

EFFECT OF AGING ON CORROSION BEHAVIOUR OF AA6061 ALUMINIUM
ALLOY

MOHD SYAHIDAN BIN MOHAMED NAWI
MA08128

Report submitted in partial fulfilment of the requirements for the award of Bachelor
of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITY MALAYSIA PAHANG

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality of this thesis is qualified for the award of the Bachelor of Mechanical Engineering.

Signature :
Name : Mdm. Juliawati Binti Alias
Position : Lecturer
Date : 22nd JUNE 2012

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “*Effect of Aging on Corrosion Behaviour of AA6061 Aluminium Alloy*” is written by *Mohd Syahidan bin Mohamed Nawi*. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

MOHD FADHLAN MOHD YUSOF

Examiner

Signature

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature:

Name: MOHD SYAHIDAN BIN MOHAMED NAWI

ID Number: MA08128

Date: 22nd JUNE 2012

This work is dedicated to my beloved parents

Mohamed Nawi Bin Mat

Saniah Binti Jamaluddin

And siblings

Special thank to my supervisor

Juliawati Binti Alias, for the endless support and guidance

And allies...

You all always have a special place in my heart.

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ABSTRACT

The material for experiments was an extruded sheet AA6061 aluminium alloys by thickness of 2 mm. We studied the influence of different artificial aging parameters on corrosion behaviour of Al-Mg-Si alloy. The Al alloys was solution treated at $490\pm 5^{\circ}\text{C}$ for 5 hours, quenched in oil at room temperature and artificial aging at 170°C , 190°C at different aging time of 60, 180 and 360 minutes respectively. After heat treatment process, the obtained alloys will be etched for microstructure seeking purpose and then were corroded in solution of 3.5% NaCl by conducting potentiodynamic polarization for electrochemical measurement. After corrosion test, samples were prepared for analyzing the surface morphology of corrosion formed after exposed to the chloride media. We observed that the lowest corrosion rate has the sample aged at 170°C for 1 hour. The highest corrosion rate happens at 190°C for 1 hour. At 190°C for 6 hours the maximum hardness is obtained, while corrosion behaviour is better for all samples by comparing with as-received sample.

ABSTRAK

Bahan yang digunakan untuk eksperimen ini adalah AA6061 aloi aluminium yang dihasilkan melalui proses penyemperitan dengan ketebalan 2 mm. Kajian yang dijalankan adalah berdasarkan pengaruh parameter penuaan tiruan yang berbeza ke atas kadar pengaratan aloi Al-Mg-Si. Aloi ini telah terawat haba pada suhu $490 \pm 5^\circ\text{C}$ selama 5 jam, dan disejukkan dengan cepat dalam minyak pada suhu bilik dan seterusnya proses penuaan tiruan pada 170°C , 190°C pada masa yang berbeza iaitu 60, 180 dan 360 minit masing-masing. Aloi terawat haba yang diperolehi akan dipunat dengan asid untuk mendapatkan struktur mikro aluminium aloi terawat haba dan seterusnya dijalankan ujian pengaratan di dalam larutan 35% NaCl melalui ujian pembelauan potentiodynamik untuk ukuran elektrokimia. Selepas ujian pengaratan, analisis morfologi terhadap permukaan sampel dijalankan untuk mengesan bentuk pengaratan yang terhasil selepas terdedah kepada klorida. Dari pemerhatian, kadar pengaratan terendah berlaku pada sampel yang melalui penuaan tiruan pada suhu 170°C selama 1 jam. Kadar pengaratan tertinggi yang berlaku adalah penuaan tiruan pada suhu 190°C selama 1 jam. Pada suhu 190°C selama 6 jam kekerasan maksimum diperolehi, manakala kelakuan pengaratan adalah lebih baik bagi semua sampel mengikut perbandingan dengan sampel kawalan.

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LIST OF SYMBOL

A	Area
Al	Aluminium
A_a	Anode area
A_c	Cathode area
Al^{3+}	Aluminium dissolve to 3 electron
Al_2O_3	Aluminium oxide
$Al(OH)_3$	Aluminium hydroxide
$AlCl_3$	Aluminium chloride
$Al(OH)_2Cl$	Aluminium oxychlorides
e	electron
E	Potential
E_{corr}	Corrosion potential
H_2	Hydrogen gas
H^+	Hydrogen ion
HNO_3	Nitric acid
i_{corr}	Corrosion current density
i_a	Anode current
i_c	Cathode current
$I_{appl reversed}$	Reverse current applied
M	Metal
n	No. of positive ion and electron
Si	Silicon
ϕ_A	Anode potential

ϕ_c	Cathode potential
ϕ_{corr}	Corrosion potential
ζ	Polarization
β_a	Anodic Tafel slopes
β_c	Cathodic Tafel slopes
$^{\circ}\text{C}$	Degree Celcius

LIST OF ABBREVIATIONS

AA	Aluminium Association
ACS	America Chemical Society
ASTM	American Society for Testing and Materials
FYP	Final Year Project
HV	Hardness Value of Vickers hardness test
mmpy	Millimeter per year
NaCl	Sodium chloride
SCE	Saturated Calomel Electrode

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The wide range use of aluminium and aluminium alloy in the transportation industry such as aircraft and automotive is based on fame mechanical characteristics of these alloys with regard to low specific weight and corrosion resistance (Enescu et al., 2010). Aluminium alloys are alloys in which the main element is aluminium itself. Further studies have been carried out on the 6xxx aluminium alloy because of their technological importance and exceptional increase in strength obtained by precipitation hardening. The other excellent characteristics of these alloys which are it can be shaped easily, low density, their good surface properties and good weld ability and take along with low price these make them commercially attractive.

Aluminium alloy is processed in very large at low cost for mostly building and architectural design works in most developing countries and it is thus quite understandable why attention is focus this series of alloys. For this project, it will focus on 6061 aluminium alloys. AA6061 is one of the most alloys widely used in 6000 series and well known due to versatile heat treatable alloy. It provide medium and high strength depend on the requirement of application.

Some aluminium alloy can be strengthening by conducting a heat treatment process. The purpose of this process is to alter the mechanical properties by increasing the value of their strength, hardness and also their corrosion resistance. The process applicable for 6061 alloy is precipitation strengthening which involve three basic steps. The solution heat treatment is the first step in the precipitation-

strengthening process. Then, the sample is rapidly cooled to a lower temperature usually water and finally follows by artificially aging. The temperature of aging is between 15 and 25 percent of the temperature different between room temperature and the solution heat-treatment temperature.

The salient features of aluminium alloy which can resist the corrosion have made these alloys very commercial for several of application. When speak of corrosion, usually we referring to the chemical attack process on metals. The AA6061 and AA6063 aluminium alloy is marine grade that can achieve high strength and great corrosion resistance. Meanwhile, the AA7075 are the aluminium that heavily use in aircraft industry. The AA7075 aluminium alloy may possess more strength that marine grade alloy has but is much more susceptible to corrosion. In other word, while the alloys have formidable performance in aircraft industry, it will perform poorly in marine applications.

Fundamentally, the aluminium is a very active metal where its nature to oxidize quickly. While a weakness for the most metal, actually this is the key for aluminium ability to resist corrosion. The present of oxygen in air, soil and water will react instantly to form aluminium oxide. The oxide layer is chemically bond to the surface of aluminium. Thus, the layer present will prevent the aluminium core for further reaction. It is different in steel corrosion which the oxide layer continuously puffs up and flakes off then exposing other surface to corrosion. The aluminium has excellent corrosion in wide range of water and soil condition because of tough oxide film form on the surface and hence providing an excellent corrosion protection except in several special cases.

1.2 PROBLEM STATEMENT

The use of aluminium alloy in variety of application is due to the superior characteristic belonging to aluminium itself. Therefore, too many researchers have been devoted to study the mechanical properties of these alloys such as strength, weld ability, formability as well as the ability to resist the corrosion. Generally, the investigation corrosion behaviour of aluminium is due to its important application in industry especially for the structure purpose. Thus, the effect of variation aging time

on corrosion behaviour of AA6061 aluminium alloy which initially has been heat treated to different temperature has been investigate in this project. The purpose is to investigate whether the corrosion rate of AA6061 aluminium alloy is being affected by the variation of aging time and temperature. Then the result is being compared to the previous experiment that has been conducted by other researchers.

1.3 OBJECTIVES

The objectives of the project that need to be achieved are:

1. To study the effect of aging on corrosion behaviour of AA6061 aluminium alloy.
2. To investigate the effect of variation aging time and temperature of heat treatment AA6061 aluminium alloy.

1.4 PROJECT SCOPES

The focus area will be done based on the following aspect:

- i) AA6061 aluminium alloy sample preparation.
- ii) Metallography to reveal the microstructure of the sample.
- iii) Perform the solution heat treated of aluminium alloys at 490° C for 30 minutes and quenched in water.
- iv) Artificial aging at 170° C and 190° C at different time 1 hours, 3 hours, and 6 hours before water quenching.
- v) Evaluate the corrosion rate by using electrochemical test based on weight loss method.
- vi) Surface analysis by using Optical Microscope.
- vii) Microstructures analysis of corrosion behaviour by using Scanning Electron Microscope (SEM).
- viii) Using Vickers hardness test to analyze the hardness of each specimen.

1.5 OVERVIEW OF THE REPORT

This project has been arranged in five chapters. The introduction has been written in this chapter. The chapter 2 will explain for the literature review. The methodology is being told in chapter 3 while the result of the experiment being discussed in chapter 4. The last chapter which is chapter 5 will be conclusion and recommendations for the entire project.

CHAPTER 2

LITERATURE REVIEW

2.1 ALUMINIUM ALLOY

Aluminium alloy are alloy which aluminium is the predominant metal. Typical alloying elements are copper, manganese, silicon, magnesium, and product. There are two types of aluminum product which are wrought and cast aluminum alloy. Cast aluminum alloy commonly used in widespread applications for structural component due to its excellent castability, corrosion resistance and particularly high strength to weight ratio in the heat treatment condition. However, the used of this cast alloy still a step backward on wide range uses of wrought aluminum alloy even though casting types provide more economical production method. This is partly because of cast aluminum alloy may contain defects such as porosity, oxides and other factors.

The most commonly used aluminum alloy designation in the United States is that of the Aluminium Association is the wrought aluminium alloy. The classification of wrought aluminium alloy is classified according to their major alloying element based on four digits numerical designation is shown in Table 2.1 (William and Javad, 2006)

Table 2.1: Wrought aluminium alloy groups

Type	series
Commercially pure aluminium (99% min)	1xxx
Copper	2xxx
Manganese	3xxx
Silicon containing alloy	4xxx
Magnesium	5xxx
Magnesium and Silicon containing alloy	6xxx
Zinc containing alloy	7xxx
Other elements containing alloy	8xxx
Unused series containing alloy	9xxx

Adapted from: Edward (2010)

2.2 AA6061 ALUMINIUM ALLOY

The AA6061 aluminium alloy is known to be age hardenable alloy which containing magnesium and silicon as the predominant alloying element. The magnesium silicide is the form of interest to be formed in these series of alloy. The 6061 Al-Mg-Si having balanced ratio of 1% magnesium and 0.6% silicon to form MgSi has set up as the standard for light weight, economical for general structure use. To achieve more strength, copper is added about 0.3% in the T6 temper compared to the copper free alloys with balanced composition of Mg and Si (Edward, 2010). The 6061 alloy largely found in the market due to its features such as good corrosion resistance, weldability, and attractive surface appearance render these alloy very useful for extruded product.

2.3 PRECIPITATION HARDENING

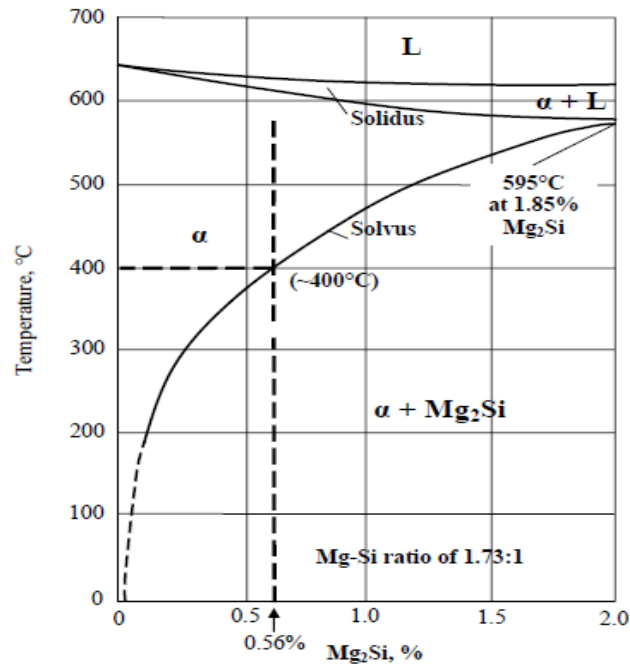


Figure 2.1: Quasi-binary phase diagram for Al-Mg-Si alloy indicating important transition zones

2.4 SOLUTION HEAT TREATMENT

The solution heat treatment or so called solution annealing is the first step to achieve precipitation hardening. The main purpose for this treatment is to put all the solute or second phase into solution. The alloy sample could be wrought or cast form is heated to a temperature lies midway between the solvus and solidus line. This process will cause single phase solid solution to form. While conducting the solutionizing, overheating and underheating should be avoid unless the desire properties such as tensile strength, fracture toughness and ductility will gradually decrease (Pat, 1999).

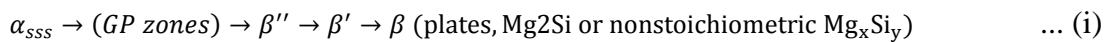
Quenching is a hardening heat treating and the quenching medium normally used is air, water, oil, or liquid polymers. As a result, supersaturated solid solution of second phase alloy will be form through this process.

2.5 AGING

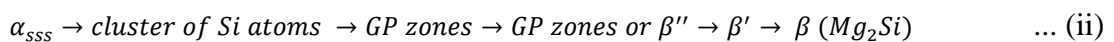
The aging hardening or precipitation hardening was first discovered in Germany when the hardness of aluminium-copper alloy was retested after it was laid in the laboratory for a week. The yielded hardness was much higher than before it was retested. Then the first name given is age hardening where the hardness gained as the alloy aged in time.

The purpose of precipitation hardening is to create a fine dispersion of precipitate particles. The particles then will resist the dislocation movement and hence strengthen the heat treated alloy. The alloy system itself should have the terminal solid solution where the solid solubility decreases with temperature to enable the precipitation hardening (William and Javad, 2006).

Due to the complex nature of precipitation, there are some difficulties to identify the chemical characteristics of fine scale microstructure. Consequently, the exact sequence of structural changes has faced controversy during aging. Several precipitation sequences have been proposed according to formation complexity. The general accepted sequence is:



Another sequence with more detail on the earlier stage of clustering and GP zone formation was proposed as:



The structure of alloy after water quenching will consist of a supersaturated solid solution and can be noted as α_{SSS} on the first stages of the sequences above. When the supersaturated solid solution is heated at a relatively low temperature, clusters of solute rich regions or Si are formed within the Al lattice and are completely coherent with it. These clusters are called GP (Guinier-Preston) Zones because they were first detected by Guinier and Preston. From the sequence, GP2 or β'' is where the peak hardness is achieved for wrought alloys. While β' is where the peak hardness is achieved for cast alloys. For β'' and β' , there is still some confusion and it is unable to provide consistent evidence regarding the formation of both phases.

2.6 FORMS OF CORROSION

2.6.1 General Corrosion

The general corrosion is very regular form of corrosion. It can be uniform (even), quasi-uniform (near-uniform), or uneven. The term of general corrosion is referring on the greatest loss of metal or material. Oxidation, sulfidation, carburization, hydrogen effects, and also hot corrosion can be account as types of general corrosion.

