)	106×10^{12}	145	120	120
I_{corr} (μA)	6.250	4.860	47.87	20.38
E_{corr} (mV)	-923	-1090	-921.9	-961.2
R_p (ohms)	-	-	544.3	1278
Corrosion Rate (mpy)	856.5×10^{-3}	658.8×10^{-3}	6.493	2.766

4. Conclusions

For the TRC 8006 Al alloys used in the present work, an increase in corrosion rate determined by both polarization curve measurements (Tafel extrapolation and LPR) observed when less is achieved at each foil thickness. This confirms that electrochemical estimation coincided with Tafel extrapolation and LPR results during short term immersion, which indicated that the data collected presented similar behaviour in variations and values. This shows both polarization techniques seem very talented and reliable crucial methods to accurately determine corrosion rate and estimate corrosion behaviour of TRC 8006 aluminium alloys.

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References

- [1] Nisancioglu, K., Holtan, H. (1978). Measurement of the critical pitting potential of aluminium. *Corrosion Science*. 18(9): 835-849.
- [2] Wang, J., Zhou, X., Thompson, G.E., Hunter, J.A., Yuan, Y. (2015). Near-surface microstructure on twin-roll cast 8906 aluminum alloy. *Metallurgical and Materials Transactions A*. 46(6): 2688-2695.
- [3] Rahimi, M., Fojan, P., Gurevich, L., Afshari, A. (2015). Aluminium alloy 8011: Surface characteristics. in *Applied Mechanics and Materials*. 2015. Trans Tech Publ.
- [4] Sanders, R. E. (2012). Continuous casting for aluminum sheet: a product perspective. *JOM*. 64(2): 291-301.
- [5] Okeoma Kelechukwu, B., Owate Israel, O., Oguzie Emeka, E., Mejeha Ihebrodike, M. (2012). Effects of Heat Treatment on the Electrochemical Corrosion Behaviour of Aluminum Alloy AA8011 in 0.1 M H₂SO₄ Aqueous Acid Media.
- [6] Barekar, N., Dhindaw, B. (2014). Twin-roll casting of aluminum alloys—an overview. *Materials and Manufacturing Processes*. 29(6): 651-661.
- [7] Davis, J.R. (1999). Corrosion of aluminum and aluminum alloys. Asm International. 10 p.
- [8] Park, S.-A., Kim, J., He, Y., Shin, K., Yoon, J. (2014). Comparative study on the corrosion behavior of the cold rolled and hot rolled low-alloy steels containing copper and antimony in flue gas desulfurization environment. *The Physics of Metals and Metallography*. 115(13): 1285-1294.
- [9] Kurt, K., Diplas, S., Walmsley, J.C., Nisancioglu, K. (2013). Effect of Trace Elements Lead and Tin on Anodic Activation of AA8006 Aluminum Sheet. *Journal of The Electrochemical Society*. 160(11): C542-C552.
- [10] Kucuk, İ . (2018). Effect of Cold Rolling Reduction Rate on Corrosion Behaviour of Twin-roll Cast 8006 Aluminium Alloys. *Cumhuriyet Science Journal*, 39 (1): 233-242.

- [11] van der Merwe, J., Palazzo, A. (2015). Comparison of linear polarization resistance corrosion monitoring probe readings and immersion test results for typical cooling water conditions. *Journal of the Southern African Institute of Mining and Metallurgy*. 115(3): 173-178.
- [12] Zou, Y., Wang, J., Zheng, Y. (2011). Electrochemical techniques for determining corrosion rate of rusted steel in seawater. *Corrosion Science*. 53(1): 208-216.
- [13] Stern, M. (1958). A method for determining corrosion rates from linear polarization data. *Corrosion*. 14(9): 60-64.