CORROSION BEHAVIOUR OF HEAT TREATED CARBON STEEL

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DEDICATION

I specially dedicate to my beloved parents
and those who have guided
and motivated me for this project

ACKNOWLEDGEMENT

First and foremost, the deepest sense of gratitude to the God, who guide and gave me the strength and ability to complete this final year project successfully. I would like to express my sincere gratitude to my supervisor Mdm. Juliawati Binti Alias for her continuous guidance, support and encouragement, which gave me huge inspiration in accomplishing this research. Her practices of professional ethics and conducts which encourages me to become confident and competent person to work individually as well as in group with minimal supervision.

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ABSTRACT

This thesis aims to investigate the corrosion behavior of high carbon steel at difference types of heat treatment and investigate the corrosion rate at difference temperature of heat treatment. Normalizing, water quenching and oil quenching of heat treatment were applied to the samples at selected temperature. The temperatures chosen for the heat treatment are 980 ˚C, 1015 ˚C and 1050 ˚C. Structural and mechanical properties of non heat treated and heat treated samples were determined using Vickers Hardness Test, optical microscope, Scanning Electron Microscopy (SEM). A standard micro hardness tester, equipped with a Vickers indenter and an indentation load of 500 gf was used for surface hardness measurement. The change of hardness and microstructure of heat treated AISI 1070 before corrosion and after corrosion were also observed. Electrochemical polarization measurement of the heat treated AISI 1070 were carried out by using a potentiostat. The polarization measurement of the heat treated AISI 1070 was conducted in a 3.5 % Sodium Chloride solution (NaCl). It was observed that the corrosion potential of AISI 1070 at normalized were higher than oil quenched and water quenched. Heat treatment for AISI 1070 in the 3.5 % Sodium Chloride solution (NaCl) posses a similar characteristic but different corrosion potential. The polarization curves on heat-treated AISI 1070 reveal a similar characteristic. The highest corrosion rate is non-heat treated AISI 1070 (13.96 mmpy) and the lowest corrosion rate is water quenched AISI 1070 at 1050 ˚C (0.5148 mmpy).

ABSTRAK

Tesis ini bertujuan untuk mengkaji sifat pengaratan keluli karbon tinggi pada perbezaan jenis rawatan haba dan mengkaji kadar pengaratan pada perbezaan suhu rawatan haba. Penyejukkan secara perlahan pada suhu bilik, penyejukkan dengan cepat menggunakan air dan penyejukkan dengan cepat menggunakan minyak adalah rawatan haba yang telah digunakan untuk sampel pada suhu yang dipilih. Suhu yang dipilih untuk melakukan rawatan haba adalah 980 ˚C, 1015 ˚C dan 1050 ˚C. Sifat-sifat struktur dan mekanikal sampel tanpa rawatan dan sampel dirawat haba ditentukan dengan menggunakan Ujian Kekerasan Vickers, mikroskop optik, Pengimbas Mikroskopi Elektron (SEM). Penguji kekerasan mikro, dilengkapi dengan penakuk Vickers dan beban takukan sebanyak 500 gf telah digunakan untuk ujian permukaan. Perubahan kekerasan dan mikrostruktur untuk sampel dirawat haba AISI 1070 sebelum pengaratan dan selepas pengaratan juga diperhatikan. Elektrokimia pengukuran pembelauan untuk sampel terawat haba AISI 1070 telah dijalankan dengan menggunakan potentiostat. Ukuran pembelauan potentiodinamik untuk sampel terawat haba AISI 1070 telah dijalankan dalam 3.5 % larutan Natrium Klorida (NaCl). Adalah diperhatikan bahawa potensi karat AISI 1070 untuk rawatan haba pada penyejukkan dengan perlahan pada suhu bilik adalah lebih tinggi daripada penyejukkan dengan cepat menggunakan air dan penyejukkan dengan cepat menggunakan minyak. Rawatan haba untuk AISI 1070 dalam 3.5 % larutan Natrium Klorida (NaCl) menunjukkan ciri-ciri yang sama tetapi menunjukkan potensi pengaratan yang berbeza. Lengkung pembelauan pada sampel rawatan haba AISI 1070 menunjukkan ciri-ciri yang sama. Kadar pengaratan tertinggi ialah untuk sampel tanpa rawatan AISI 1070 (13.96 mmpy) dan kadar pengaratan terendah adalah untuk sampel penyejukkan dengan cepat menggunakan air AISI 1070 pada suhu 1050 ˚C (0.5148 mmpy).

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LIST OF SYMBOLS

α	Alpha ferrite
°C	Degree Celsius
%	Percentage
b_a	Anodic Tafel slopes
b_c	Cathodic Tafel slopes
cm	Centimeter
e^-	Electrons
E	Potential
E_{appl}	Potential applied
E_{corr}	Corrosion potential
i_{corr}	Corrosion current density
In	Natural logarithm
kg	Kilogram
kV	Kilovolts
kΩ	Kilo ohms
mm	Millimetre
m	Meter
mA	Milliampere
m/s	Meter per second
mV/s	Millivolts per second
R_p	Resistant potential
s	Second
V	Voltage
wt%	Weight percentage
μ	Micro
γ	Gamma ferrite
ζ	Polarization expressed

LIST OF ABBREVIATIONS

A	Area
AISI	American Iron and Steel Institute
BCC	Body-centered cubic
C	Carbon
CR	Corrosion rate
EW	Equivalent weight
d	Density
FCC	Face-centered cubic
Fe	Iron
Fe^{2+}	Iron ion
Fe_3C	Cementite
H_2O	Water
HSLA	High Strength Low Alloy Steel
HV	Hardness value
L	Liquid
M	Metal
Mn	Manganese
mmpy	millimetre per year
NaCl	Sodium Chloride
O_2	Oxygen gas
OH	Hydroxide
P	Phosphorus
Pt	Platinum
SEM	Scanning Electron Microscopy
S	Sulphur
Si	Silicon
Wt	Weight
FKM	Faculty of Mechanical Engineering
FYP	Final Year Project
UMP	Universiti Malaysia Pahang

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Corrosion can be defined as the deterioration of a material resulting from chemical attack by its environment. Most corrosion of materials involves the chemical attack of metals by electrochemical cells. By studying equilibrium conditions, the tendencies of pure metal to corrode in a standard aqueous environment can be related to the standard electrode potential of the metals. However, since corroding systems are not at equilibrium, the kinetics of corrosion reactions must also be studied. Some examples of kinetic factors affecting corrosion reaction rates are the polarization of the corrosion reactions and the formation of pasive films on the metals. Corrosion can be controlled or prevented by many different methods. To avoid corrosion, materials that are corrosion-resistant for a particular environment should be used where feasible. For many cases corrosion can be prevented by the use of metallic, inorganic, or organic coatings. The proper engineering design of equipment can also be very important for many situations, for some special cases, corrosion can be controlled by using cathodic or anodic protection system (Smitch, 2006).

Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. Heats Treatment is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability, and restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics. Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material.

1.2 PROBLEM STATEMENT

Carbon steel is used in large applications such as in marine, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction and metal-processing equipment. Carbon steel will corrode when two chemical processes involve, which is oxidation and reduction. Oxidation is the process of stripping electrons from an atom and reduction occurs when an electron is added to an atom. Carbon steel can corrode in many media including most outdoor atmospheres. Corrosion scientists and corrosion engineers are the important people to improve the understanding the causes of corrosion or applied scientific knowledge to control the corrosion. The corrosion normally lead to spend highly cost for replacing corroded structures, for example replace a machinery or their components, such as condenser tubes, mufflers, pipelines and metal roofing, including necessary labor. Beside that, to prevent the corrosion, extra cost is needed to use corrosion resistant materials (Revie and Uhlig, 2008). Analysis on the corrosion behaviour of heat treated carbon steel has been investigated in this project.

1.3 OBJECTIVES OF STUDY

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

i. To study the corrosion behaviour of high carbon steel at differences type heat treatment.
ii. To investigate the corrosion rate at difference temperature of heat treatment.

1.4 PROJECT SCOPE

The project scopes for this project are listed below:

i. The raw material that used is high carbon steel.
ii. Sample preparation of high strength steel based on plate with dimension 15 mm in length, 15 mm width with thickness 3 mm for all sample.
iii. Every sample will quench in water, quenching in oil and normalizing at different temperature.
iv. Compositional and microstructure analysis before & after exposure to the high temperature.
v. Analysis corrosion rate by using electrochemical test.
vi. Microstructure analysis by using optical and scanning electron microscopy (SEM).
vii. Hardness test by using Vickers hardness test machine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Corrosion is very serious problems occur on the metal and make difficult to an engineer. The corrosion happen will affect the performance especially in the industry. There are several examples that show how the corrosion cost is very high while doing the maintenance. The chemical company have to spent big money to prevent or maintenance the corrosion and the petroleum industry always also spent about million dollars per day to protect underground pipelines and another spends on painting steel to prevent rusting by a marine atmosphere.

Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Non-metals are not included in the definition of corrosion. Since corrosion involves chemical changes, everyone must be familiar with principle of chemistry in order to understand the corrosion reaction because most of the corrosion happens in the world due to electrochemical. In the corrosion we can divide two types which are corrosion science and corrosion engineering. The corrosion scientist studies corrosion mechanism to improve the understanding of the causes of the corrosion and improve the ways to prevent or minimize damage caused by corrosion. The corrosion engineer is the person responsible to applies scientific knowledge to control corrosion. Loss of metal by corrosion is a waste not only of the metal, but also of the energy, the water, and the human effort that was used to produce and fabricate the metal structure in the first place. The three main reasons for the importance of the corrosion are economics, safety, and conservation.

2.2 TYPES OF CORROSION DAMAGE

Corrosion is often thought of only in terms of rusting and tarnishing. However, corrosion damage occur in other ways as well, resulting for example, in failure by cracking or in loss of strength or ductility. In general, most type of corrosion, with some exceptions, occur by electrochemical mechanism, but corrosion products are not necessarily observable and metal weight loss need to be appreciable to result in major damage (Revie and Uhlig, 2008).

The corrosion behaviour of engineering materials is influenced by many factors such as:

i. Chemical composition and microstructure of the metal
ii. Chemical composition of environment
iii. Physical parameters such as temperature, convection, irradiation , etc.
iv. Mechanical forces including tensile stresses, shocks or friction

Because the corrosion behaviour of metals is governed by complex interaction involving many parameters, it manifests itself in numerous often unanticipated forms. The corrosion resistance of a given metal is not an intrinsic property of that metal, but a system property. The same metal may rapidly corrode in a certain environment while under different conditions it is stable. From a more fundamental point of view, the corrosion resistance of metals is essentially determined by the reactivity of the metal-environment interface. Certain types of corrosion damages found in practice present a characteristic appearance that provides a hint as to their probable origin a mechanism (Landolt, 2007).There are several types of corrosion, depending on the metal, corrosive agent, geometry and environment.

i. Uniform corrosion: Uniform corrosion is a loss of material distributed uniformly over the entire surface exposed to the corrosive environment. Metals in contact with strong acids are sometimes subject to uniform corrosion

ii. Galvanic corrosion: Galvanic corrosion also called bimetallic corrosion, result from the formation of an electrochemical cell between two metals. The corrosion of the less noble metal is thus accelerated
iii. Crecive corrosion: Crecive corrosion is caused by a difference of oxygen availability between two sites on a passive metal that leads to the formation of an electrochemical cell. A selective attack within cracks and at other sites of poor oxygen acces is frequently observed
iv. Pitting corrosion: Pitting corrosion is observed on passive metals in presence of certain anions (in particular chloride) when the potential exceeds a critical value. This process typically produces cavities with diameters on the order of several tens of micrometers.
v. Intergranular corrosion: Intergranular corrosion is a selective attack of grain boundaries. Often, it is related to thermal treatments that lead preferred precipitation of phases at grain boundaries.
vi. Selective corrosion: Selective corrosion also called selective leaching or dealloying implies the selective dissolution of one of the components of an alloy that forms a solid solution. It leads to the formation of a porous layer made of the more noble metal.
vii. Erosion corrosion: Erosion corrosion is the result of an electrochemical reaction combined with a material loss by mechanical wear due to impingement of solids or a fluid.
viii. Stress corrosion cracking: stress corrosion cracking is result from the combined action of corrosion and of mechanical stress. It manifests itself by crack information at stress levels well below the ultimate tensile strength of material.

Eight types of corrosion damage are shown as in Figure 2.1.

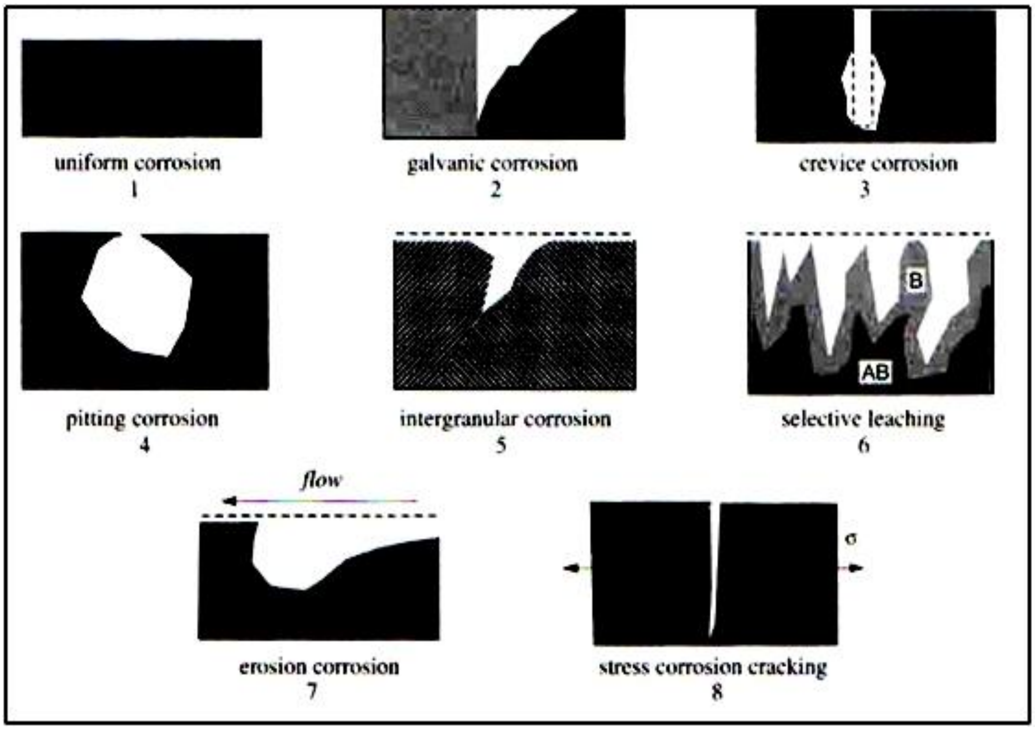


Figure 2.1: Eight types of corrosion damage

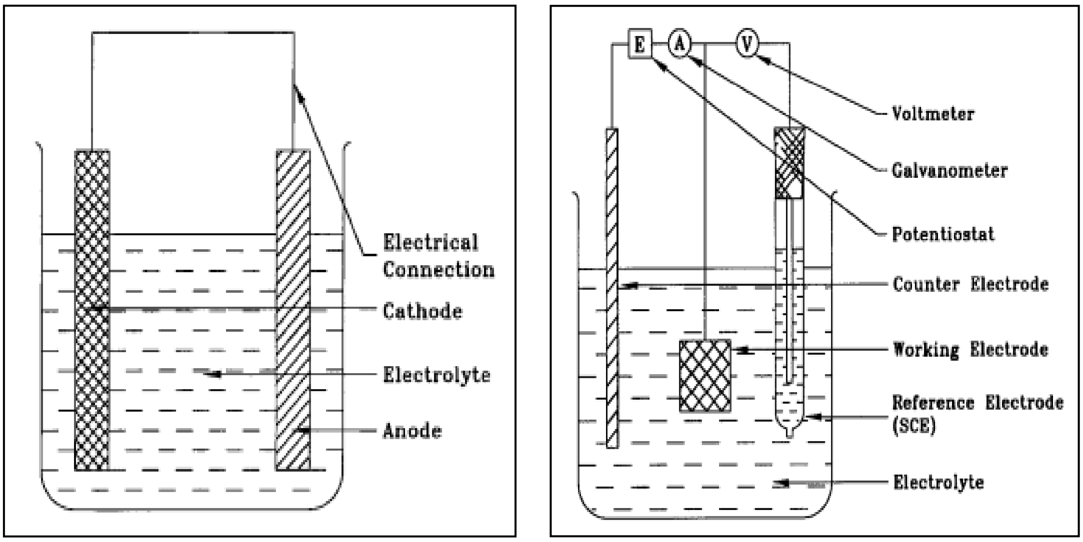
Source: (Landolt, 2007)

2.3 CORROSION CONCEPTS

Corrosion can be defined as degradation of quality and properties in a material due to the chemical reaction between the components of the material and the surrounding during electrochemical process. Electrochemical process is general process which requires the presence of an anode, a cathode, an electrolyte, and an electrical circuit in order to active the reaction.

First, the metal at the anode was dissolved and the electrons were produced from the anode as shown in Figure 2.2. The number of electrons produced was depends on the type of the metal was used. After the electrons were produced at the anode, the corrosion current was generated by the electrons and the electrons were transferred to the cathode through the electrolyte as a transfer medium. Eq. (2.1) shows that the general reaction that occurs at the anode.

$$M \rightarrow M^{n+} + e^- \qquad (2.1)$$



(a) **(b)**

Figure 2.2: The basic corrosion cell: a) Schematic of basic wet corrosion cell, b) schematic of electrical circuitry for Polarization measurement

Source: (Tavakkolizadeh and Saatdarmanesh, 2001)

The reaction at the anode shows that a loss of electrons, or oxidation as clearly shown in Figure 2.2. The electrons produced at the anode were flow to the cathode through the electrolyte which initiates a reaction to occur at the cathode. The reaction in cathode was depends on the medium of transfer which can be divided into three groups which are acidic solution, alkaline solution and neutral solutions. All of these reactions in each solution involve a gain of electrons and a reduction process which occurred at the cathode as shown in Eq. (2.2) which in neutral solution. If the medium is in alkaline and neutral aerated solutions, the predominant cathodic reaction was shown in Eq. (2.2) .There is an important consideration when the reactions at cathode and anode were generated which is the number of electrons produced at the anode must equal the number of electrons gained at the cathode since there can be no net gain or loss of electrons (Tavakkolizadeh and Saatdarmanesh, 2001).

$$O_2 + 2H_2O + 4e^- \rightarrow 4(OH^-) \qquad (2.2)$$

For example, if iron (Fe) was placed at the anode which exposed to aerated, corrosive water, the anodic reaction was shown in Eq. (2.3) which oxidation was occurred. However, at cathode, reduction of oxygen was occurred as shown in Eq. (2.1) .Based on the Eq. (2.3), two electrons were produced during the reaction at anode. However, based on Eq. (2.2), four electrons were required in order to balance the reaction at cathode.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \tag{2.3}$$

Based on the concept of reaction, the number of electrons produced at the anode must equal the number of electrons gained at the cathode since there can be no net gain or loss of electrons. Thus, the anodic reaction was modified and shown as Eq. (2.4) while the cathodic reactions would be similar with previous equation. Finally, an overall oxidation-reduction reaction was shown in Eq. (2.5) which summarized the oxidation-reduction reaction occurred at the cathode and anode.

$$2\ Fe \rightarrow 2Fe^{2+} + 4e^{-} \tag{2.4}$$

$$2Fe + O^{2} + 2H_2O \rightarrow 2Fe^{2+} + 4(OH^{-}) \tag{2.5}$$

However, after the dissolution at anode, the ferrous ions or known as Fe^{2+} generally oxidize to ferric ions (Fe^{3+}) as shown in Eq. (2.6) and these will combine with hydroxide ions (OH^{-}) formed at the cathode to give a corrosion product called rust (FeO(OH), $Fe_2O_3 \cdot nH_2O$ or $Fe(OH)_3$)as shown in Eq. (2.7) and Eq. (2.8). The important issue to remember is that anodic dissolution of metal occurs electrochemically while the insoluble corrosion products are formed by a secondary chemical reaction as shown in the equation below.

$$4Fe^{2+} + O_2 \rightarrow 4Fe^{3+} + 2O^{2-} \tag{2.6}$$

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^{+} \tag{2.7}$$

$$Fe(OH)_3 \rightarrow FeO(OH) + H2O \tag{2.8}$$

2.4 CARBON STEEL

High strength, low alloy (HSLA) steels derive their name from their higher strengths relative to plain low-carbon steels with nominal ferrite pearlite microstructure.

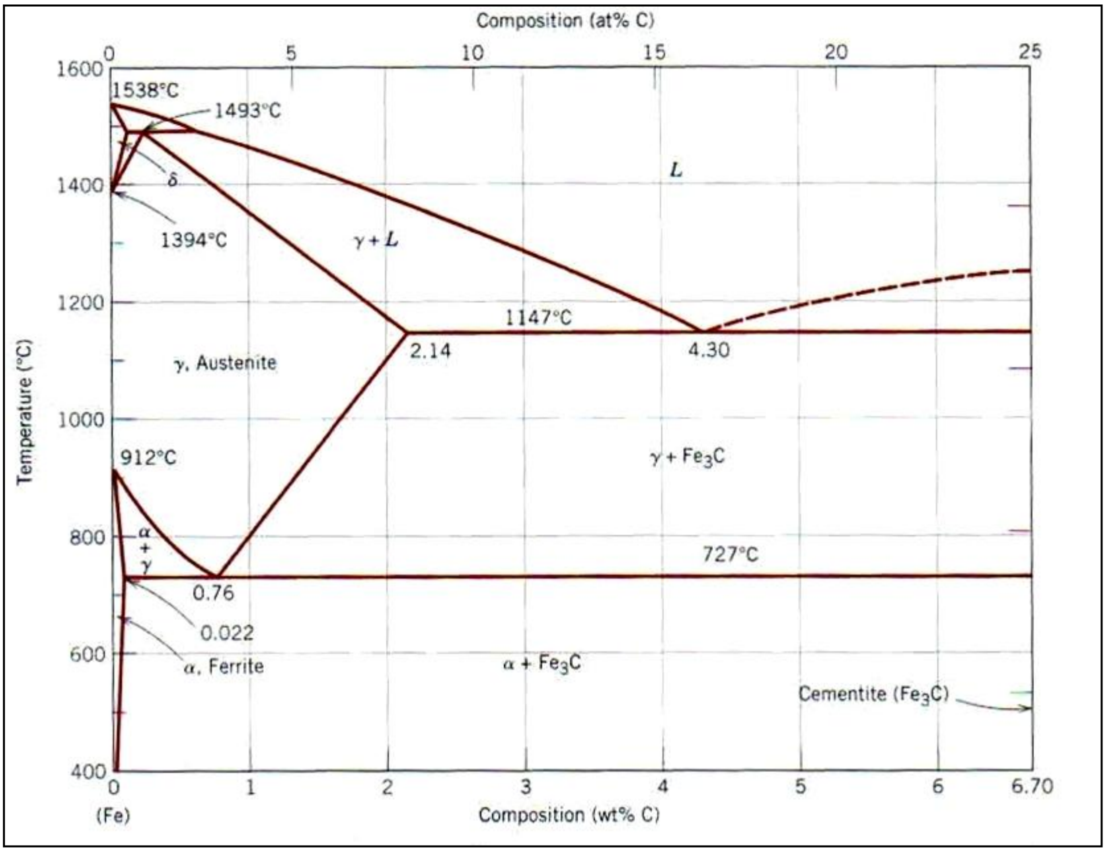


Figure 2.3: The iron-iron carbide phase diagram

Source: (Callister and Rethwish, 2008)

2.4.1 The iron-carbon system

Pure iron when heating experiences two changes in crystal structure before it melts. At room temperature the stable form is called as ferrite or α iron has a BCC crystal structure. Ferrite experiences a polymorphic transformation to FCC austenite, or γ iron, at 912 °C. This austenite persists to 1394 °C, at that temperature the FCC austenite reverse back to BCC phase which is δ ferrite. It finally melts at 1538 °C. All these changes occur along the left vertical of the phase diagram.

Cementite is formed when composition extend only to 6.7 wt% C. The iron-carbon system may be divided into two parts which is iron-rich portion as in figure and the others are pure graphite for compositions between 6.7 wt% and 100 wt%. Carbon is an interstitial impurity in iron and form a solid solution consist of α and δ ferrite also with austenite. Small concentrations of carbon are soluble in the BCC α ferrite and the maximum soluble is at the 0.22 wt% at 727 °C. The austenite, γ when alloyed with carbon alone is nit stable below 727 °C. The maximum solubility of carbon in austenite is at 2.14 wt% which is occurring at 1147 °C. Phase transformation involving austenites are very important in the heat treating of steels (Callister and Rethwish, 2008).

