UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: CHARACTERISATION AND MODELLING OF STATIC RECOVERY PROCESS OF ALUMINIUM-COPPER ALLOY

SESI PENGAJIAN: 2008/2009

Saya, **MOHD HOSNI BIN ISMAIL (850208-11-5175)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:
8829 (MN),
Kampung Jeram, Manir,
21200 Kuala Terengganu,
Terengganu Darul Iman.

AHMAD SYAHRIZAN BIN SULAIMAN
(Nama Penyelia)

Tarikh: **12 NOVEMBER 2008** Tarikh: **12 NOVEMBER 2008**

CATATAN: * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

◆ Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

CHARACTERISATION AND MODELLING OF STATIC RECOVERY PROCESS OF ALUMINIUM-COPPER ALLOY

MOHD HOSNI BIN ISMAIL

A report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Ahmad Sulaiman

....

Name of Supervisor: DR. AHMAD SYAHRIZAN BIN SULAIMAN

Position: HEAD OF PROGRAM FACULTY OF MECHANICAL ENGINEERING

Date: 13 NOVEMBER 2008

....

Name of Panel: NUR AZHANI BINTI ABD RAZAK

Position: LECTURER

Date: 14th November 2008

STUDENT'S DECLARATION

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

....

Name: MOHD HOSNI BIN ISMAIL

ID Number: MA06006

Date: 12 NOVEMBER 2008

To my beloved mother and father

ACKNOWLEDGEMENTS

First of all I would like to express my fully gratitude and praise 'Alhamdulillah' to Allah the Almighty for completion of this research. To my flexible, dedicated guider and supervisor Dr Ahmad Syahrizan bin Sulaiman, I would like to express my appreciation to my final year project supervisor for his irreplaceable encouragement and guidance. A person of innumerable skills, he has eased the way through a demanding project during a busy time in my life.

I would like to express my admiration to my lovely family, my labmates, mechanical's lab staff, my friend and many other personnel I have spoken with about this project. I thank all of them for sharing their helpfulness, ideas and kindness.

Last but not least, I want to take these favorable moments to express gratefulness to all of them again which are very much appreciated as friends and mentors. Without them, this project will not be perfect.

ABSTRACT

The main objective of this project is to determine the activation energy of aluminium-copper alloy using interrupted of tensile test procedure. The interrupted process was conduct at recovery stage, which is to investigate effect of recovery due to influence of pre-strain. The process of recovery is to relieve the internal residual stresses during cold work. The specimens were tested at variable pre strain (2.5%, 5%, 7.5%, 10%.), temperature (100 °C, 150 °C, 200 °C and 250 °C) and at different annealing time (1 hour, 2 hour, 3 hour and 4 hour). The specimens were machining using lathe machine from larger stock before go to the annealing process. The process of annealing was carried out using box furnace by holding the specimens at an elevated temperature. After the annealing process, the specimens were tested using tensile test machine. This process is required to find the value of yield stress of undeformed material, deformed and at static recovery condition. The value of yield stress depends on the condition of the annealing process. From the data of yield stress, the graph of the X_{rec} (degree of recovery) versus pre-strain, temperature and time can be plot. By using linear line equation of the graph, the activation energy can be calculate by implement the equation of Friedel's model. The value of activation energy depends on the value of the temperature and time that has been used. From the experiment, the value of activation energy at variable temperature is 630 kJ/mol and for the variable time is 211 kJ/mol. From the data of the research it can be use to validate the equation of Friedel's model by make a comparison between the value of activation energy with the data from the journal.

ABSTRAK

Objectif utama dalam kajian ini adalah untuk menentukan tenaga pengaktifan pada aluminium kuprum aloi menggunakan proses gangguan ujian tegangan. Proses gangguan telah dijalankan pada keadaan pemulihan, yang mana untuk menyisat kesan pemulihan terhadap pra-terikan. Proses pemulihan adalah untuk melegakan baki tekanan dalaman sepanjang kerja sejuk. Spesimen-spesimen adalah diuji pada pra-terikan berubah-ubah (2.5%, 5%, 7%, 10%), suhu (100 °C, 150 °C, 200 °C dan 250 °C) dan dipelbagai masa penyepuhlindapan (1 jam, 2 jam, 3 jam dan 4 jam). Spesimen-spesimen telah dimesin menggunakan mesin larik daripada bahan mentah sebelum pergi kepada proses penyepuhlindapan. Proses penyepuhlindapan telah dijalankan menggunakan relau dengan meletakkan spesimen-spesimen di satu suhu yang tinggi. Selepas proses penyepuhlindapan, spesimen-spesimen telah diuji menggunakan mesin ujian tegangan. Proses ini adalah diperlukan bagi mendapatkan nilai tegasan alah bahan yang belum berubah, yang telah berubah dan pada keadaan pemulihan statik. Nilai tegasan adalah bergantung kepada keadaan proses penyepuhlindapan Daripada data bagi tegasan, graf untuk Xrec(darjah pemulihan) melawan pra terikan, suhu dan masa boleh di lukiskan Dengan menggunakan persamaan garis lurus, nilai untuk pengaktifan tenaga boleh ditentukan oleh persamaan "Friedel's model". Nilai tenaga pengaktifan adalah bergantung kepada nilai suhu dan masa yang telah digunakan. Daripada eksperimen, nilai tenaga pengaktifan untuk suhu adalah 630 kJ / mol dan untuk masa adalah 211 kJ / mol. Daripada data kajian, ia boleh digunakan untuk menentukan samada persamaan "Friedel's model" boleh disahkan dengan membuat perbandingan dengan nilai pengaktifan tenaga yang diperoleh daripada jurnal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ε	Strain
$\Delta\sigma$	Stress range
σ_m	Yield stress of deformed material
σ_o	Yield stress of recover material
σ_r	Yield stress of undeformed material
X_{rec}	Degree of recovery
Q	Activation energy
t	Time
R	Gas constant
T	Temperature

