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THE EFFECT OF HEAT TREATMENT ON THE OPEN CIRCUIT POTENTIAL OF MAGNESIUM SACRIFICIAL ANODE

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ABSTRACT

Magnesium sacrificial anode that possess high value of open circuit potential, E_{oc} is needed as it can protect larger area of underground metal structure in cathodic protection. Solution treatment was applied on magnesium sacrificial anode at 150, 200, 250, 300 and 350 °C for 8 hours and cooled in different medium (furnace, air, water, iced water and iced salt water) to obtain the above criteria. The open circuit potential versus saturated calomel electrode was studied in backfill solution using by Gill/AC Potentiostat. It was found that low solution treatment at 150 °C with high cooling rate gave the highest value of open circuit potential, whereas solution treatment at high temperature (350°C) with iced water quench gave the lowest value of open circuit potential.

Keywords: Cathodic protection, Sacrificial anode, Heat treatment, Open circuit potential

INTRODUCTION

Aluminium, magnesium and zinc alloys are used as sacrificial anodes for metal protection in aqueous and soil environments. Aluminium and zinc-based alloys are widely used for cathodic protection (CP) of steel in marine environments, while magnesium-based alloys are more appropriate in high resistivity environments, because of their theoretical low half-cell potential, as well as the possibility of high current capacity inherent negative potential and high current output per unit weight is desirable capacity to drain the current (Gabricle and Scantlebury, 2003; Campillo *et al.*, 1997). Magnesium anodes generally have voltage around -1.55V to -1.7V vs. saturated calomel electrode higher than that of other galvanic anodes (PWTB, 2001). Campillo *et al.*, (1997) found that by heat-treating a commercial anode alloy, the current efficiency could be increased by as much as 40% above the as-cast efficiency. Structure was finer grained (5 to 10 µm vs 100 µm for the cast Mg) with very fine precipitates distributed in the matrix. This produced more general corrosion as opposed to pitting corrosion. The presence of Mn-rich particles (which are cathodic to Mg) at the grain boundaries were responsible for anode inefficiency. They also found that by heat treating to certain temperature also increased the value of open circuit potential. Therefore, the present study has focused on the effect of solution treatment and its cooling method on the commercial magnesium anode to the open circuit potential (E_{oc}) value.

EXPERIMENTAL PROCEDURE

A commercial magnesium anode was selected for solution treatment at 150 – 350 °C for 8 hours using high temperature oven. Different cooling methods were applied which were furnace, air, water, iced water and iced salt water cooling respectively. Temperature for each cooling medium is shown in Table 1. After cooling process, the specimens were stored in freezer at -10 °C. For open circuit potential (E_{oc}) measurement, the samples were ground up to 1200 grit SiC paper. The samples then were ultrasound cleaned by acetone and rinsed by distilled water. The specimens were dried and stored in dry cabinet for at least one day before testing.

Table 1: Temperature of cooling medium.

Method	**T /°C**
Furnace cooled	0.56°C /min
Air cooled	28
Water	26
Iced Water	0
Iced Saltwater	-12.5

Chemical composition of commercial Mg alloy anode was analyzed by optical emission microscope (OES 5500 VERSION II). The electrolyte was backfill solution containing 75% gypsum, 20% bentonite and 5% natrium sulphate that was originated from 7 g backfill powder in 1000 ml distilled water. This solution was prepared according to soil simulation as stated in ASTM G-97 (ASTM, 2003). The E_{oc} measurements were carried out for 15 hours using a Gill/AC Potentiostat. Experiments on E_{oc} were carried out in a 1 L corrosion cell by using a saturated calomel electrode (SCE) as reference electrode. Mg alloy specimens were encapsulated in polyester resin. The chemical composition of Mg anode is shown in Table 2.

Table 2: Composition of magnesium alloy anode.

Element	Mg	Mn	Fe	Si	Cu
wt%	99.7	0.2	0.047	0.01	0.009

RESULTS AND DISCUSSION

Table 3 shows the average value of E_{oc} after 15 hour. It was observed that by applying different solution treatment and cooling method, E_{oc} of the specimen were varied.