When the solubility limit of carbon in α ferrite is exceeded below 727 °C the cementite will be formed (Fe_3C) at composition α + Fe_3C phase region. Cementite is brittle and very hard. At 4.3 wt% C and 1147 °C eutectic exist for the iron-iron carbide system. The eutectic reaction for the iron-iron carbide system is shown as in Eq. (2.9).

$$L \longrightarrow \gamma + Fe_3C \text{ (Cooling)} \tag{2.9}$$

The liquid solidifies and will form austenite and cementite phases. The subsequent cooling to room temperature will make additional phase changes. The eutecyoid point exists at composition 0.76 wt% and temperature of 727 °C. The eutectoid reaction for the iron-iron system may represent as in Eq. (2.10) below.

$$\gamma \text{ (0.76 wt\% C)} \longrightarrow \alpha \text{ (0.022 wt\% C)} + Fe_3C \text{ (6.79 wt\% C)} \tag{2.10}$$

(cooling)

2.4.2 Microstructure in iron-carbon alloy

The microstructure develops on the metal is depend on both carbon content and heat treatment. The eutectoid when slowly cooled through the euctectoid temperature which is consist of alternating layers (α and Fe_3C) will make the pearlite microstructure. It called pearlite because it has the appearance of mother of pearl when viewed under microscope at low magnifications.

Hypoeutectoid alloy is less than eutectoid. Cooling an alloy of this composition about the vertical line and occur between 0.022 wt% C and 0.76 wt% C at phase diagram. Hypereutectoid alloy is microstructure form at containing between 0.76 wt% C and 2.14 wt% C, which are cooled from temperature within the γ phase field (Callister and Rethwish, 2008).

2.5 MARTENSITE

Martensite is the hard microstructure that found in quenched carbon steel. Martensite may occur any phase produced by a martensitic or displace transformation. The phase may have different composition, crystal structure, and properties than does martensite in steel.

Two major morphologies of martensite are lath and plate; develop in heat treatable carbon steels. The designations of the two morphologies originated from the shape of the individual units of martensite. The board-shaped units of martensite that form in low and medium carbon steel called as the lath design. Meanwhile, the board-shaped of martensite that form in high carbon steel called as the plate design. In metallographic specimens, section through martensite laths and plates are revealed by polishing and etching. Generally, this cross section will appear to be needlelike or circular, and the latter adjectives are often used to describe martensite microstructure (Krauss, 2005).

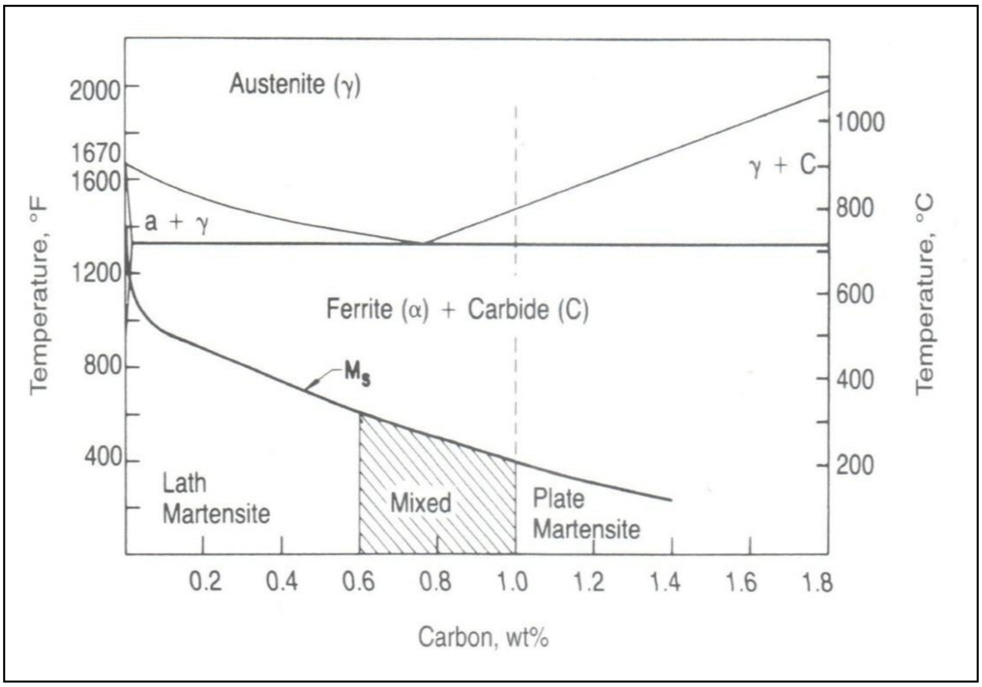


Figure 2.4: Ranges of lath and plate martensites formation in iron-carbon alloys

Source: (Krauss, 2005)

2.6 HEAT TREATMENT

Heat treatment is procedure for producing martensite steels which ordinarily involve continuous and rapid cooling of an austenitized specimen in some type of quenching medium such as water, oil and air. The optimum properties of steel after quenched and then tempered can be realized only, during quenching heat treatment, the specimen has been converted to a high content of martensite. The formation of any pearlite or bainite will result in other than the best combination of mechanical characteristic. During the quenching treatment, the specimen is cooled at uniform rate and the surface will always cool more rapidly than interior region. After that, the austenite will transform over a range of temperature, yielding a possible variation of microstructure and properties with position within specimen (Callister and Rethwish, 2008).

Normalizing is a heat treatment in which material exposed to an elevated temperature at extended time period and then slowly cooled at room temperature.

Normalizing process will make relieve stress, increase softness, ductility, toughness and produce a specific microstructure.

Quenching is a heat treatment in which process of cooling a metal very quickly. This is most often done to produce a martensite transformation. In ferrous alloys, this will often produce a harder metal, while non-ferrous alloys will usually become softer than normal.

Tempering is a heat treatment in which enhance the ductility and toughness of martensite and these internal stresses relieved. Tempering is accomplished by heating martensitic steel to a temperature below the eutectoid. At the quenching state, the martensite being very hard is so brittle that it cannot use for most application. Therefore the tempering will do.

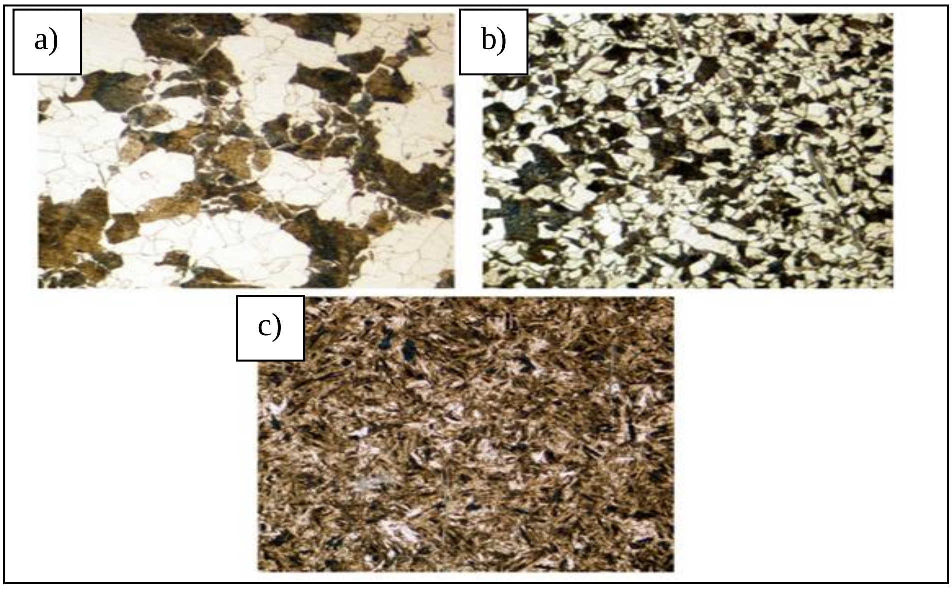


Figure 2.5: Microstructure of the steel after (a) annealing, (b) normalizing and (c) full martensitic transformation (500x)

Source: (Okan and Mustafa, 2009)

2.7 ELECTROCHEMICAL POLARIZATION

The polarization test is performed to investigate the corrosion properties of a material in a certain solution. This test provides not only an estimate of the corrosion rate of a material in a solution, but also can be used for the assessment of the galvanic corrosion rate of two materials coupled together. During this test, the potential difference between the material and the reference electrode is monitored, as well as the current. In the polarization test setup, a reference electrode and the working electrode (material under study) are connected via a high impedance voltmeter. A counter electrode (usually platinum, Pt) is connected to the working electrode via a galvanometer and a variable voltage source. The three electrodes are then placed in a glass container filled with the solution under study. For solutions with a relatively low conductivity, the reference and working electrodes are placed as close as possible to each other to prevent any possible potential drop. A polarization plot can be obtained by scanning from some potential below the free corrosion potential to some potential above it. Each plot will have two branches, one corresponding to the cathodic polarization (below E_{corr}), and the other to the anodic polarization (above Ecorr).The corrosion current density of the coupled system can be predicted by superimposing the polarization plots of two different materials in one graph. Such a plot is commonly referred to as the Evans diagram (Fontana, 1987). Usually more than one cathodic and anodic reaction occurs in a system. For example, hydrogen evolution can occur on both electrodes, both electrodes can corrode, and more than one corrosion product can be developed. The Evans diagram can also be used to predict the overall corrosion rate of a system.

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. Eq. (2.11) represents the relationship of polarization with the different between the potential of anodic or cathodic polarization and its corrosion potential

$$\zeta = E - E_{corr} \tag{2.11}$$

If the polarization of $\zeta > 0$, it is anodic current flow, while $\zeta < 0$, it is cathodic current flow (Winston and Herbert, 2008).

2.7.1 Tafel extrapolation

At large polarization, in the potential region where the rate of a single partial corrosion reaction predominates, the graphical representation in coordinates E-log I_{appl}, for reactions under pure activation control give straight lines (so called Tafel lines), as in Figure 2.6. At potentials well away from the corrosion potential, the applied current density reflects the kinetics of only on the corrosion reactions.

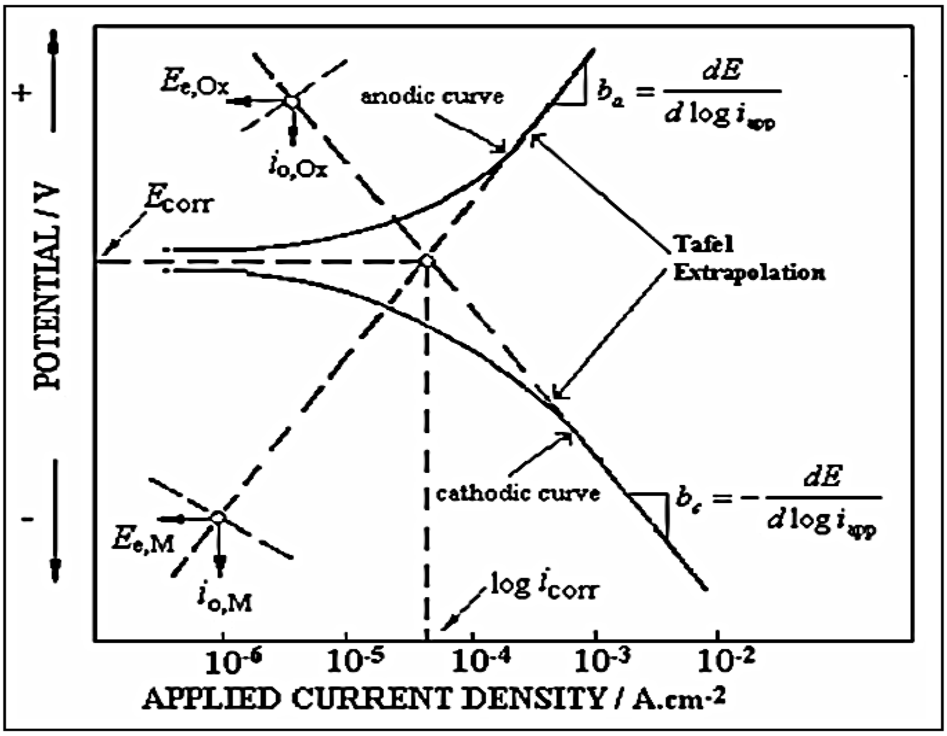


Figure 2.6: Polarization curves for a corrosion system under activation control

Source: (Winston and Herbert, 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.

$$E_{appl} = E_{corr} + \beta_a \log \frac{i}{i_{corr}} \tag{2.12}$$

$$E_{appl} = E_{corr} + \beta_b \log \frac{i}{i_{corr}} \tag{2.13}$$

where βa and βc are positive constant (Winston and Herbert, 2008).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is one of the most important considerations in order to complete any research and development. The main reason to make a methodology is to assure that the project will be on time and following the planning that has made until it finished. Methodology is a serious process, activities and task to state the step or the structure in conducting the experimental work for the research. By using the objectives and scopes as the guideline, methodology can be described as the root of the research.

3.2 FLOW CHART

The methodology flow chart is purposed to give guidelines and directions to successfully accomplish the objectives of this project. A methodology has been constructed like Figure 3.1.

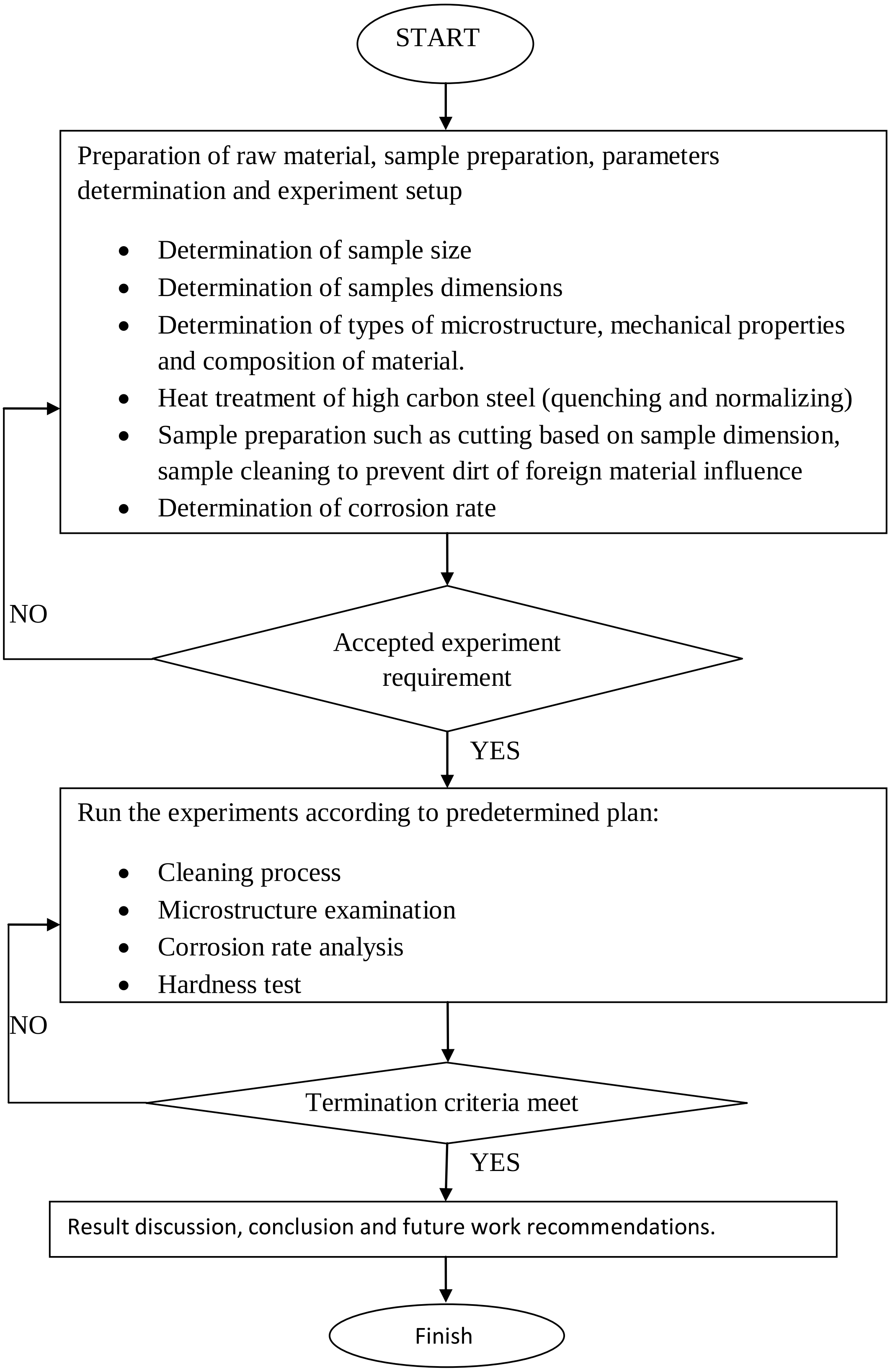


Figure 3.1: Project flow chart

3.3 SAMPLE PREPARATION

In this project, AISI 1070 has been used. AISI 1070 undergo heat treatment in order to increase high strength steel. Initially, AISI 1070 was cut into 200 mm length by using the bend saw in mechanical laboratory. According to the project scopes, there are about 10 sample has been used in this project. The dimension for every sample is 15 mm in length, 15 mm width with thickness 3 mm as shown in Figure 3.2.

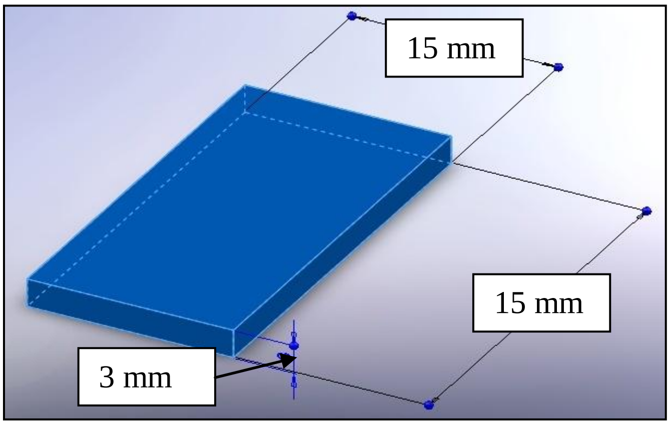


Figure 3.2: The sample after being cut

3.3.1 Composition analysis

A spark emission spectrometer as shown in Figure 3.3 was used to analyze the composition of metal. Before undergo the testing composition analysis process, the surface of the sample must be flat enough. There are two possibilities that the sample might not flat due to the grinding error and others elements takes place on the surface of sample such as corrosion reaction. The sparking emission light reflected out from the sample and this will incorrect or inaccurate measurement.

In order to conduct the composition analysis process, cleaning the spark chamber before every testing analysis is started. This can help to prevent the spark chamber from promoted to the next analysis. Besides that, ensure specimen is enclosed to the spark chamber and a holder place on the specimen to avoid hold tied the specimens to the spark chamber. Every specimen must conduct the metal analysis more than 3 times in order to get accurate or precise result. Figure 3.4 is shown as the sample after composition analysis and Table 3.1 shown as chemical composition of AISI 1070 steel.

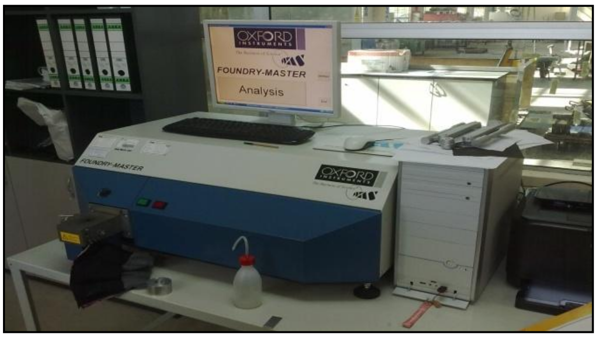


Figure 3.3: A spark emission spectrometer

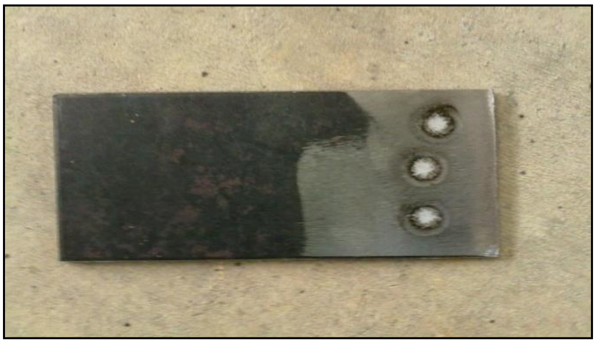


Figure 3.4: Sample after composition analysis

Table 3.1: Chemical compositions for AISI 1070 steel

	Wt.%				
	C	**Si**	**Mn**	**P**	**S**
Sample composition	0.666	0.220	0.623	0.003	0.003
Standard AISI 1070 composition.	0.65-0.75	0.15-0.3	0.6-0.9	0.04 max	0.05 max

3.3.2 Normalizing and quenching

Three samples were heated at 980 °C, 1015 °C and 1050 °C for 90 minutes. Each sample is normalized, quenched in water and quenched in oil. The sample heated by furnace as in Figure 3.7.

Figure 3.5: Furnace used for heating process

3.3.3 Microstructure examination

In order to determine microstructure of the sample, metallographic examination will be carried out. The microstructure of all steel was examined by using optical and scanning electron microscopy (SEM). The process includes are:

i. Sectioning by sectioning cut-off machine.
ii. Mounting the sample by using hot mounting, as shown in Figure 3.8.
iii. Grinding with 3 abrasives grit; 240, 320, 800 and 1200 emery papers, as sown in Figure 3.7.
iv. Polishing with diamond clothes includes 6μ, 3μ and 1μ, as shown in Figure 3.8.
v. Etching with 2 % Nital (Ethanol and nitric acid), as shown in Figure 3.9.

Figure 3.6: Hot mounting machine used for mounting all samples

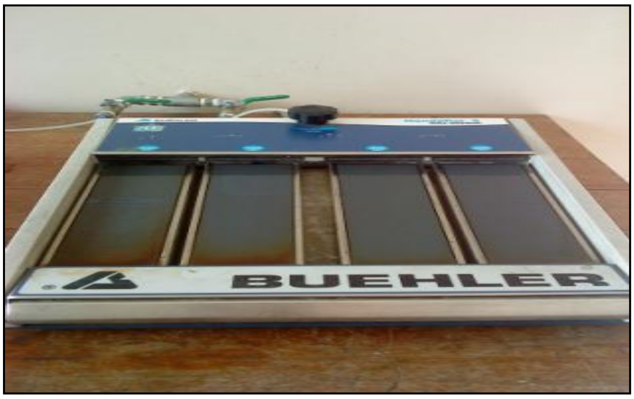


Figure 3.7: Grinding machine used for samples preparation

Figure 3.8: Polishing machine used for samples preparation

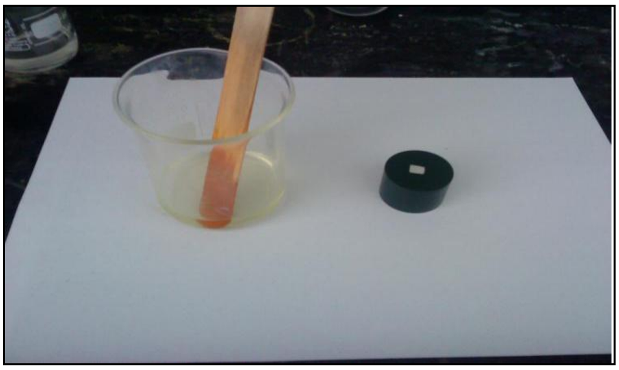


Figure 3.9: Etching process for microstructure examination

3.3.4 Sample testing

The all specimens heated at different temperature which is 980 °C, 1015 °C and 1050 °C followed by heat treatment chosen. The heating times for all specimens are 90 minutes period. The shape of the specimens after it had been cut is in the shape of cubic with 15 mm x 15 mm dimensions. The heating temperatures for the sample are as list in Table 3.2.

Table 3.2: Sample preparation

Sample	**Heat treatment**	**Temperature (°C)**
1	As received	-
2	Normalizing	980
3	Normalizing	1015
4	Normalizing	1050
5	Water quench	980
6	Water quench	1015
7	Water quench	1050
8	Oil quench	980
9	Oil quench	1015
10	Oil quench	1050

3.4 ELECTROCHEMICAL TEST

The electrochemical polarization experiments were carried out using a potentiostat as shown in Figure 3.10. Three electrode cell configurations were employed for the polarization measurements. One side of sample, whose area 2.25 cm^2, was exposed to the solution. The parameters were setting as shown in Table 3.3.

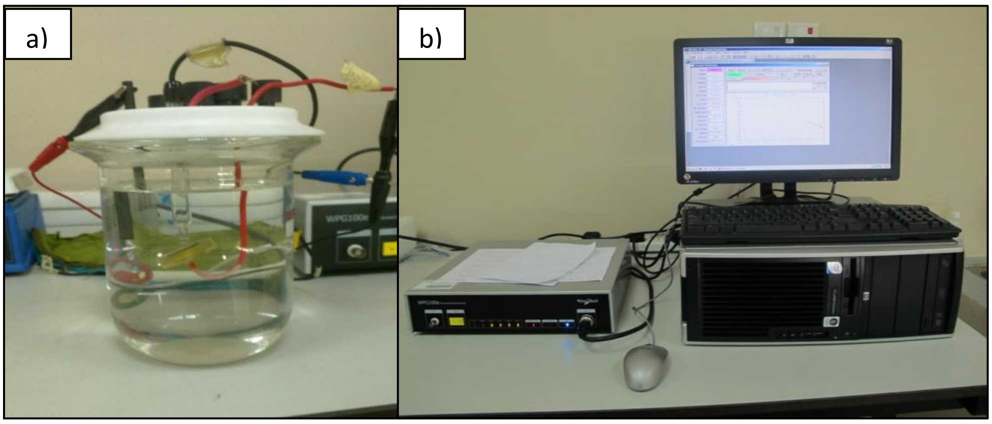


Figure 3.10: Electrochemical Test apparatus: (a) specimen was exposed to the 3.5% NaCl solution, (b) Computer-controlled potentiostat.

