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Comparison Study of Magnesium Anodizing by using Alternating Current (AC) and Direct Current (DC)

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ABSTRACT. The corrosion behavior of a AZ80 Magnesium alloy which anodized using a different power source AC and DC up to 30 V in an alkaline silicate solution containing 60 g/L sodium hydroxide, 10 g/L sodium silicate and 40 g/L sodium phosphate has been investigated using linear polarization method. The change of the oxide film morphology both of anodized sample also examined using scanning electron microscopy. Anodization of the AZ80 Mg alloy significantly improves its corrosion resistance for both power source as the potential applied up to 30 V. The Tafel polarization method result demonstrated that corrosion resistant was also increased by voltage applied which also lead to better corrosion resistant. Sample that been anodized with AC power source has more compact surface with pores structure compared to the sample anodized with DC power source. The anodic film is mainly composed of MgO, Mg_2SiO_4 and $Mg_3(PO_4)_2$.

Keywords: *Anodizing, Magnesium AZ80, Corrosion, Characterization;*

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1. INTRODUCTION

Magnesium alloys have many outstanding properties relative to other engineering materials such as low density, high strength, great damping capability, excellent fluidity for casting, high temperature conductivity, low heat capacity, less negative electrochemical potential, suitable for recyclability, and non-toxicity. These properties make magnesium alloys attractive to many industries especially in the automotive and aerospace sectors where the strength/weight ratio is main concern. Magnesium (Mg) alloys have been seen as a promising alternative to aluminum alloy [1, 2].

However, despite all of the advantages of the Mg alloy, their poor corrosion and wear resistance limits their usage specifically in harsh environments [3]. Proper surface treatment such as anodizing is vital further to produce protective film which can help in corrosion protection of magnesium.

Anodizing is an electrolytic oxidation process where the surface of the metal is converted into a thick and stable oxide film. Making an anodizing under high voltage using DC current has attracted many researchers due to excellent adherence between the coating and substrate [4-6]. Higher voltage oxidation film is generally porous and brittle and sparking might occur at higher potential hence reduce the mechanical properties of magnesium alloys [7]. However, a limited study is found on comparing between both anodizing process using different power sources which are alternating current (AC) and direct current (DC) at low potential. This research aims to compare the different of both power sources to oxide film formed on the surface of magnesium alloy.

2. MATERIALS AND METHODS

Rectangular shape (15 mm×15 mm×3 mm) of magnesium alloy AZ80 (Al 7.5 wt.%, Zn 0.22 wt. %, Mn <0.51 wt.%, Si <0.01 wt.%, others <0.01 wt.% balance Mg) were used as substrates in this study. All samples were prepared from the same area of a cast ingot in order to minimize the differences in composition and microstructure. After grinding up to 1200 grit paper, the samples were first cleaned with acetone and then ultrasonically cleaned in distilled water. Electrolytes were prepared from solutions of 60 g/L sodium hydroxide, 10 g/L sodium silicate and 40 g/L sodium phosphate.

During anodizing process, the samples to be coated and a platinum electrode used as a cathode were connected to a DC and AC power source. The electrolyte was stirred by magnetic stirring equipment in order to maintain a uniform distribution of solution concentration and temperature. Microstructure analysis performed using JOEL-JSM-6460LA Instrument to characterize the surface morphology of the samples before and after anodizing process with different power source. X-ray diffraction (XRD) analysis performed using a Shimadzu XRD 6000 diffractometer at 2θ values of 20-80° with Cu Kα radiation to determine the phases of the anodic film and later analyzed by X'Pert High Score Plus software.

Polarization measurements were conducted using a custom three electrode flat corrosion cell system which has a 1 cm^2 exposed area for a working electrode to expose its flat surface to the electrolyte in the cell. The working electrode specimen in a slot holder outside the cell was attached tightly to the window by a steel screw bolt through the holder. The bolt pushed the specimen firmly against the window, and also acted as an electrical conductor to connect the working electrode specimen to an electrochemical measurement system. Platinum plate was used as counter electrode and saturated calomel electrode (SCE) were used as reference electrode in 3.5 wt.% NaCl solution. The measurement was performed using AUTOLAB PGSTAT 204 and analyzed using NOVA software. The scanning rate for potentiodynamic polarization was 1 mVs^{-1} and the scan potential range used was -2.0 to 1.5 V Vs SCE.

