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# ELECTROCHEMICAL CORROSION CHARACTERISTICS OF ALUMINIUM ALLOY 6061 T6 IN DEMINERALISED WATER CONTAINING 0.1% CHLORIDE ION

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## ABSTRACT

*Direct current electrochemical method is one of the techniques has been used to study the corrosion behaviour of metal/alloy in its environment. This paper attempts to investigate the corrosion behaviour of Al 6061 T6 immersed in Reactor TRIGA Mark II pool water containing about 0.1% NaCl content. The result shown that the corrosion rate value of the aluminium 6061 T6 increased with the presence of 0.1% Ion Chloride content in the deminelised water reactor pool as compared to normal water. This is due to aggressiveness of chloride ion attack to metal surface. Beside corrosion rate analysis, the further tests such as corrosion behaviour diagram, cyclic polarization have been carried and the results have been reported.*

## ABSTRAK

*Kaedah elektrokimia arus langsung merupakan salah satu teknik yang telah digunakan untuk mengkaji ciri-ciri kakisan logam / aloi di dalam persekitaran. Kertas kertas ini menerangkan penyiasatan tentang ciri-ciri kakisan Al 6061 T6 apabila direndam dalam kolam air Reaktor TRIGA Mark II yang mengandungi kira-kira 0.1% kandungan NaCl. Hasil eksperimen ini menunjukkan bahawa nilai kadar kakisan Aluminium 6061 T6 meningkat dengan kehadiran Ion 0.1% Ion klorida di dalam kolam reaktor air suling berbanding dengan air suling biasa. Ini adalah disebabkan serangan agresif ion klorida ke permukaan logam. Selain analisis kadar kakisan, ujian lanjut seperti rajah kelakuan kakisan, polarisasi kitaran telah dijalankan dan keputusan telah dilaporkan.*

**Keywords :** Direct Current Electrochemical Method, Ion Chloride, Corrosion rate, Al 6061 T6

## INTRODUCTION

Aluminium alloy 6061 T6 is a precipitation hardening aluminium alloy that containing magnesium and silicon as a major alloying element. By suitable quenching and aging a fine precipitates of $Mg_2Si$ can be developed which imparts high strength to the alloy while still retaining adequate ductility. In this T, or tempered, condition the alloy finds application in some water cooled reactors and has been found to provide exceptionally good service (1).

Aluminium has been employed as a structural material in most research reactor due of its good mechanical properties and weld ability. The Aluminium alloy 6061 T6 has been successfully used in structural application in several research reactor including Reactor TRIGA Mark II PUSPATI. The grid plate of the control rod was made from the aluminium alloy 6061 T6.

Electrochemical testing is a famous technique to study the corrosion behaviour of the material in the electrolyte. This technique is popular because they can be carried out in a short period of time. A very useful electrochemical technique used for corrosion studies is the Tafel plot, where the corrosion current can be easily determined. This technique can be a very useful approach to investigate the aluminium corrosion cause by different electrolytes due to different of electrolyte conductivity. In additional, the tafel plot was used to study different corrosion inhibitors in order to identify the corrosion inhibitor and the concentration providing the best protecting performance against aluminium corrosion. (2)

## MATERIAL AND METHOD

### *Chemical Composition Testing*

The Aluminium alloy 6061 T6 was analyzed using Spark Emission Spectroscopy. The result was shown as per table 1. From the result, it was confirm that the material are Al 6061 T6 that was practically used as a structural material in nuclear reactor.

Table 1 : Chemical composition of Al 6061 T6

| Element | Actual Reading (%wt) | Standard Chemical Composition (%wt) |
|---|---|---|
| Al | 97.7 | 95.8-98.6 |
| Si | 0.502 | 0.4-0.8 |
| Fe | 0.413 | Max 0.7 |
| Cu | 0.206 | 0.15-0.4 |
| Mn | 0.115 | Max 0.15 |
| Mg | 0.756 | 0.8-1.2 |
| Cr | 0.211 | 0.04-0.35 |
| Ti | 0.0118 | Max 0.15 |
| Zn | 0.005 | Max 0.25 |

### *Electrochemical Testing*

Test specimens of 1cm$^2$ with 5.00 mm thickness with composition mentioned above were cut from the stock sheet. Prior to any test the samples were mechanically grinded on a range of silicon carbide paper up to 1000 grit finish and finally polished with diamond paste up to 1µm particle size until a mirror finished was obtained. The test specimens were washed in distilled water and rinsed using acetone. Test specimens with 1cm$^2$ exposure surface area were put in specimen holder and exposed to contaminated demineralised water test solution attached to corrosion flask.