Table 3: The Average Of E_{oc} 15 Hour Test Duration

Specimen	E_{oc}/V_{SCE}
As Received	-1.6456
150 °C Water quenched	-1.5877
150 °C Iced water quenched	-1.6037
150 °C Iced salt water quenched	-1.6713
150 °C Air cooled	-1.6633
150 °C Furnace cooled	-1.6566
200 °C Water quenched	-1.6112
200 °C Iced water quenched	-1.6618
200 °C Iced salt water quenched	-1.6454
200 °C Air cooled	-1.6539
200 °C Furnace cooled	-1.6312
250 °C Water quenched	-1.6616
250 °C Iced water quenched	-1.6512
250 °C Iced salt water quenched	-1.5652
250 °C Air cooled	-1.6262
250 °C Furnace cooled	-1.5910
300 °C Water quenched	-1.5711
300 °C Iced water quenched	-1.5680
300 °C Iced salt water quenched	-1.5399
300 °C Air cooled	-1.5595
300 °C Furnace cooled	-1.5605
350 °C Water quenched	-1.4895
350 °C Iced water quenched	-1.4550
350 °C Iced salt water quenched	-1.4911
350 °C Air cooled	-1.4931
350 °C Furnace cooled	-1.4867

Generally, the result shows the solution treatment temperature has plays important role in E_{oc} behaviour. It shows that low temperature solution treatment at 150 °C results to more negative E_{oc} (-1.6713 V_{SCE}), compared to high temperature solution treatment. It was observed that solution treatment at 350 °C results the lowest E_{oc} (-1.4550 V_{SCE}). This statement was shown in detail in Figure 1. Apart of that, it was observed that specimen which solution treated above 250 °C has low negative E_{oc} compared to as received specimen. Thus, this meant that solution treatment temperature above 250 °C not has a capability to increase the E_{oc} and also reduce its potential.

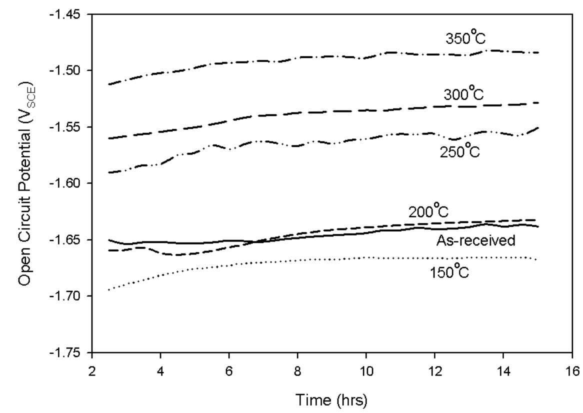

Fig 1: E_{oc} Value of Mg Alloy Anode Solution Treated at Different Temperature and Cooled in Iced Salt Water.

Figure 2 shows the cooling method also plays important role affecting the E_{oc}. It displays the E_{oc} was gradually increase depend on cooling medium temperature where lower temperature of cooling medium results higher E_{oc}. For 150 °C solution treatment, specimens that quenched in iced salt water was observed results the high and stable value of E_{oc} (-1.6713 V_{SCE}).

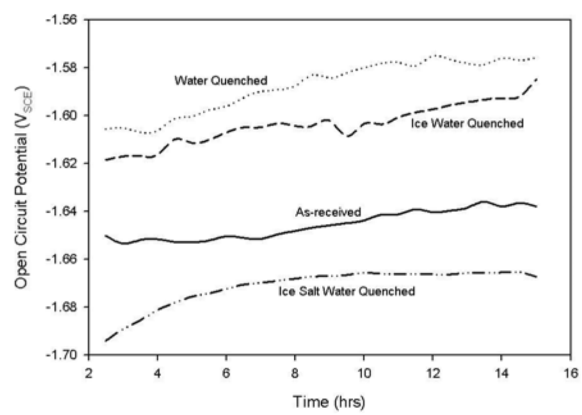

Fig. 2. E_{oc} Value of Mg Alloy Anode Solution Treated at 150 °C in Different Cooling Method in Iced Salt Water

It is believed that by solution treating the Mg alloy anode at 150 °C, the α-Mn phase tend to dissolve in the Mg matrix. Then rapid cooling cause the α-Mn phase remains dissolve in the Mg matrix. This could reduce the tendency of Mg to corrode along the grain boundary as the Mn-rich impurity phase that is cathodic to the Mg grain (Gummow, 2004). Solution treatment at temperature above 250 °C may cause by insoluble particles of iron-manganese, second phase manganese, silicon and copper. These impurities may act as local galvanic cell within the matrix which reduce the E_{oc} (Campillo *et al.*, 1997). Further study on the microstructure and phase that occur in the solution treated Mg anode will be carried out to confirm the above effect.

CONCLUSIONS

Heating the magnesium alloy anode to certain temperature and cooled in suitable method could increased the value E_{oc}. It was found that solution treatment at 150 °C with high cooling rate gave the highest value of open circuit potential whereas solution treatment at high temperature (350 °C) and iced water quench gave the lowest value of open circuit potential.

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