3. RESULTS AND DISCUSSION

3.1 Polarization Measurement. The results of linear polarization experiments at different voltages and power source was summarized in Table 1. The anodic behavior of Mg alloys is strongly influenced by the voltage applied [8]. The corrosion resistance of AZ80 magnesium alloys is enhanced significantly as the anodizing potential applied is increased. This is notable by the decrease in Corrosion current (Icorr) and shift of Corrosion potential (Ecorr) in the noble direction (more positive values) for both anodized sample in comparison with AZ80 substrate. The corrosion rate drops from 0.689 mm/year to 0.571, 0.236, 0.211 and 0.112 mm/year for DC power source and drops from 0.883 mm/year, 0.3987, 0.2867, 0.1263 and 0.0579 mm/year. Different passive and active states were found, depending on the applied voltage and power source on the substrate. At different anodizing voltage, the anodized coatings have different formation processes.

Table 1 Results of potentiodynamic corrosion tests experiment using Tafel extrapolation method

Power Source	Sample	Icorr(μA)	icorr(μA/cm^2)	Ecorr (V)	Corrosion rate (mm/year)
DC	10V	25.266	32.186	-1.4507	0.68861
	15V	13.255	16.885	-1.0175	0.571
	20V	8.4337	10.744	-1.2768	0.23607
	25V	7.6186	9.7052	-1.4121	0.21325
	30V	4.0149	5.1145	-1.2529	0.11238
AC	10V	31.57	40.217	-1.1394	0.88369
	15V	14.245	18.146	-1.2323	0.39873

20V	10.241	13.046	-1.0608	0.28666
25V	4.5116	5.7473	-1.1259	0.12628
30V	2.6387	2.0714	-1.344	0.057981

Fig. 1 shows potentiodynamic curves tested on AZ80 magnesium alloys before and after anodizing processes by using different power source at 30 V. Corrosion potential for both anodized sample are shifted in the more positive electropositive value compared to AZ80 substrate. Its is shows these both sample indicate a higher corrosion resistance [9].