Table 3.3: Electrochemical Test setting

Parameters	Descriptions
Potential range	-1.5 V to 0 V
Scan rate	20 mV/s
Sampling time	30 s
Sample area	2.25 cm^2
Solution	3.5% NaCl
Working electrode	Sample (AISI 1070)
Counter electrode	Graphite
Reference electrode	K/KCl

3.5 CLEANING PROCESS

Before samples were cleaned, their appearance were observed and recorded. Location of deposits, variations in types of deposits, or variations in corrosion products were extremely important in evaluating the type of corrosion. There are two methods for removing deposited, namely mechanical cleaning, which depends on the procedures such as water hydro blasting, can remove soft and loose deposited. Chemical cleaning procedures which depend on suitable chelants could be considered the most effective for removing internal deposits (Al-Mayouf, 1997). In this experiment the samples were cleaned in water, followed by acetone, and dried in a cold blast of air to avoid oxidation. Figure 3.11 is show the example of sample before and after cleaning process. Cleaning process will remove the corrosion product at the surface of the sample.

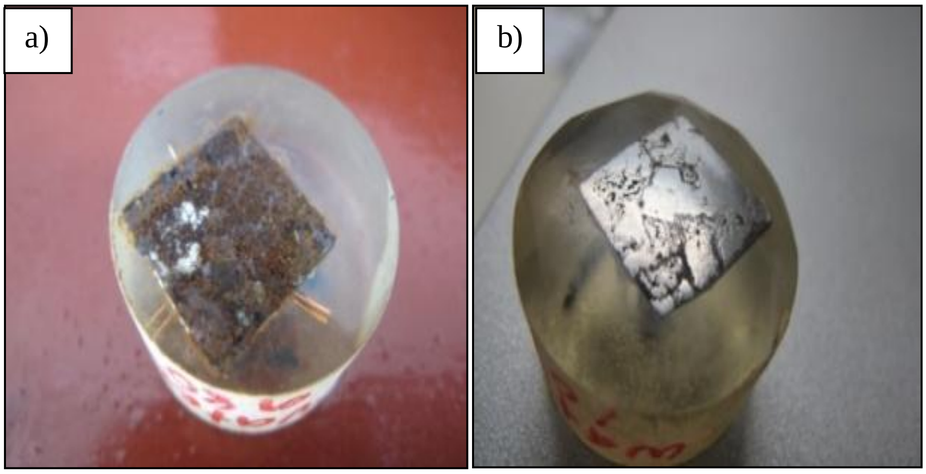


Figure 3.11: a) The sample surface before cleaning process and b) the sample surface after cleaning process

3.6 VICKER'S HARDNESS TEST

All the samples then undergo hardness test. Hardness test is doing before and after experiment. This test is to obtain the hardness value of sample exposed to a range of temperature. Figure 3.11 show the Vicker's Hardness Test machine.

For this experiment, the location need to be observed for the intended to be pressed and make sure the surface of the specimen is flat. The indenter was pressed into the samples by an accurately controlled test force. The force has been maintained about ten seconds and the indenter is removed after the dwell time is complete. The marking on the sample surface for hardness test as shown in Figure 3.12. Hardness readings were taken three times per sample and take the average hardness value. Figure 3.13 show the indenter type, shape, load and formula for Vicker's Hardness Test.

Figure 3.11: Vicker's Hardness Test machine

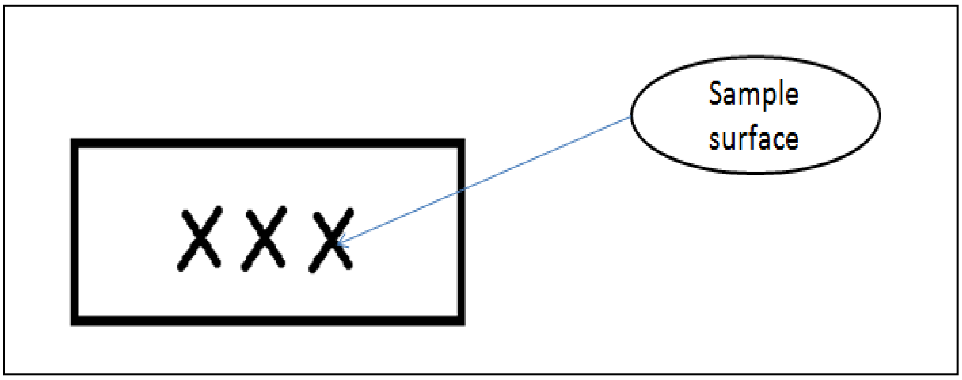
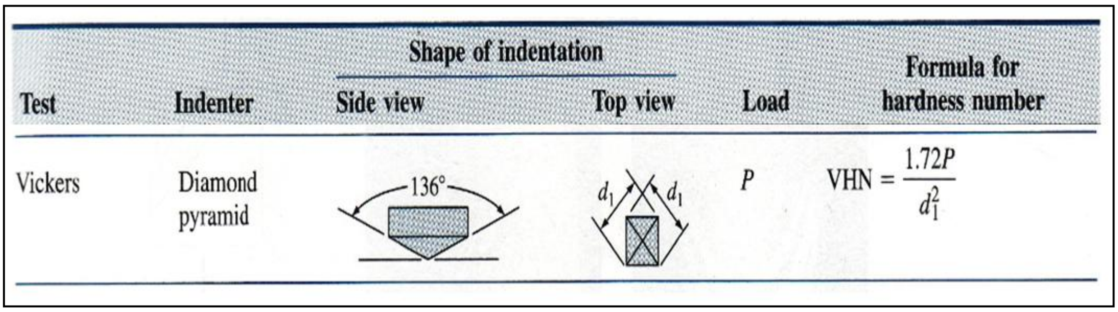


Figure 3.12: Marking on the samples surface for hardness test



Test	Indenter	Shape of indentation		Load	Formula for hardness number
		Side view	Top view		
Vickers	Diamond pyramid	136°	d_1 d_1	P	$\mathrm{VHN} = \frac{1.72P}{d_1^2}$

Figure 3.13: Indenter type, shape, load and formula for Vicker's Hardness Test

Source: (Callister and Rethwish, 2008)

3.7 CORROSION RATE

The corrosion rate measurements have been expressed by using potentiodynamic polarization method. The expression mils penetration per year is the most desirable way of expressing corrosion rates. The corrosion rate is calculated by the formula given as shown in Eq. (3.1).

$$CR = \frac{i_{corr} KEW}{dA} \tag{3.1}$$

Where:

CR= Corrosion rate, mm/year

i_{corr} = Corrosion current, amps

K = 3272, mm/amp*cm*year

EW= Equivalent weight, grams/equivalent

d= Density, gram/cm^3

A= Sample area, cm^2

Source: (Landolt, 2007)

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, there were separated into two parts which are result and discussion. In part result, there were discussed about the comparison about before and after corrosion. However, the part discussion was aimed on investigation relationship the different heat treatment between corrosion rates. Potentiodynamic polarization test were employed to study the corrosion behavior of high carbon steel in sodium chloride. The potentiodynamics experiments were carried out using a computer-controlled potentiostat. Three electrode cell cell configurations were employed for the polarization measurements (Totik, 2004). The result of hardness test, microstructure analysis and corrosion rate for all specimens is showed in this chapter.

4.2 MICROSTRUCTURE ANALYSIS BY OPTICAL MICROSCOPE

The optical microscope is the principal tool used to characterize the internal grain structure of steel. Traditionally, the structure revealed by the microscope is called the microstructure. The mechanical properties of given steel are strongly influenced by its microstructure. An optical microscope uses reflected light to generate an image. A beam of light is directed down onto the surface and the image is generated either on film or the eye by light reflected along the same direction. This is performed on specimens either cut to size or mounted in a resin mold. The samples are polished to a fine finish, normally one micron diamond paste, and usually etched in an appropriate chemical solution prior to examination on a microscope.

4.2.1 As received

The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification. Microstructure for AISI 1070 steel at 100x magnification and 500x magnification is shown as in Figure 4.1.

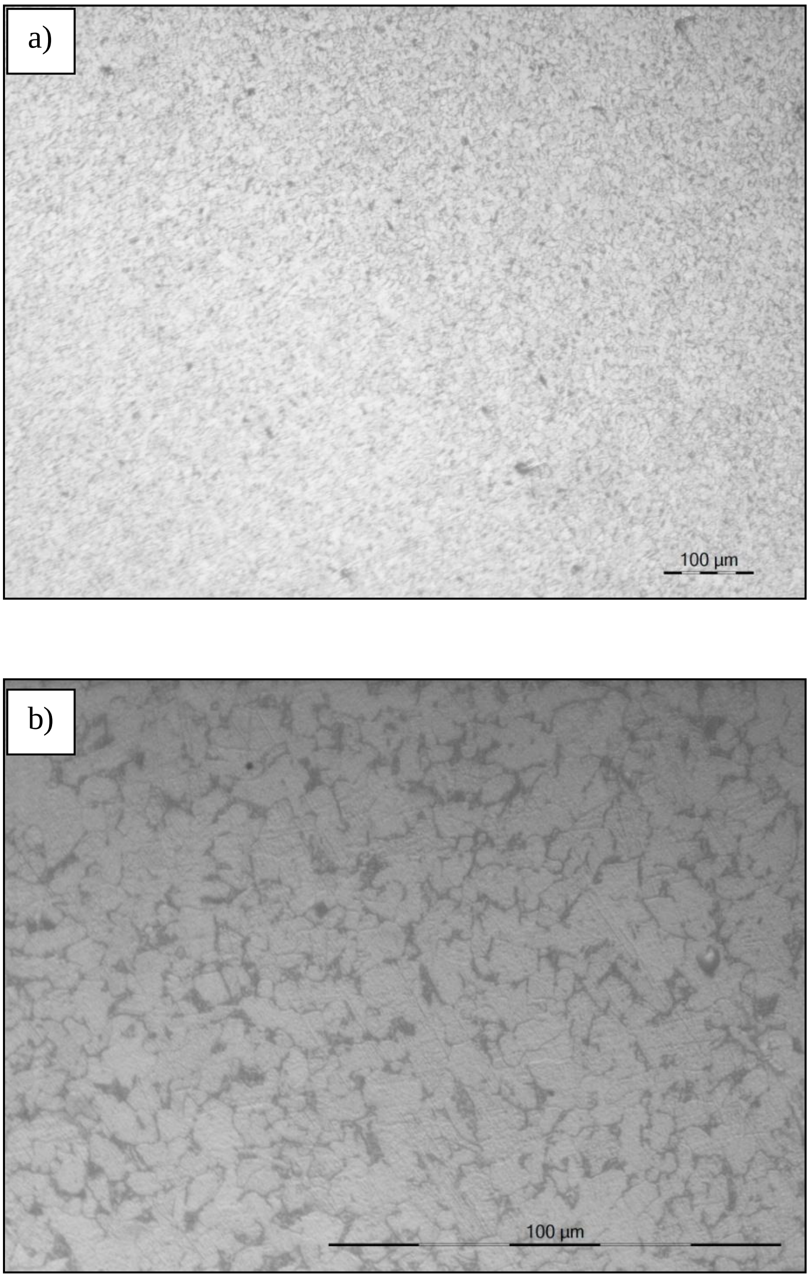


Figure 4.1: Microstructure for AISI 1070 steel: a) 100x magnification, b) 500x magnification.

4.2.2 Normalized

Normalized is a heat treatment in which material exposed to an elevated temperature at extended time period and then slowly cooled at room temperature. Normalizing process will make relieve stress, increase softness, ductility, toughness and produce a specific microstructure. The microstructures of normalized for AISI 1070 steel at 980 °C at 100x magnification and 500x magnification is shown as in Figure 4.1. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification

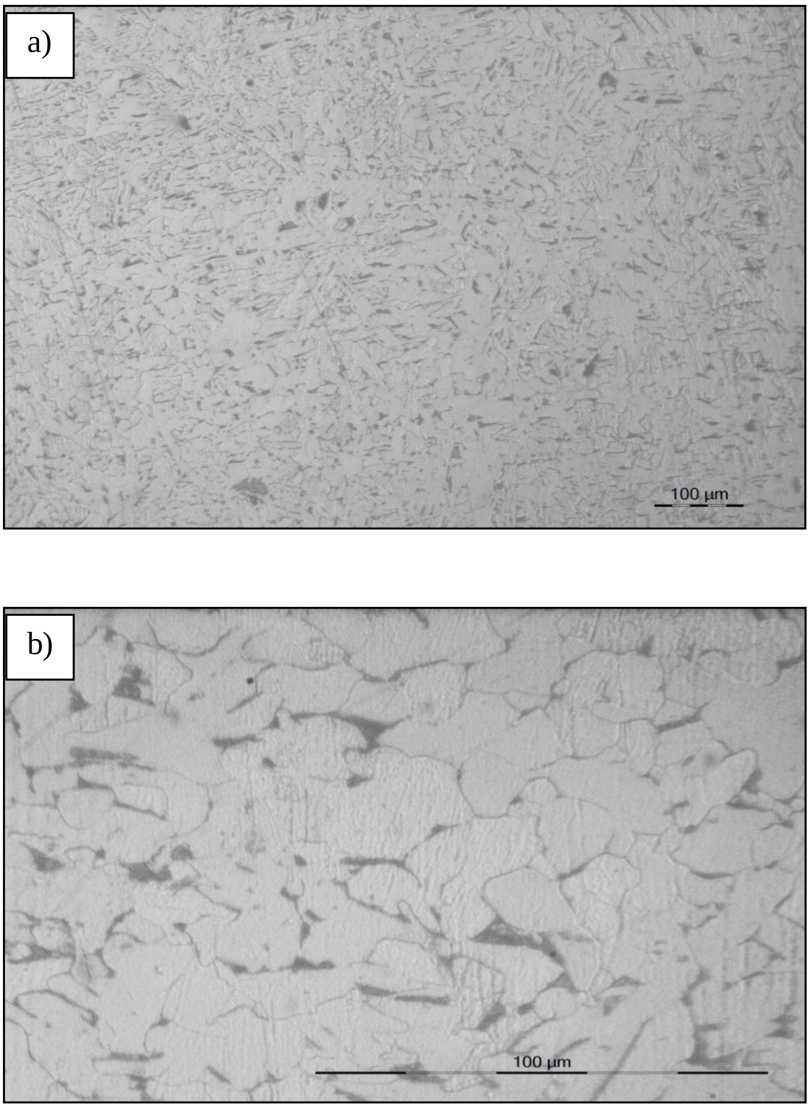


Figure 4.2: Microstructures of normalized for AISI 1070 steel at 980 °C: a) 100x magnification, b) 500x magnification

Figure 4.3 shows the microstructures of normalized for AISI 1070 steel at 1015 °C for 100x magnification and 500x magnification. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification.

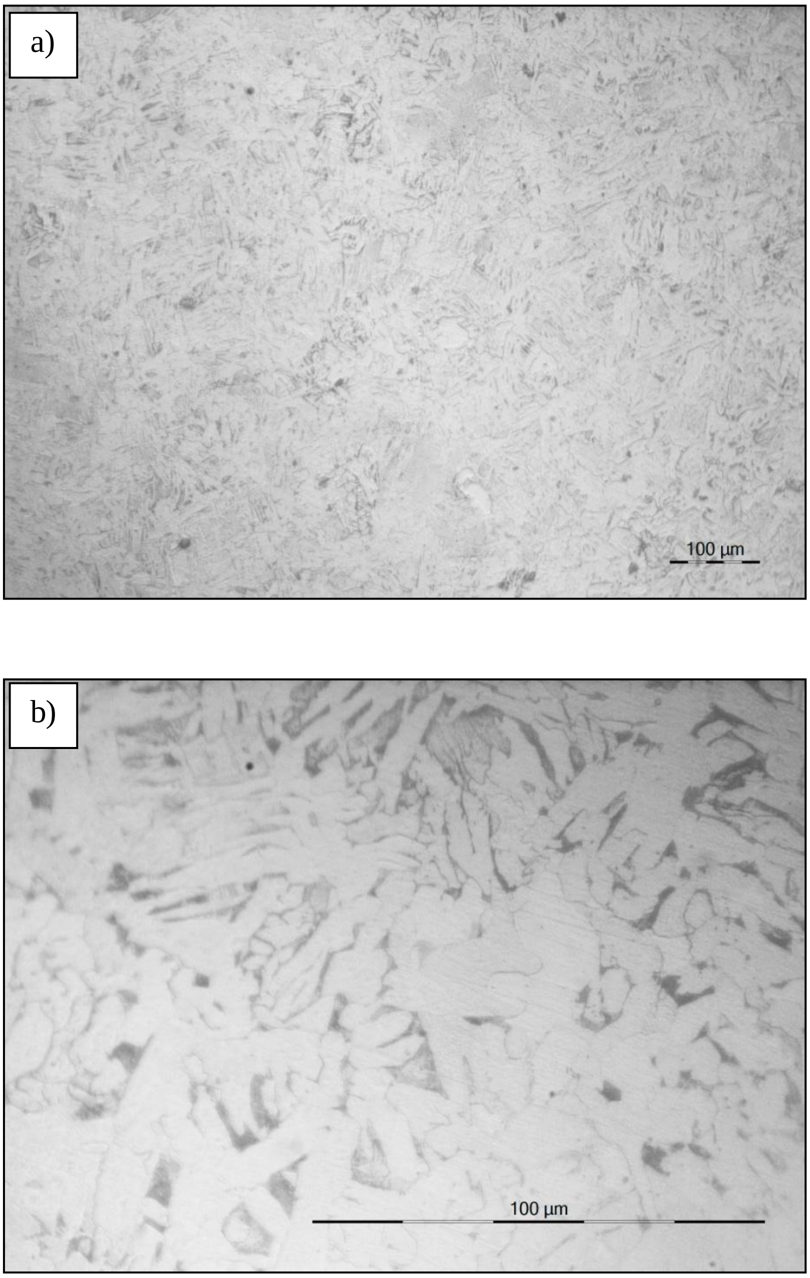


Figure 4.3: Microstructures of normalized for AISI 1070 steel at 1015 °C: a) 100x magnification, b) 500x magnification

Figure 4.4 shows the microstructures of normalized for AISI 1070 steel at 1050 °C for 100x magnification and 500x magnification. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification.

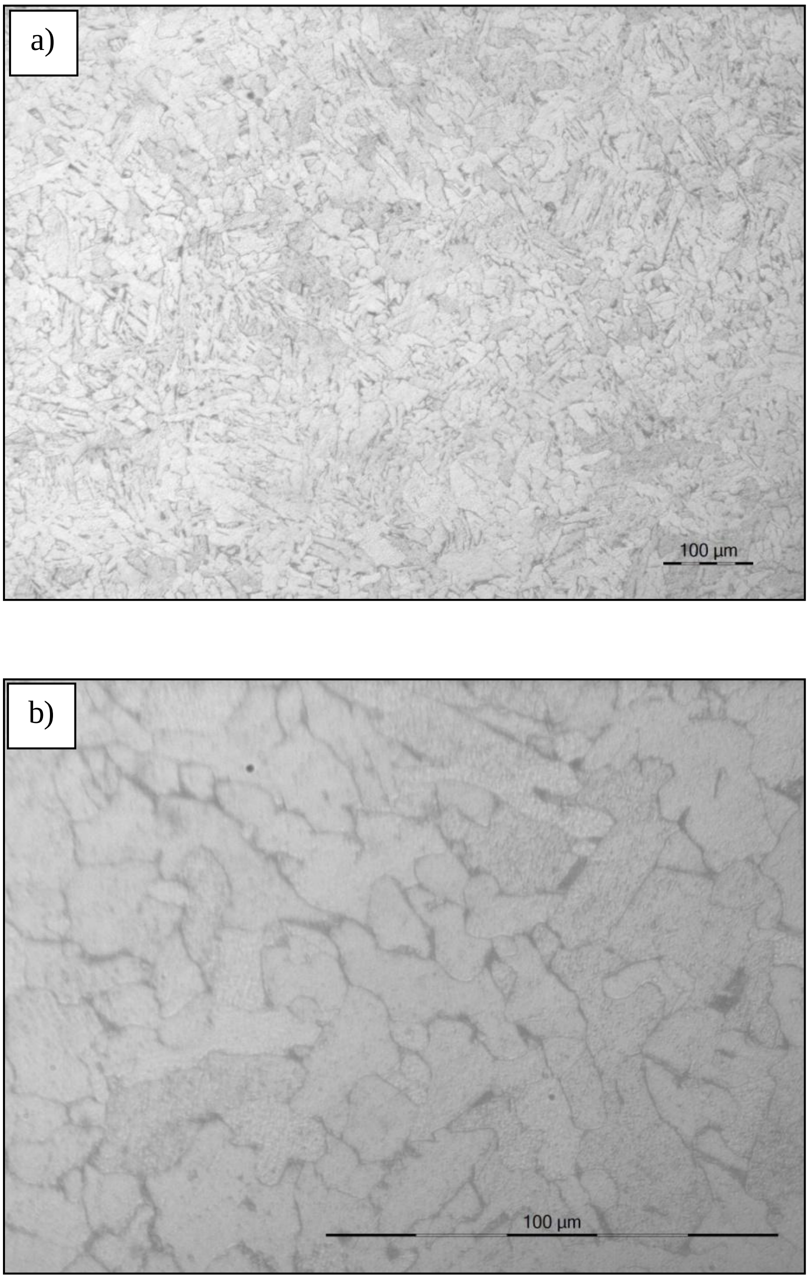


Figure 4.4: Microstructures of normalized for AISI 1070 steel at1050 °C: a) 100x magnification, b) 500x magnification

This is high carbon steel, which contains about 0.66 % carbon (as a proportion of its mass).The steel is heated to about 980 °C,1015 °C and 1050 °C, and then allowed to cool slowly or naturally in air. This allows the steel to develop a microstructure of ferrite and pearlite. The ferrite is the light background or matrix in the picture. The dark areas are pearlite. The pearlite is hard and it gives the steel strength. The ferrite is soft and it gives the steel ductility and toughness. If the amount of carbon in the steel is increased, this increases the amount of pearlite in the steel. This has the effect of increasing the strength, but it also decreases the ductility and toughness. Steel which has low carbon content (less than 0.1 %) has low strength and very good ductility. It can be easily formed and shaped. Meanwhile the steel, which has a high carbon content (about 0.8 %), has high strength and hardness, but cannot be easily deformed. The strength of the steel can be increased by quenching and then tempering (Okan and Mustafa, 2009).

4.2.3 Water quenched

Quenching can be done by plunging the hot steel into the water. The water adjacent to the hot steel vaporizes, and there is no direct contact of the water with the steel. This slows down cooling until the bubbles break and allow water contact with the hot steel. As the water contacts and boils, a great amount of heat is removed from the steel. With good agitation, bubbles can be prevented from sticking to the steel, and thereby prevent soft spots (Okan and Mustafa, 2009).

The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification. Figure 4.5 shows the microstructures of water quenched for AISI 1070 steel at 980 °C for 100x magnification and 500x magnification.