LIST OF ABBREVIATIONS

AA	Aluminum alloy
Al	Aluminium
ASTM	American Society for Testing and Materials

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Mechanical properties of metals can be changed by thermo-mechanical processing. This is typically done by combining various types of mechanical deformation and annealing processes. One stage of annealing process is the static recovery process which occurs at temperature below recrystallization temperature and without mechanical deformation effect. Static recovery usually involve motion annihilation of point deflects as well as annihilation and rearrangement of dislocation resulting in the formation of subgrain and subgrain boundaries.

A unique feature of recovery process is that it does not involve any change in the grain structure of the cold worked metal. The only changes taking place are the dislocation arrangement within existing grain. This project will study about static recovery of aluminium-copper alloy. By using static recovery behavior, it will be then used to develop a mathematical model using Fridel's model. The mathematical model will be useful as a tool for predicting commercial product of mechanical properties.

1.2 PROBLEM STATEMENT

To investigate of static recovery process due to influence of pre-strain of aluminium-copper alloy.

1.3 THE OBJECTIVE OF THE RESEARCH

To validate Friedel's model of static recovery process of aluminium-copper alloy for tensile test with the pre-strain 5% at different temperature and time.

1.4 SCOPES OF THE PROJECT

This research is focus on the effect of pre-strain due to static recovery process at different time and temperature. The scopes of this project are;

(i) The material that used in this project which is limited to aluminium-copper alloy.
(ii) Operate lathe machine to making the specimens.
(iii) Annealing using box furnace.
(iv) Pre-strain at 2.5%, 5%, 7.5% and 10%
(v) Test specimen using tensile test machine.

CHAPTER 2

LITERATURE REVIEW

2.1 ANNEALING PROCESS

Annealing is one of the processes of heat treatment. Heat treatment is the process that involves the heating and cooling process for the purpose of achieving the desired mechanical properties and performance of a material by changing its microstructure or its residual stress pattern.

In the annealing process the structure and properties of the material will changes after heated and held at suitable temperature and then cooled at a fairly slow rate. There are three stage of annealing process which is recovery, recrystalization and grain growth. This process will occur due to the increasing of temperature.

The purpose of the annealing process is to reduce hardness, refine the grain structure, restore ductility, and remove internal stresses of the material. This process also will improving machinability, facilitating cold working, producing a desired microstructure and obtaining desired physical, mechanical, or other properties.

Figure 2.1 show the effect of structure and properties of the material due to increasing of temperature. In this research, the annealing process that involve is the static recovery stage. At the static recovery stage the internal residual stress will decrease while the ductility will decrease and no changes occur for strength.