However, general uniform corrosion is rare toward aluminium except in several special cases such as highly acidic or alkaline corrosive reagents. Aluminium alloys of the 1xxx, 3xxx, 5xxxx, and 6xxx series by many natural waters. Corrosions of aluminium is occurred when the presence of moisture and oxygen. The significant factors that involves in corrosion of aluminium include water pH, temperature, and conductivity. The conductivity is more toward the availability of cathodic reactant, presence of heavy metals, and corrosion potentials of the specific alloys. In chloride containing solutions, the corrosions occur regarding the pH range of 5.5-8.5 is less than either in distinctly acid or distinctly alkaline. In this pH range, aluminium is passive metal and normally undergoes localized corrosion rather than general uniform corrosion. However, the result obtained significantly related or depending on specific aluminium alloy under investigation.

2.6.2 Localized Corrosion

Localized corrosion is the most hazardous corrosion because it cannot be predicted easily just like general corrosion. There are several consequences affected by localized corrosion such as putting some equipment out of service and cause fatal accidents in a few circumstances.

Pitting type of corrosion usually concern in application involving passive metal and alloys in aggressive environment. Pitting corrosion of passive metal is commonly observed in presence of chlorides and other halides. Halide ions such as Cl^- can rise to severe localized corrosion. Generally, aluminium does not pit in

oxygen containing solution of nonhalide salts, because aluminium is not polarized to pitting potential at normal service. Pitting corrosion formed at weak points of the oxide or hydroxide passivating film of the alloy.

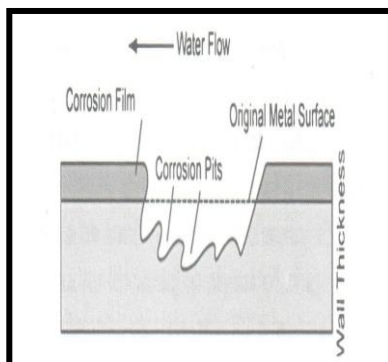


Figure 2.2: Localize corrosion of pitting form.

Source: Edward (2010)

2.7 PASSIVITY OF ALUMINIUM ALLOYS

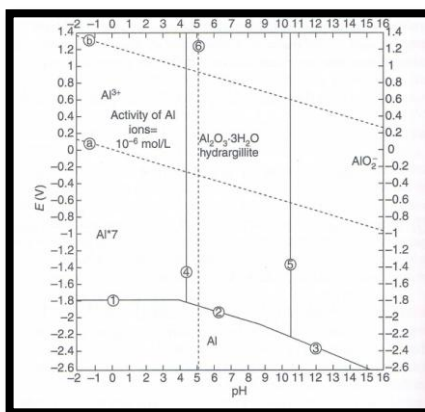


Figure 2.3: Pourbaix diagram of aluminium

Source: Edward (2010)

The role of thermodynamics has been used extensively to evaluate the corrosion tendency or pattern of metals. The figure above is describing the electrochemical potentials and equilibrium determined from the free enthalpy ΔG and the chemical equilibrium between the different metallic compounds in solution

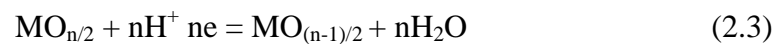
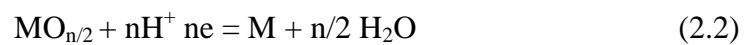
as applied in the Nernst equation. The Pourbaix diagram of aluminium indicates that hydrargillite, $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$, is the stable phase between about pH 4 - 9.

Generally, there are four types of reactions to consider:

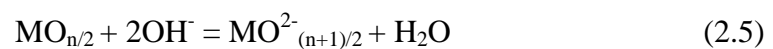
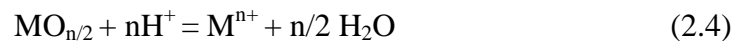
1. The reaction that depend on the electrochemical potential equilibrium between a metal and its ions such as



2. The reactions depend on both E and pH.



3. The reactions depend on pH only such as equilibrium in acid or alkaline medium between an oxide and dissolve ions.



4. There are some reactions that are independent of E (no exchange of electrons) or pH.



Where, n = No. of positive ion and electron

M = Metal

The aluminium possess high resistance to corrosion because the presence of thin and highly stick film of aluminium oxide. When aluminium surface exposed to air or water, the film will rapidly form and grow. At the pH range 4-9 where the aluminium is passive, it is protected by its oxides and hydroxides. Indeed this film is considered to be responsible for the successful use of aluminium in many structural applications (Winston and Herbert, 2008). In contact to the wet environment, the external side of the oxide film hydrolyzes to form hydrated oxides such as bayerite below 70°C and boehmite formed at above 100°C .

Pure 1100 and 6061-T aluminium has been found corroded at decreasing rates with time when exposed to the tropical environment of Panama. After 16 years of exposure, total weight losses were 67 and 63 g/m². It was observed that deepest pits were 0.84 and 2.0 mm respectively for small size test panels. But the weight losses and pits deep have found to increase with a great amount which is 347 and 103 g/m² and the deepest pits measured 2.8 mm for each of them for the same period of time (Winston and Herbert, 2008).

Upon the immersion of various commercial alloys in seawater at Key West, Florida, for 368 days period, pit occurrence is depending to their corrosion potentials. The corrosion potential ranging from -0.4 to -0.6V for most which contained some alloyed copper have mean depth of pitting equal to 0.15-0.99 mm. Meanwhile, for those alloys which possess more active potential ranging from -0.7 to -1.0 showed no pitted (Winston and Herbert, 2008).

Base on analysis of poultrice taken from 50 cars driven in four major North America cities has shown the presence of ions such as sodium, calcium, sulphate, and chloride in great quantities. The presence of these element are because of road deicing and dust-control practice. The sulphate maybe contributed by the acid deposition commonly associated with pollution (Winston and Herbert, 2008).

2.8 CORROSION MECHANISMS

Pitting corrosion is initiated when the aluminium alloys are in the pH range where it is passive. In aerated solution, the cathodic side reaction is oxygen reduction while halide ions accelerating the anodic reaction whereas chloride is the most common element present.

Localized would also initiated by the same local aggressive solution such as saturated solution of aluminium chloride (AlCl₃) has pH of 3-3.5 just into the region where the oxide layer is unstable. Aluminium normally does not corrode in nonhalide solution because the pitting potential can say noble that it is in halide solution. Pitting corrosion usually start with a spot when anodic current is distributed on a small

surface and lead to deep perforation. The presence of oxygen or any oxidant essentially results to the pit.

2.9 CORROSION RATES MEASUREMENT

Transient or so called non-steady-state electrochemical techniques are widely used in corrosion science. Other than determining corrosion rate, by using these techniques, we are able to distinguish reaction phenomena with different time constants. The time of charge transfer reactions at the electrode-electrolyte interface normally slower than transport phenomena in the electrolyte. The most commonly used electrochemical non-steady-state method as follows:

2.9.1 Electrochemical Polarization

Electrochemical polarization test methods are very close related for understanding and studying corrosion resistance of materials hence the effect of changes in corrosive environment. The basic tool of dc electrochemical such as cyclic voltammetric, potentiodynamic, potentiostatic, and galvanostatic are the rapid method of investigation. They can perform the criteria for protection of anodic and cathodic protection and susceptibility to several forms of corrosion. By using the methods mentioned above as conjunction, the pitting, crevice, and active-passive of aluminium alloy can be easily exhibited. As an example, the determination of critical pitting potential in some chloride media of aluminium alloy are advanced subjects in controlling this type of corrosions. DC techniques has the possibility in studying and exploring the influence of alloying element on the film produced with respect to active and passive region immersed in different electrolyte. Here, it can describe the performance of the aluminium with different alloying elements.

By referring to mixed electrodes system where the reactions take place simultaneously at a metal-electrolyte interface, polarization ζ expresses the different between the potential of anodic or cathodic polarization and its corrosion potential.

$$\zeta = E - E_{\text{corr}} \quad (2.7)$$

If the polarization of $\zeta > 0$, it is anodic current flow, while $\zeta < 0$, it is cathodic current flow.

2.9.2 Tafel Extrapolation

In experimentally creating the polarization diagram, the first measurement is corrosion potential, ϕ_{corr} , when the applied current, I_{appl} is zero. The working electrode has been polarized anodically to establish one of the dash lines in Figure 2.4. The polarization was repeated, but with I_{appl} reversed to obtain the second dash line. The graph of ϕ versus I_{appl} has been plotted on the nobler and the more active sides of the corrosion potential.

The anodic tafel region has been extrapolated from to the equilibrium anode potential, ϕ_A to determine exchange current density, i_{oa} . Similarly, from the tafel region that has been extrapolated to the equilibrium potential, ϕ_c to determine the exchange current density i_{oc} . Hence, the i_{corr} can be determine by extrapolating from either to anodic or cathodic Tafel region to the corrosion potential ϕ_{corr} , where $i_c = i_a$ for condition that $A_a = A_c$ (anode-cathode area ratio=1).

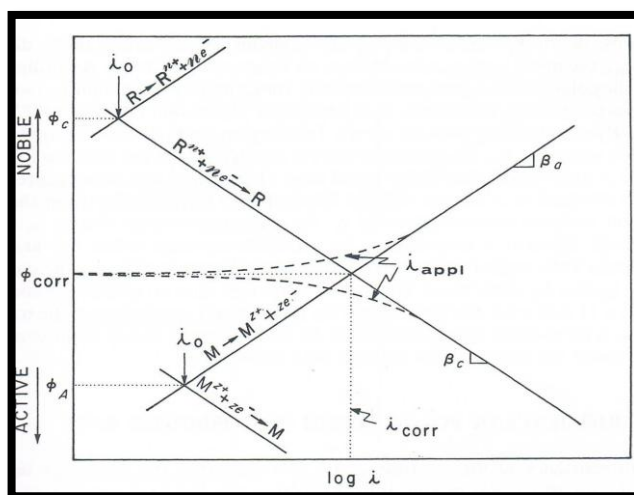


Figure 2.4: Polarization diagram

Source: Winston, R.R. and Herbert, H.U. 2008

The metal can be say in active state when exposed to the new material with certain media condition. It tends to be dissolution or attack since it is not in stable naturally or thermodynamically. But, there is also certain tendency to return to its stable state. Therefore, the polarization test is where the corrosion potential and current would be determined by turn specimens into active state. According to ASTM G5, the plots of E_{appl} versus $\log I$ are called Tafel plot. Hence, the current density is determined by using these two equations.

$$E_{appl} = E_{corr} + \beta_a \log \frac{i}{i_{corr}} \quad (2.8)$$

$$E_{appl} = E_{corr} - \beta_c \log \frac{i}{i_{corr}} \quad (2.9)$$

where β_a and β_c are positive constant.

2.10 METALLOGRAPHIC

To study and understand the behaviour of microstructures, microconstituents, existing defects, and other characteristics of internal structure, it is significant to use several of instruments. In order to reveal the information toward the structure of material which involve the scale from micro to nano range, the use of optical metallography and scanning electron microscopy are the major equipment that can review the structure. By using this equipment it can perform the structure of grain, grain boundaries, microphase, and line defect of the materials (William and Javad, 2006).

2.10.1 Metallurgical Microscope

The surface of a small sample is prepared through several procedures such as grinding, polishing, and etching. The sample prepared then examines by using a metallurgical microscope or inverted microscope according to visible incident light. The principle of the inverted microscope where it can reveal the grain and grain boundaries is phenomenon between incidents light through grain boundaries itself. The result of etching the material essentially produces tiny groves along the boundaries of the grains. When the groves are exposed to incident light in a

metallurgical microscope, these grooves do not reflect the light intensely as the grain. Hence, because of the reduced light reflection, the grooves appear as dark line, thus revealing the grain boundaries.

2.10.2 Scanning Electron Microscope

Scanning electron microscope is an important tool in science and engineering. They function are to measure microscopic feature, fracture characterization, microstructure studies, thin coating evaluation, surface contamination examination, and also for failure analysis of material. As opposed to inverted microscopy where the material is exposed to incident light, the scanning electron microscopy (SEM), a beam of electron is exposed in a pinpointed spot on the surface of targeted specimen, hence collects and displays the electronic signals given off by the material.

Basically, an electron gun produces an electron beam in an evacuated column that is focused and directed so that it hit on small spot on the target. Scanning coils allow the beam to scan a small area of the surface of the sample. Low angle backscattered electron mix with the protuberances of the surface and once again generate the backscattered electron to produce an electronic signal, then preview the image having depth of field 300 times that inverted microscopy which is about 10 micrometer at 10000 diameters magnification. The resolution of many SEM is about 5 nm with the wide range in between 15 to 10000 times magnification.

The SEM is very useful when dealing in material analysis for the examination of fractures surface material. It cans clearly delineating the grain surface and the depth of perception. Qualitative and quantitative information can be obtained when SEM is together with an energy dispersive x-ray (EDS) spectrometer.

2.11 VICKERS HARDNESS TEST

Hardness test is a measured of how the metal would resist to its plastic or permanent deformation. It operation is measured by forcing the indenter into the surface of materials. The indenter material for Vickers hardness test usually pyramid form made of a material much harder than the material being tested which is

diamond. The indenter in form of pyramid with a square base and the angle of 136° between opposite face of indenter going to indented into the specimen. The load to be applied may vary in range of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals on the specimen left by the indenter after removal are then calculated using a microscope and the value of the average will be taken. The area of sloping surface of indentation is calculated. The Vickers hardness then obtained by dividing the kgf load by the square mm area of indentation. The formula below is describing the value of hardness that can be manually calculated before the modern digital Vickers hardness tester is developed where it perform the calculation automatically and displaying the result.

$$HV = \frac{2F \sin \frac{136^\circ}{2}}{d^2} = 1.854 \frac{F}{d^2} \quad (2.10)$$

The hardness number could be used is either in term of kgf per mm^2 or can be converted into Pa, by noting that the Pa unit for hardness is unequal to as pressure. The hardness number is determined by the load per unit area of the indentation and not the area normal to the force, therefore it is not pressure. The Vickers hardness test can be applied for all metal and it also has one of the widest scales among hardness test. The unit of hardness is known as Vickers Pyramid Number (HV) or so called Diamond Pyramid Hardness (DPH). The Vickers hardness result displayed should be reported like 800/HV which mean the Vickers hardness is 800 with applied test load or force of 10 kgf.

The advantages of Vickers hardness test are able to obtain extremely precise readings and the use of only one type of indenter toward all the metal and surface treatment. The Vickers test is also able to measure the hardness of softest and hardest material with different load applied.

Over the period, now the technology becomes more advances and thus eliminating the entire error and influence of operator over the result and hence reducing the repeatability and also reproducibility to get an accurate reading. Working with the PCs and software that has been developed then enables us to perform automatic calculation consequently, the time consumption will be reduced.

The geometry of the indenter used in Vickers hardness test has been described such as follows:

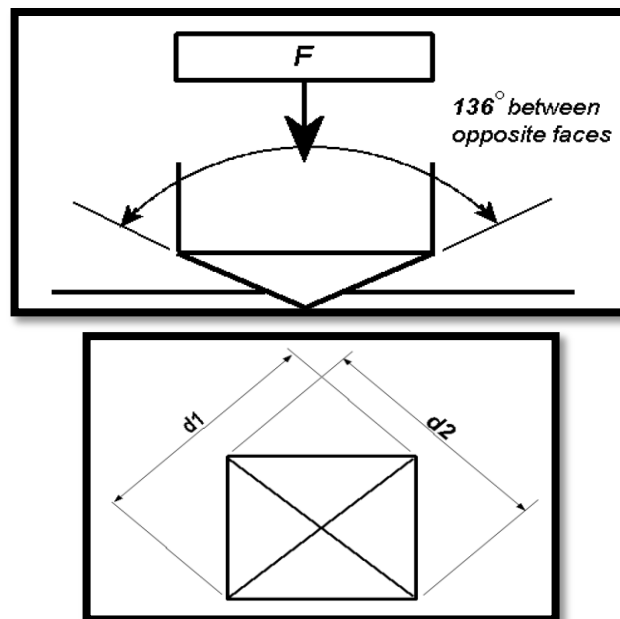


Figure 2.5: The indenter of Vickers hardness test.