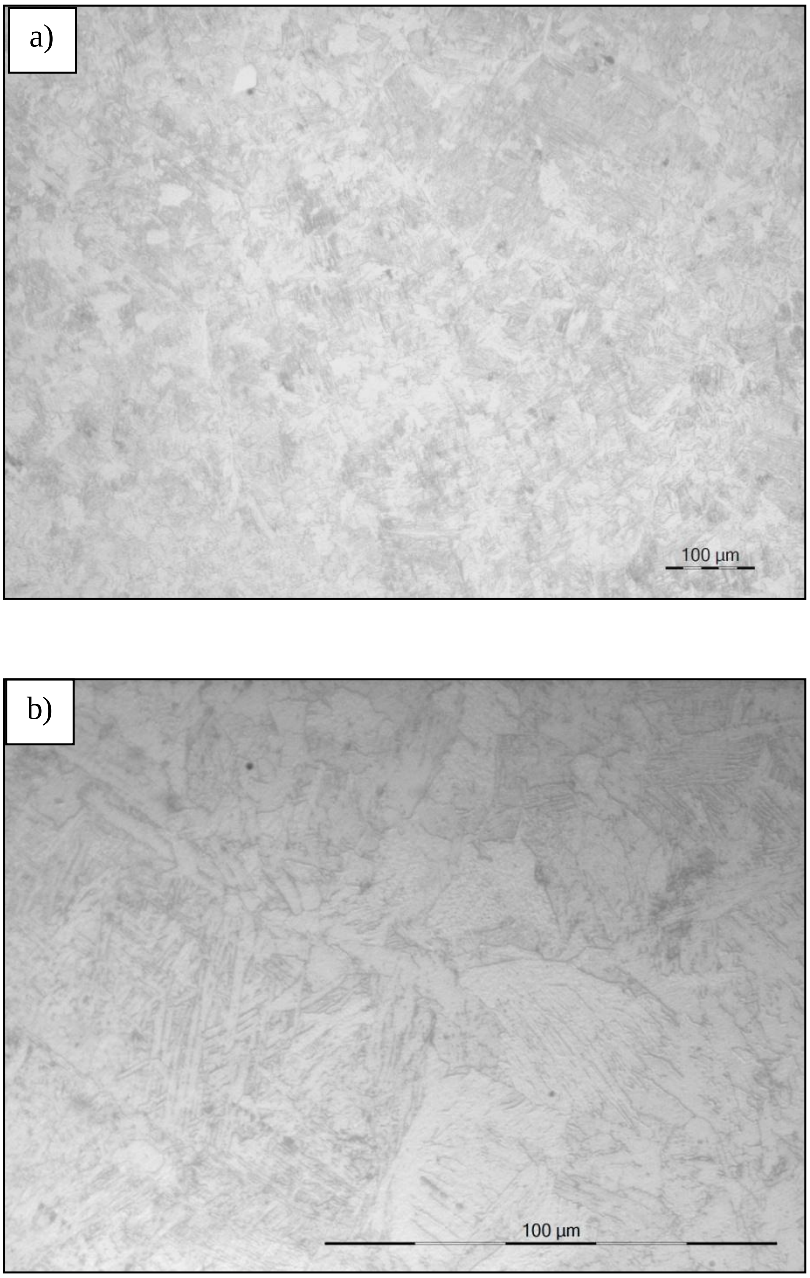


Figure 4.5: Microstructures of water quenched for AISI 1070 steel at 980 °C: a) 100x magnification, b) 500x magnification

The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification. Figure 4.6 shows the microstructures of water quenched for AISI 1070 steel at 1015 °C for 100x magnification and 500x magnification.

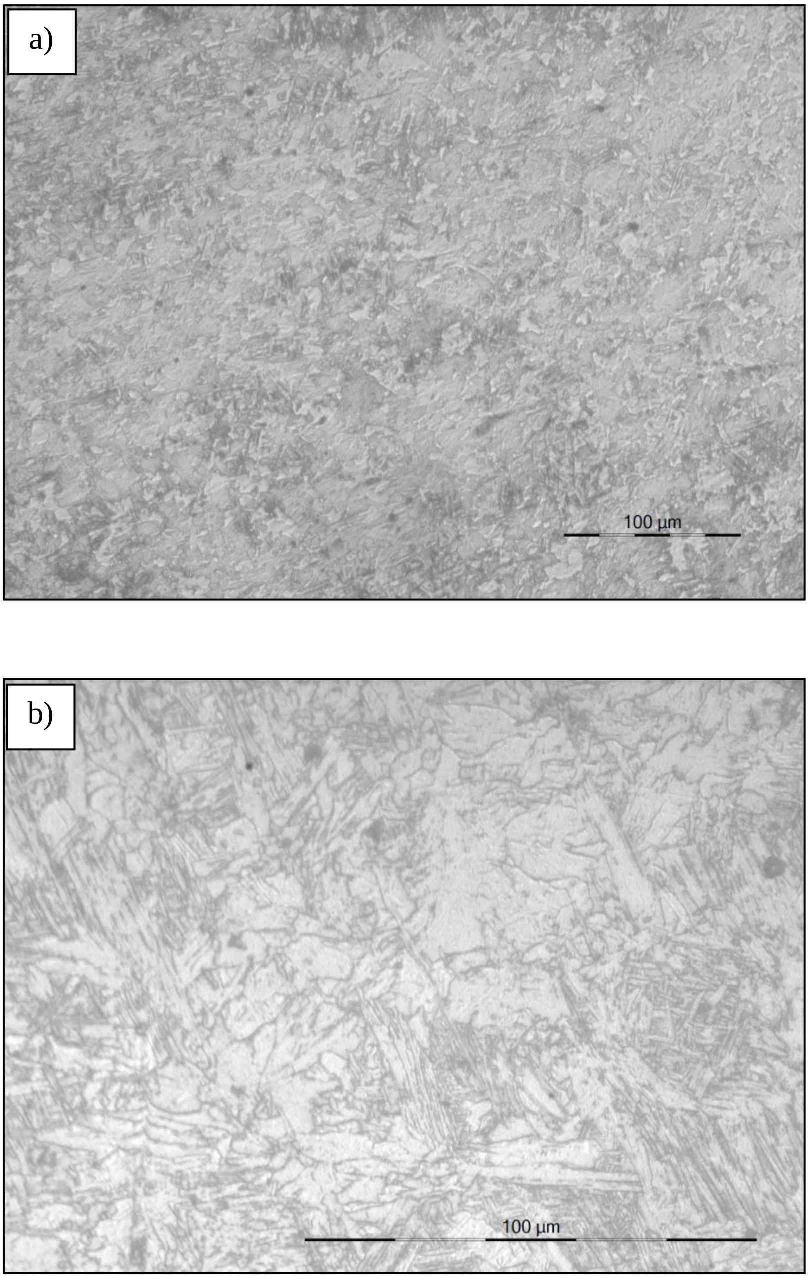


Figure 4.6: Microstructures of water quenched for AISI 1070 steel at 1015 °C: a)100xmagnification, b) 500x magnification

Figure 4.7 shows the microstructures of water quenched for AISI 1070 steel at 1050 °C for 100x magnification and 500x magnification. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification.

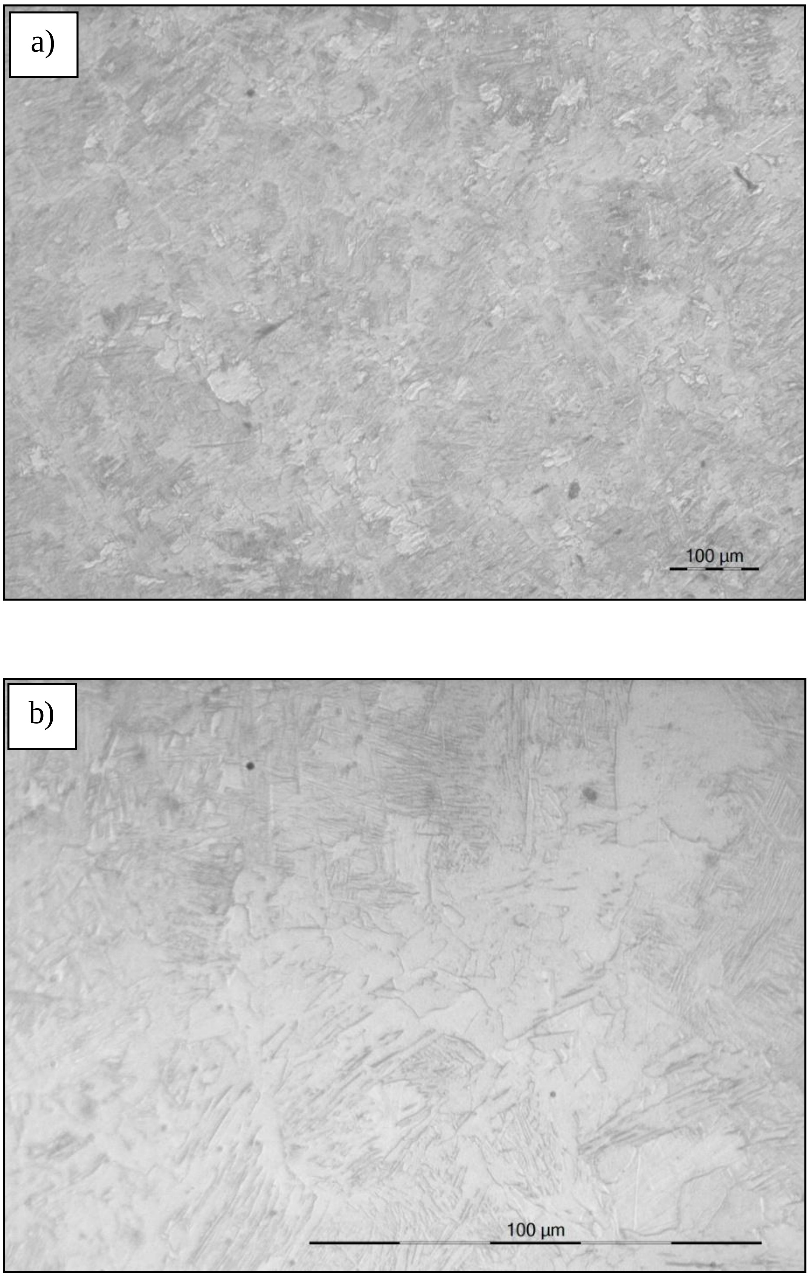


Figure 4.7: Microstructures of water quenched for AISI 1070 steel at 1050 °C: a) 100x magnification, b) 500 magnification

This is the same steel as the normalized steel, but after heating to about 980 °C, 1015 °C and 1050 °C it was quenched in water. This cooled the steel very quickly and instead of developing the ferrite and pearlite microstructure, a martensitic microstructure was produced. The ferrite and pearlite form by phase transformations involving diffusion. The martensite is extremely hard. This is because of carbon atoms which become trapped during the quick diffusion less phase transformation.

4.2.4 Oil quenched

Oil is used when a slower cooling rate is desired. Since oil has a very high boiling point, the transition from start of martensite formation to the finish is slow. The microstructures of oil quenched for AISI 1070 steel at 980 °C for 100x magnification and 500x magnification is shown as in Figure 4.8.

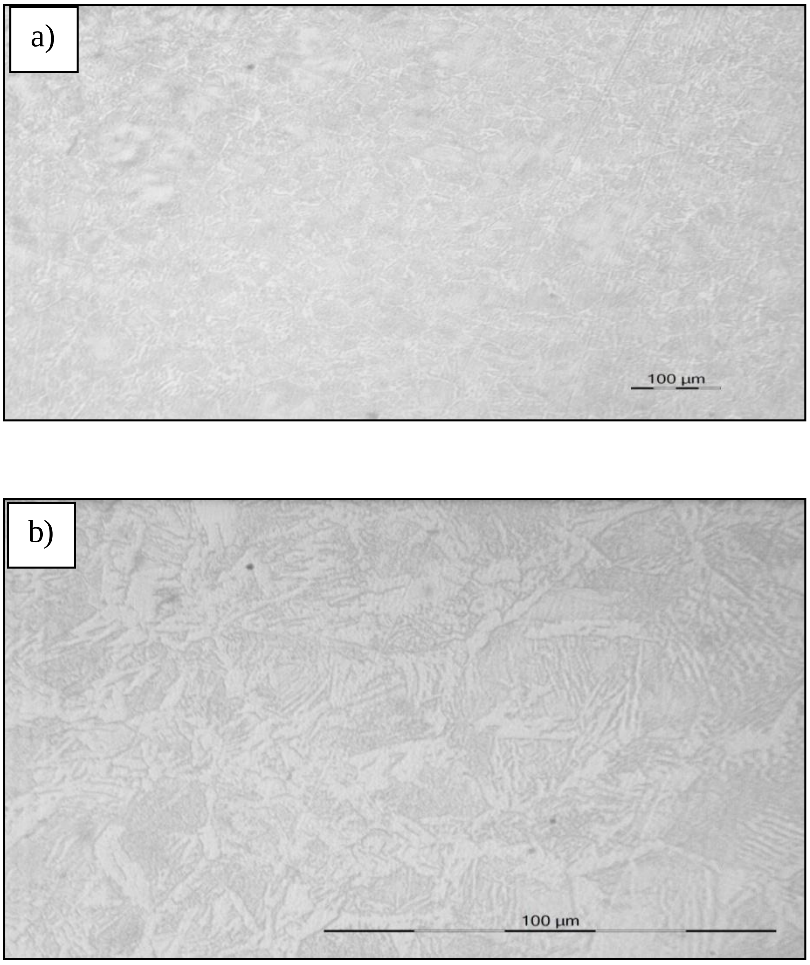


Figure 4.8: Microstructures of oil quenched of AISI 1070 steel at 980 ˚C: a) 100x magnification, b) 500x magnification

Figure 4.9 shows the microstructures of oil quenched for AISI 1070 steel at 1015 °C for 100x magnification and 500x magnification. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification.

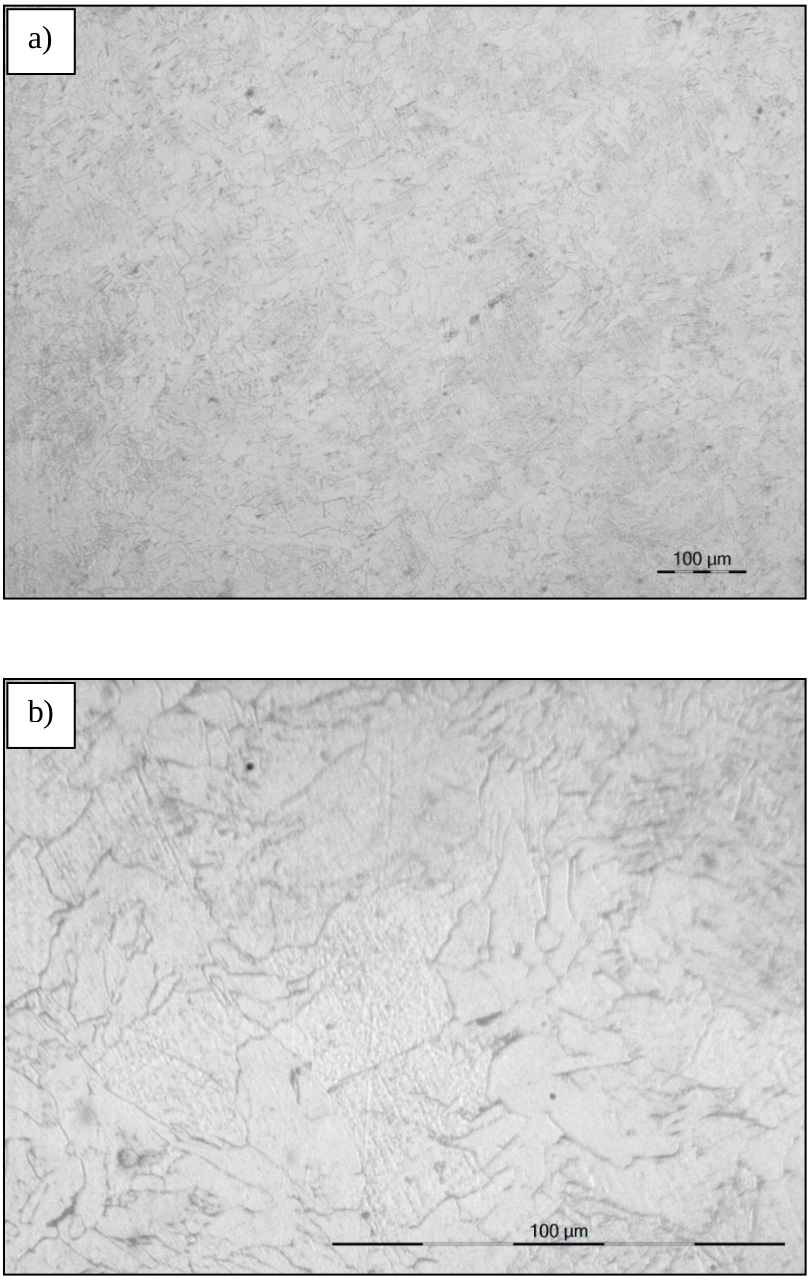


Figure 4.9: Microstructures of oil quenched for AISI 1070 steel at 1015 °C: a) 100x magnification, b) 500x magnification

Figure 4.10 shows the microstructures of oil quenched for AISI 1070 steel at 1050 °C for 100x magnification and 500x magnification. The grains boundary for the sample at 500x magnifications is clearer than the sample at 100x magnification.

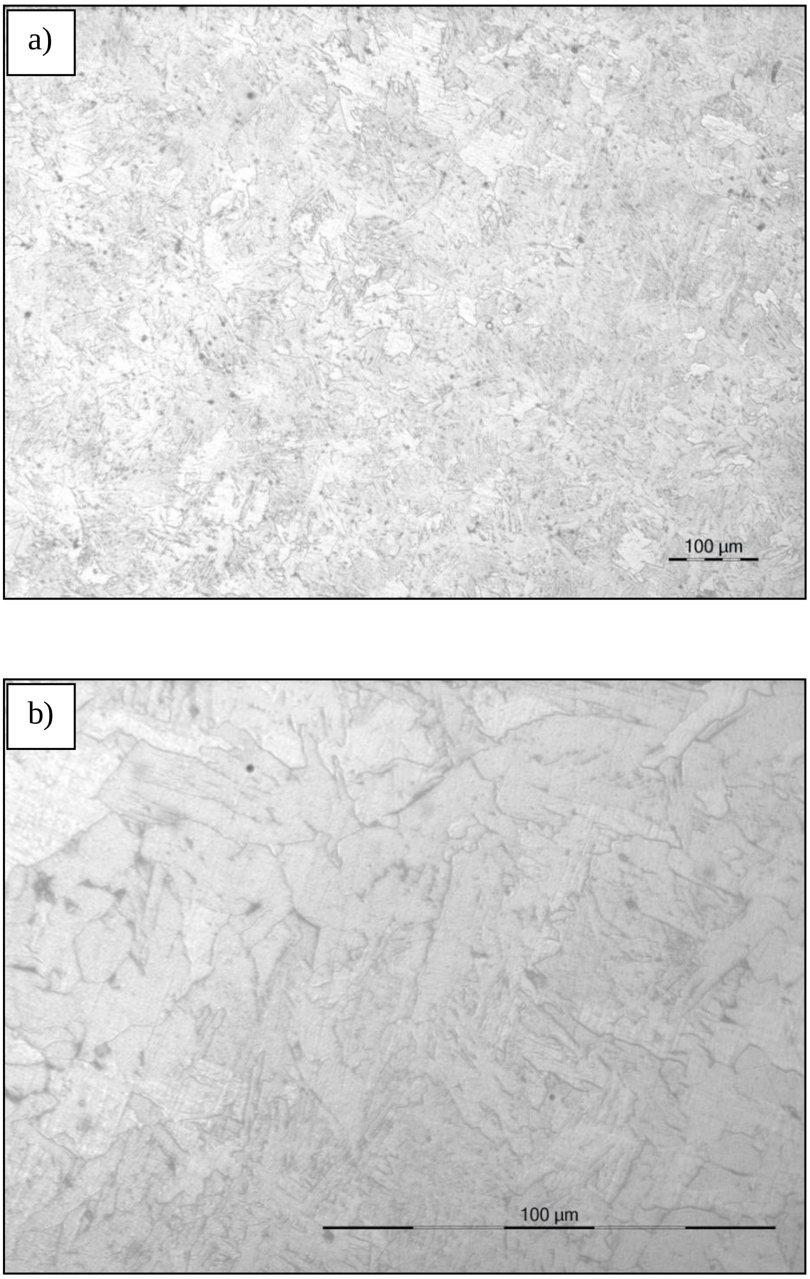


Figure 4.10: Microstructures of oil quenched for AISI 1070 steel at 1050 °C: a) 100x magnification, b) 500x magnification

This is the same steel as the normalized steel, but, after heating to about 980 °C, 1015 °C and 1050 °C it was quenched in oil. A martensitic microstructure was produced same with quenched in water. The different about quenched in oil and quench in water is the cooling rate. Oil is used when a slower cooling rate is desired. Since oil has a very high boiling point, the transition from start of martensite formation to the finish is slow and this reduces the likelihood of cracking (Okan and Mustafa, 2009). SEM is scientific instruments that use a beam of energetic electrons to examine samples on a very fine scale. Figure 4.11 shows the SEM image after corrosion for AISI 1070 after normalized at 980 °C for 250x magnification and 2000x magnification.

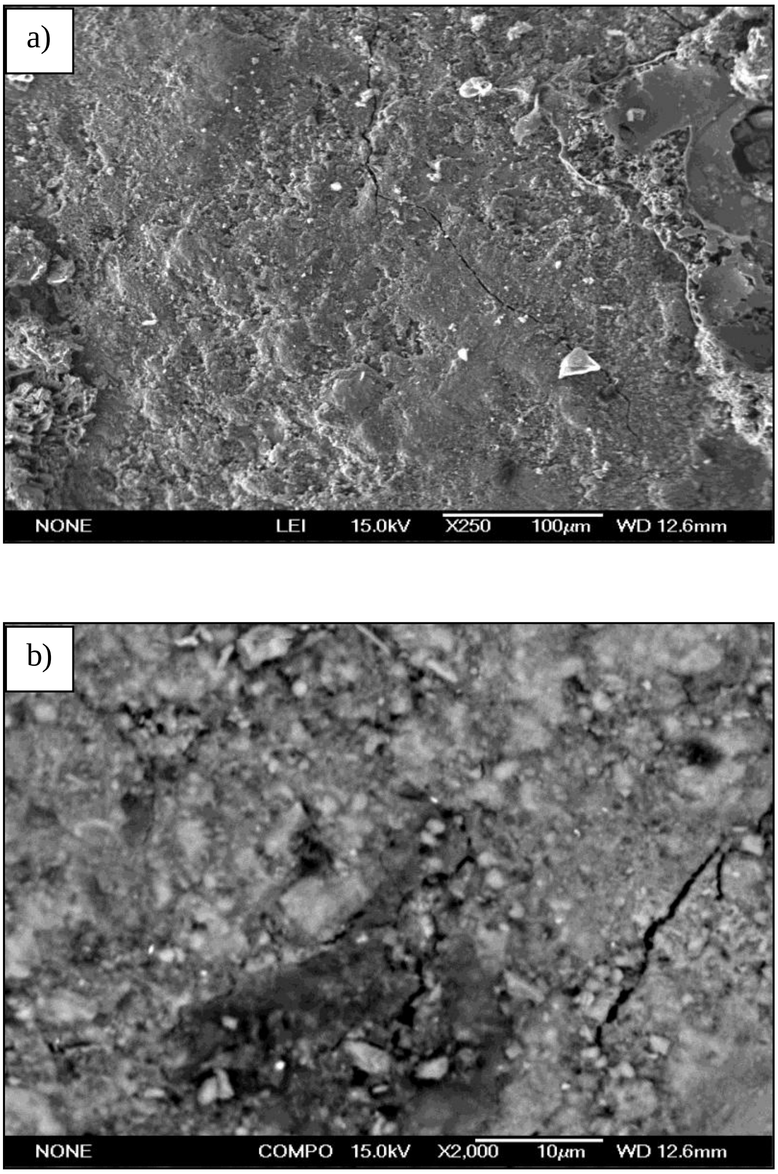


Figure 4.11: SEM image after corrosion for AISI 1070 after normalized at 980 °C: a) 250x magnification, b) 2000x magnification

Figure 4.12 shows the SEM image after corrosion for AISI 1070 after water quenched at 980 °C for 250x magnification and 3000x magnification

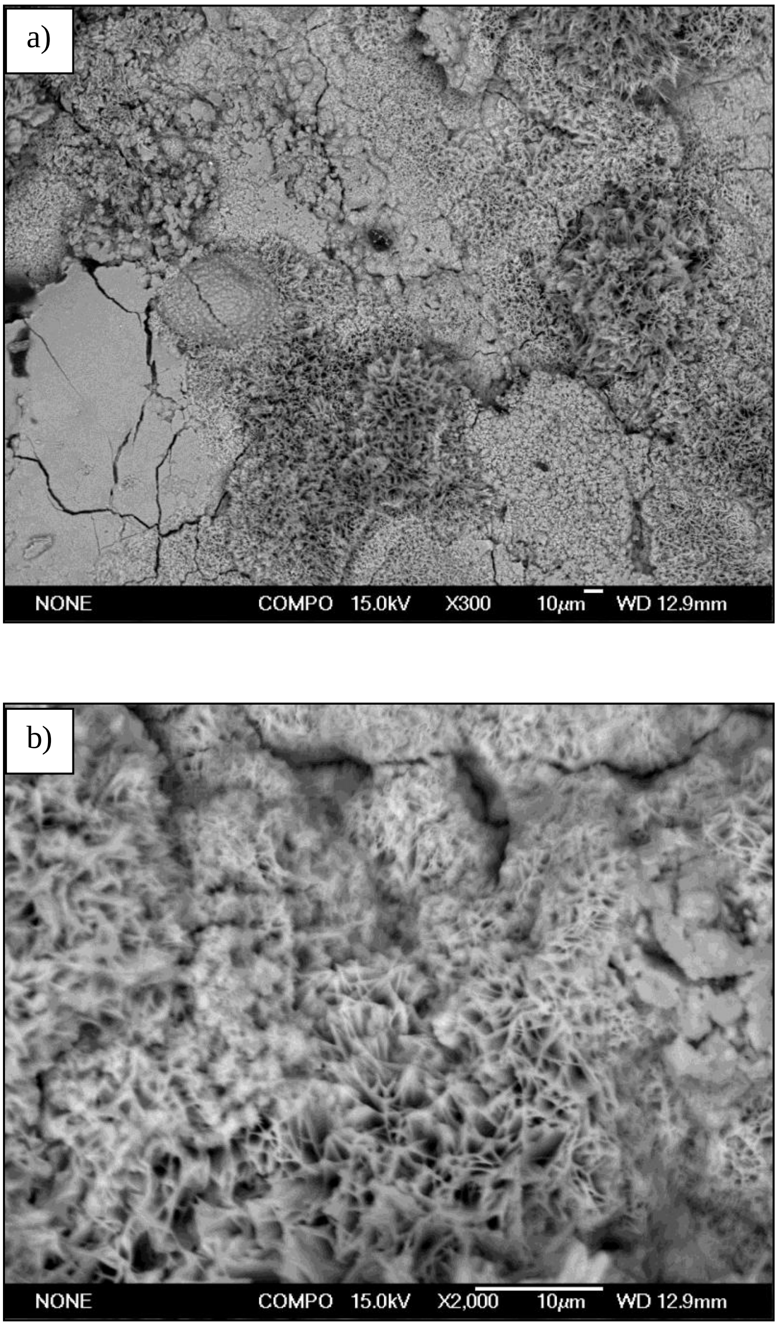


Figure 4.12: SEM image after corrosion for AISI 1070 after water quenched at 980 °C: a) 300x magnification, b) 2000x magnification

4.3 HARDNESS TEST RESULT

The hardness of the nonheat-treated and heat treated AISI 1070 before and after corrosion were measured as Vickers hardness. A standard micro hardness tester, equipped with Vickers indenter and an indention load of 500 gf was used for surface hardness measurement. Tables 4.1 show the result after corrosion and before corrosion for nonheat-treated and heat treated AISI 1070 for sample at 1050 °C.