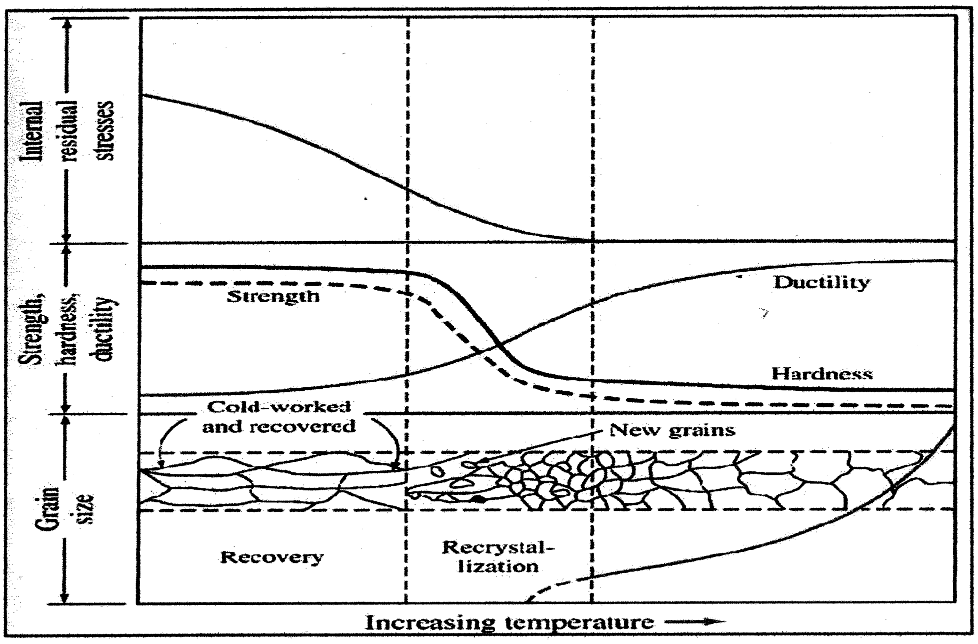


Figure 2.1: Effect of annealing on the structure and mechanical property changes of the cold-worked metal [6]

The rate of heating and cooling may have to be controlled. In alloy systems, the solubility of an alloying element changes with temperature [2]. Annealing will homogenize the structure so that mechanical properties are uniform [1]. It may allow some grains to grow at the expense of others, and the coarse grained structure will have lower strength [2].

2.2 RECOVERY

The slightest stage of annealing is recovery. Recovery is the process of reduction residual stresses in a cold-worked that is affected by holding the specimen at an elevated temperature. No gross microstructure will change occurs in this process [5]. During recovery there is some polygonization which is caused by formation of minute subgrains within the stressed grains. Recovery occurs over specific temperature range for each metal or alloy family. When temperature reached, increased of atomic mobility allows the rearrangement of dislocations into normal array.

In this stage of annealing, the movement of dislocations into less stressed arrangement reduces the elastic stresses in the metal grains. With low levels of cold work this is all that occurs, there being insufficient strain energy left to power subsequent annealing. At this stage there is slight decrease in hardness and strength, but the metal becomes much more resistant to stress corrosion cracking.

At the recovery stage, the material will restores some of the original softness without changing the visible grain structure. In most metals, ductility drops rapidly with even a small degree of cold work while recovery increases ductility without greatly affecting strength. Recovery anneal is a useful method for producing a material of higher strength yet reasonable ductility [2].

2.3 RECRYSTALLIZATION

Recrystallization is a process of heat treatment that occurs when heating is continued to temperature of about one-third to one-half times absolute melting point (T_m). This process will changes the grain structure of the metal. At this condition crystals begin to grow from nuclei in the most heavily deformed part of metal. It will cause the formation of new and refined grains structure. Recrystallization affected the hardness and strength of material to become decrease but it will more ductile and increase the elongation [4].

The factors affecting recrystallization are:

(i) Small amount deformation necessary before recrystallization can occur. The amount of deformation is depends on the material.

(ii) Highest amount of cold work will lowered the crystallization temperature for particular metal.

(iii) Alloying increases the recrystallization temperature.

(iv) Recrystallization only happens above recrystallization temperature. Higher temperature of recrystallization will shorted the time needed at that temperature for given crystal condition to be achieve.

(v) The structure of grain size depends on the temperature, the higher the temperature the larger the grain size.

(vi) The amount of cold work prior affects the size of grains. The largest amount of cold work the smaller resulting grain size.

2.4 TENSILE TEST

Tensile test is used to measures the strength of material [3] Tensile test sample used in this project are typically cylindrical rods with reduced diameter in the center. Prior to testing, the original cross-sectional area of the reduced section of the tensile sample is measured and two gage marks of known separation distance are place on the sample. The test sample is mounted in a tensile test machine using grippers or jaws. One jaw is fixed to the base of the testing machine, and the other is affixed to a movable crosshead. During test, the crosshead is moved to create tensile force in the test sample. The force is measured by the force transducer and the tensile stress is calculated by dividing the force by the original cross sectional area. The strain is calculated by dividing the change in length of the sample by the original length. The stress-strain curve is approximately linear and the slope of that curve is elastic modulus. The modulus of elasticity is the slope of the linear portion of the stress-strain curve [1].