2.12 CONCLUSION

In conclusion, this chapter has been described briefly about the process needed for this project as well as the useful information to guide the researcher once experiment is carried out. It is very important to know the fundamental of the experiment base on previous research and text book. All information is gathering through this chapter to convenient the investigation of the study and hence, helps the reader to gain understanding toward this project.

CHAPTER 3

METHODOLOGY

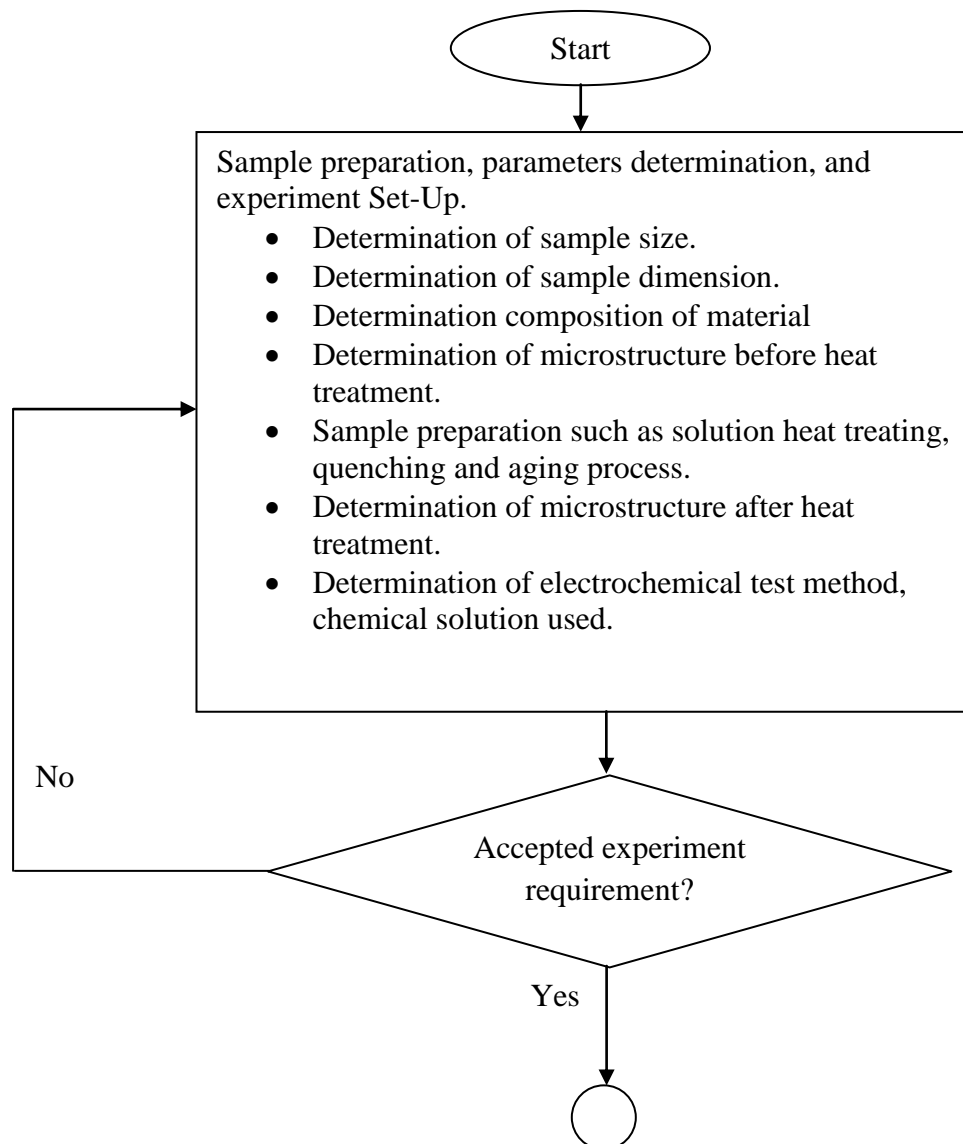
3.1 INTRODUCTION

Methodology plays a significant role in while conducting any research in order to ensure the research following the right path until the project is complete. By preparing the methodology, it will enable the project satisfied the objective that have been stated and hence, as a guidance through entire experimentation.

Generally, methodology will provide the structure of research. While the scopes of study act as a guideline, the framework of methodology will drive the research and come out with the expected result that essentially based on the objectives stated. The methodology is best to describe as a mechanism that gives the right figure before the experiment is begin. It succinctly showing the series, activity, and task include the techniques while investigating the point of interest. It will guarantee the research with fewer obstacles, thus moving forward smoother with the structured proposed.

3.2 METHODOLOGY FLOW CHART

The achievement of project objectives is closely related to the methodology that has been constructed like figure 3.1. The main purpose of the flow chart is to give guidelines and direction toward attainment of successful project objectives.



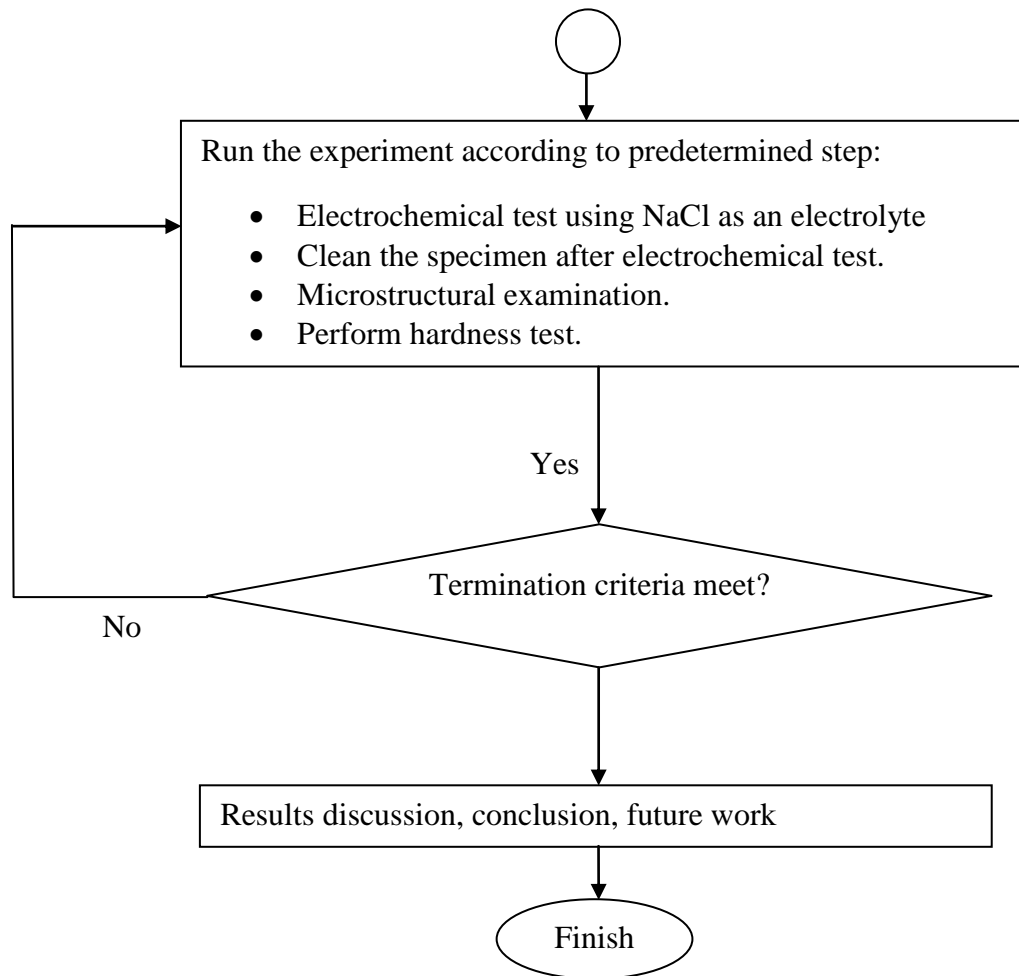


Figure 3.1 Flow Chart

3.3 SAMPLE PREPARATION

The aluminium of AA6061 has been chosen to carry out the research based on their corrosion behaviour after several process of heat treatment. The very first step required is sample preparation before undergoing further step. The aluminium alloy was cut into 10 mm length, 10 mm width, and 2 mm thickness. The total numbers of specimen needed are about 7 specimens. To satisfy the objectives this is to compare the behaviour of corrosion with the variation of aging time and temperature. The temperatures of aging will be set up are 170°C and 190°C. Meanwhile the aging times are 1 hours, 3 hours, and 6 hours as list in Table 3.1.

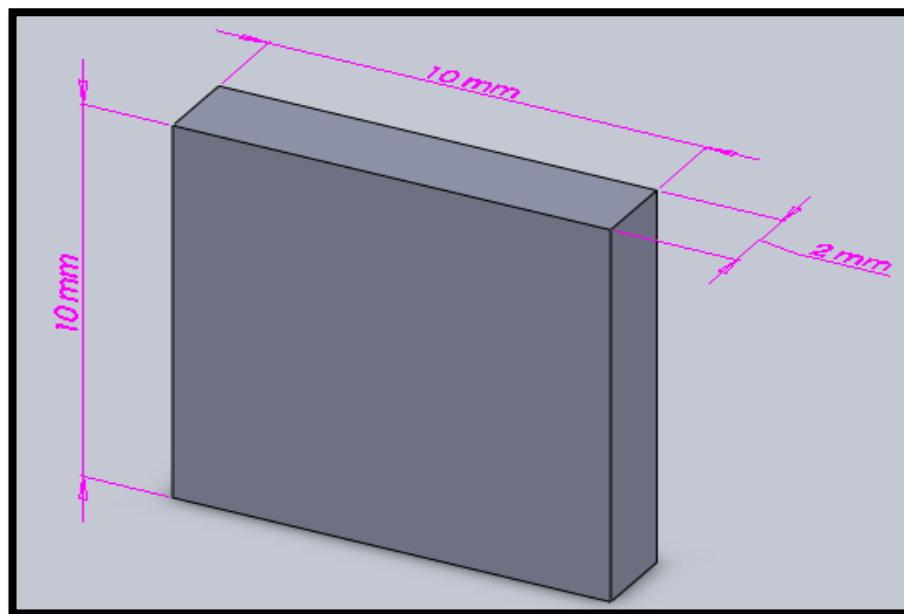


Figure 3.2: Sample dimension

Table 3.1: Sample preparation

Sample	Process
A	Control
B	SHT at 490°C for 5 hours and aging at 170°C and for 1 hours
C	SHT at 490°C for 5 hours and aging at 190°C and for 1 hours
D	SHT at 490°C for 5 hours and aging at 170°C and for 3 hours
E	SHT at 490°C for 5 hours and aging at 190°C and for 3 hours
F	SHT at 490°C for 5 hours and aging at 170°C and for 6 hours
G	SHT at 490°C for 5 hours and aging at 190°C and for 6 hours

3.3.1 Solution Heat Treated

Solution heat treated is the second step after all seven specimens have been prepared. All specimens except the control specimen has been heat treated at temperature 490 °C for 5 hours by using the furnace. This process is for the purposed to alter the physical properties and chemical properties and hence to provide super saturated solid solution. The melting temperature of aluminium is 660°C, thus, solution heat treated at 490°C will not exceed melting temperature of aluminium as parent element in 6061 aluminium alloy. After that, all the solution heat treated specimens had been quenched in water at room temperature.



Figure 3.3: Furnace

3.3.2 Aging

The specimen quenched then undergone aging process which are the third step in precipitation hardening. The main purpose is to investigate the effect of aging on corrosion behaviour of 6061 aluminium alloy. The temperature has been selected

for aging are 170°C and 190°C while the times are 1 hours, 3 hours, and 6 hours has been classified such as table 3.2 below;

Table 3.2: Aging process

Sample	Temperature (°C)	Time (hour)
A	170	1
B	190	
C	170	3
D	190	
E	170	6
F	190	

Hereafter, all sevens specimen has undergone several process describes in the figure below. While seeking for microstructure of each sample, the clean and polished surfaces are desired. The steps have been taken as outline below:

- i. The specimen was cut to get desired shape.
- ii. Copper wire was embedded into cold mounting for electrochemical test.
- iii. The sample was grinded using the grit of 240, 320, 400, and 600. It starts with the rough grit and follows by the finer grit.
- iv. Finally, specimens were being polished using three polish machines with 6 μ , 3 μ , and 1 μ Polycrystalline diamond until mirror-like acquired.



(a) cold mounting and embed the
Copper wire



(b) grinding process

Figure 3.4: (i) Sample preparation



Figure 3.4: (ii) Sample preparations polishing with 6 μ Polycrystalline diamond polishing with 3 μ Polycrystalline diamond and 1 μ Polycrystalline diamond.

The microstructure after heat treatment has to be determining in order to investigate the effect of precipitation hardening process. Therefore, the etching process has to be carry first by the composition of etchant listed in Table 3.3.

Table 3.3: Composition of etchant for aluminium alloys

Etchant	Conc.	Condition	Comment
Methanol	25 ml	10-60 sec	Pure aluminium,
Hydrochloric acid	25 ml		Aluminium-magnesium
Nitric acid	25 ml		alloy and aluminium-
Hydroflouric acid	1 drop		Magnesium-silicon alloys

Adapted from: Metallographic Etchants (2009)

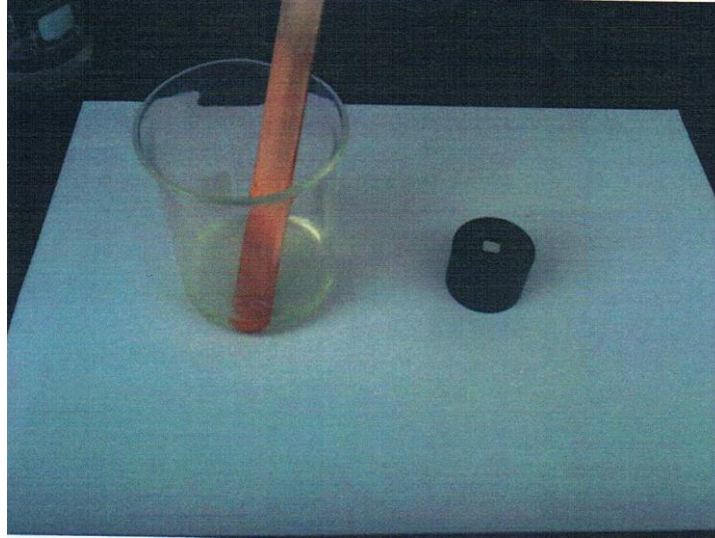


Figure 3.5: Etching process

3.3.3 Surface Analysis

When the sample size and dimension have been determined, there are very significant to find a figure of microstructure before moving to the next step which is precipitation hardening. The microstructure is for the purpose to compare with the structure after carrying the heat treatment. Consequently, it will give the information of the effect of heat treatment toward aluminium alloy itself. The microstructure of all the AA 6061 aluminium alloy specimens including the control specimen has been taken. Here, both microstructures which are before and after heat treatment will be taken by using optical microscope. The processes that were undergone in surface analysis were cold mounting, grinding, polishing and etching.



Figure 3.6: Inverted optical microscope

3.4 ELECTROCHEMICAL TEST

The purposed of experiment is to determine the corrosion rate of an aluminium alloy AA 6061 after precipitation hardening. Their outstanding features toward corrosion resistance have made it very commercial alloy in automotive industry and hence the usage for structure purpose.

On this project, the corrosion rate has been evaluated using potentiostat based on potential dynamic mode. The potentiostat is used to control the variation of potential apply to electrode surface while observing the current during the experiment to achieve the desired degree of polarization. The electrochemical cell is set up to consist of three different electrode namely reference, working, and counter electrode. The working electrode is a set of sample number used in this project which are sevens specimen.



Figure 3.7: Electrochemical cells interconnect with WPG 100 potentiostat and computer.