Table 4.1: Hardness values for different heat treatment at 1050 °C

Hardness value, HV	As receive	Normalizing	Oil	Water
Before corrosion	109.40	141.93	191.20	273.17
After corrosion	107.23	140.21	188.34	271.30

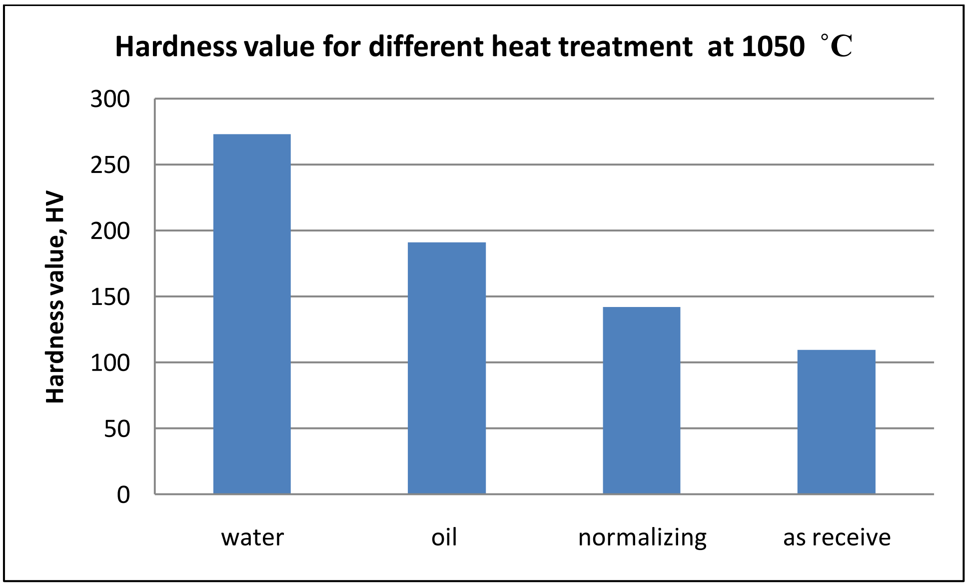


Figure 4.13: Bar chart of hardness value for different heat treatment at 1050 °C

The hardness changes of the heat treated AISI 1070 are shown in Figure 4.13. The highest hardness value for different heat treatments was obtained for water quenched as 273.17 HV (before corrosion) and 271.30 HV (after corrosion). The lowest hardness value was obtained for as received sample which is about 109.40 HV (before corrosion) and 107.23 HV (after corrosion. This different value of hardness is influenced by the existence of the martensitic structure obtained.

4.4 POTENTIODYNAMIC TEST

The corrosion behaviors of AISI 1070 were also determined by polarization measurement. These results were obtained by IVMAN software. Anodic and cathodic polarization curves of AISI 1070 in sodium chloride are shown in figure. Figure 4.14 shows the tafel extrapolation plot obtained in 3.5 % NaCl solution for as received sample.

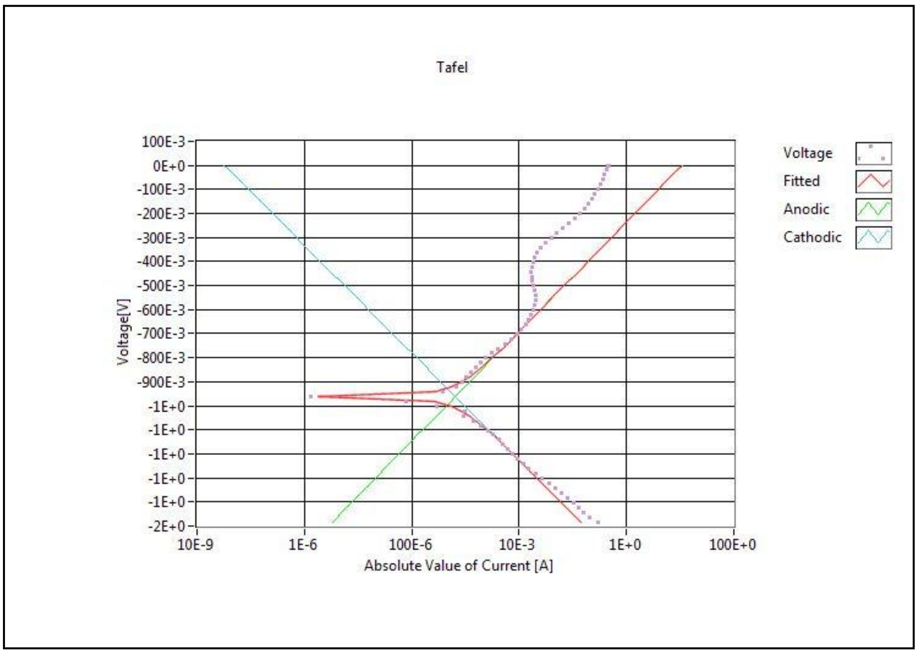


Figure 4.14: Tafel extrapolation plot obtained in 3.5 % NaCl solution for as received sample

Figure 4.15 and 4.16 show the tafel extrapolation plot obtained in 3.5 % NaCl solution for normalized at 980 °C and 1015 °C.

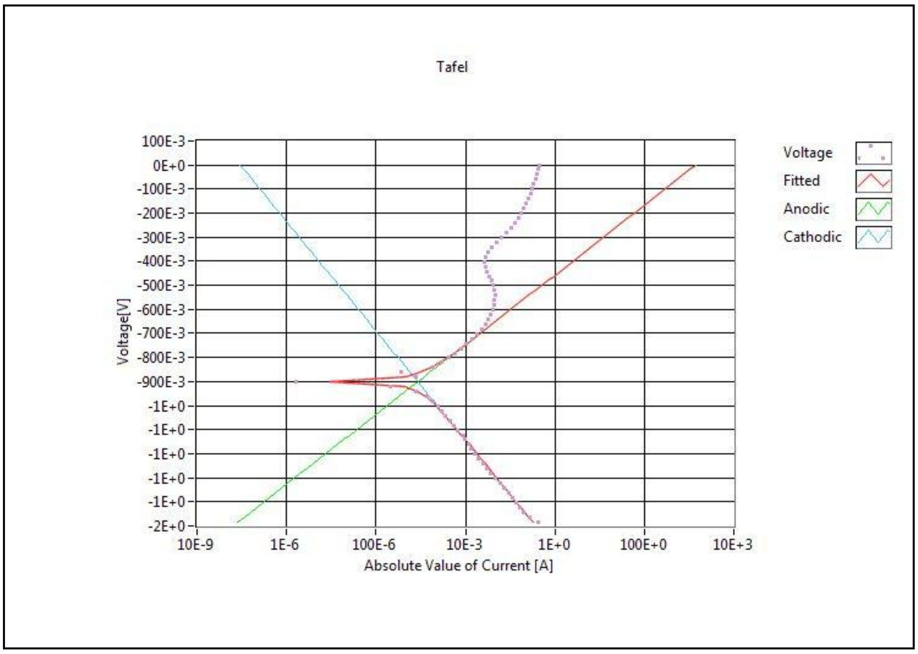


Figure 4.15: Tafel extrapolation plot obtained in 3.5 % NaCl solution for normalized at 980 °C

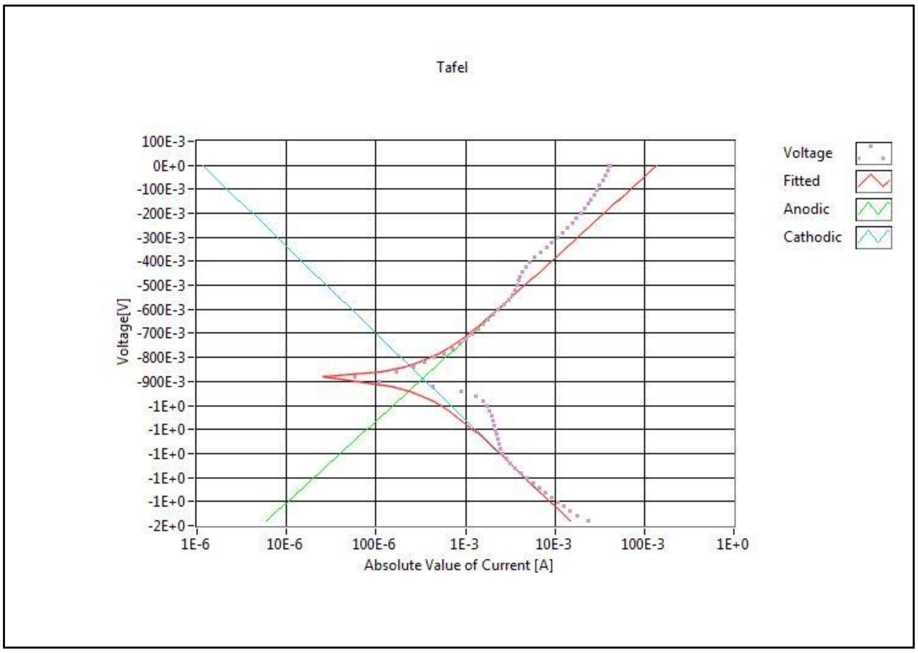


Figure 4.16: Tafel extrapolation plot obtained in 3.5 % NaCl solution for normalized at 1015 °C

Figure 4.17 and 4.18 show the tafel extrapolation plot obtained in 3.5 % NaCl solution for normalized at 1050 °C and water quenched at 980 °C.

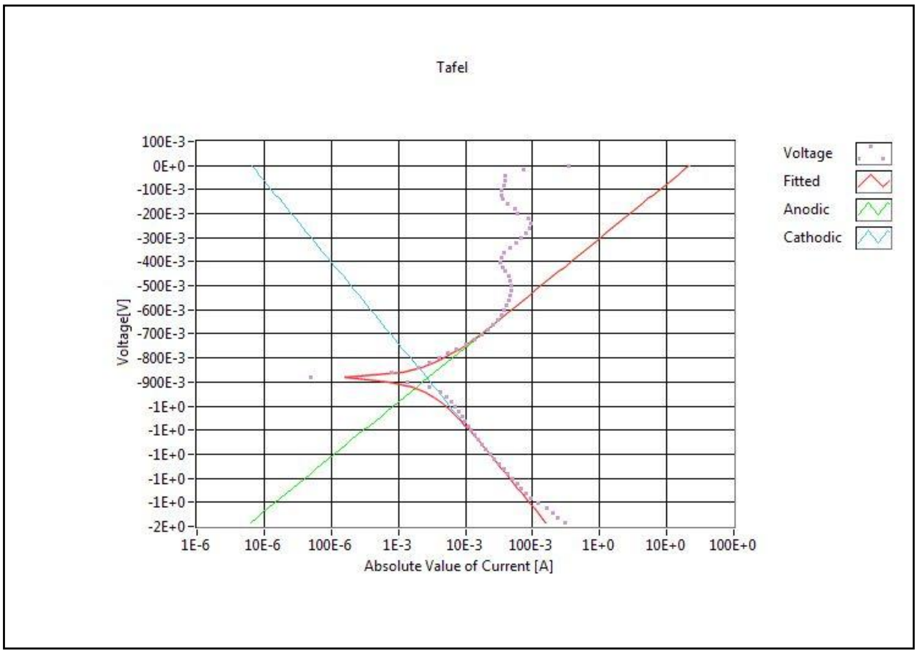


Figure 4.17: Tafel extrapolation plot obtained in 3.5 % NaCl solution for normalized at 1050 °C

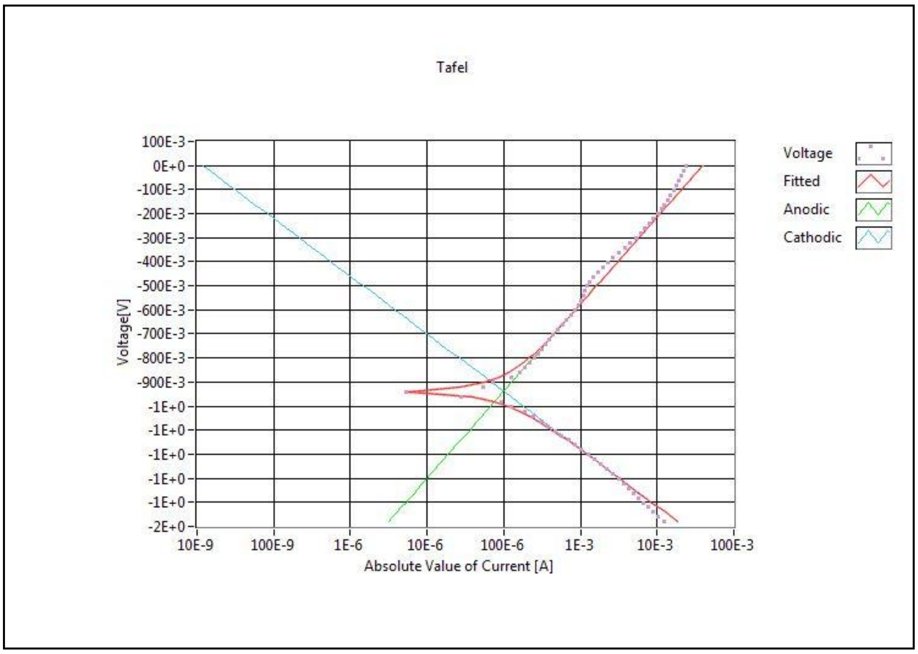


Figure 4.18: Tafel extrapolation plot obtained in 3.5 % NaCl solution for water quenched at 980 °C

Figure 4.19 and 4.20 shows the tafel extrapolation plot obtained in 3.5 % NaCl solution for water quenched at 1015 °C and 1050 °C.

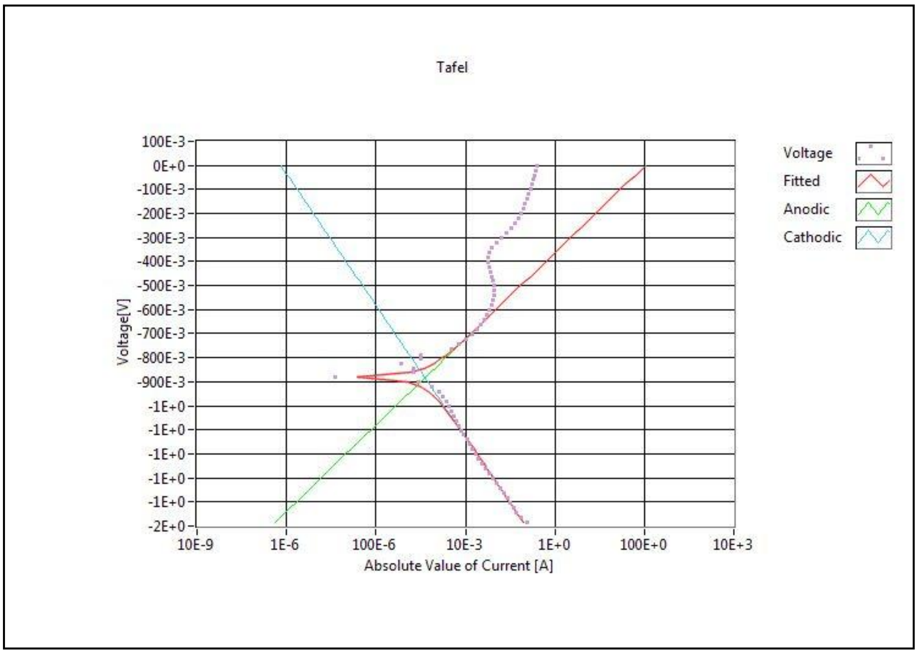


Figure 4.19: Tafel extrapolation plot obtained in 3.5 % NaCl solution for water quenched at 1015 °C

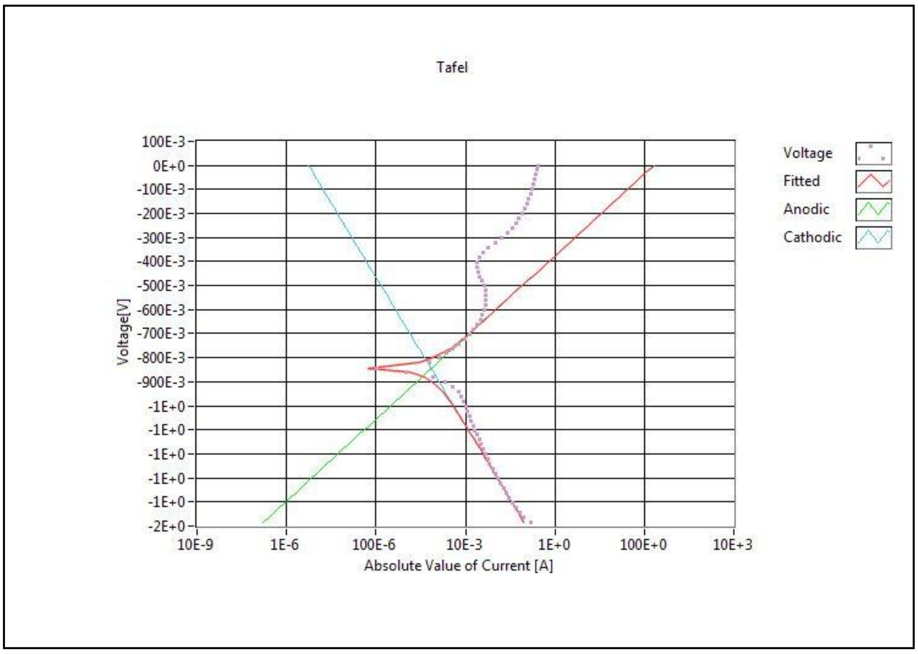


Figure 4.20: Tafel extrapolation plot obtained in 3.5 % NaCl solution for water quenched at 1050 °C

Figure 4.21 and 4.22 shows the tafel extrapolation plot obtained in 3.5 % NaCl solution for oil quenched at 980 °C and 1015 °C.

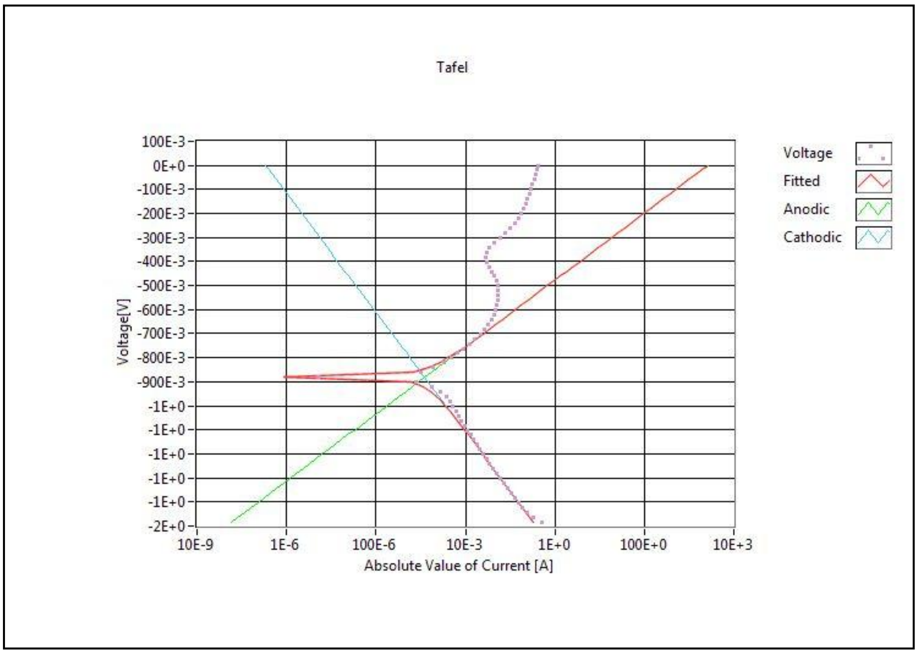


Figure 4.21: Tafel extrapolation plot obtained in 3.5 % NaCl solution for oil quenched at 980 °C

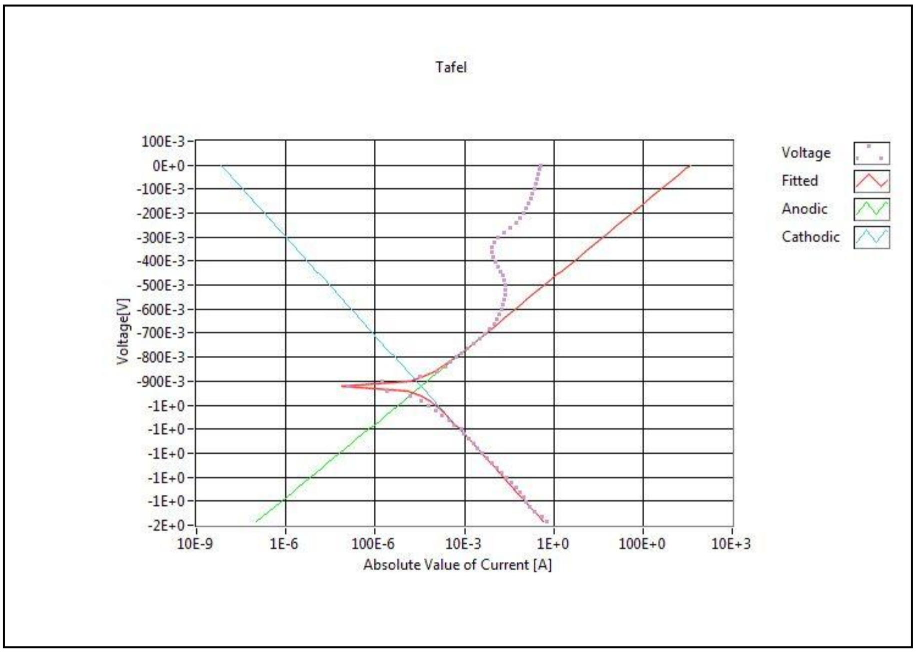


Figure 4.22: Tafel extrapolation plot obtained in 3.5 % NaCl solution for oil quenched at 1015 °C

Figure 4.23 shows the tafel extrapolation plot obtained in 3.5 % NaCl solution for oil quenched at 1050 °C.