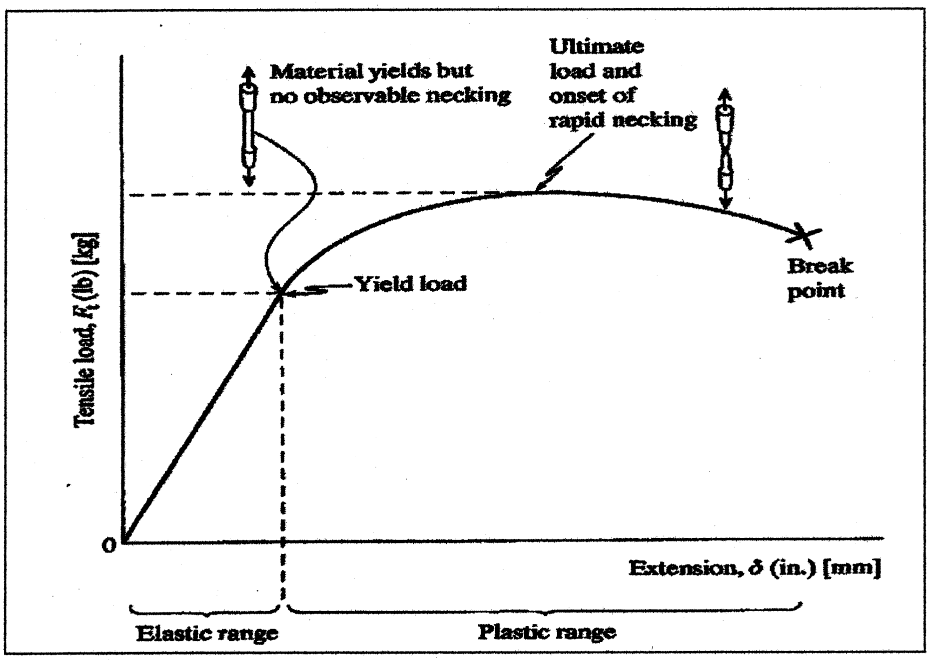


Figure 2.2 Force deflection curve [1]

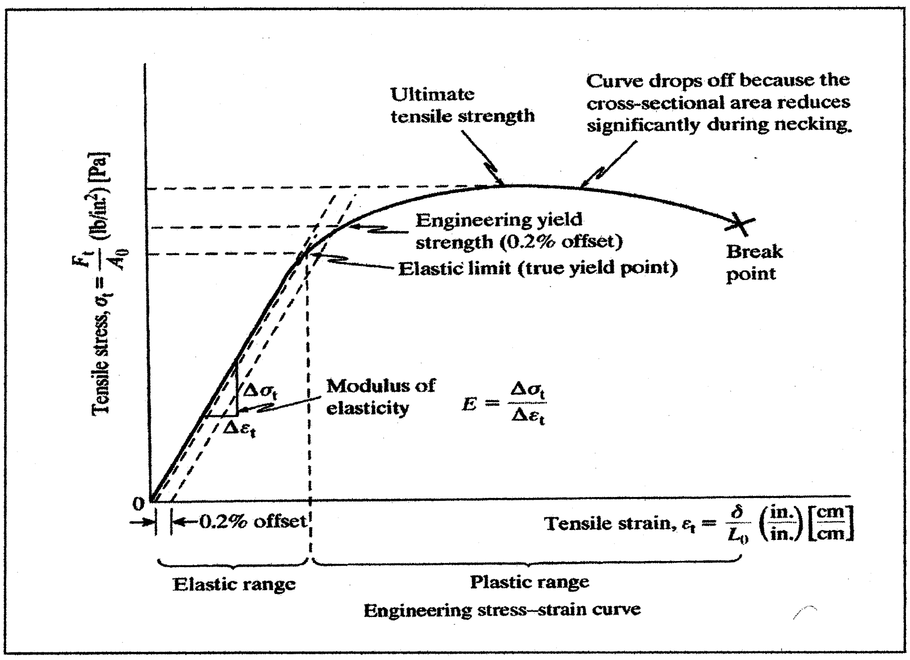


Figure 2.3 Stress-Strain curve [1]

Figure 2.2 and 2.3 show the force displacement of ductile metals. Using static recovery, differential of stress ($\Delta\sigma$) can be determined. 0.2% of elastic range often considers the yield point to occur at an offset strain.

2.5 EFFECT OF THE RATE OF LOADING

The rate of loading can have a significant effect on the stress-strain curve of materials. This is particularly so at elevated temperatures. At room temperature the stress-strain curve of metals may be considered independent of the rate of loading for a certain range of rates of loading of practical interest. At high rates of loading the yield stress and modulus of elasticity of ductile materials increase with the rate of loading.

Moreover, the magnitude of the plastic component of strain that precedes fracture of ductile materials is reduced considerably as the rate of loading is increased. That is, the material becomes less ductile. In the fact at very high rates of loading materials, which are ductile at ordinary rates of loading, behave as brittle. These effects are more pronounced at elevated temperature.

At high rates of loading, it is difficult to maintain a constant temperature during a test since there is not enough time for heat generated to dissipate into the environment. That is, a high rate of loading the process of deformation is approximately adiabatic. In order to take into account the effect of the rate of loading on the stress-strain curve of a material, it must be consider as time dependent. That is, first or higher time derivatives of stress or strain must be included in its stress-strain relation.