As the aluminium 6061 is the working electrode, saturated calomel will be used as reference electrode that allows the potential at working electrode maybe measured in accurate manner. Meanwhile, the counter electrode is used to provide accurate measurement toward current across working electrode. The counter electrode should be composed of highly corrosion resistance material; therefore, the graphite rod was used in this cell.

Next, the assembled cell then connected to the computer with software and plotter to record and analyse polarization data. There are few parameter have been set first with desired value such as sampling time, temperature, voltage, density, and area of the sample for test purposed. The IVMAN software was connected potentiostat as a function to interpret data. Hence, the corrosion rate can be acquired by using Tafel plot and also Linear Polarization Resistance analysis.



Figure 3.8: Electrochemical cell

In order to perform an electrochemical analysis, a set of component must be set up with the very careful assembling step. According to objective of the study, the aging process contributing the most of result variation for each specimen, thus the sample should be prepared with the best guard with regard to relate parameters. Eventually, the electrochemical test is able to be performed.

3.4.1 Solution Preparation

When making a solution one should first decide the degree of purity of the solution to produce. There normally have three categories of chemical purity which is laboratory, Reagent, and ACS (America Chemical Society). The laboratory found to be widely used in education for secondary school and college level. But, the ACS grades are guaranteed by the Specification of the Committee on Analytical Reagent. The most significant feature for producing a solution may involve a precise substance weighing either dry material or liquid. Therefore, the solution used in this project is sodium chloride (NaCl) of 3.5% concentration. The experiment has been conducted in room temperature 25°C.

The formula for weight percent is, (w/v): $\frac{\text{mass of solute (g)}}{\text{volume of solution (100 ml)}} \times 100$

3.4.1.1 Procedure for NaCl solution

A 3.5% NaCl solution containing 3.5 gram of sodium chloride dissolve in 100 ml distilled water. Firstly, 3.5 g of sodium chloride were weighed before it poured into volumetric flask containing about 80 ml distilled water. Once the sodium chloride has dissolved completely and swirls the flask gently if necessary, then add water to bring the volume up to the final 100 ml.

3.5 MICROSTRUCTURAL EXAMINATION

After completing the electrochemical test, the corrosion have found on specimen has been examine by using Optical Measurement. The surface of corroded aluminium has been revealed by using Optical Measurement to obtain the form of corrosion produced after electrochemical test.



Figure 3.9: Optical Measurement

3.6 PERFORMING HARDNESS TEST

After complete revealing the microstructure of corroded aluminium, the entire specimens then undergo the hardness test. The Vickers hardness tests were used in order to determine the micro hardness value of the specimens. The machine as shown in Figure 3.8 was done in the surface treatment laboratory assisted by laboratory person in charge.



Figure 3.10: Hardness test device.

While evaluating the hardness test, the location need to be observed for the indenter to be pressed and make sure the surface of the specimen is flat. The indenter was pressed by an accurately control test forced. To get the specific dwell time, the force on the specimen has been maintained for about 10 seconds. After the indenter is lifted up, the indent left on the specimen surface with the shape of square. The size of indentation has been measured in order to get diagonal measurement of the indentation. Ten hardness reading has been taken per sample and then were averaged.

3.7 ANALYSIS OF DATA

The analysis of data going to be the next step which include data cleaning, initial data analysis, main data analysis, and final data analysis. To produce a better result, the very first and important step has been done is data cleaning. The data has been collected will be inspect and then made it right if there are any error occurred.

Next, the initial data analysis has been performed. The purpose of carrying this step is to ensure that the data collected were based on project objectives and scopes. After that, the main data analysis has been carried before completing the last step which is final data analysis. Here, in main data analysis, this is where the filtrations of the data that is not based on objectives and scopes going to be put aside. Finally, in final data analysis, once again the inspection has been done to have the data that is relating to the objectives and scopes.

3.8 CONCLUSION

Since the purpose of this project is to investigate the effect of aging on corrosion behaviour of 6061 aluminium alloy, thus, the entire process has been described above is very significant. The experiment must follow every single step to ensure that it has proceeded according to the flow chart. The entire following step has been done then promoted to the next step which is result analysis that has been collected while conducting the experiment.

CHAPTER 4

EXPERIMENTAL RESULTS AND DISCUSSION

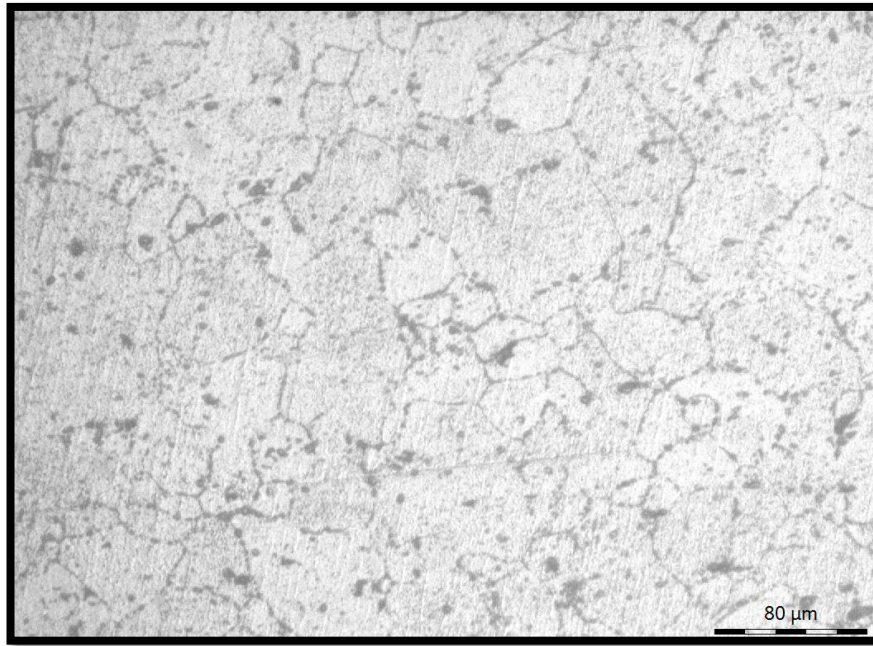
4.1 INTRODUCTION

This chapter will be discussing the entire result and data have been collected from the experiment. The experiment encompasses precipitation hardening that consist of solution heat treatment, quenching and aging process. The sample obtained from precipitation hardening will be tested in term of hardness by using Vickers hardness test and corrosion rate by using electrochemical test. On top of that, the surface morphology will first to be discussed to obtain the microstructure of each sample involved in this experiment. This chapter will play a significant role to ensure the objective of the probe.

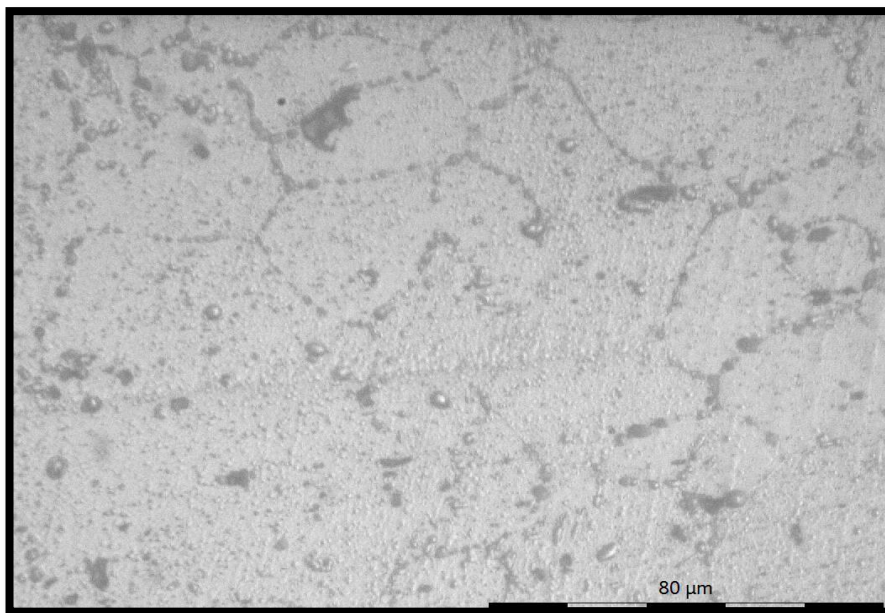
4.2 SURFACE ANALYSIS

Firstly, the microstructures of aluminium alloy which undergone different sample preparation have been revealed by using optical microscope before the electrochemical test. The microstructure was revealed after etching by using aluminium etchant. The sample was etched for 2 minutes in order to get a clear figure of microstructure.

The figures of surface microstructure of different sample preparation before the corrosion test at 200x, and 500x magnifications is shown in figure 4.1 until figure 4.7.

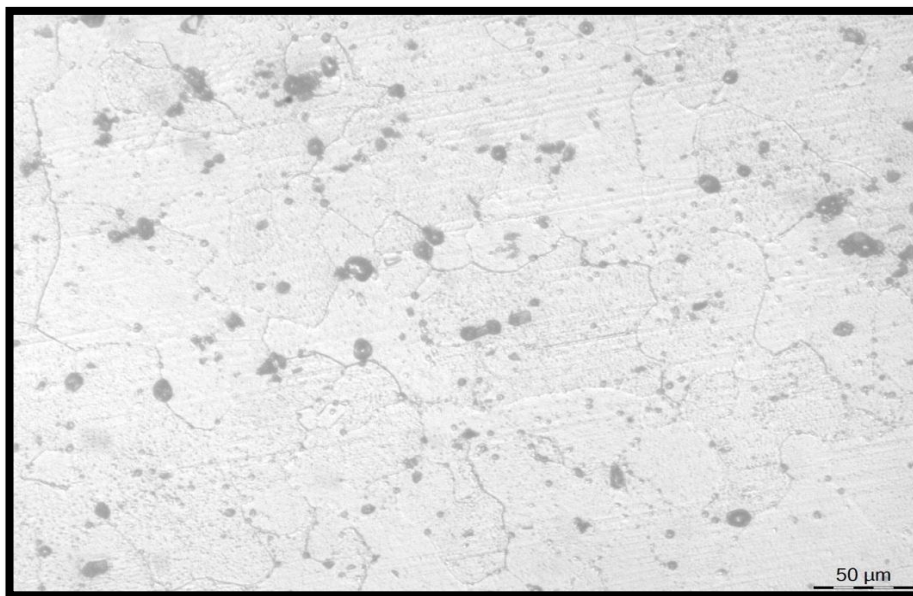


(a) At magnification 200x

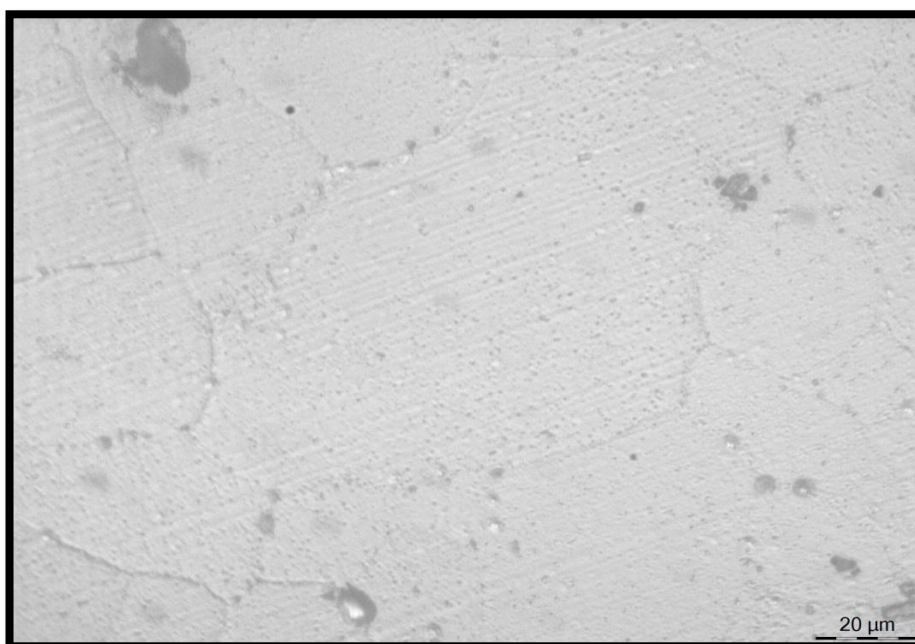


(b) At magnification 500x

Figure 4.1: Microstructure as-receive aluminium

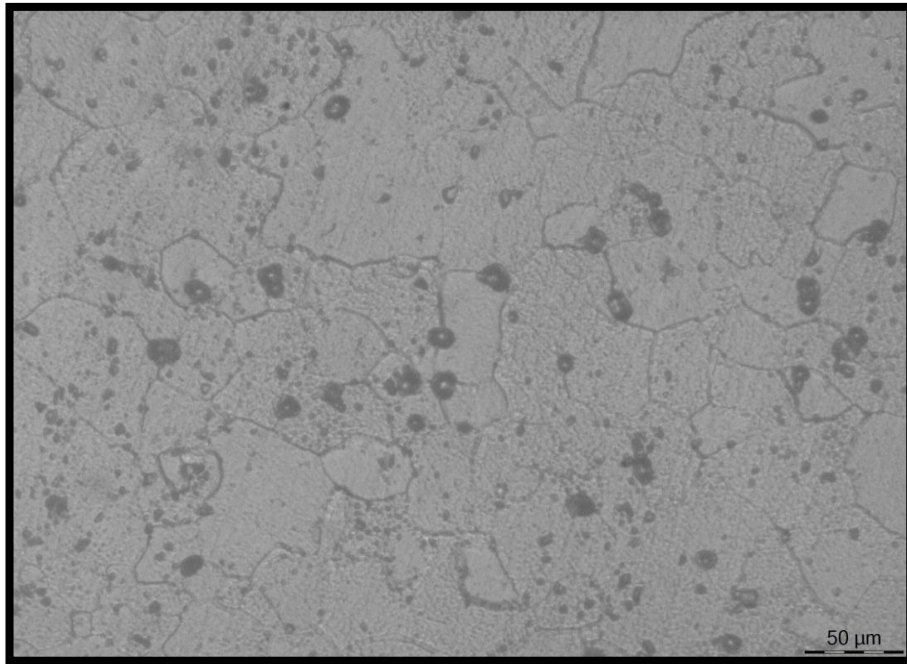


(a) At magnification 200x

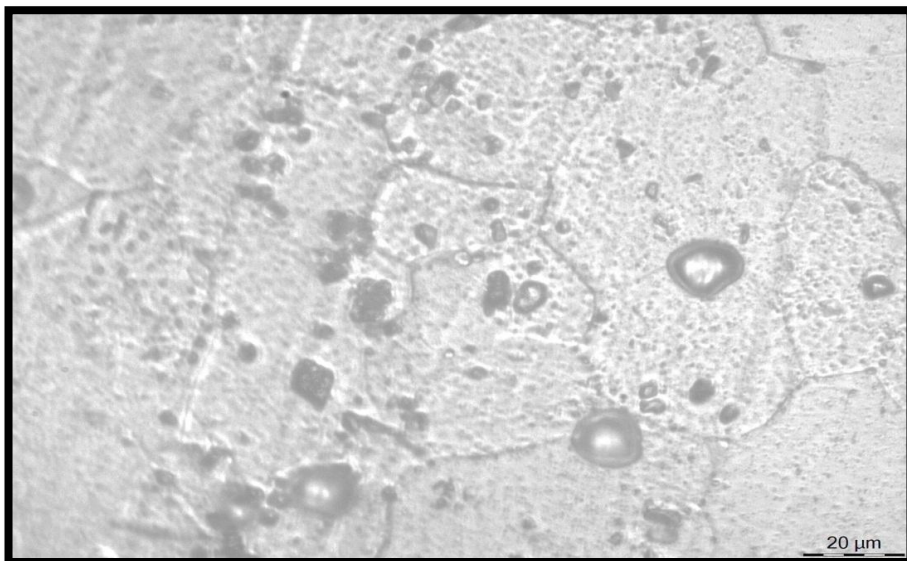


(b) At magnification 500x

Figure 4.2: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 170°C for an hour