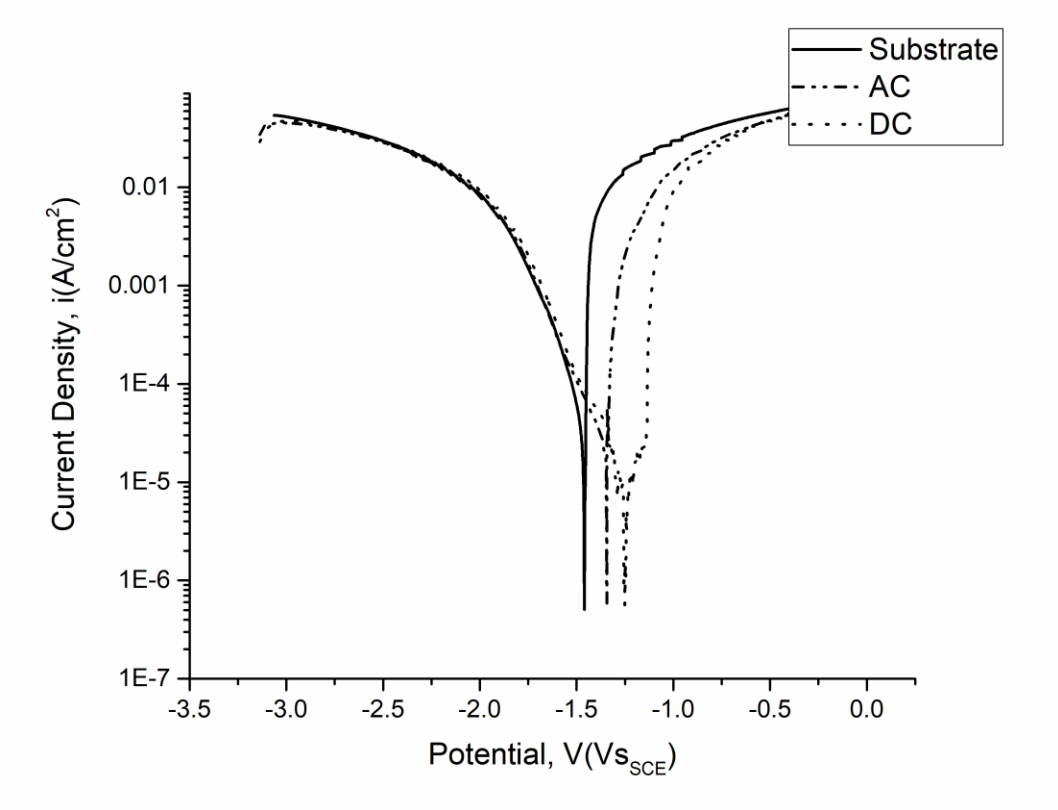
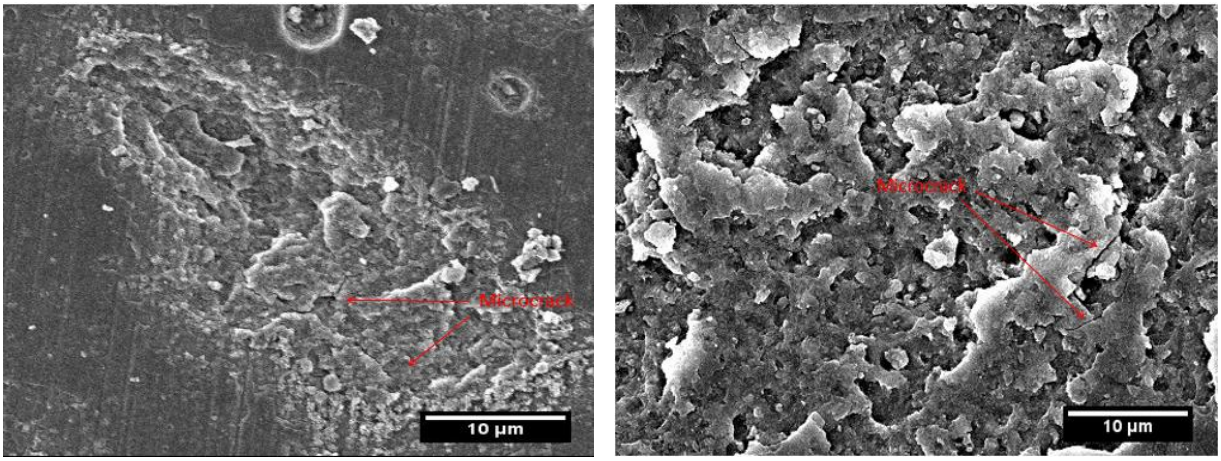


Fig. 1 Potentiodynamic polarization curves for the anodized specimens both AC and DC at 30 V

3.2 Surface morphology analysis. The microstructures of anodic films on AZ80 magnesium alloys show in Fig. 2. Both samples has a granular rough surface with microcracks. However, sample that been anodized with AC power source has more compact surface with pores structure compared to the sample anodized with DC power source that show non-uniformity of coating. The coating on DC power source form with island like shape compared to AC power source that is more uniform. Micro cracks are noticeable on the coated surface (Fig. 2). The formation of cracks caused by thermal stresses resulted from rapid cooling of the oxides by the electrolyte. The electrolyte act as a coolant agent in the anodizing process. This is agreed by El Mahallawy et. al that studied on AZ91 magnesium alloy [9]. These differences on surface result from the differences of spark behavior and evolution of gases, as in AC power source the spark phenomena was stronger and accompanied with higher evolution of gases and generation of heat compared to DC power sources.

3.3 Phase Composition. The XRD pattern of the anodized film is shown in Fig. 3. The XRD pattern shows that both of the anodized sample is mainly composed of MgO, Mg_2SiO_4 and $Mg_3(PO_4)_2$. This shows the components

of the electrolyte which is Silicon (Si) and Phosporus (P) and the AZ80 substrate (Mg) participate in the anodic film formation during anodizing process. The XRD spectrum of AC anodized sample exhibit more Mg_2SiO_4 phase compared to DC sample. Silicate medium (Mg_2SiO_4) contributed to the better corrosion resistant where the silicate medium function as a seal to porosity of the anodic coating [10].



a) b)

Fig. 2 Surface morphology of the anodized AZ80 Mg Alloy with a different power source (a) DC and (b) AC at 30V