2.6 EFFECT OF TEMPERATURE

A change in the temperature of the particles of a body produces a change of their dimensions (deformation). The particles of ordinary materials expand when heated and contract when cooled. That is the normal component of strain increase as the temperature increases and decrease as the temperature decreases, while shearing components of strain are not affected by changes of temperature.

Generally, all the mechanical properties of material are affected by changes of temperature. The ductility and brittleness of materials depends on their temperature. Moreover, if a metal specimen is subjected to a constant axial centroidal force at a temperature higher than its recrystallization temperature, its normal components of strain will continue to increase with time until the specimen fractures.

2.7 EFFECT OF TIME

When a thermally isolated body made from an elastic material is subjected to external forces, all the work performed by these forces is stored in the body as elastic energy. Upon unloading, this energy is used to restore the body to its undeformed configuration. Consider a thermally isolated body made of an elastropic material in an unstressed unstrained state of thermodynamic equilibrium at the uniform temperature. When the body is subjected to external forces inducing plastic component of strain, only part of work performed by these forces is stored in the body as elastic energy.

The remaining is converted to heat and raises the temperature of the body. Moreover, upon removal external forces, the body does not revert to its undeformed configuration and its temperature remain higher than that at its underformed stress-free, strain-free state. The total amount of energy used to raise the temperature of a particle depends not only upon the final state of stress at this particle. but also upon the way this particle was stressed.

However, the total amount of energy used to raise the temperature of a particle is not dependent upon the time history of stress acting on this particle. For example, the total amount of energy used to raise the temperature of a particle depends on the number of cycles of loading and unloading and on the magnitude of the components of stress acting on the particle during each cycle. It does depend on the rate of loading and unloading or on the time it remained under load.

2.8 ALUMINIUM-COPPER ALLOY

Aluminiumalloy are best known for low density and corrosion resistance. Electrical conductivity, ease fabrication and appearance are also attractive features.

The importance of aluminium within others metal has increased due to its low density. With the aid of solid solution and precipitation hardening mechanisms, materials great strength can be produced with an often very high strength to weight ratio. Aluminium alloy have been the main constructional material for aircraft and are beginning to make larger inroad into the construction of land vehicles as bumpers, wheels, and some body component. In this project aluminium-copper alloy was selected to done the analysis.

Aluminium-copper alloy is one of the aluminium alloys in group of non-ferrous metal. The 2024 series Al-Copper alloy acquire great strength and reasonable ductility in the age-hardened condition. This group includes copper (Cu) as the major alloying element. Silicon (Si), manganese (Mn), magnesium (Mg), nickel (Ni) and titanium (Ti) may be added to the alloys of 2024 series as minor alloying elements. Aluminium-copper alloys are heat-treatable. Solution treatment followed by either artificial or natural aging allows considerable increasing the yield strength (4-6 times). Ductility of the alloy decreases as a result of the heat treatment. Aluminium-copper alloys (2024 series) usually are used in aircraft structures and propellers, automotive body part and screw fittings [7].

Table 2.1: Themal properties of Al-Cu alloy

Thermal Properties	**Metric**
Specific Heat Capacity	0.880 J/g-°C
Thermal Conductivity	170 W/m-K
Melting Point	540.6 - 643 °C
Annealing Temperature	413 °C

2.9 FRIEDEL'S MODEL

Friedel's model is an empherical method to determine relationship between the amount of recovery, time and temperature. By using true stress – true strain curve of static recovery process the degree of recovery (X_{rec}) can be determined [8].

Using tensile test machine the graph of stress versus strain can be plot. Figure 2.2 shown the point of yield stress of deformed material (σ_m), yield stress of undeformed material (σ_o) and yield stress of recover material (σ_r).