Experiments were carried out at ambient temperature in stagnant demineralised water condition collected from research reactor TRIGA Mark II. In order to study of the effect Sodium Cloride to the system, the demineralised water from reactor pool was added with 1ppm NaCl and 0.1% NaCl. The electrochemical measurement were performed in corrosion cell system model K47, suspended in corrosion flask, with a twin high density, non permeable, graphite counter electrode and reference electrode bridge tube. The measurements were carried out using a gamry's software.

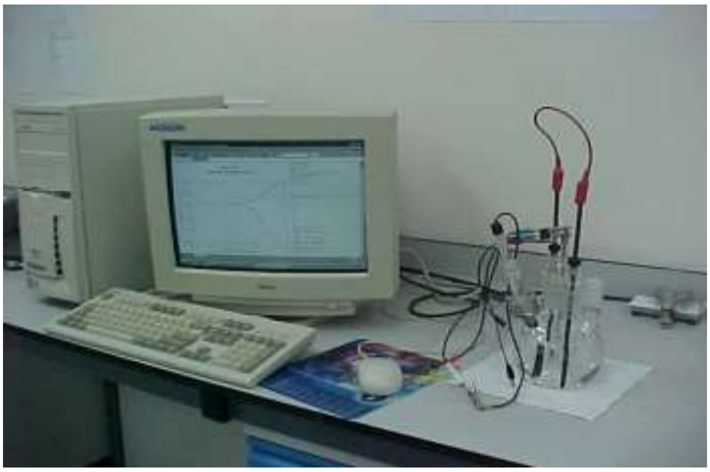


Figure 1 : Corrosion test apparatus

## RESULTS AND DISCUSSION

The polarization tafel curves of the Aluminium alloy 6061 T6 was measured in three test solution as shown in the figure 2. Polarization, both in cathodic and anodic direction, started at open circuit potential observed after 60 minute of immersion in test solution

### *Corrosion Potentials and Cathodic Tafel Plots*

In stagnant reactor pool water and its content small amount of ion chloride up to 0.1% NaCl, the corrosion potential shifted towards more negative values from -419 to -593mV with respect to Saturated Calomel Electrode (SCE). Results also show the cathodic current density of test specimens increased with increasing chloride content in reactor pool water. Cathodic reduction of oxygen reaction was occurred and followed as equation below:

$$O_2 + 2H_2O + 4e \rightarrow 4OH^-$$

Therefore the pattern of each cathodic Tafel slope is quite similar but indicates different values of corrosion potential and cathodic current density tested.

### *Anodic Tafel plots*

The anodic Tafel slopes are in the region $20\text{x}10^{-3}$ – $102\text{x}10^{-3}$ V/decade in a given test environment, indicating that the anodic dissolution processes occur with significantly activation polarization. The reaction of anodic dissolution process is

$$Al \rightarrow Al^{3+} + 3e$$

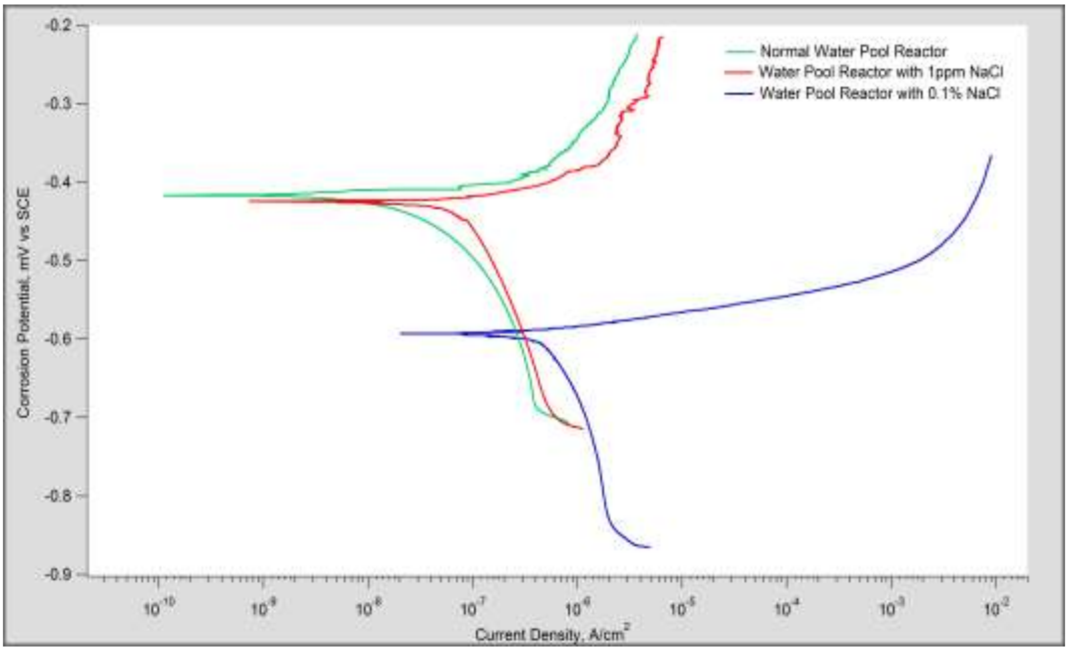


Figure 2 : Tafel plot graph for Aluminium 6061 T6 in three different of chloride content in reactor pool at ambient temperature.