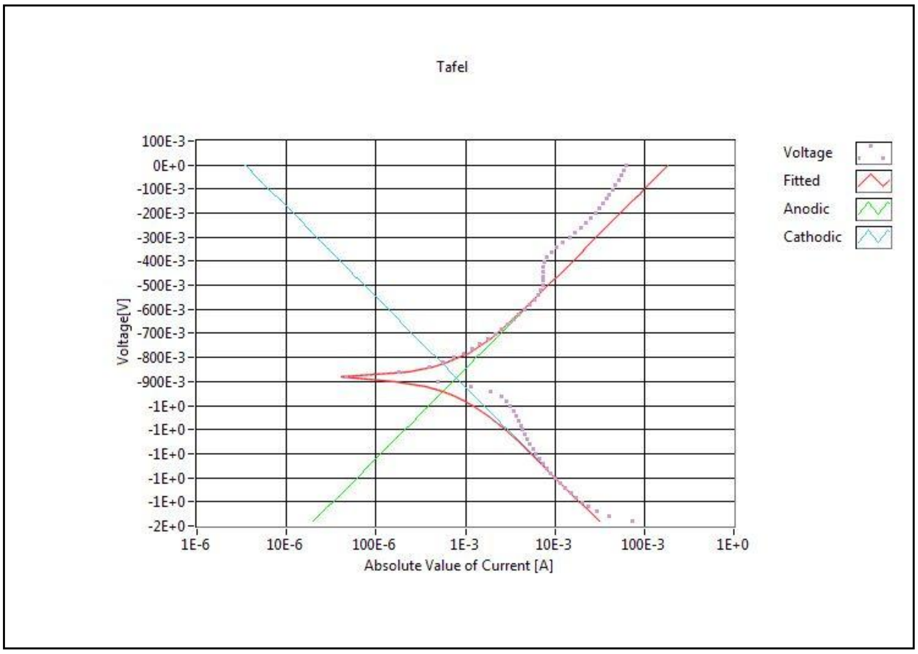


Figure 4.23: Tafel extrapolation plot obtained in 3.5 % NaCl solution for oil quenched at 1050 °C

The electrochemical parameters such as corrosion potential (E_{corr}), corrosion current density (i_{corr}), anodic Tafel slopes (b_a), cathodic Tafel slopes (b_c) are listed in Table 4.2. The data in Table 4.2 can be interpreted as follows:

Table 4.2: Electrochemical parameters of heat treated high carbon steel in 3.5 % NaCl solution

Heat treatment	**$E_{corr,}$ (V)**	**i_{corr} (mA)**	**b_a (V/dV)**	**b_c (V/dV)**	**R_p (kΩ)**	**CR (mmpy)**
As receive	-0.8847	2.7060	0.2268	0.3382	21.78	13.96
Normalizing 980 °C	-0.8452	1.7340	0.1699	0.3081	27.42	8.945
Normalizing 1015 °C	-0.8827	1.2600	0.1792	0.2737	37.33	6.499
Normalizing 1050 °C	-0.8846	0.7925	0.3738	0.3748	102.5	4.088
Water quench 980 °C	-0.9007	0.8645	0.1448	0.2269	44.4	4.460
Water quench 1015 °C	-0.9616	0.6475	0.2274	0.2236	75.60	3.340
Water quench 1050 °C	-0.9385	0.0998	0.3619	0.2393	626.9	0.5148
Oil quench 980 °C	-0.8816	1.2410	0.1392	0.2478	31.19	6.402
Oil quench 1015 °C	-0.9218	1.0730	0.1528	0.2056	35.47	5.536
Oil quench 1050 °C	-0.8875	0.3334	0.3393	0.3610	227.8	1.720

The corrosion potential and corrosion current densities obtained from the polarizations curves are listed in Table 4.2. The lowest potential value is obtained for water quench at 1050 °C (-0.9385 V), while the highest value is obtained for normalized at 980 °C (-0.8452 V). In addition to the corrosion potential, the lowest corrosion current density (i_{corr}) was obtained for water quench at 1050 °C (0.0998 mA). It can be seen from Table 4.2 that water quench at 1050 °C have better corrosion resistance than of the other type heat treatment. The graphs of corrosion rate vs temperature for all heat treatment are shown as in Figure 4.24, Figure 4.25 and Figure 4.26.

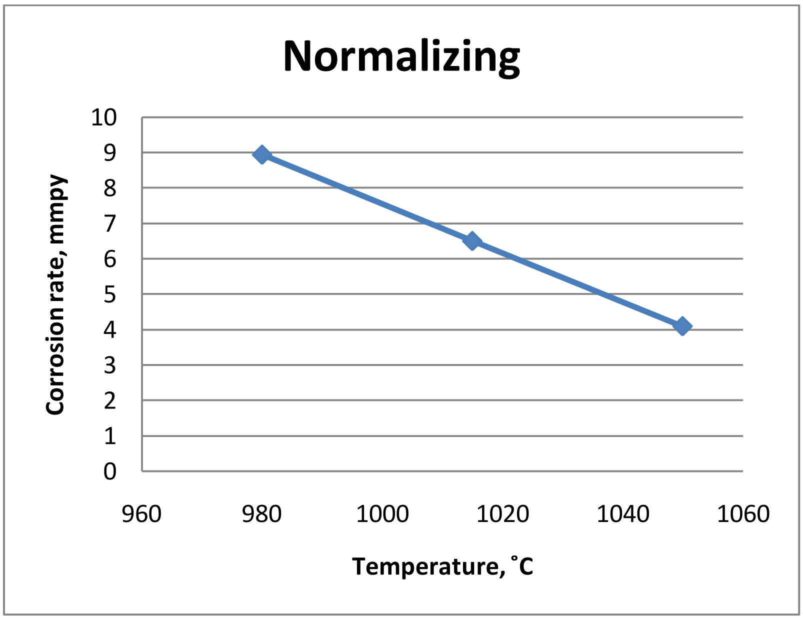


Figure 4.24: Graph of corrosion rate vs temperature for normalizing

From the Figure 4.24, the corrosion rate of sample is decreasing when exposed at high temperature of normalizing. Normalized at 980 °C is higher corrosion rate (8.945 mmpy) followed by normalized at 1015 °C (6.499 mmpy) and 1050 °C (4.088 mmpy).

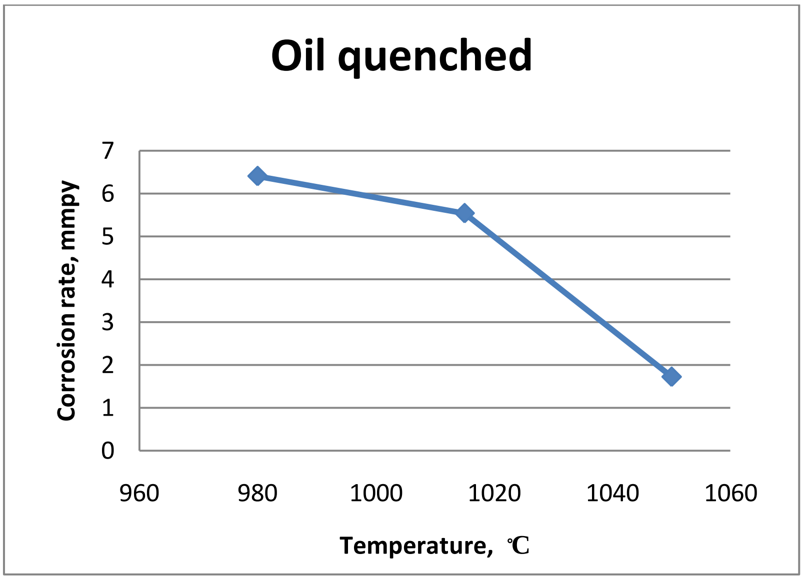


Figure 4.25: Graph of corrosion rate vs temperature for oil quenched

From the Figure 4.25, the corrosion rate of sample is decreasing when exposed at high temperature of oil quenched. Oil quenched at 980 is higher corrosion rate (6.402 mmpy) followed by oil quenched at 1015 °C (5.536 mmpy) and 1050 °C (1.720 mmpy).

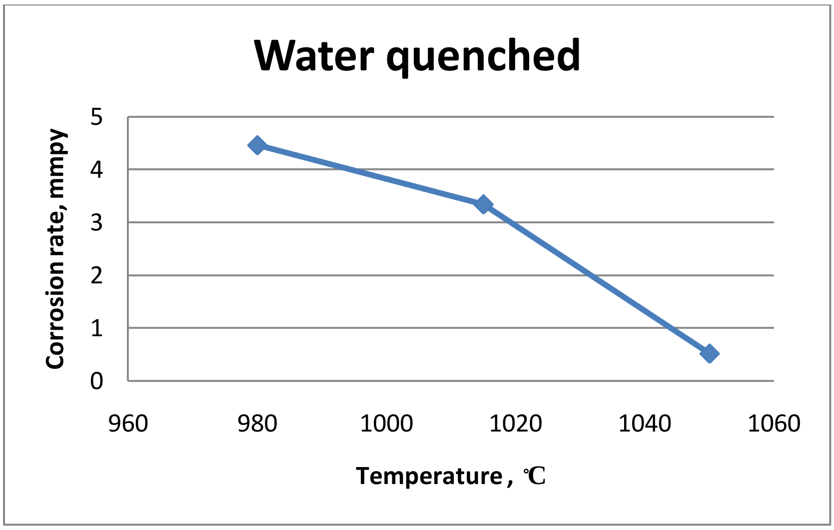


Figure 4.26: Graph of corrosion rate vs temperature for water quenched

From the Figure 4.16, the corrosion rate of sample is decreasing when exposed at high temperature of water quenched. Water quenched at 980 °C is higher corrosion rate (4.460 mmpy) followed by water quenched at 1015 °C (3.340 mmpy) and 1050 °C (0.5148 mmpy).

4.5 POTENTIODYNAMIC POLARIZATION

The potentiodynamic polarization technique is generally used to determine the corrosion resistance of a substance in a given solution, and it also detects any tendency of the substance to passivity. The result from the potentiodynamic measurement of the heat treated high carbon steel in the 3.5 % NaCl solutions are shown in Figure 4.27, Figure 4.28 and Figure 4.29.

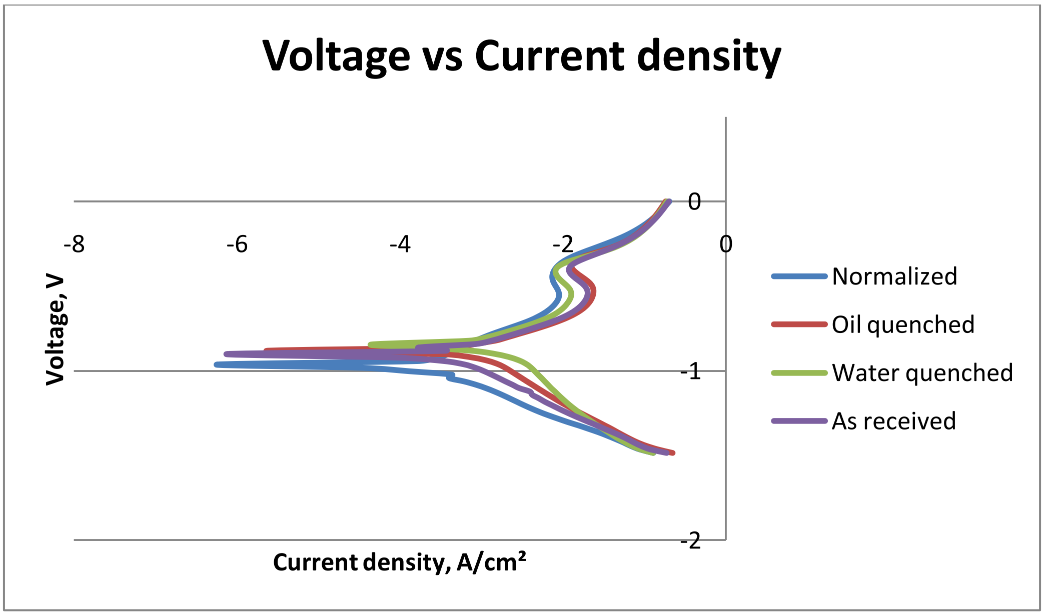


Figure 4.27: Polarization curves in 3.5% NaCl solution of heat treated carbon steel at 980 °C

The polarization curves of the heat treated carbon steel at 980 °C reveal a similar characteristic. The lowest potential value is obtained for the water quenched heat treatment (-0.9007 V), while the highest potential value is obtained for the normalized heat treatment (-0.8452 V). The polarization curve indicate that water quench at 980 °C is more effective on the corrosion behavior of the other heat treatment.

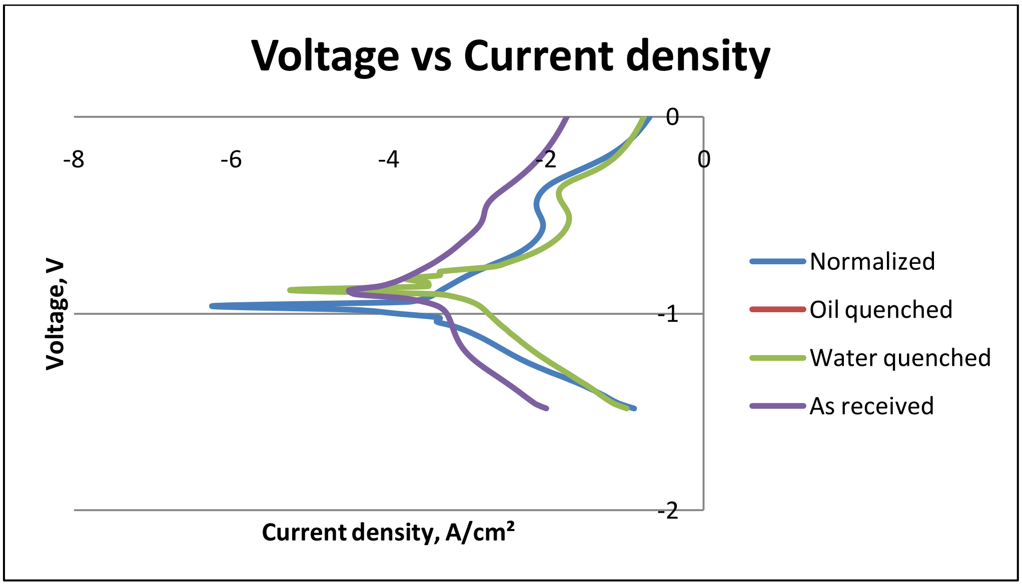


Figure 4.28: Polarization curves in 3.5 % NaCl solution of heat treated carbon steel at 1015 °C

The polarization curves of the heat treated carbon steel at 1015 °C reveal a similar characteristic. The lowest potential value is obtained for the water quenched heat treatment (-0.9616 V), while the highest potential value is obtained for the normalized heat treatment (-0.8827 V). The polarization curve indicate that water quench at 1015 °C is more effective on the corrosion behavior of the other heat treatment

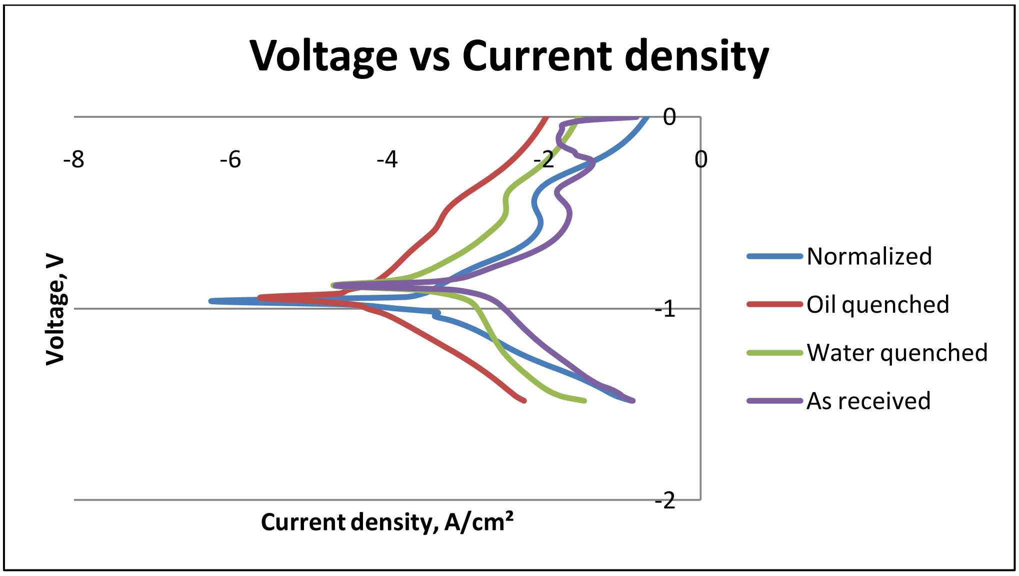


Figure 4.29: Polarization curves in 3.5% NaCl solution of heat treated carbon steel at 1050 °C

The polarization curves of the heat treated carbon steel at 1050 °C reveal a similar characteristic. The lowest potential value is obtained for the water quenched heat treatment (-0.9385 V), while the highest potential value is obtained for the normalized heat treatment (-0.8846 V). The polarization curve indicate that water quench at 1050 °C is more effective on the corrosion behavior of the other heat treatment

4.6 PITTING CORROSION

Pitting corrosion is observed on passive metals in presence of certain anions (in particular chloride) when the potential exceeds a critical value. This process typically produces cavities with diameters on the order of several tens of micrometers (Landolt, 2007). Figure 4.30, Figure 4.31, Figure 4.32 and Figure 4.33 shows the pitting corrosion occurs on the samples. Pitting is observe to interact with general corrosion and appear to be involved in the continually changing morphology of the corroded structure. Water quench is less pitting corrosion than the other heat treatment.

Figure 4.30 and Figure 4.31 show the pitting on as received sample and normalized sample after cleaning for 50x magnification.

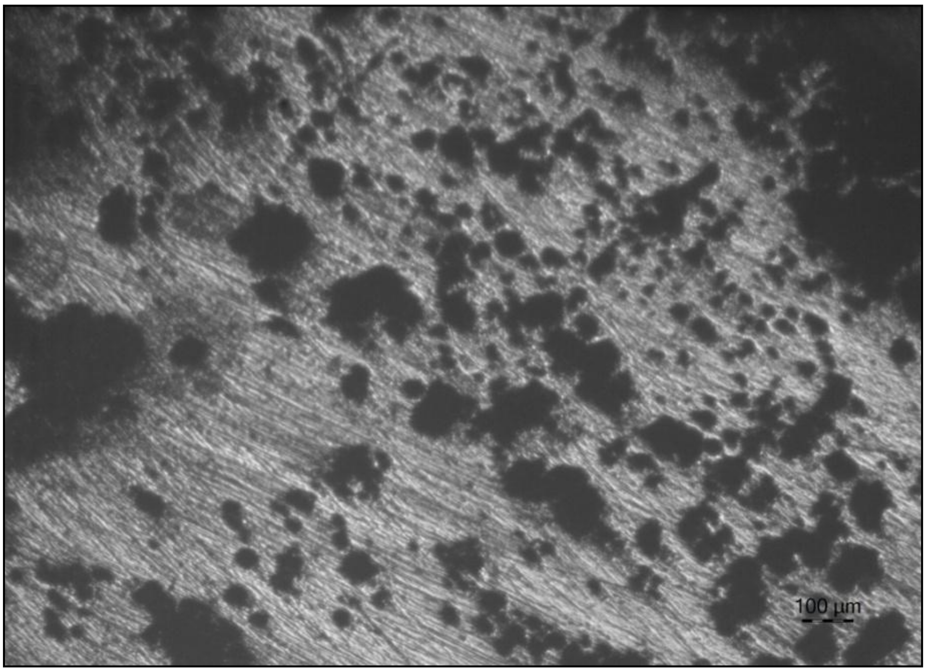


Figure 4.30: Pitting on as received sample after cleaning (50x magnification)

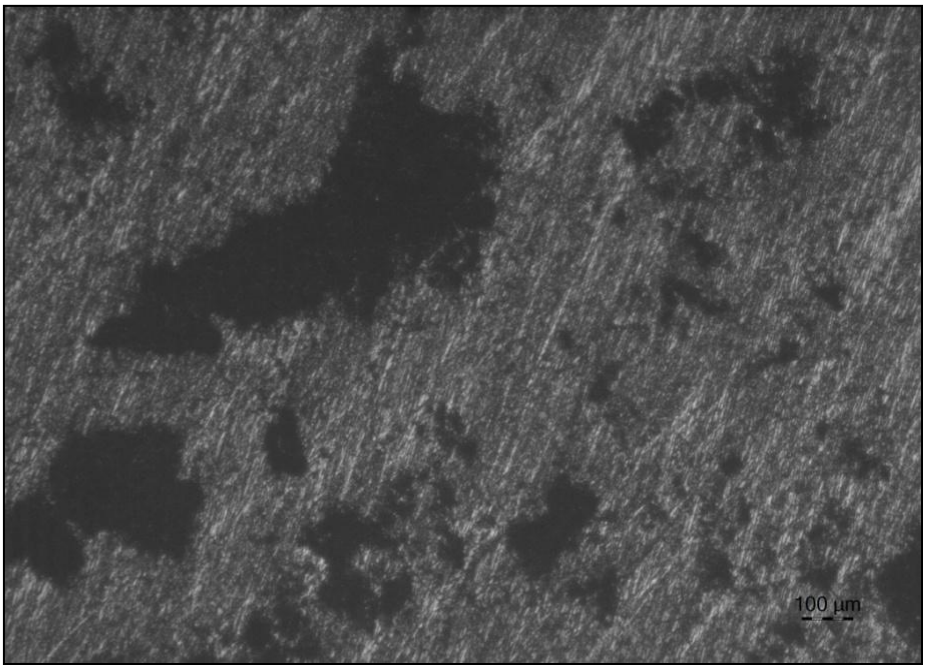


Figure 4.31: Pitting on normalized sample at 1050 °C after cleaning (50x magnification)

Figure 4.32 and Figure 4.33 show the pitting on oil quenched sample and water quenched sample after cleaning for 50x magnification.

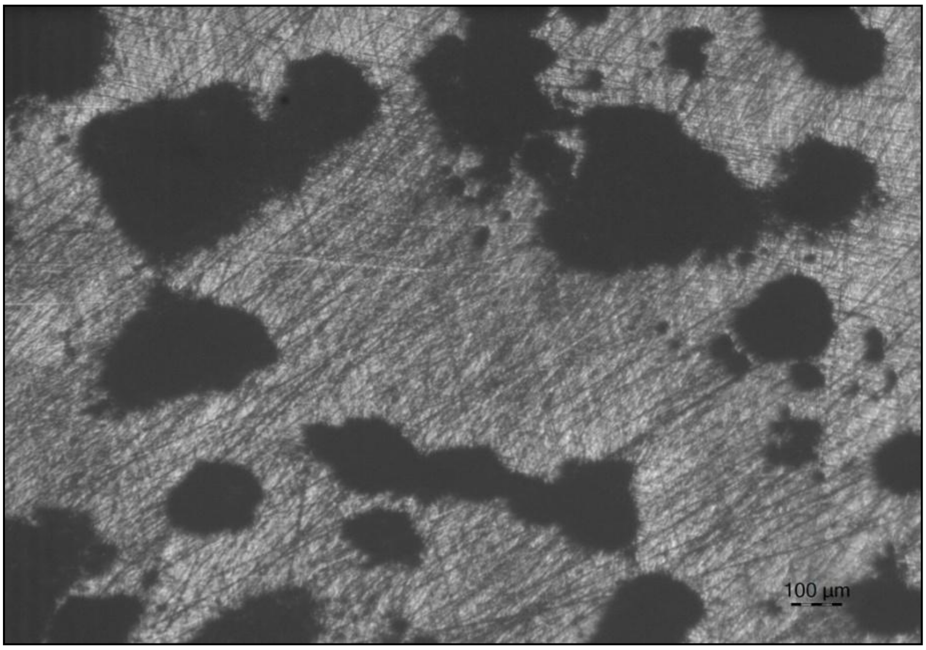


Figure 4.32: Pitting on oil quenched sample at 1050 °C after cleaning (50x magnification)

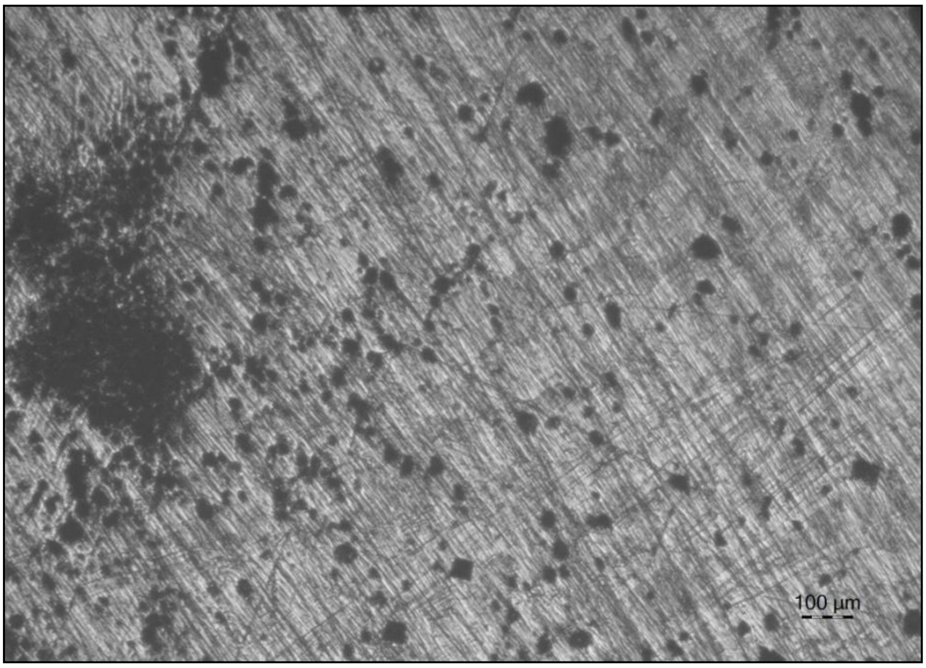


Figure 4.33: Pitting on water quenched sample at 1050 °C after cleaning (50x magnification)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 INTRODUCTION

This chapter will conclude the research according to the result obtained in chapter 4 and briefly discussed about the recommendation that can be applied for the future work. In this project, two main objective were investigated which is to study corrosion behavior of heat treated carbon steel and investigate the corrosion rate for different heat treatment of carbon steel. The objectives have been achieved since the experiment has been done and the result of corrosion rate and corrosion behavior determined.