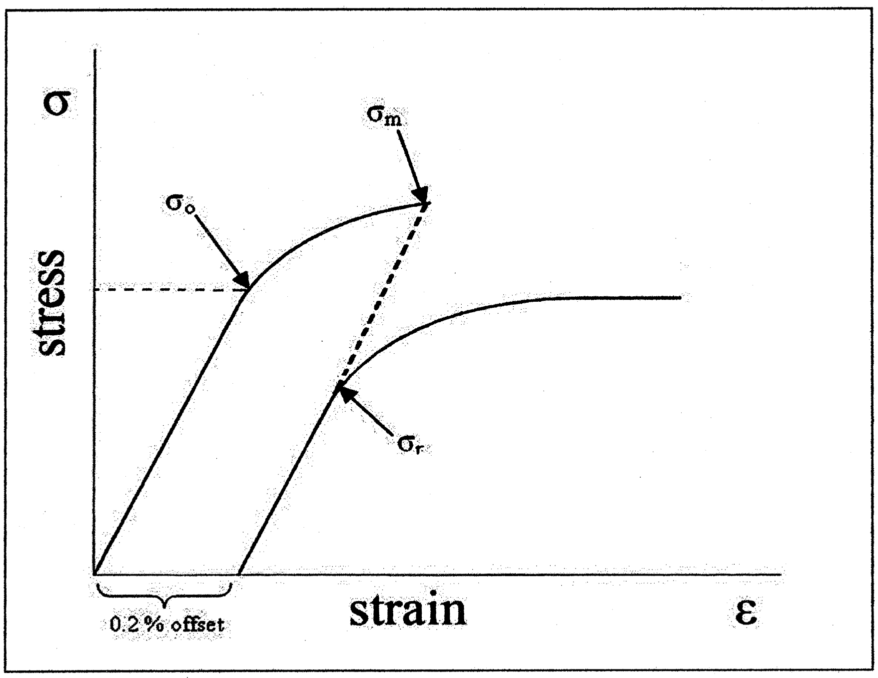


Figure 2.4 Stress versus strain of recovery process

$$X_{rec} = \frac{\sigma_m - \sigma_r}{\sigma_m - \sigma_o} \tag{2.1}$$

X_{rec} = degree of recovery

σ_m = yield stress of deformed material

σ_r = yield stress of recover material

σ_o = yield stress of undeformed material

From the data that get from tensile test the value of degree of recovery (X_{rec}) can be calculate. From the equation, the graph of degree of recovery versus time and temperature can be plot. From the graph, the equation of linear line equation can be finding. The equation of linear line equation can be express in the equation of Friedel's model equation (e.q 2.2).

$$X_{rec} = c_1 \ln t - \frac{Q}{RT} \tag{2.2}$$

where c_1=constant

t=time (second)

Q=activation energy (kJ/mol)

R = molar gas constant (8.3144 J/mol.K)

T = temperature (Kelvin)

2.9.1 Reverse Calculation

The activation energy from the journal was used to make a comparison between the values of research to make sure the value of activation energy is correct. Equation 2.2 was applied to data depicted in Figure 2.5 to find the value of activation energy of the journal to compare between the results of the research. The value of degree of recovery, X_{rec} at constant time at 1 hour has been selected from the graph. From the data, the graph degree of recovery, X_{rec} versus 1/time can be plot to find the value of linear line equation. From the equation, the slope is use to find the activation energy by using Friedel's model equation. Figure 2.5 below show the degree of recovery, X_{rec} versus time.

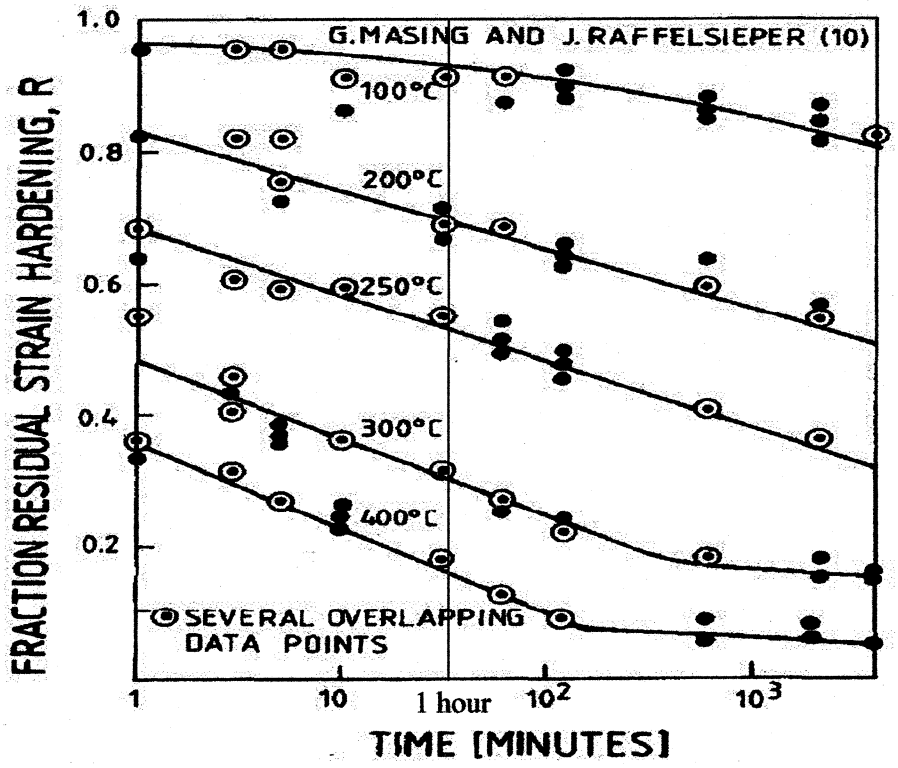


Figure 2.5 – Modelling of the Masing and Raffelsieper [9].