The increases in corrosion rate (Table 1) from 0.6787x10-3 to 5.542x10-3 mm/yr, on containing chloride in reactor pool water showed that corrosion is anodically controlled. The current density, $I_{corr}$ was shifted to right side position that was resulting of increasing corrosion rate. It means that the aluminium become more active in corrosion process by present of ion chloride. In the whole anodic polarization range, all the tafel plot show active behaviour.

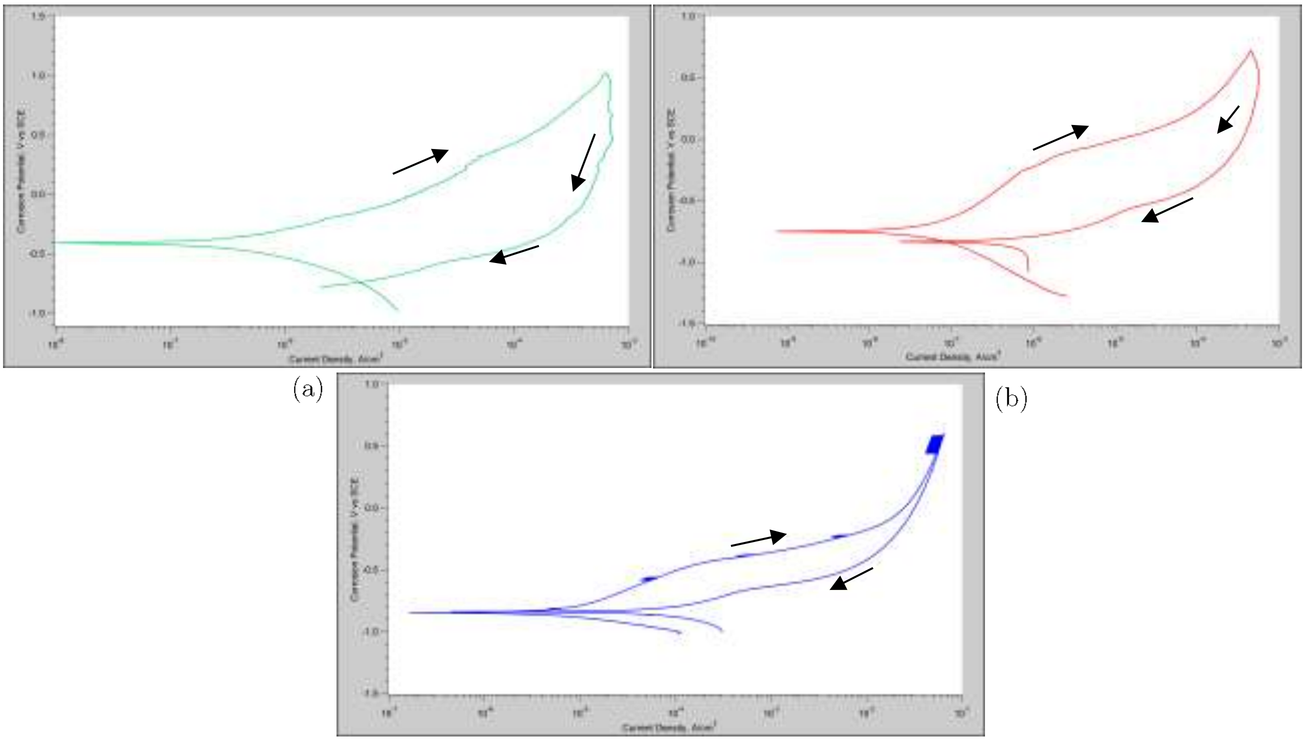
The overall analysis of aluminium in three different electrolyte was shown in the Table 1.