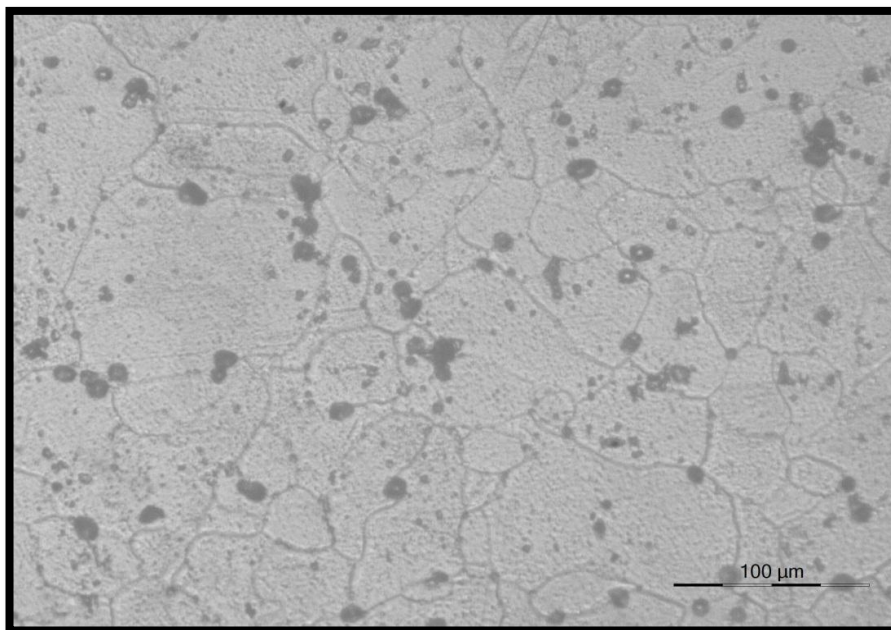


(a) At magnification 200x

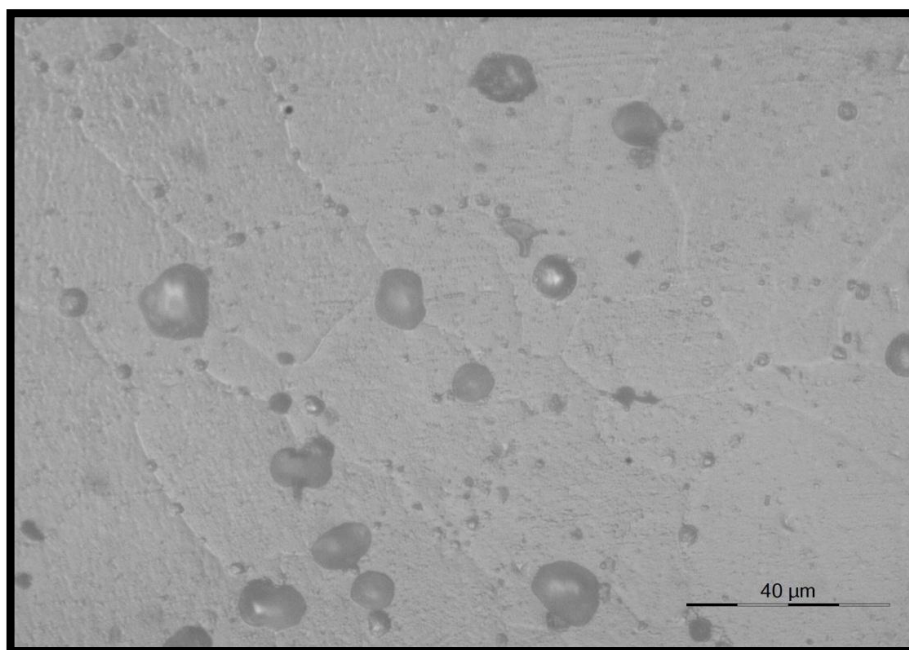


(b) At magnification 500x.

Figure 4.3: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 170°C for 3 hours

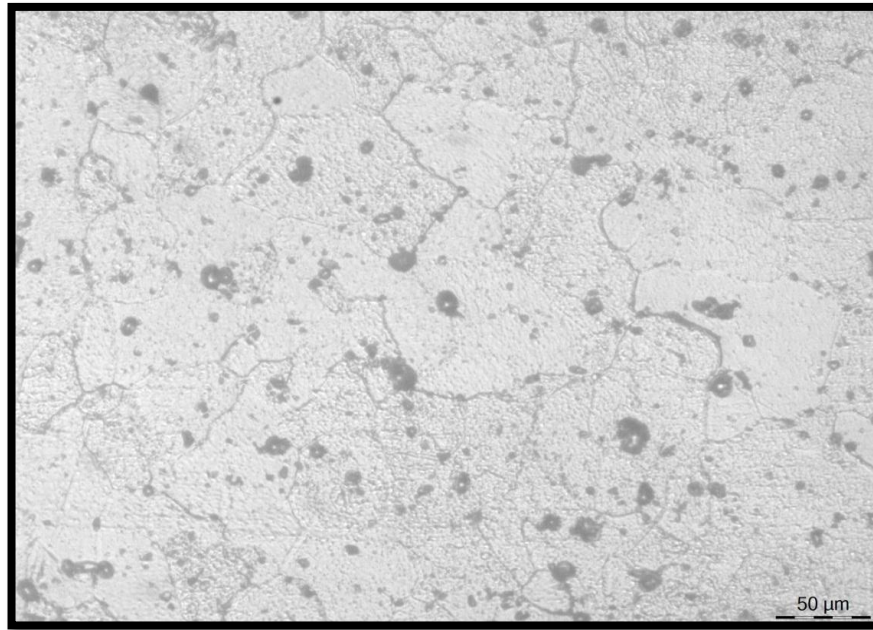


(a) At magnification 200x

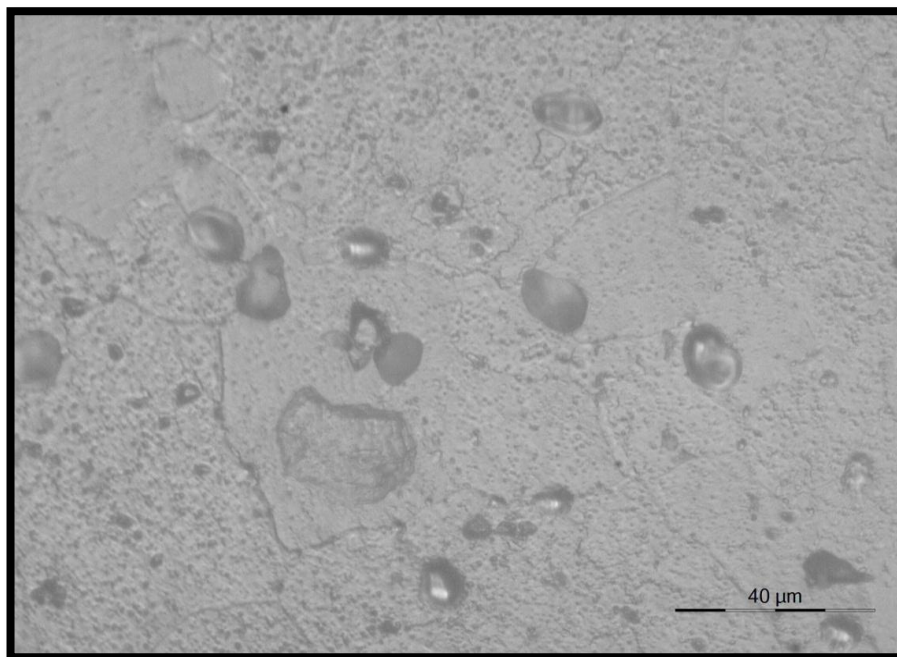


(b) At magnification 500x

Figure 4.4: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 170°C for 6 hours

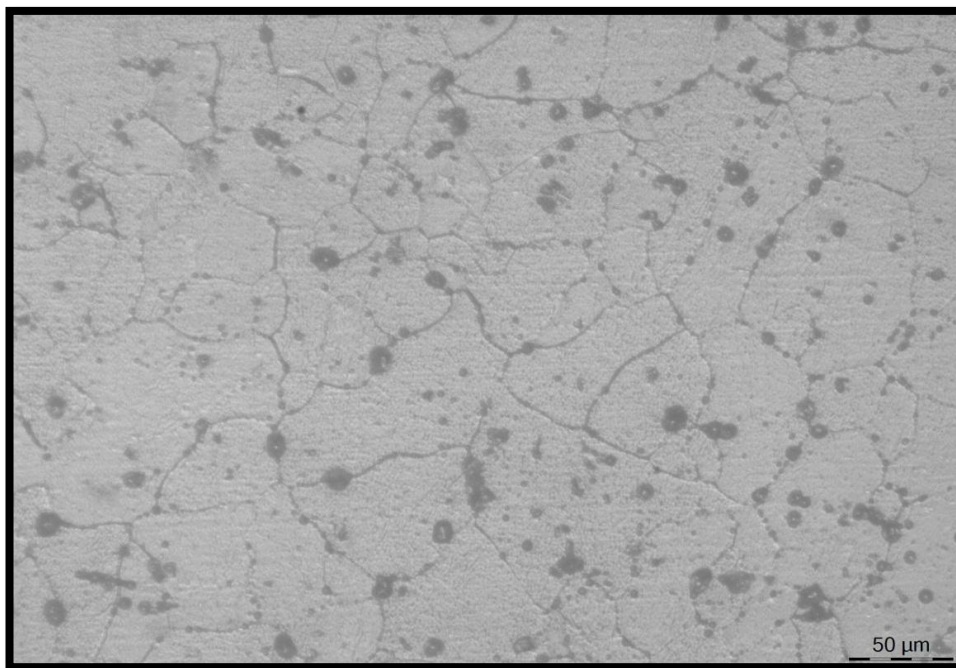


(a) At magnification 200x

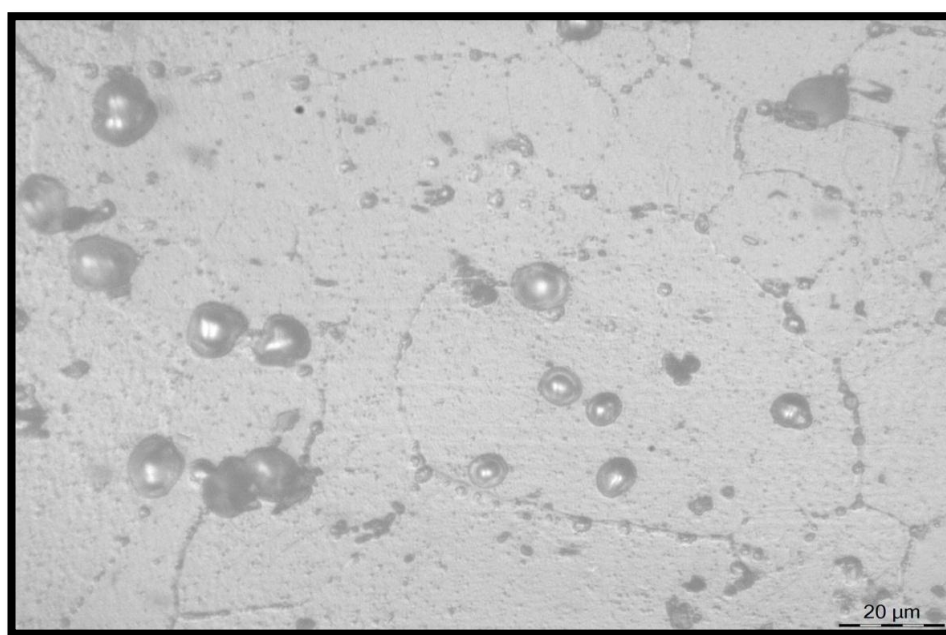


(b) At magnification 500x

Figure 4.5: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 190°C for an hour

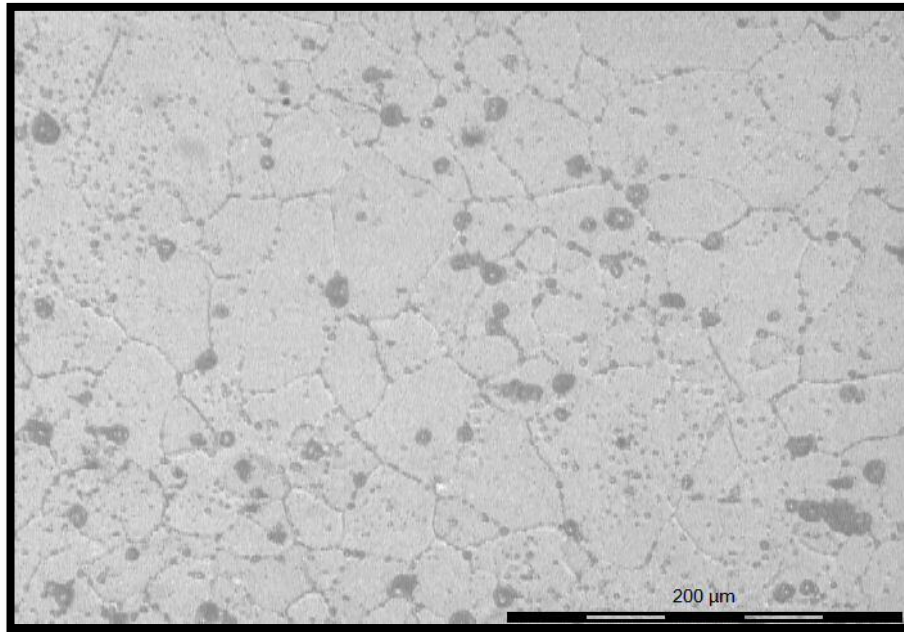


(a) At magnification 200x

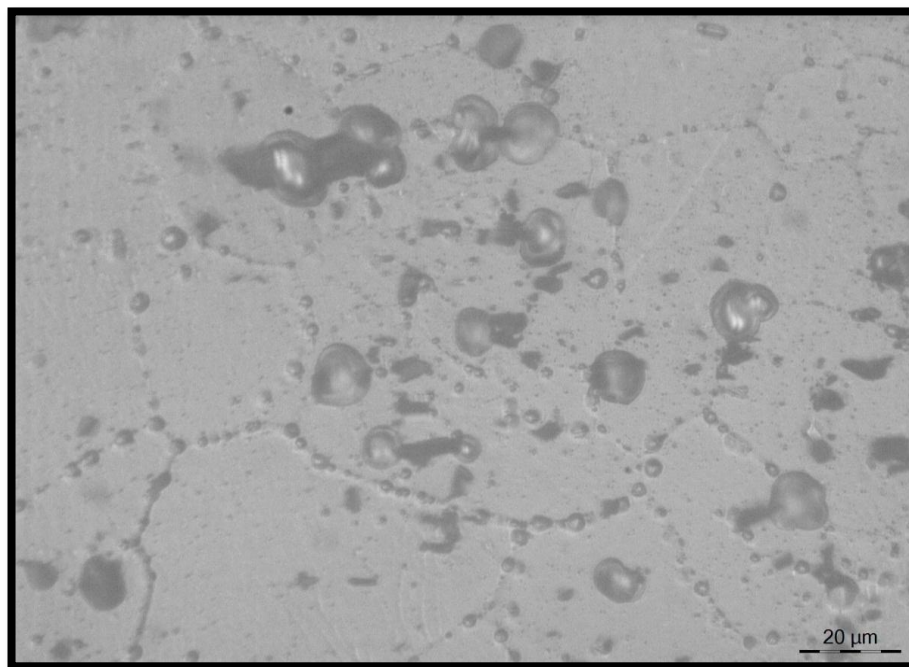


(b) At magnification 500x

Figure 4.6: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 190°C for 3 hours



(a) At magnification 200x



(b) At magnification 500x.