5.1 CONCLUSION

In this project, heat treatment for AISI 1070 in the 3.5 % NaCl solution posses a similar characteristic but different corrosion potential. The polarization curves on heat-treated AISI 1070 reveal a similar characteristic. The highest corrosion rate is non-heat treated carbon steel (13.96 mmpy) and the lowest corrosion rate is water quenched AISI 1070 at 1050 °C (0.5148 mmpy). The differences of corrosion rate between heat treatment are cause of development of microstructure during heat treatment process. In addition, the hardness value before and after corrosion is consider no change. The value of hardness difference is not significant because too small differences about before and after corrosion. The hardness value only will change when the microstructure is change. From this project, corrosion does not affect the microstructure of the sample and it only occurs at a surface of the sample.

5.2 RECOMMENDATIONS

i. Heat treated AISI 1070 by water quenched is better corrosion resistance and it is suitable for used in the industries.
ii. The structure using heat treated AISI 1070 by water quench will decreasing the cost of the industries in order to prevent corrosion or replacing the corroded structure.
iii. Heat treated AISI 1070 by water quench suitable for heavy industries because it has the highest hardness value.

REFERENCES

Al-Mayouf, A.M. 1997. Corrosion of iron in aquoeus solutions containing a chemical cleaning agent. *Desalination.* **114**: 29-36.

Callister, W.D., Jr. and Rethwish, D.G. 2008. Fundamentals of Materials Science and Engineering. Third ed. USA: McGraw-Hill.

Carneiro, R.A., Ratnapuli, R.C., Lins.V.D.F.C. 2003. The influence of chemical composition and microstructure of API linepipe steels on hydrogen induced cracking and sulfide stress corrosion cracking.*Materials Science and Engineering*.**357**: 104-110.

Dieter, L. 2007. *Corrosion And Surface Chemistry of Metals.* First ed. Boca Raton: CRC Press.

Fontana, M.G. *Corrosion Engineering,* 3rd edition. McGraw-Hill,USA, 1987.

Krauss,G.2005. *STEELS : Processing, Structure, and Performance. First ed*. United States of America: ASM International.

Ma, Y., Li, Y. and Wang, F. 2009. Corrosion of low carbon steel in atmospheric environments of different chloride content. *Corrosion Science*. **51**: 997-1006.

Okan,T. and Mustafa,U. 2009.On the microstructural and mechanical characterization of a low carbon and micro-alloyed steel. *Materials and Design* . **30**: 3274-3278.

Revie, R.W. and Uhlig, H.H. 2008. *Corrosion and Corrosion Control*. Fourth ed. Hoboken New Jersey: John Wiley & Sons, Inc.

Smitch, W.F. and Hashemi, J. 2006. *Foundation of Materials Science and Engineering*. Fourth ed. New York, America: Mcgraw-Hill Higher Education.

Talekar, A., Chandra,D., Chellappa, R., Daemen, J.,Tamura,N. and Kunz,M. 2008. Oxidation kinetics of high strength low alloy steels at elevated temperature. *Corrosion Science*. **50**: 2804-2815.

Tavakkolizadeh, M. and Saatdarmanesh, H. 2001. Galvanic of carbon and steel in Aggressive environments. Journal of Composites For Construction. **19**: 200-210.

Totik, Y. 2004. The corrosion behavior of manganese phosphate coatings applied to AISI 4140 steel subjected to different heat treatments. *Surface & Coatings Technology*. **200**: 2711-2717.

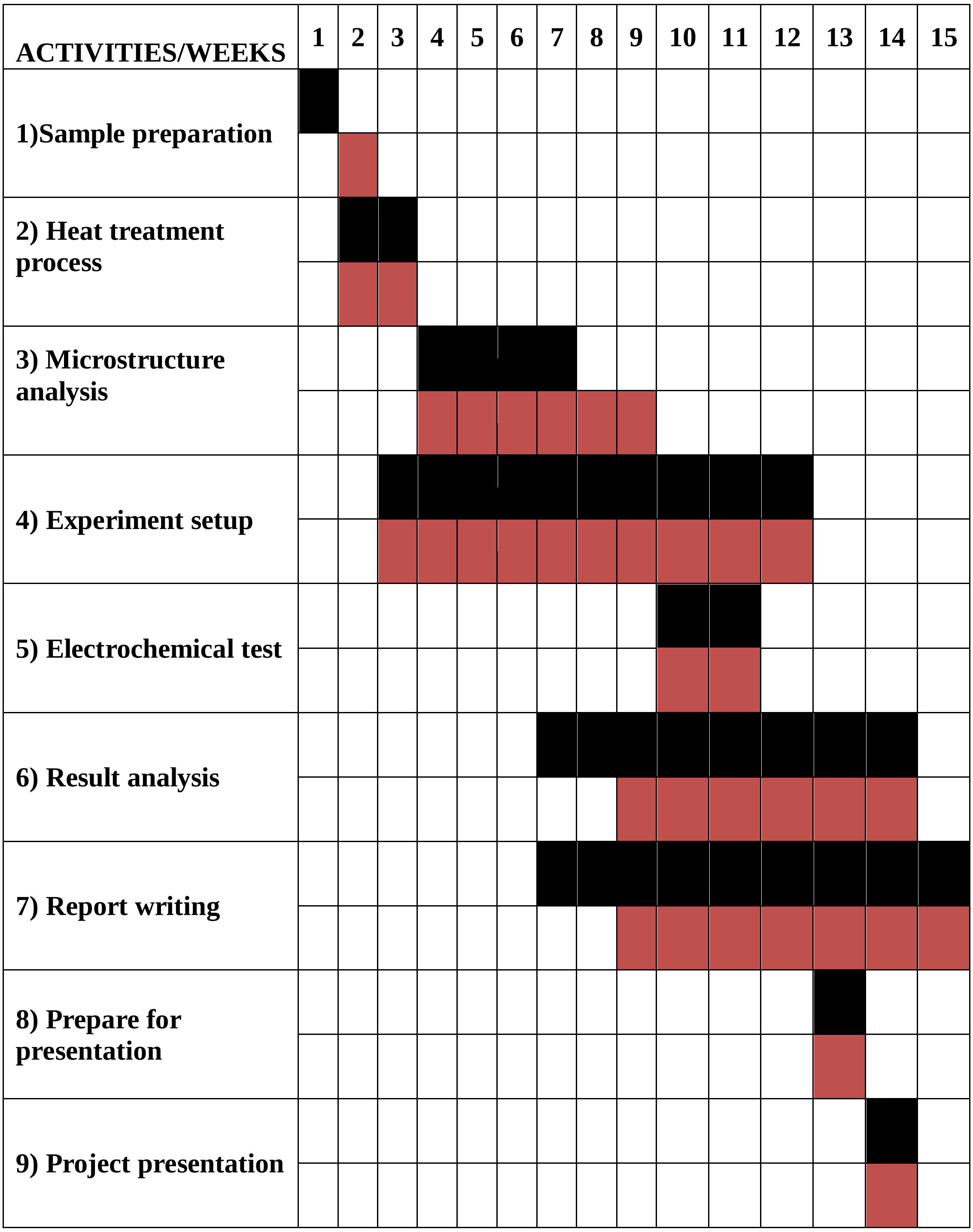
Winston, R.R. and Herbert, H.U. 2008. *Corrosion and Corrosion Control*. Fourth ed. Canada: John Wiley & Sons, Inc

Khaled, K.F. and Amin, M.A. 2009. Corrosion monitoring of mild steel in sulphuric acid in presence of some thiozole derivative- Molecular dynamics, chemical and electrochemical studies. *Corrosion Science*. **51**: 1964-1975.

Wang, C.Y., Shi.J., Cao, W.Q. and Dong, H. 2010. Characterization of microstructure obtained by quenching and partitioning process in low alloy martensitic steel. *Material Science and Engineering A*. **527**: 3442-3449.

APPENDIX A2

Gantt chart for Final Year Project 2



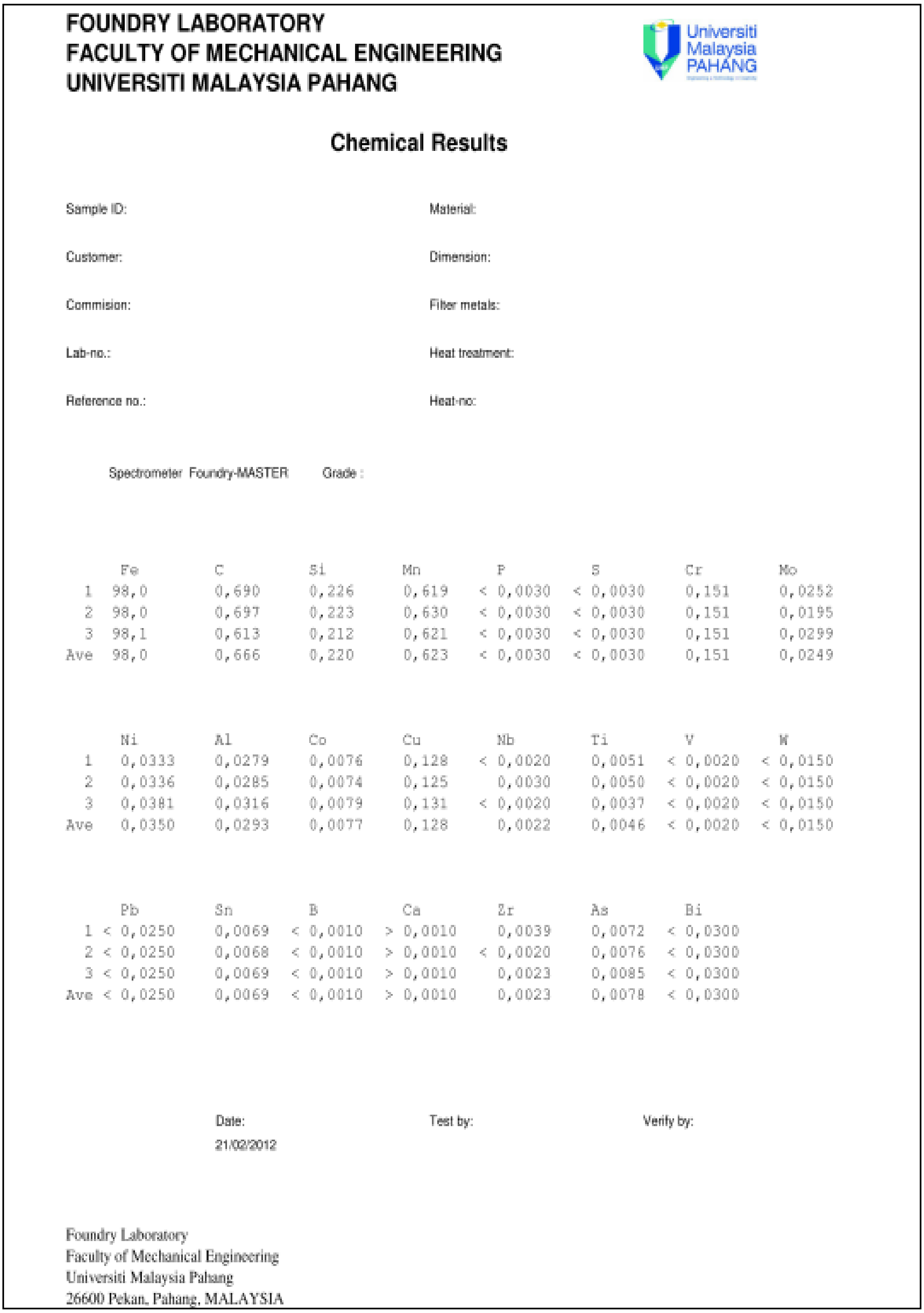
ACTIVITIES/WEEKS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1)Sample preparation	■														
		🟥													
2) Heat treatment process		■	■												
		🟥	🟥												
3) Microstructure analysis				■	■	■									
				🟥	🟥	🟥	🟥	🟥	🟥						
4) Experiment setup			■	■	■	■	■	■	■	■	■	■			
			🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥			
5) Electrochemical test										■	■				
										🟥	🟥				
6) Result analysis							■	■	■	■	■	■	■	■	
									🟥	🟥	🟥	🟥	🟥	🟥	
7) Report writing							■	■	■	■	■	■	■	■	■
									🟥	🟥	🟥	🟥	🟥	🟥	🟥
8) Prepare for presentation													■		
													🟥		
9) Project presentation														■	
														🟥	

■ Planning

🟥 Actual

APPENDIX B

Compositional analysis result



FOUNDRY LABORATORY
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

Universiti Malaysia PAHANG

Chemical Results

Sample ID:

Material:

Customer:

Dimension:

Commision:

Filter metals:

Lab-no.:

Heat treatment:

Reference no.:

Heat-no:

Spectrometer Foundry-MASTER Grade :

	Fe	C	Si	Mn	P	S	Cr	Mo
1	98,0	0,690	0,226	0,619	< 0,0030	< 0,0030	0,151	0,0252
2	98,0	0,697	0,223	0,630	< 0,0030	< 0,0030	0,151	0,0195
3	98,1	0,613	0,212	0,621	< 0,0030	< 0,0030	0,151	0,0299
Ave	98,0	0,666	0,220	0,623	< 0,0030	< 0,0030	0,151	0,0249

	Ni	Al	Co	Cu	Nb	Ti	V	W
1	0,0333	0,0279	0,0076	0,128	< 0,0020	0,0051	< 0,0020	< 0,0150
2	0,0336	0,0285	0,0074	0,125	0,0030	0,0050	< 0,0020	< 0,0150
3	0,0381	0,0316	0,0079	0,131	< 0,0020	0,0037	< 0,0020	< 0,0150
Ave	0,0350	0,0293	0,0077	0,128	0,0022	0,0046	< 0,0020	< 0,0150

	Pb	Sn	B	Ca	Zr	As	Bi
1	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0039	0,0072	< 0,0300
2	< 0,0250	0,0068	< 0,0010	> 0,0010	< 0,0020	0,0076	< 0,0300
3	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0023	0,0085	< 0,0300
Ave	< 0,0250	0,0069	< 0,0010	> 0,0010	0,0023	0,0078	< 0,0300

Date:
21/02/2012

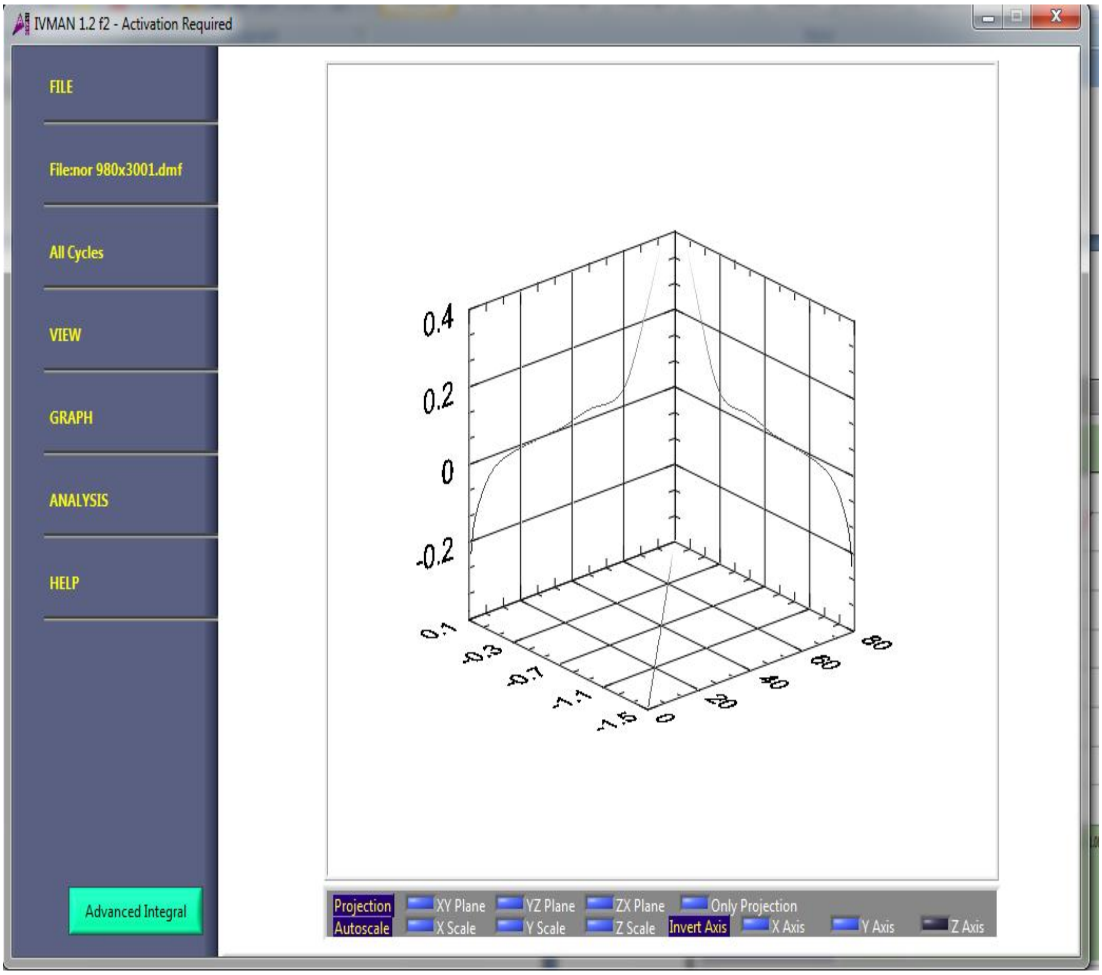
Test by:

Verify by:

Foundry Laboratory
Faculty of Mechanical Engineering
Universiti Malaysia Pahang
26600 Pekan, Pahang, MALAYSIA

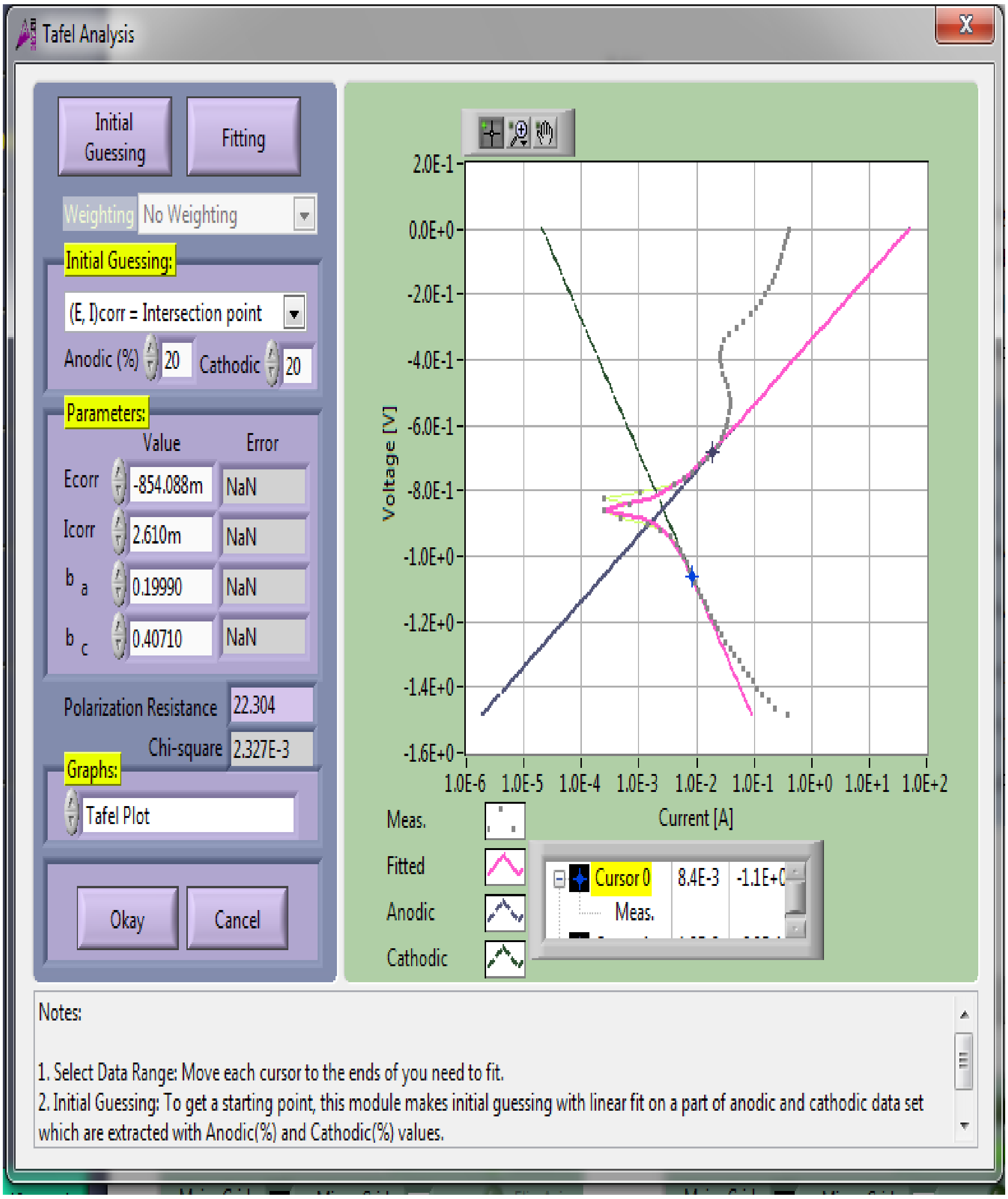
APPENDIX C

IVMAN software



APPENDIX D

Tafel Analysis in IVMAN software



Weighting: No Weighting

Initial Guessing:

(E, I)corr = Intersection point

Anodic (%) 20 Cathodic 20

Parameters:

	Value	Error
Ecorr	-854.088m	NaN
Icorr	2.610m	NaN
b_a	0.19990	NaN
b_c	0.40710	NaN

Polarization Resistance 22.304

Chi-square 2.327E-3

Graphs: Tafel Plot

Cursor 0	8.4E-3	-1.1E+0
Meas.		

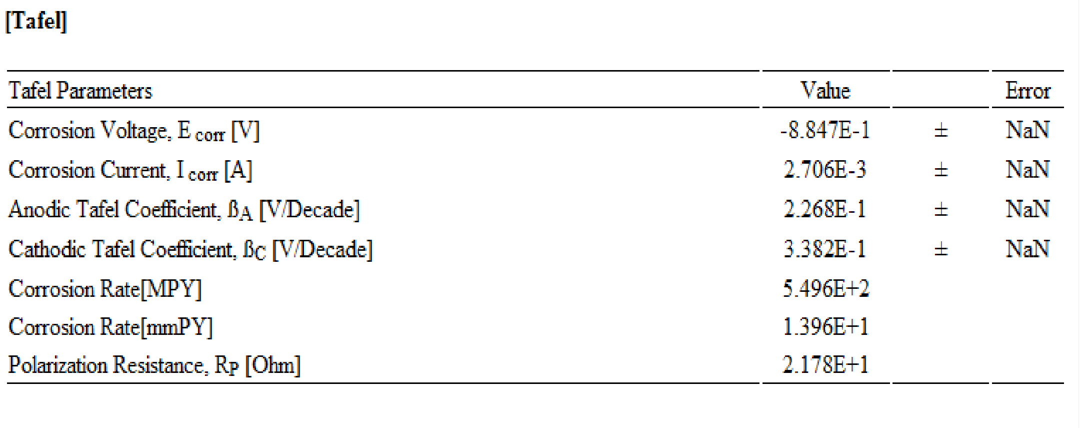
Notes:

1. Select Data Range: Move each cursor to the ends of you need to fit.
2. Initial Guessing: To get a starting point, this module makes initial guessing with linear fit on a part of anodic and cathodic data set which are extracted with Anodic(%) and Cathodic(%) values.