Table 1 : Tafel analysis of Al 6061 T6 in contaminated demineralised water with normal condition, 1 ppm NaCl and 0.1% NaCl

| | Anodic Tafel Constant (V/decade) | Cathodic Tafel Constant (V/decade) | Corrosion Current Density, $I_{corr}$ (A/cm$^2$) | Corrosion Potential, $E_{corr}$ (mV) | Corrosion Rate (mm/yr) |
|---|---|---|---|---|---|
| Normal Water | 102.1e-3 | 301.5e-3 | 61.60 nA | -419.0 | 0.6787e-3 |
| With 1 ppm | 35.70e-3 | 346.6e-3 | 95.60 nA | -425.0 | 1.052e-3 |
| With 0.1% NaCl | 20.70e-3 | 277.6e-3 | 503.0 nA | -593.0 | 5.542e-3 |

### *Cyclic Polarization Analysis*

Pitting studies were conducted by the well-known ASTM cyclic polarization techniques. A typical cyclic polarization diagram is shown in figure 3. The diagram shows repassivation potential $E_R$ and corrosion potential $E_{corr}$.. Pitting potential ($E_p$) is the reproducible experiment measurement characteristic of pit initiation. Repassivation potential ($E_R$) exist between the oxide covered metal and electrolyte. Pits do not initiate or propagate below $E_R$. From the figure 3, there are no pitting potential $E_p$ appear in the diagram.



(a) (b)

(c)

Figure 3: Cyclic Polarization for Aluminium alloy 6061 T6 in (a) normal water reactor pool (b) with 1ppm NaCl (c) with 0.1% NaCl

Table 3 : Cyclic Polarization test result

| Sample | Mean $E_{corr}$ (mV) | $E_R$(mV) | Pitting susceptibilitty ($E_R$ - $E_{corr}$) |
|---|---|---|---|
| Al 6061 T6 in normal reactor pool | -413.0 | -742.0 | -329.0 |
| Al 6061 T6 with 1ppm NaCl | -756.0 | -836.0 | -80 |
| Al 6061 T6 in 0.1% NaCl | -849.0 | -837.0 | 12 |

The range of $E_R$-$E_{corr}$ was indicate the conservative measure of pitting susceptibility. The negative value means that there are no pitting will be occur. The high range in positive value means that there are likelihood that pitting will occur at all. From the experiment, it was shown that increasing the chloride content in the solution caused Aluminium alloy 6061 T6 was tendency for pitting corrosion.

Pitting corrosion in aluminium alloys has recently been comprehensively reviewed by Szklararska-Smialowska (6). Aluminium is known to undergo pitting corrosion in solution containing Cl- and F- ion (3-5). Figure 4 show the theoretical of cyclic polarization of the metal . At the potential above $E_{pit}$, new pits are initiating and growing. Therefore, the difference between $E_p$ and $E_{corr}$ give the safety indication of the material integrity due to corrosion resistance to the environment. High value indicate that material resistance to the corrosion.

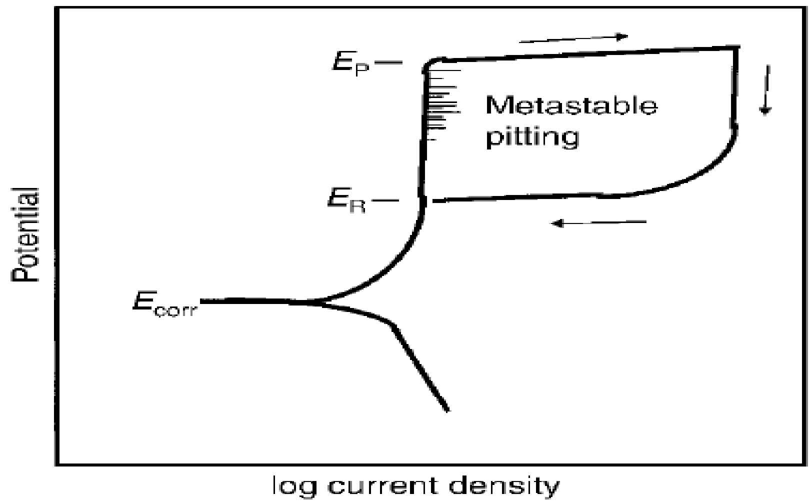


Figure 3: Schematic of plarization curve showing critical potentials and metastable pitting region. Ep, pitting corrosion; ER, repassivation potential; E corr, corrosion potential. Source : Ref 1

The analysis of polarization test result shown that Al 6061 T6 have a high active range before it reach a passive point where this material have high corrosion resistance when immersed in demineralised water reactor pool. The pitting susceptibility range was slightly drop in positive sign by present of the ion chloride in the reactor pool. It means that, the corrosion resistance of Aluminium alloy 6061 T6 was reduce and slowly contribute to the pitting corrosion when value of $E_R$ more than value of $E_{corr}$. In general, pitting is not regarded as a particularly damaging form of corrosion in aluminium, but it could act as a pre requisite to more severe modes of corrosion such as stress corrosion cracking and corrosion fatigue, as they frequently initiate and grow from pits (7)

## CONCLUSION

Aluminium alloy 6061 T6 have a high corrosion resistance in demineralised water reactor pool. The presence of the chloride ion was reduce the integrity of aluminium to resist the corrosion. In order to control of the corrosion from occur, the conductivity of the demineralised water must be control by reduce the chloride ion content that contribute to the corrosion.

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