Figure 4.7: Microstructure of aluminium after Solution treated at $490 \pm 5^\circ\text{C}$ for 5 hours and quenched in oil at room temperature followed by aging at 190°C for 6 hours

The aging process seems to influence the microstructure of AA6061 aluminium alloy in term of grain boundaries formation. The grain boundaries become smaller as aging process has been carried out with different time and temperature.

Theoretically, the enhancement of sample undergone precipitation hardening is due to the precipitate formed and hence improved dislocations. So far it has been shown that the mechanical properties were highly influenced by the precipitates of a hardening (Mg₂Si) phase (Mrowka, 2010).

Table 4.1: Sample preparation

Sample	Process
A	As-receive
B	SHT at 490°C for 5 hours and aging at 170°C and for 1 hours
C	SHT at 490°C for 5 hours and aging at 190°C and for 1 hours
D	SHT at 490°C for 5 hours and aging at 170°C and for 3 hours
E	SHT at 490°C for 5 hours and aging at 190°C and for 3 hours
F	SHT at 490°C for 5 hours and aging at 170°C and for 6 hours
G	SHT at 490°C for 5 hours and aging at 190°C and for 6 hours

4.3 HARDNESS

The table shown below is the hardness value measured by taking three reading at different places. The graph plotted is based on average value of each sample harden at variation of aging time and temperature.

Table 4.2: Hardness values of as receive and the sample have undergone various aging time and temperature.

Sample	Hardness Value (HV)			Average
	1	2	3	
A	104.6	103.5	124.3	110.8
B	69.6	50.2	54.7	58.2
C	84.5	76	84.4	81.6
D	85.3	82.7	92.2	86.7
E	66.7	61.4	66.7	64.9
F	79.9	68.4	66.6	71.6
G	87.5	89.5	91.6	89.5

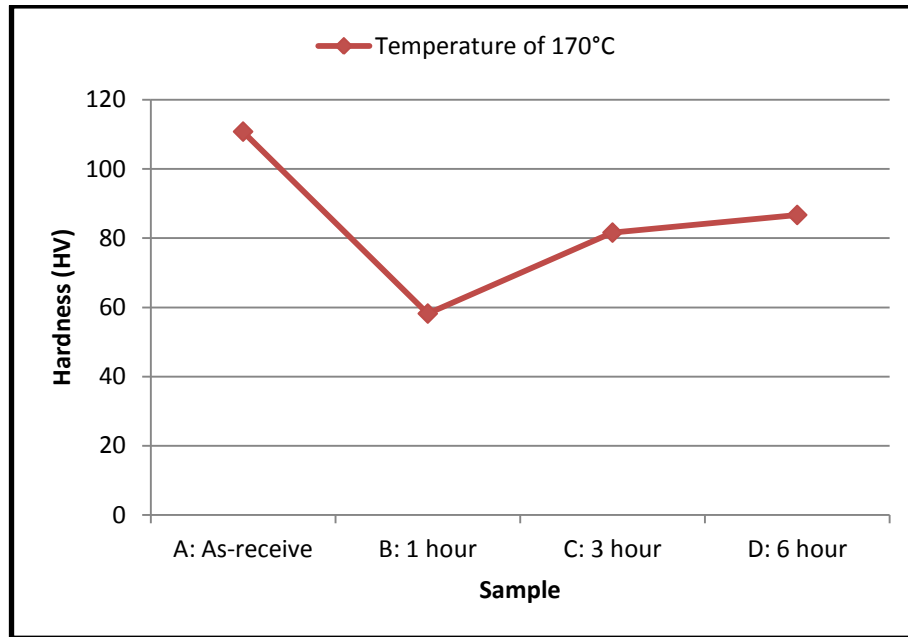


Figure 4.8: Hardness value of as-receive and heat treated sample at temperature of 170°C

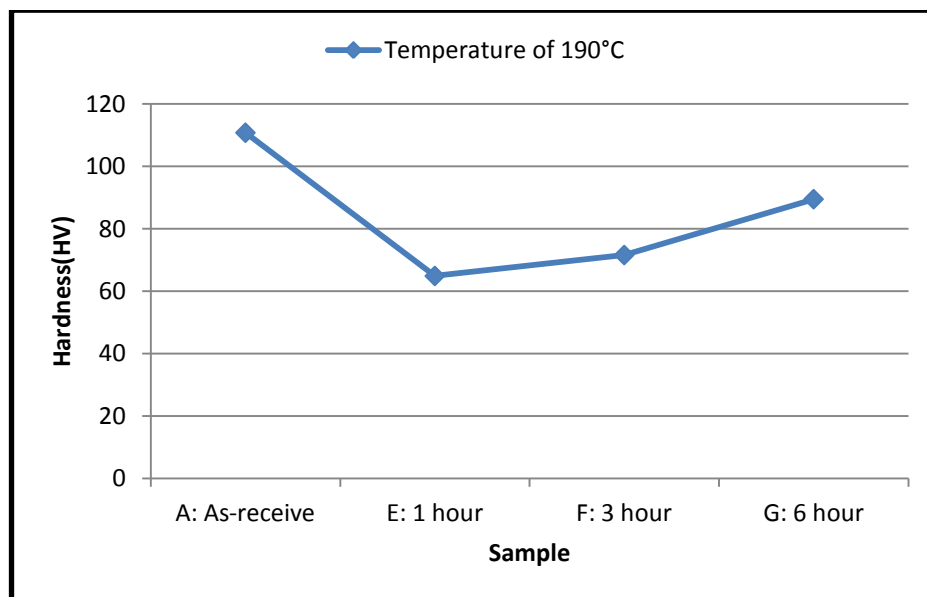


Figure 4.9: Hardness value of as-receive and heat treated sample at temperature of 190°C

According to figure 4.8, precipitation harden samples seem to have retrogression in hardness value instead of as-receive sample. But, the aging process with variation of time have influenced the value of hardness being harden, where at

one, three, and six hours give the value of 58.2 HV, 81.6 HV, and 86.7 HV respectively. Although the value of hardness is reduce from as- receive which is 110.8 HV, it is matter of time. With further aging time, the value might be increase up above as-receive level. This probe only use one until six hours for maximum aging time probably still just minimum range to show how the sample being harden by precipitation hardening process.

The aging process with temperature of 190°C shows the same graph pattern. And still, the values of harden sample are below as-receive grade. The value produced after aging process at one, three, and six hours are 64.9 HV, 71.6 HV, and 89.5 HV respectively. In conclusion, increase in aging temperature will increase the hardness value with equal time range which is one, three, and six hours. The hardness initially increase rapidly with the increase in aging time reaching the peak value, after which hardness decrease. All of the investigated as-cast alloys reached maximum hardness after aging at 175°C by the value of 128.7HB alloy 6061 for 48 hours (Mrowka, 2010).

4.4 POTENTIODYNAMIC POLARIZATION

The corrosion of each sample has been obtain by using electrochemical test where as the corrosion occur faster than weight loss measurement method. The corrosion rate can be acquired according to potentiodynamic setup parameter and strongly depending upon the voltage range chosen and scan rate.

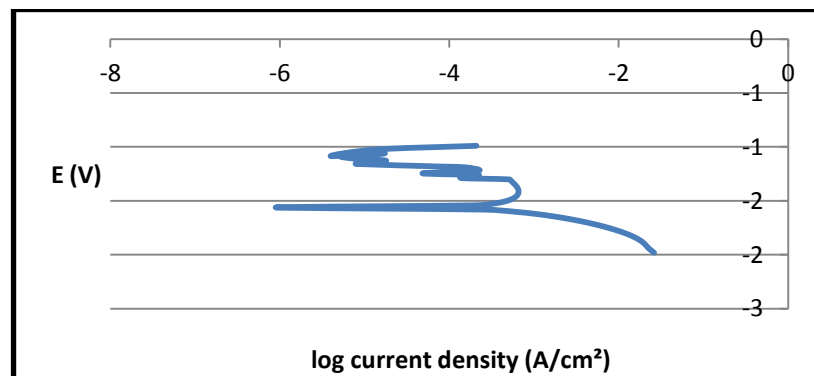
Table 4.3: Potentiodynamic setup parameter

Parameter	
Initial E (V vs SCE))	-2
Final E (V vs SCE)	-1
scan Rate (mV/s	20
Sampling Time (s)	1
sample Area (cm ²)	1
Density (gm/cm ³)	2.7
Equivalent weight	9
Cond Time (s)	0

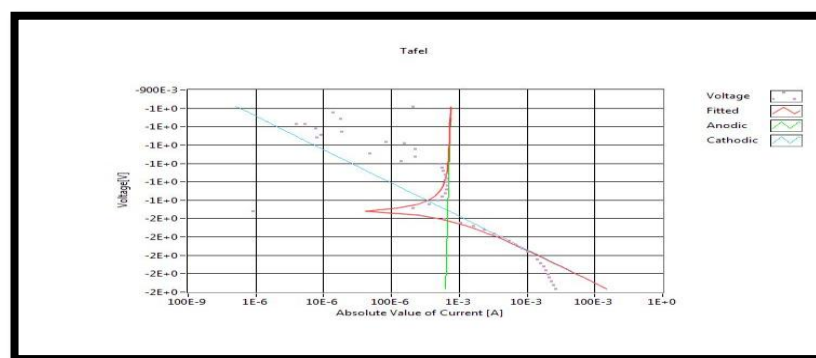
Table 4.3: Continued

Parameter	
Cond E (V)	0
initial Delay (s)	10
Delay Limit (mV/s)	0.1

In order to compare the corrosion rate by using method mentioned above, each sample needs to have the same parameter shown in Table 4.3. Consequently, we will be able to figure out the most and least sample to corrode.

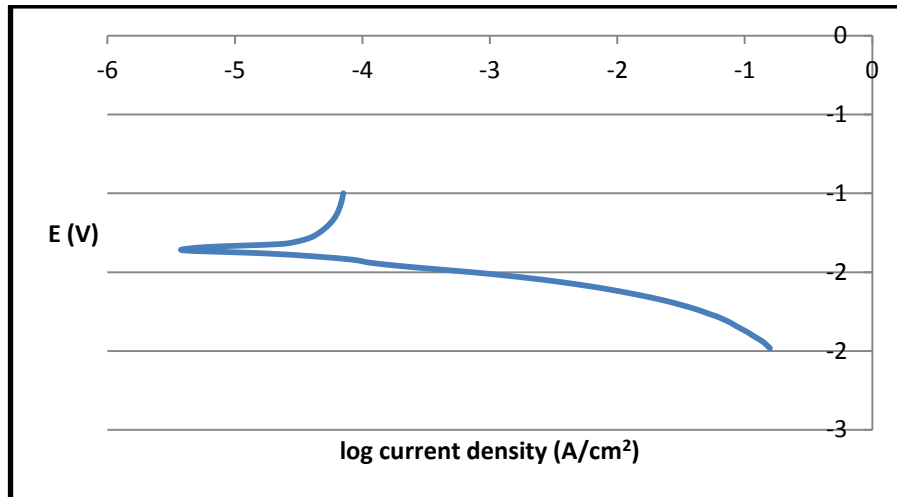


(a) Potentiodynamic polarization

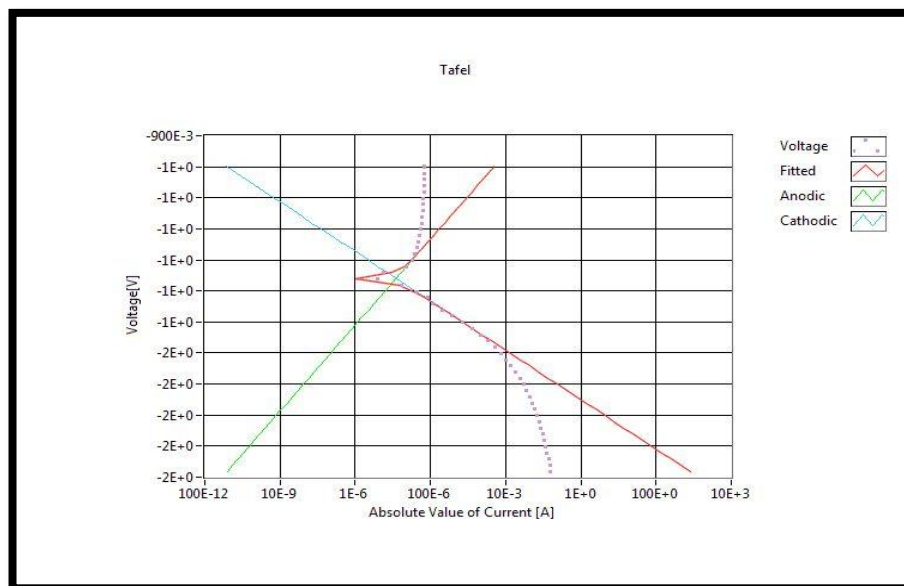


(b) Tafel extrapolation plot

Figure 4.10: Experiment obtained in 3.5% NaCl solution for as-receive sample of aluminium alloy AA 6061 undergone

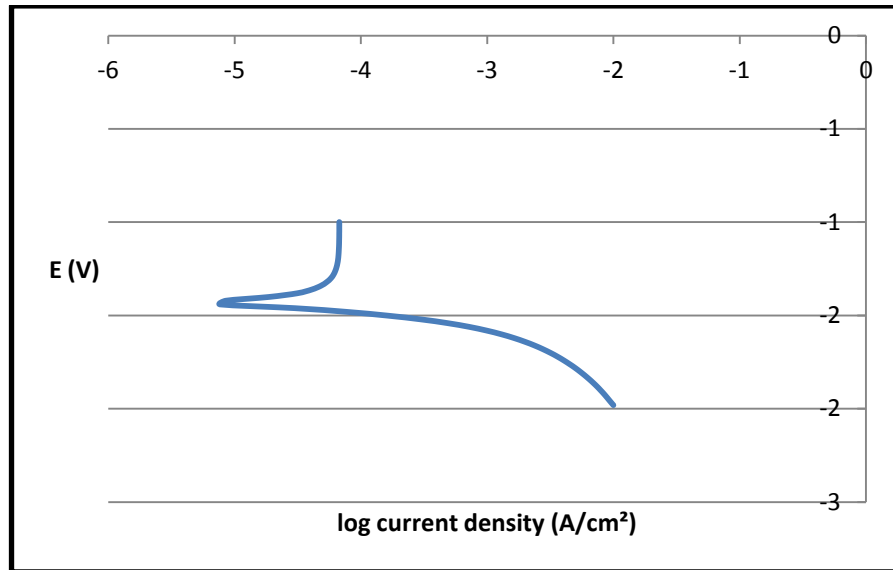


(a) Potentiodynamic polarization

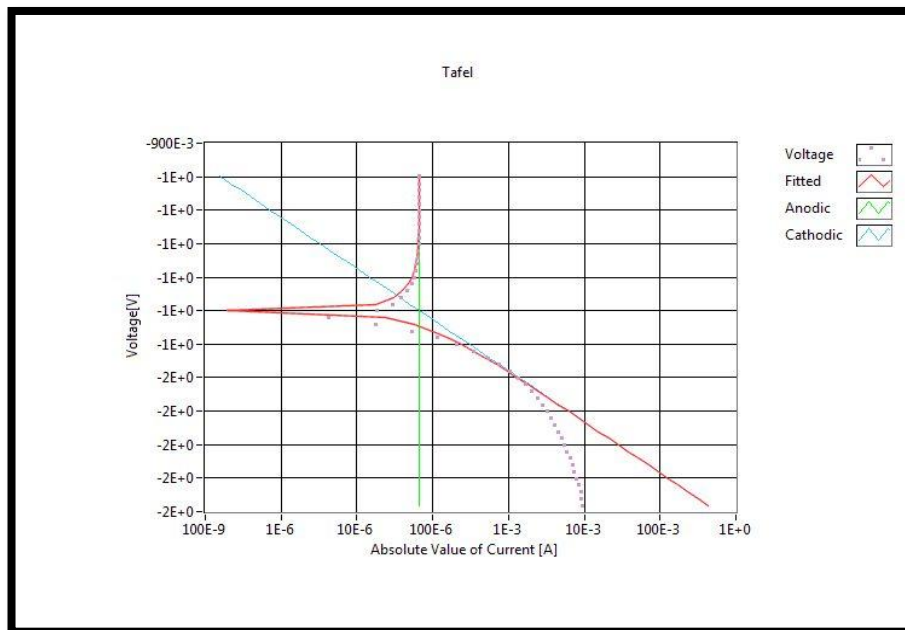


(b) Tafel extrapolation plot

Figure 4.11: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 170°C for an hour undergone