APPENDIX E

Tafel extrapolation result

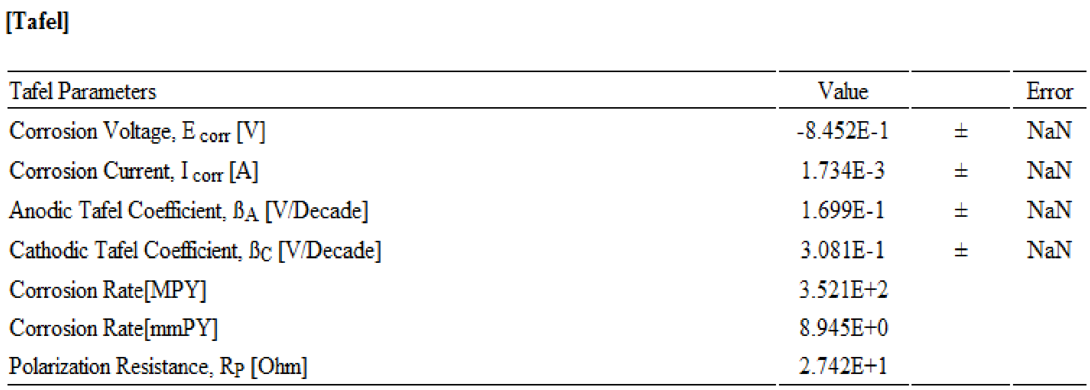
As received



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-8.847E-1	±	NaN
Corrosion Current, I_{corr} [A]	2.706E-3	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	2.268E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	3.382E-1	±	NaN
Corrosion Rate[MPY]	5.496E+2		
Corrosion Rate[mmPY]	1.396E+1		
Polarization Resistance, R_P [Ohm]	2.178E+1		

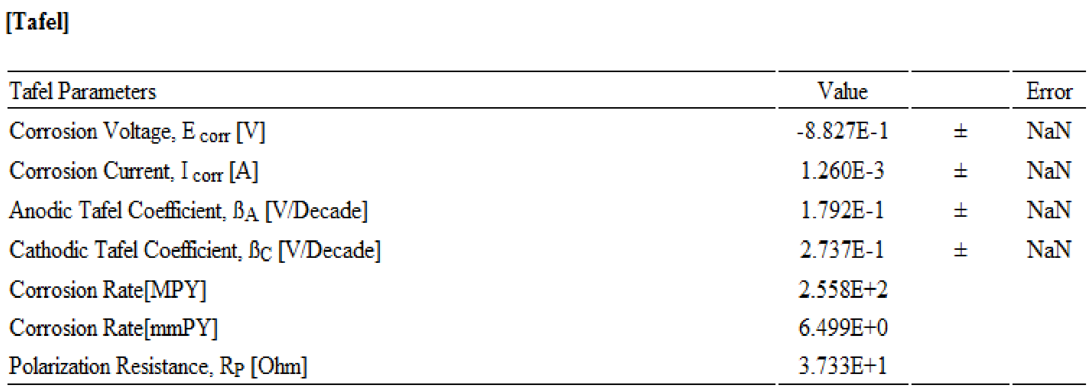
Normalizing 980



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-8.452E-1	±	NaN
Corrosion Current, I_{corr} [A]	1.734E-3	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	1.699E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	3.081E-1	±	NaN
Corrosion Rate[MPY]	3.521E+2		
Corrosion Rate[mmPY]	8.945E+0		
Polarization Resistance, R_P [Ohm]	2.742E+1		

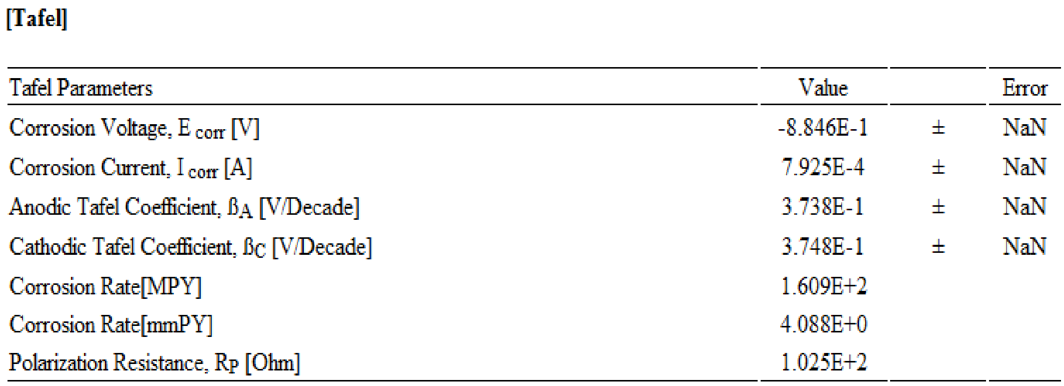
Normalizing 1015



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-8.827E-1	±	NaN
Corrosion Current, I_{corr} [A]	1.260E-3	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	1.792E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	2.737E-1	±	NaN
Corrosion Rate[MPY]	2.558E+2		
Corrosion Rate[mmPY]	6.499E+0		
Polarization Resistance, R_P [Ohm]	3.733E+1		

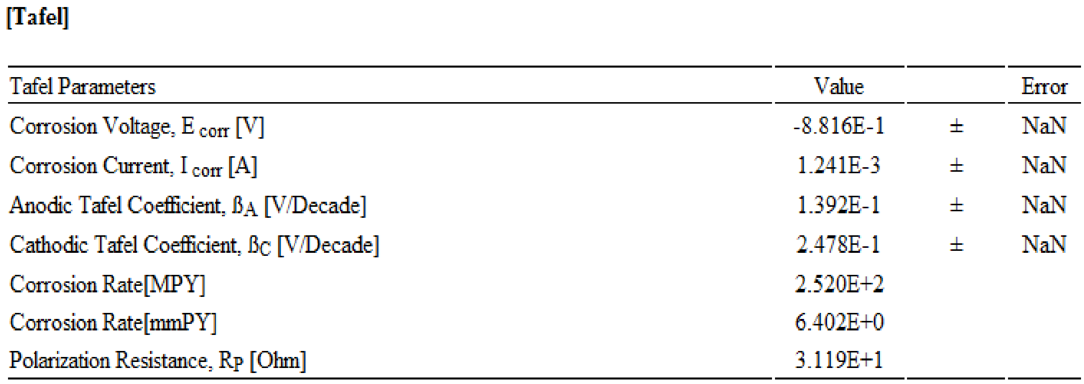
Normalizing 1050



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E corr [V]	-8.846E-1	±	NaN
Corrosion Current, I corr [A]	7.925E-4	±	NaN
Anodic Tafel Coefficient, ßA [V/Decade]	3.738E-1	±	NaN
Cathodic Tafel Coefficient, ßC [V/Decade]	3.748E-1	±	NaN
Corrosion Rate[MPY]	1.609E+2		
Corrosion Rate[mmPY]	4.088E+0		
Polarization Resistance, RP [Ohm]	1.025E+2		

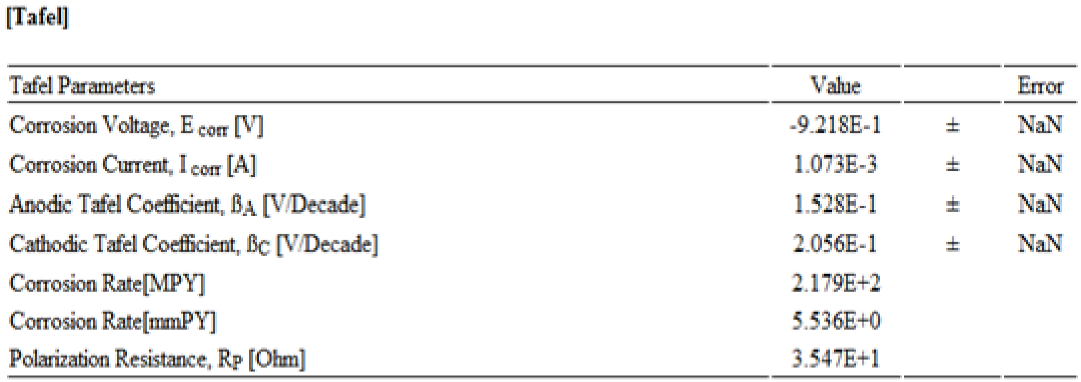
Oil 980



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E corr [V]	-8.816E-1	±	NaN
Corrosion Current, I corr [A]	1.241E-3	±	NaN
Anodic Tafel Coefficient, ßA [V/Decade]	1.392E-1	±	NaN
Cathodic Tafel Coefficient, ßC [V/Decade]	2.478E-1	±	NaN
Corrosion Rate[MPY]	2.520E+2		
Corrosion Rate[mmPY]	6.402E+0		
Polarization Resistance, RP [Ohm]	3.119E+1		

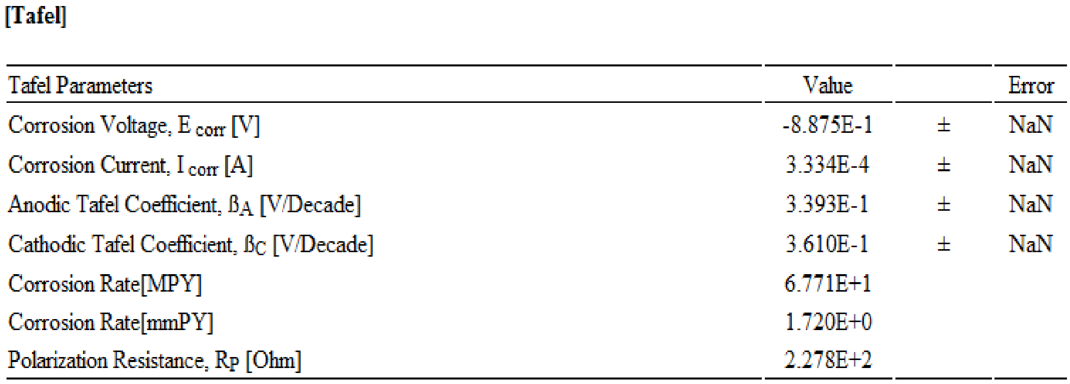
Oil 1015



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E corr [V]	-9.218E-1	±	NaN
Corrosion Current, I corr [A]	1.073E-3	±	NaN
Anodic Tafel Coefficient, ßA [V/Decade]	1.528E-1	±	NaN
Cathodic Tafel Coefficient, ßC [V/Decade]	2.056E-1	±	NaN
Corrosion Rate[MPY]	2.179E+2		
Corrosion Rate[mmPY]	5.536E+0		
Polarization Resistance, RP [Ohm]	3.547E+1		

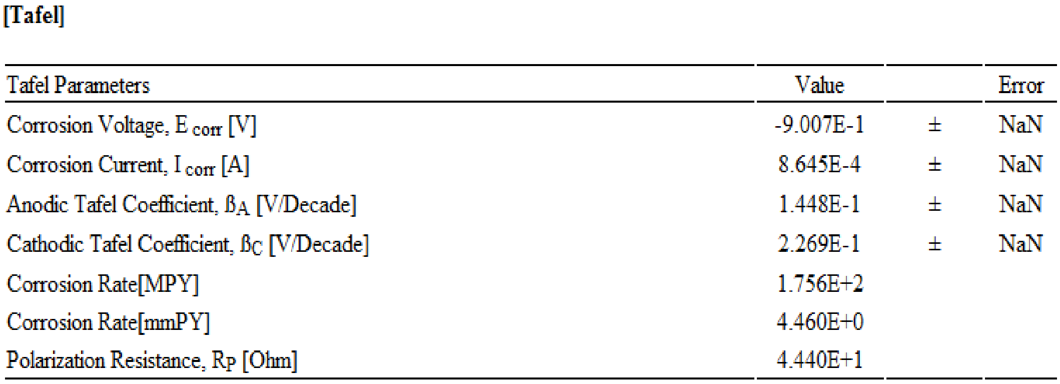
Oil 1050



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-8.875E-1	±	NaN
Corrosion Current, I_{corr} [A]	3.334E-4	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	3.393E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	3.610E-1	±	NaN
Corrosion Rate[MPY]	6.771E+1		
Corrosion Rate[mmPY]	1.720E+0		
Polarization Resistance, R_P [Ohm]	2.278E+2		

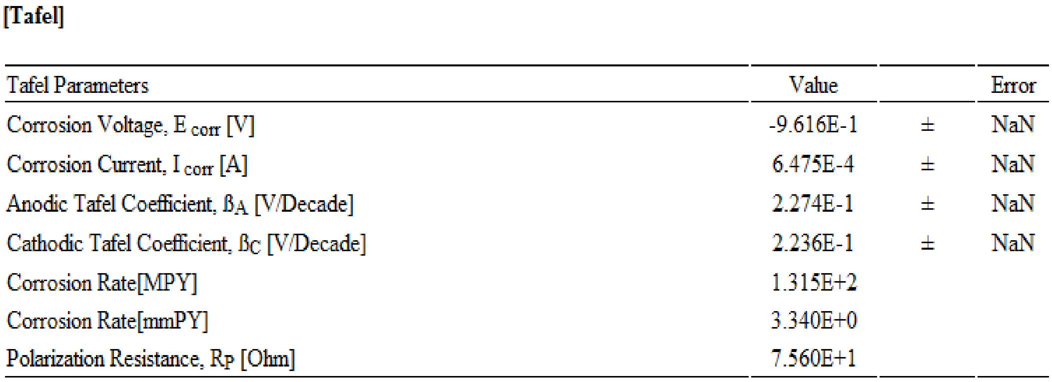
Water 980



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-9.007E-1	±	NaN
Corrosion Current, I_{corr} [A]	8.645E-4	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	1.448E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	2.269E-1	±	NaN
Corrosion Rate[MPY]	1.756E+2		
Corrosion Rate[mmPY]	4.460E+0		
Polarization Resistance, R_P [Ohm]	4.440E+1		

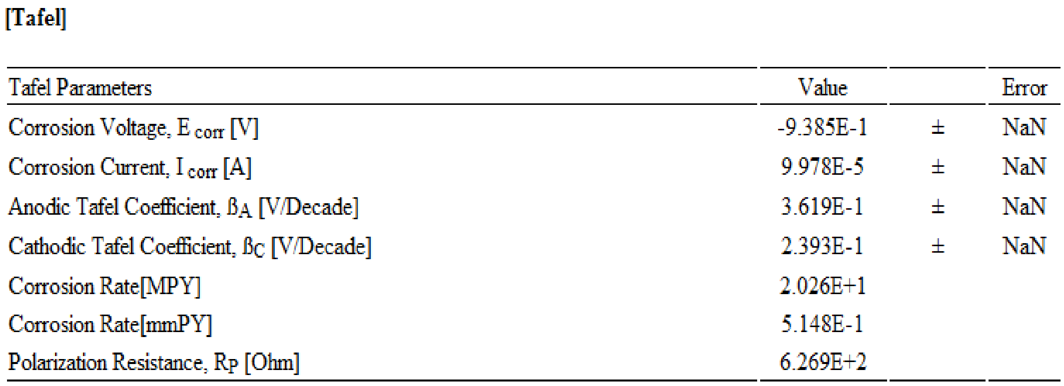
Water 1015



[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-9.616E-1	±	NaN
Corrosion Current, I_{corr} [A]	6.475E-4	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	2.274E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	2.236E-1	±	NaN
Corrosion Rate[MPY]	1.315E+2		
Corrosion Rate[mmPY]	3.340E+0		
Polarization Resistance, R_P [Ohm]	7.560E+1		

Water 1050

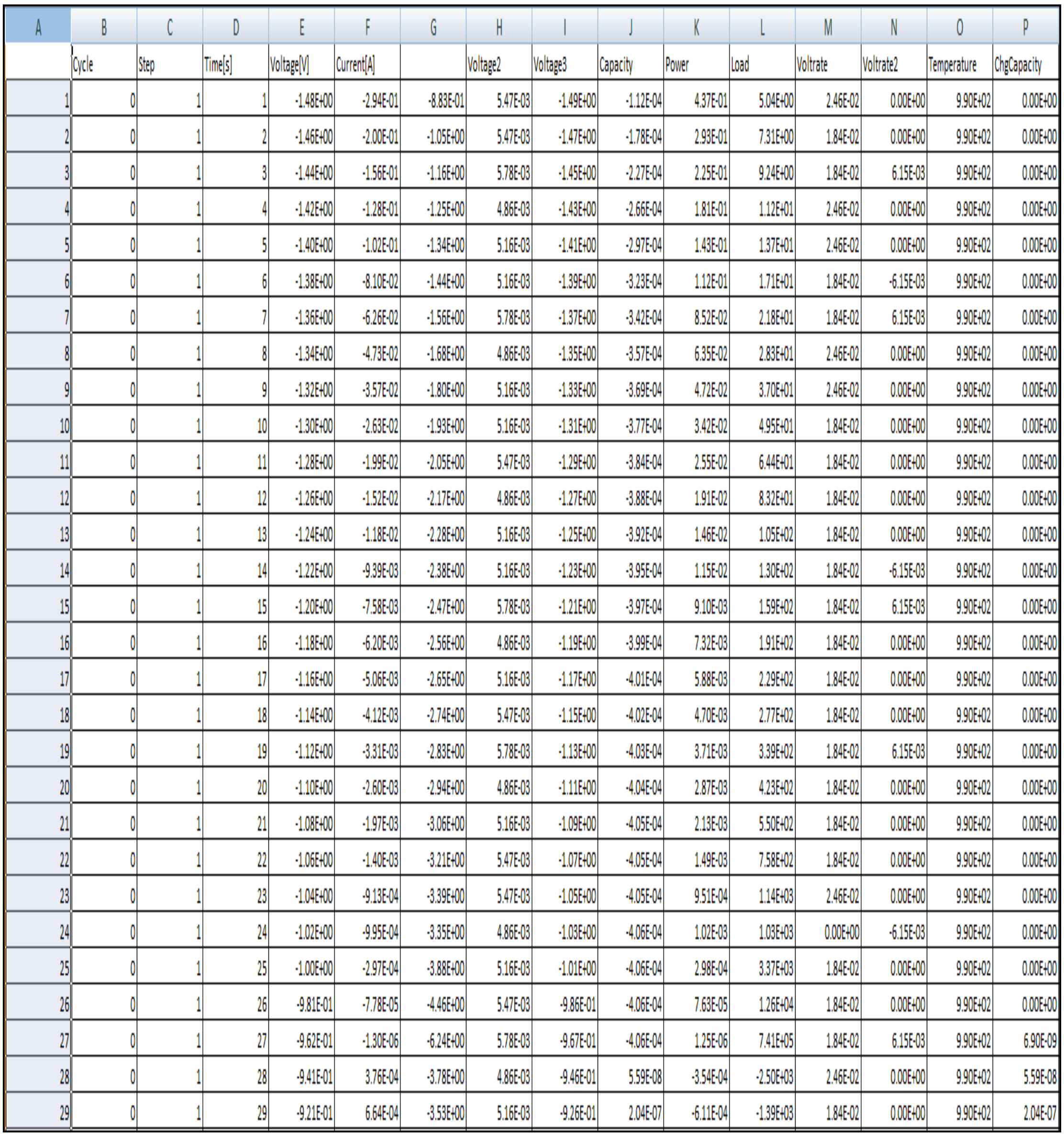


[Tafel]

Tafel Parameters	Value		Error
Corrosion Voltage, E_{corr} [V]	-9.385E-1	±	NaN
Corrosion Current, I_{corr} [A]	9.978E-5	±	NaN
Anodic Tafel Coefficient, β_A [V/Decade]	3.619E-1	±	NaN
Cathodic Tafel Coefficient, β_C [V/Decade]	2.393E-1	±	NaN
Corrosion Rate[MPY]	2.026E+1		
Corrosion Rate[mmPY]	5.148E-1		
Polarization Resistance, R_P [Ohm]	6.269E+2		

APPENDIX F

Exported result from IVMAN software



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
	Cycle	Step	Time[s]	Voltage[V]	Current[A]		Voltage2	Voltage3	Capacity	Power	Load	Voltrate	Voltrate2	Temperature	ChgCapacity
1	0	1	1	-1.48E+00	-2.94E-01	-8.83E-01	5.47E-03	-1.49E+00	-1.12E-04	4.37E-01	5.04E+00	2.46E-02	0.00E+00	9.90E+02	0.00E+00
2	0	1	2	-1.46E+00	-2.00E-01	-1.05E+00	5.47E-03	-1.47E+00	-1.78E-04	2.93E-01	7.31E+00	1.84E-02	0.00E+00	9.90E+02	0.00E+00
3	0	1	3	-1.44E+00	-1.56E-01	-1.16E+00	5.78E-03	-1.45E+00	-2.27E-04	2.25E-01	9.24E+00	1.84E-02	6.15E-03	9.90E+02	0.00E+00
4	0	1	4	-1.42E+00	-1.28E-01	-1.25E+00	4.86E-03	-1.43E+00	-2.66E-04	1.81E-01	1.12E+01	2.46E-02	0.00E+00	9.90E+02	0.00E+00
5	0	1	5	-1.40E+00	-1.02E-01	-1.34E+00	5.16E-03	-1.41E+00	-2.97E-04	1.43E-01	1.37E+01	2.46E-02	0.00E+00	9.90E+02	0.00E+00
6	0	1	6	-1.38E+00	-8.10E-02	-1.44E+00	5.16E-03	-1.39E+00	-3.23E-04	1.12E-01	1.71E+01	1.84E-02	-6.15E-03	9.90E+02	0.00E+00
7	0	1	7	-1.36E+00	-6.26E-02	-1.56E+00	5.78E-03	-1.37E+00	-3.42E-04	8.52E-02	2.18E+01	1.84E-02	6.15E-03	9.90E+02	0.00E+00
8	0	1	8	-1.34E+00	-4.73E-02	-1.68E+00	4.86E-03	-1.35E+00	-3.57E-04	6.35E-02	2.83E+01	2.46E-02	0.00E+00	9.90E+02	0.00E+00
9	0	1	9	-1.32E+00	-3.57E-02	-1.80E+00	5.16E-03	-1.33E+00	-3.69E-04	4.72E-02	3.70E+01	2.46E-02	0.00E+00	9.90E+02	0.00E+00
10	0	1	10	-1.30E+00	-2.63E-02	-1.93E+00	5.16E-03	-1.31E+00	-3.77E-04	3.42E-02	4.95E+01	1.84E-02	0.00E+00	9.90E+02	0.00E+00
11	0	1	11	-1.28E+00	-1.99E-02	-2.05E+00	5.47E-03	-1.29E+00	-3.84E-04	2.55E-02	6.44E+01	1.84E-02	0.00E+00	9.90E+02	0.00E+00
12	0	1	12	-1.26E+00	-1.52E-02	-2.17E+00	4.86E-03	-1.27E+00	-3.88E-04	1.91E-02	8.32E+01	1.84E-02	0.00E+00	9.90E+02	0.00E+00
13	0	1	13	-1.24E+00	-1.18E-02	-2.28E+00	5.16E-03	-1.25E+00	-3.92E-04	1.46E-02	1.05E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
14	0	1	14	-1.22E+00	-9.39E-03	-2.38E+00	5.16E-03	-1.23E+00	-3.95E-04	1.15E-02	1.30E+02	1.84E-02	-6.15E-03	9.90E+02	0.00E+00
15	0	1	15	-1.20E+00	-7.58E-03	-2.47E+00	5.78E-03	-1.21E+00	-3.97E-04	9.10E-03	1.59E+02	1.84E-02	6.15E-03	9.90E+02	0.00E+00
16	0	1	16	-1.18E+00	-6.20E-03	-2.56E+00	4.86E-03	-1.19E+00	-3.99E-04	7.32E-03	1.91E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
17	0	1	17	-1.16E+00	-5.06E-03	-2.65E+00	5.16E-03	-1.17E+00	-4.01E-04	5.88E-03	2.29E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
18	0	1	18	-1.14E+00	-4.12E-03	-2.74E+00	5.47E-03	-1.15E+00	-4.02E-04	4.70E-03	2.77E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
19	0	1	19	-1.12E+00	-3.31E-03	-2.83E+00	5.78E-03	-1.13E+00	-4.03E-04	3.71E-03	3.39E+02	1.84E-02	6.15E-03	9.90E+02	0.00E+00
20	0	1	20	-1.10E+00	-2.60E-03	-2.94E+00	4.86E-03	-1.11E+00	-4.04E-04	2.87E-03	4.23E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
21	0	1	21	-1.08E+00	-1.97E-03	-3.06E+00	5.16E-03	-1.09E+00	-4.05E-04	2.13E-03	5.50E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
22	0	1	22	-1.06E+00	-1.40E-03	-3.21E+00	5.47E-03	-1.07E+00	-4.05E-04	1.49E-03	7.58E+02	1.84E-02	0.00E+00	9.90E+02	0.00E+00
23	0	1	23	-1.04E+00	-9.13E-04	-3.39E+00	5.47E-03	-1.05E+00	-4.05E-04	9.51E-04	1.14E+03	2.46E-02	0.00E+00	9.90E+02	0.00E+00
24	0	1	24	-1.02E+00	-9.95E-04	-3.35E+00	4.86E-03	-1.03E+00	-4.06E-04	1.02E-03	1.03E+03	0.00E+00	-6.15E-03	9.90E+02	0.00E+00
25	0	1	25	-1.00E+00	-2.97E-04	-3.88E+00	5.16E-03	-1.01E+00	-4.06E-04	2.98E-04	3.37E+03	1.84E-02	0.00E+00	9.90E+02	0.00E+00
26	0	1	26	-9.81E-01	-7.78E-05	-4.46E+00	5.47E-03	-9.86E-01	-4.06E-04	7.63E-05	1.26E+04	1.84E-02	0.00E+00	9.90E+02	0.00E+00
27	0	1	27	-9.62E-01	-1.30E-06	-6.24E+00	5.78E-03	-9.67E-01	-4.06E-04	1.25E-06	7.41E+05	1.84E-02	6.15E-03	9.90E+02	6.90E-09
28	0	1	28	-9.41E-01	3.76E-04	-3.78E+00	4.86E-03	-9.46E-01	5.59E-08	-3.54E-04	-2.50E+03	2.46E-02	0.00E+00	9.90E+02	5.59E-08
29	0	1	29	-9.21E-01	6.64E-04	-3.53E+00	5.16E-03	-9.26E-01	2.04E-07	-6.11E-04	-1.39E+03	1.84E-02	0.00E+00	9.90E+02	2.04E-07

APPENDIX A1

Gantt chart for Final Year Project 1

ACTIVITIES/WEEKS	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															■
															🟥

■ Planning

🟥 Actual