This is accordance with the tafel polarization curve result presented in the Fig. 1. The formation mechanism of MgO can be shown by the following reactions [11] :

$$Mg = Mg^{2+} + 2e \quad (1)$$

$$Mg^{2+} + 2OH = Mg(OH)_2 = MgO + H_2O \quad (2)$$

$$4OH = 2H_2O + O_2 + 4e \quad (3)$$

$$2Mg + O_2 = 2MgO \quad (4)$$

A high temperature phase transformation occurs between SiO_2 and MgO at sparking areas, and finally transforms into Mg_2SiO_4:

$$SiO_2 + 2MgO = Mg_2SiO_4 \quad (5)$$

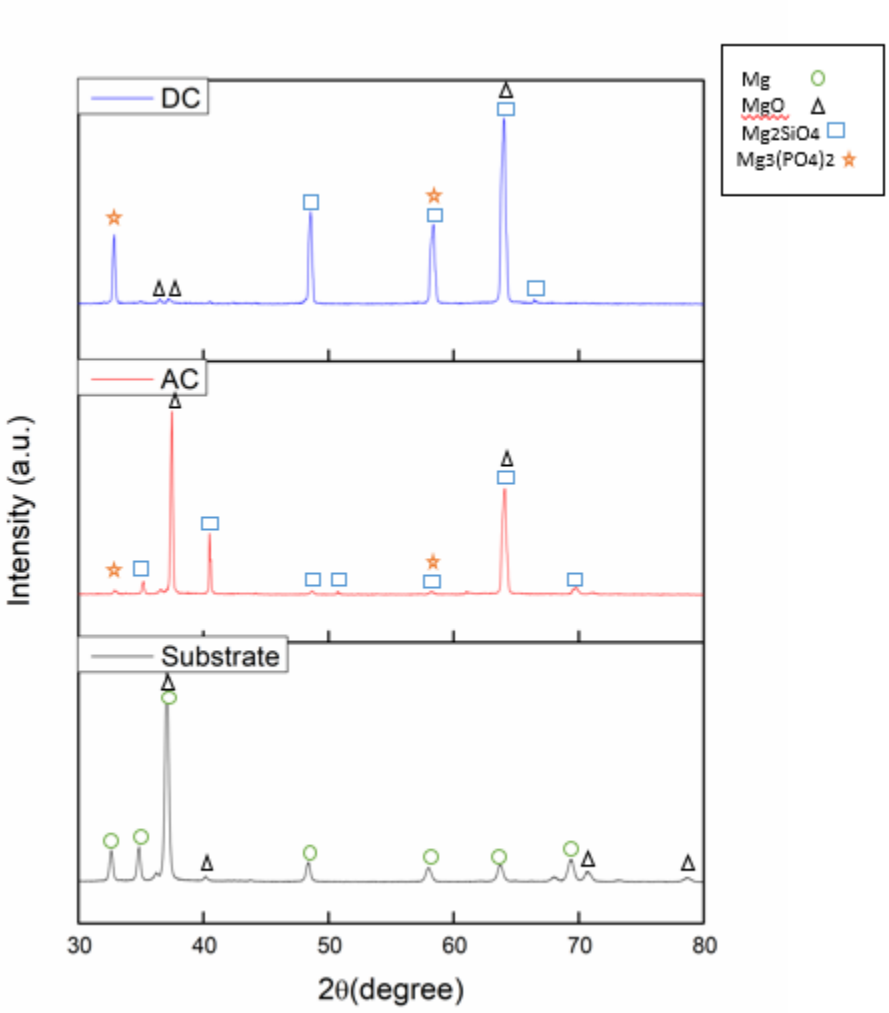


Fig. 3 XRD pattern for anodized sample

4. SUMMARY

In this work, anodizing completed at different potential in order to access the effect power source on the surface morphology and the anodic behavior. This study found that the increased of the anodizing potential up to 30 V will enhance the corrosion resistance of AZ80 magnesium alloys significantly for both power source AC and DC. However, the sample that anodized with 30 V AC power source is much more compact than the basic film, which results in better corrosion resistance compared to the sample anodized with DC which is 0.0579 mm/year and 0.11238 mm/year respectively. The anodized film for both power source basically has granular rough surface with some microcracks. The anodic film is mainly composed of MgO, Mg_2SiO_4 and $Mg_3(PO_4)_2$

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