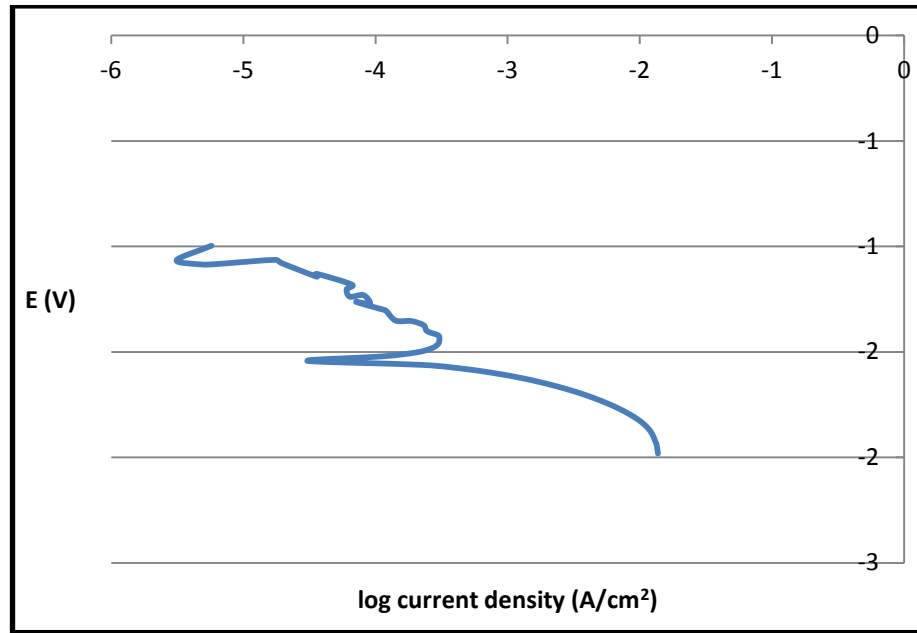


(a) Potentiodynamic polarization

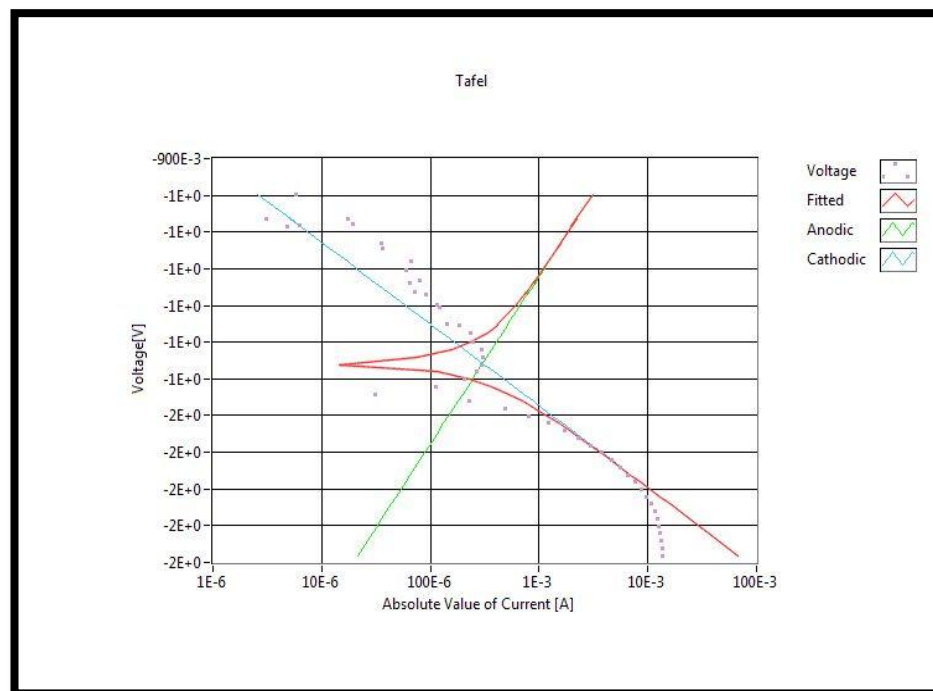


(b) Tafel extrapolation plot

Figure 4.12: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 170°C for three hours undergone

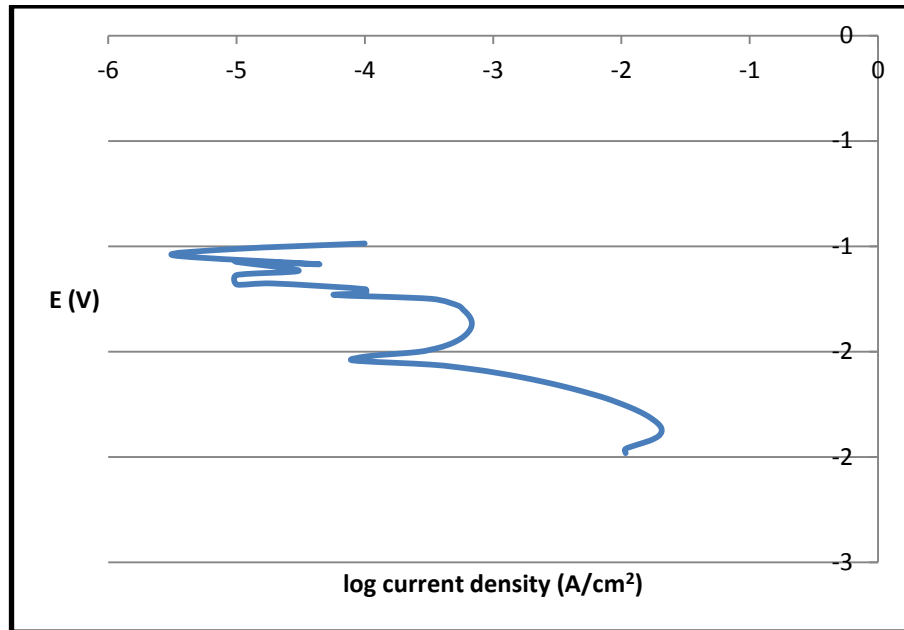


(a) Potentiodynamic polarization

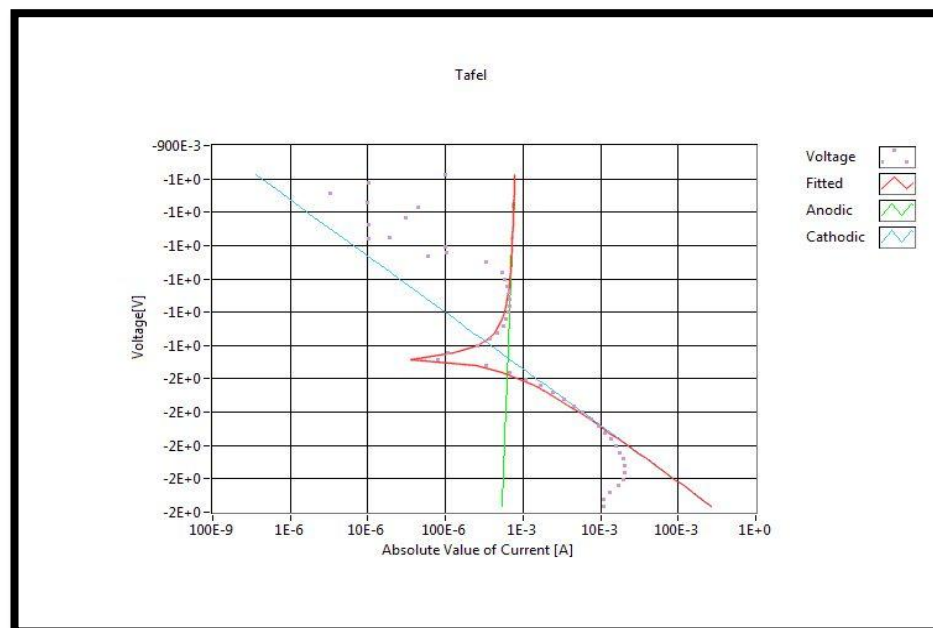


(b) Tafel extrapolation plot

Figure 4.13: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 170°C for six hours undergone

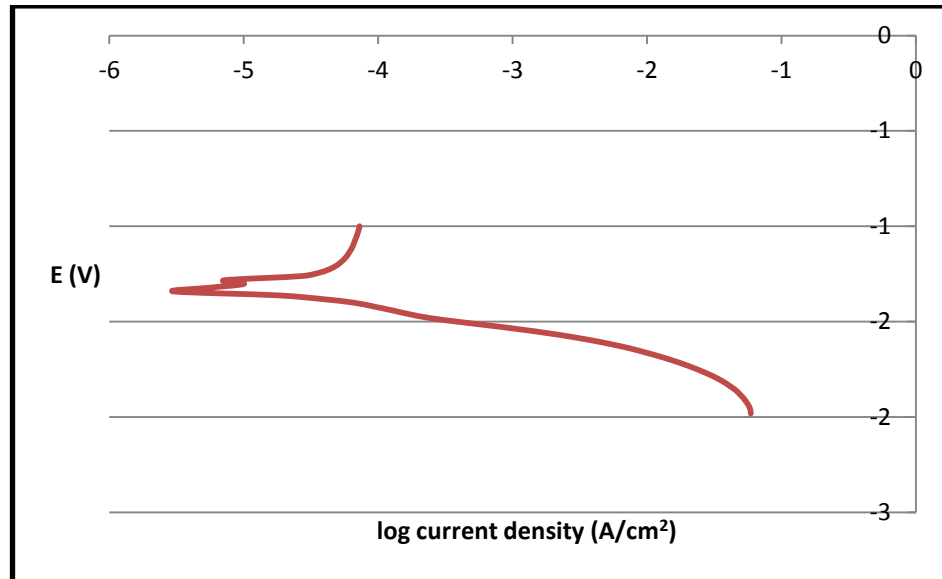


(a) Potentiodynamic polarization

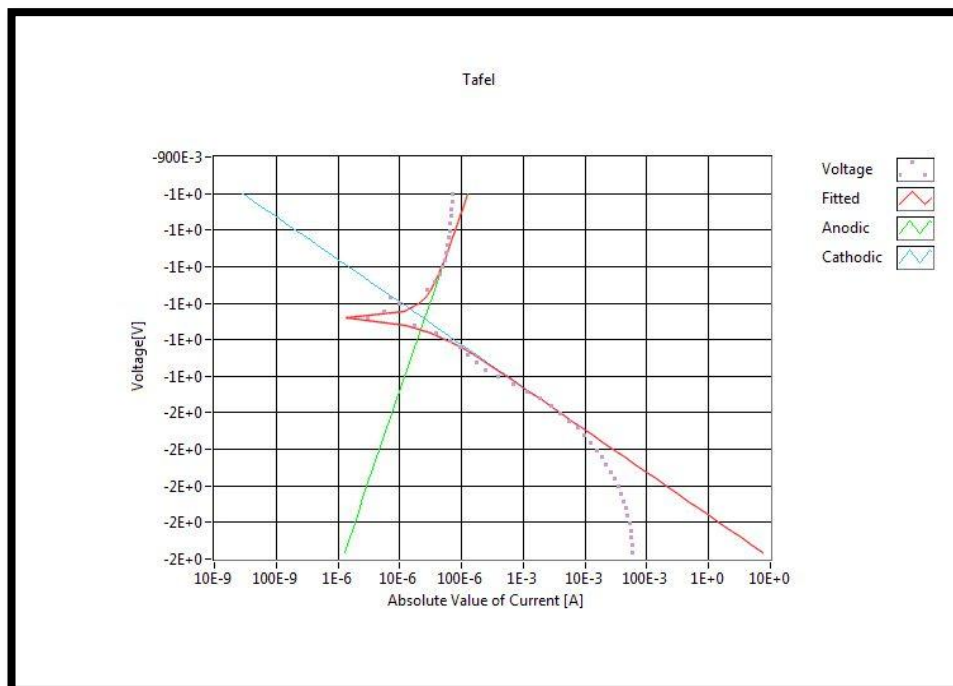


(b) Tafel extrapolation plot

Figure 4.14: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 190°C for an hour undergone

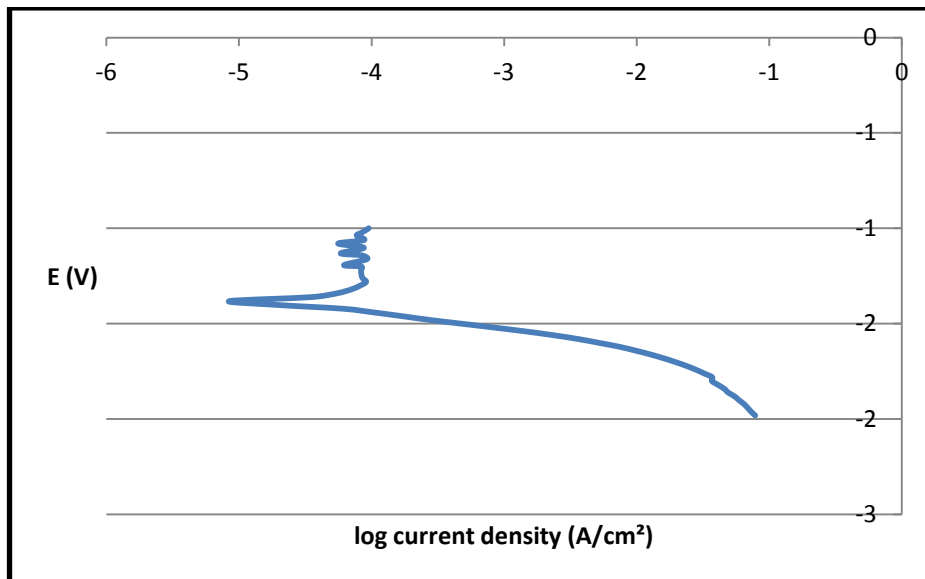


(a) Potentiodynamic polarization

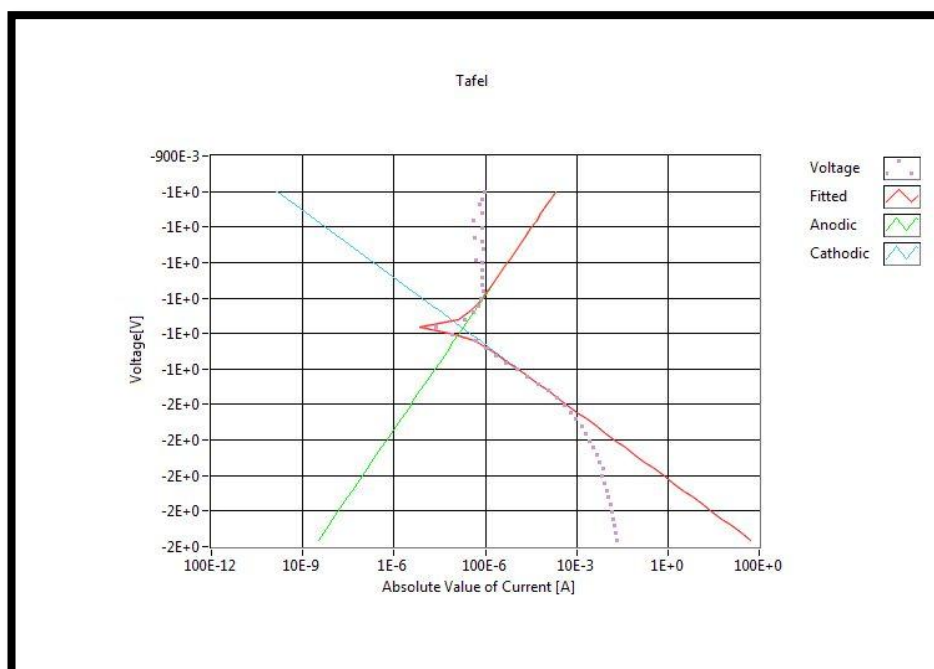


(b) Tafel extrapolation plot

Figure 4.15: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 190°C for three hours undergone



(a) Potentiodynamic polarization



(b) Tafel extrapolation plot

Figure 4.16: Experiment obtained in 3.5% NaCl solutions after solution treated at $490 \pm 5^\circ \text{C}$ for 5 hours, quenched in oil at room temperature followed by aging at 190°C for six hours undergone

4.4.1 Corrosion Rate

Essentially, Table 4.4 is listing the corrosion rate of each sample while others parameter such as E_{corr} , I_{corr} , β_a , β_c and R_p are needed to calculate the value of corrosion rate by using Tafel extrapolation method in 3.5% NaCl solution. The tafel extrapolation is obtained by aided software called IVMAN and eventually the corrosion rate would be measured after inserting the value of sample area, aluminium density, and equivalent weight of aluminium.

Table 4.4: Corrosion Rates Determined by Tafel Extrapolation Method in 3.5% NaCl solution.

Sample	E_{corr} (V vs SCE)	I_{corr} (A/cm ²)	β_a (V/decade)	β_c (V/decade)	R_p (ohm)	Corr Rate (mmpy)
A	-1.557	0.0006767	12.9	0.1811	114.6	7.38
B	-1.359	0.00001229	0.1384	0.07966	1787	0.134
C	-1.401	0.00006733	304.7	0.1525	983.1	0.7343
D	-1.458	0.0003025	0.4563	0.2227	214.8	3.3
E	-1.537	0.0006381	5.953	0.1693	112	6.96
F	-1.344	0.00002529	0.4905	0.1167	1618	0.2759
G	-1.385	0.00003224	0.1887	0.09453	848.2	0.3517

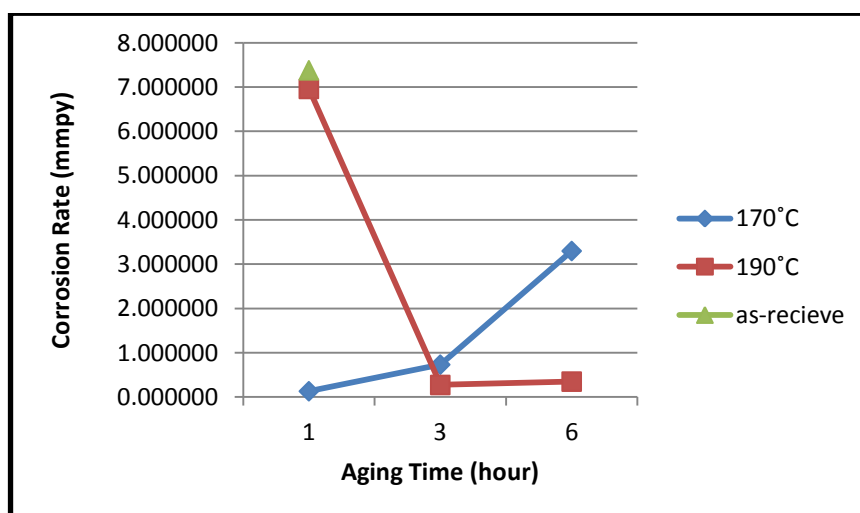


Figure 4.17: The value of corrosion rate of as receives and the sample that have undergone various aging time and temperature.

The graph trend in Figure 4.17 shows that the samples have been aged at temperature of 170°C with increase in aging time will increase the corrosion rate. While at temperature of 190°C, the trend shown is completely different because the increase in aging time seems to increase the corrosion resistance. From the graph instead, as-receive sample can be well determine to poss the least corrosion resistance toward chloride media.

According to Table 4.4, as-receive sample give the highest corrosion rate value which is 7.38 mmpy. Compare with the sample that have undergone precipitation hardening or aged at 170°C, the corrosion rate is increase as aging time is increase. Whereas, at an hour aging time the corrosion rate is 0.134 mmpy and gradually increase at three hours aging time with the value of 0.7343 mmpy while at six hours give the value of 3.3 mmpy. The different of corrosion rate become significant between three and six hours aging time.

The corrosion rate obtained from age hardening at 190°C against the graph trend for previous temperature because samples tend to resist the corrosion as aging time increase. The significant is shown at one and three hours aging time with value of 6.96 mmpy and 0.2759 mmpy respectively. At six hours, corrosion rate is increase with insignificant value of 0.3517 mmpy.

The desirable mechanical properties of commercial aluminium alloy are developed as a result of heterogeneous microstructures and acquired by proper alloying edition and heat treatment or precipitation hardening which is much closed related toward this field of study. The commercial alloy especially is high strength aluminium alloy use in aerospace application. The distribution of second phase or intermetallic particles would be the dominant feature for heat treated aluminium alloy microstructure from localized corrosion perspective. Commonly such particles will exhibit electrochemical characteristics that differ from the behaviour of the matrix, rendering the alloy susceptible to localized forms of corrosion (Birbilis and Buchheit, 2005).

4.5 PITTING MECHANISM

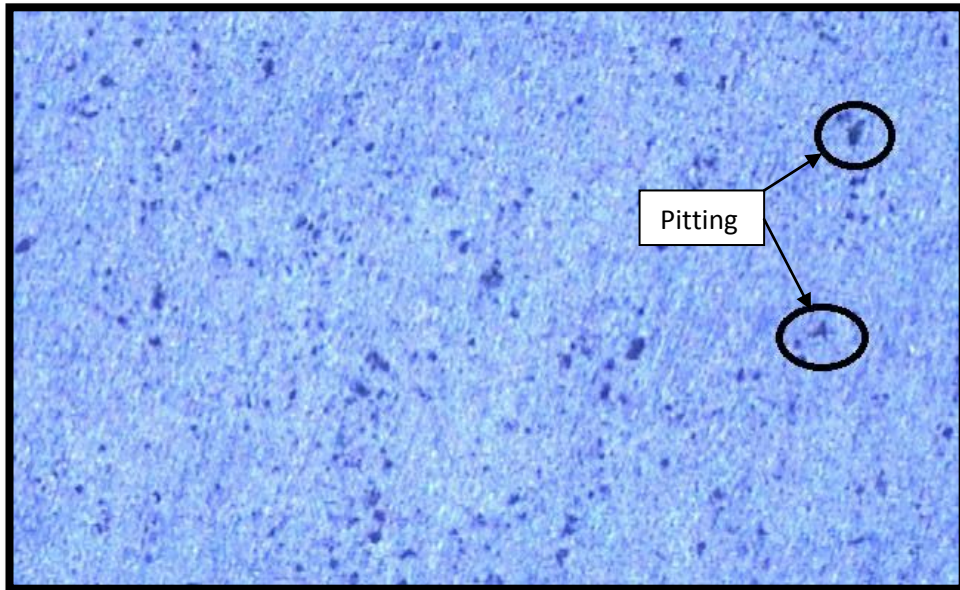


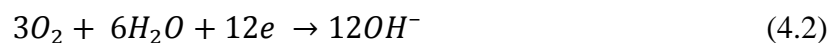
Figure 4.18: Surface morphology of AA6061 aluminium alloy after electrochemical test in the solution of 3.5% NaCl.

Pitting corrosion is defined as localized corrosion due to passive film on metal surface breakdown after being exposed to solution containing halide ions. The aggressive media such as NaCl causes pit initiation and growth in autocatalytic manner, where the local environment within the pit becomes more aggressive with decrease of pH value and increase in chloride concentration (Srinivasa and Prasad, 2004).

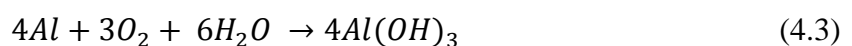
Anodic reaction: occur at the bottom of the pit.



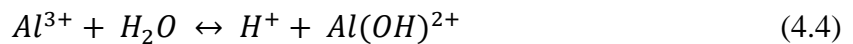
Cathodic reaction: reduction of oxygen



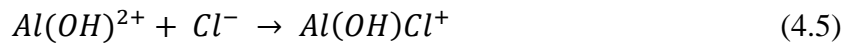
Net reaction:



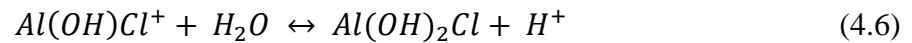
However, there is no clear knowledge on the composition of the salt layer. In the literature two different types of pit's salt are mentioned which are Aluminum chloride (AlCl_3) and aluminium oxychlorides $\text{Al}(\text{OH})_2\text{Cl}$ and $\text{Al}(\text{OH})\text{Cl}_2$. Depending upon the kind of a salt different pH of the solution within the pit can be expected. In the case of the presence of AlCl_3 the pH should be as low as 1. On the other hand, the saturated solution of $\text{Al}(\text{OH})_2\text{Cl}$ exhibits a pH 3 (Szkłarska-Smiałowska, 1999). Ionization of aluminium bare surface occur rapidly and hence undergoing hydrolysis process.



Then, aluminium hydroxide will react with chloride as cathodic reaction below.



And then, react with water producing acidic solution.



CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will conclude the result obtained in previous chapter and disclosed some recommendation that can be applied for future work. The main objective of the probe is to investigate the effect of aging on corrosion behaviour of AA6061 aluminium alloy. All experiment has been done successfully and hence, the investigation will come out with several conclusions with regard to the main objective mentioned above. On top of that, recommendation for further study on corrosion behaviour and precipitation hardening process will be discussed.

5.2 CONCLUSION

Several conclusions obtained from the investigation are:

- i. Aging process is found to influence the corrosion behaviour of AA6061 aluminium alloy in chloride containing solution with regard to the distribution of second phase or intermetallic particles.
- ii. The variation of aging time and temperature has been found to influence on the corrosion rate, hardness, and also the microstructure of as-receive AA6061 aluminium alloy since such second phase particles will exhibit electrochemical characteristics that differ from the behaviour of the matrix
- iii. The increases in aging time at a specific temperature tend to reduce the corrosion resistance of aged sample because it was highly influenced by the precipitates of a hardening (Mg_2Si) phase.

5.3 RECOMMENDATIONS

This probe can be explained in further details with several recommendations respect to the main objective which is to investigate the effect of aging on corrosion behaviour of AA6061 aluminium alloy. The following aspects could be taken into consideration:

- i. Experiment repetition is necessary.
- ii. Investigate the effect of aging on corrosion behaviour in other aggressive media such as in acid and alkaline.
- iii. Obtaining aging process by longer duration of soaks time.
- iv. Increase the potential range or using a small scan rate.

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APPENDIX A

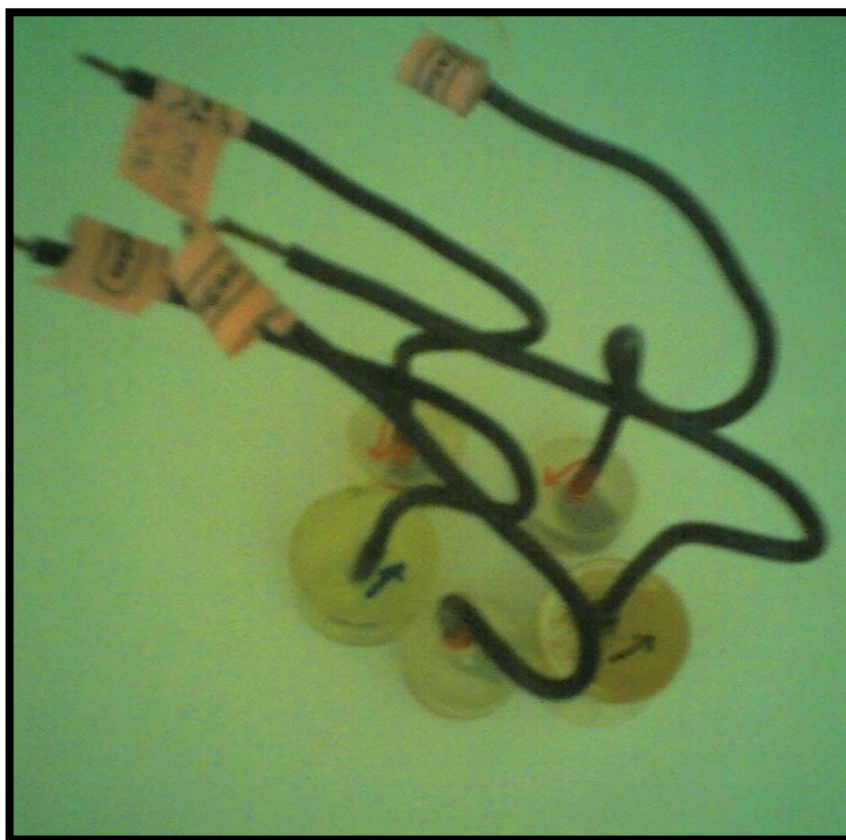


Figure 6.1: Sample for electrochemical cell

APPENDIX B

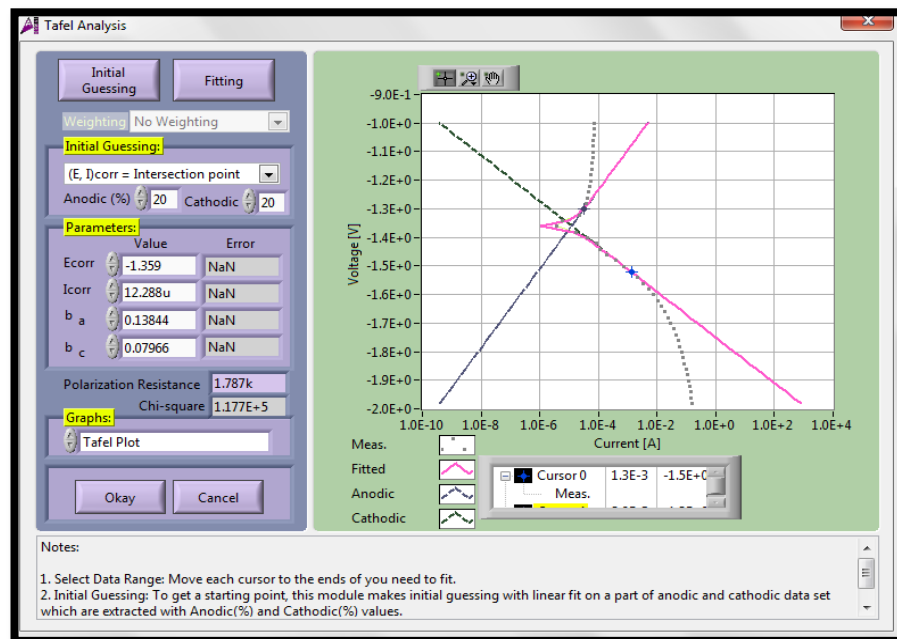


Figure 6.2: Tafel extrapolation using IVMan Software

The 'Tafel Parameters' dialog box contains the following text: 'Following parameters are needed to calculate corrosion rate. Estimate or check them.'

Parameters to be estimated or checked:

- Equivalent Weight [g] : 9.000E+0
- Density [g/cm³] : 2.700E+0
- Area [cm²] : 1

Additional parameters:

- b_a : 0.138 V/div
- b_c : 0.080 V/div

An 'OK' button is located at the bottom right.

Figure 6.3: Parameters needed to measure the corrosion rate using IVMan software

APPENDIX C

Gantt chart for FYP 1

PROJECT ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1) Got the project title and arrange discussion time with supervisor															
2) Meeting with supervisor															
3) Rough idea about the project															
4) Do research and collect the information															
5) Prepare for chapter 1 (introduction)															
6) Prepare for chapter 2 (literature)															
7) Prepare for chapter 3 (methodology)															
8) Prepare for presentation															
9) Project presentation															