Figure 2.5 show the fraction residual strain hardening (R) of iron versus time. From the graph, re-plot the graph of each temperature at constant time to get the linear line equation. From the linear line equation, applied the equation of Friedel's model to find the value of activation energy (Q). The data of degree recovery are show in the table below.

Table 2.2: Degree of recovery at different temperature

Temp.(Celsius)	Xrec.
100	4.814815
200	33.14815
250	46.66667
300	59.44444
400	80.74074

From the data re-plot the graph of fraction of recovery (X_{rec}) versus 1/Temperature to find the linear line equation.

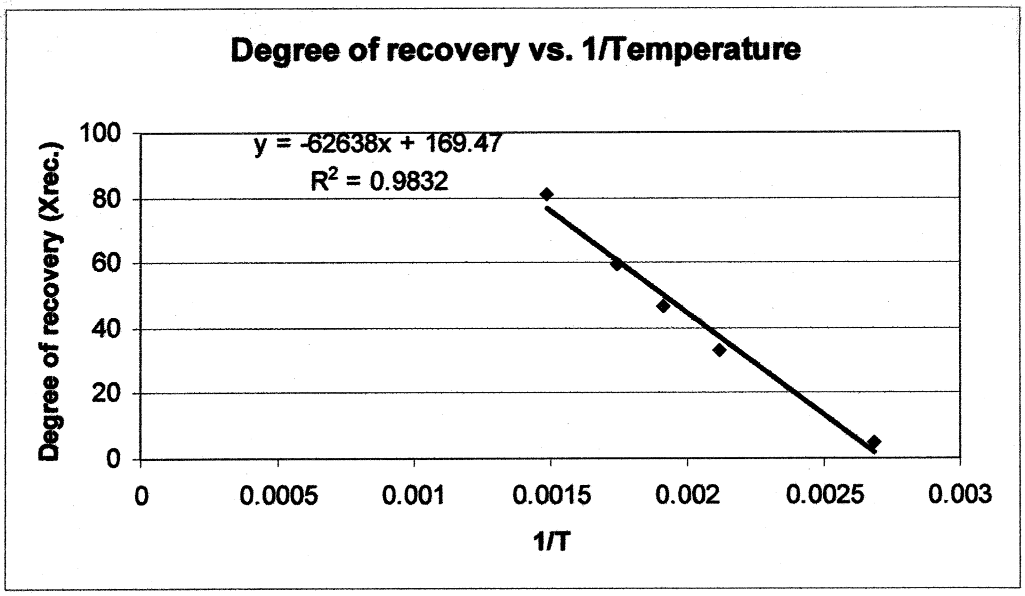


Figure 2.6: Fraction of recovery versus 1/Temperature

From the data of the graph, the value of the activation energy can be calculate using Friedel's model equation (e.q 2.2). The calculation of activation energy as shown as following:

Linear line equation:

$$y = -62638\ x + 169.47$$

Friedel's model:

$$X_{rec.} = c_1 \ln t - \frac{Q}{RT}$$

$$Gas\ constant\ (R) = 8.31432 \frac{J}{mol}$$

Equalize equation of linear line and Fridel's model:

$$-62638 = -\frac{Q}{R}$$

Calculate activation energy

$$Q = 62638 \times 8.31432 \frac{J}{mol}$$

$$Q = 521 \frac{kJ}{mol}$$

The value of activation energy of data from figure 2.5 has been calculate using Friedel's model equation. The value activation that has been calculate from the journal is 521 kJ/mol.

2.9.2 Arrhenius Equation

The relationship for the energies of molecules in a gas had found by Arrhenius experimentally for the effect of temperature on chemical reaction rates. Arrhenius found that the rate of many chemical reactions as a function of temperature could be expressed by the relationship [1]:

$$\text{Arrhenius rate equation:} \quad \text{Rate of reaction} = Ce^{-Q/RT} \tag{2.3}$$

where Q=activation energy (kJ/mol)

R = molar gas constant (8.3144 J/ mol.K)

T = temperature (Kelvin)

C=rate constant, independent of temperature

The Arrhenius equation (2.3) is commonly rewritten in the natural logarithmic form as:

$$\ln \text{rate} = \ln \text{constant} - \frac{Q}{RT} \tag{2.4}$$

From the figure 2.5 of fraction of residual strain hardening versus annealing time at varies temperature is used to plot graph relation of reaction time and temperature at different residual strain hardening. From the graph, the slope of each strain is use to determine the activation energy at different reaction of strain hardening by using the equation of 2.4. The relation between slope and activation energy can describe as equation follow:

$$slope, m = -\frac{Q}{R} \tag{2.5}$$

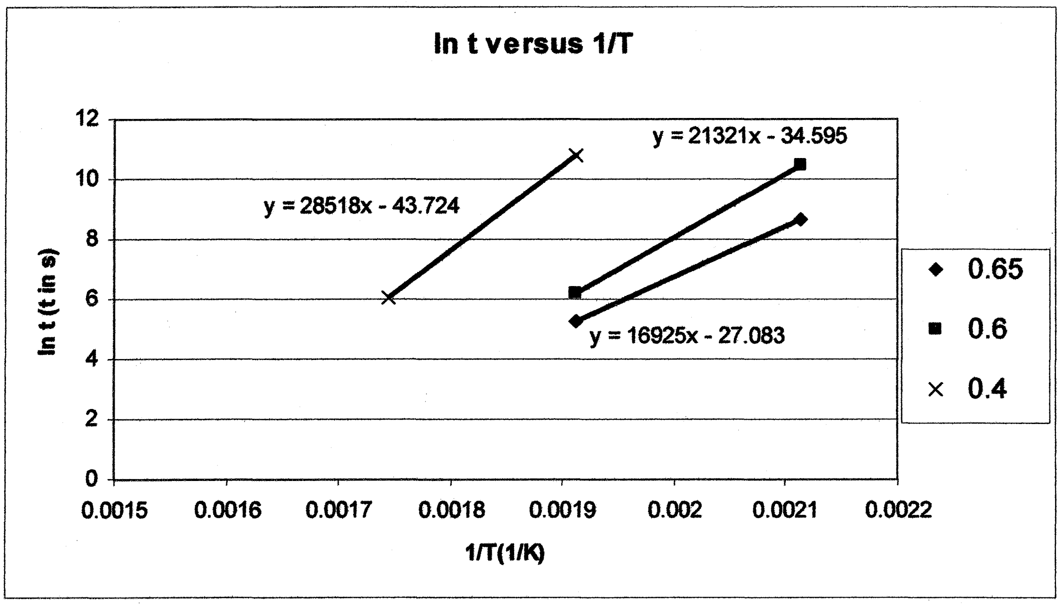


Figure 2.7: Reaction rate versus 1/Temperature

Figure 2.7 show the reaction rate of annealing versus inverse temperature at 0.4, 0.6 and 0.65 fraction of strain hardening. By using equation 2.5, the value of activation energy could be determined at different fraction of strain. The relation of activation energy and fraction of strain could be express by figure 2.8:

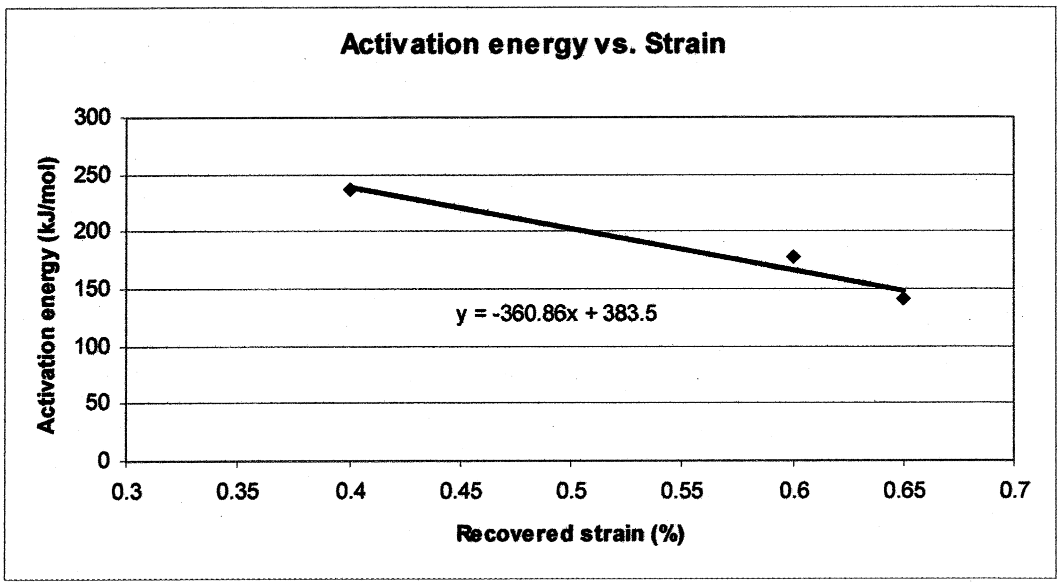


Figure 2.8 Relation between activation energy and fraction of strain

Figure 2.8 show the relationship between activation energy and fraction of strain hardening at 0.4, 0.6 and 0.65. From the figure, show that the value of activation energy is decrease due to the increases of fraction of strain.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In order to complete a research, methodology is the one of the most important thing to be considered to make sure that the thesis or research run smooth and will get expected result which is needed. Methodologies also use to determine the research follow the objective that had been stated earlier or in other word, to follow the guideline based on the objective.

In methodology, the structure of the research is a significant thing that should be considered. Methodology also can be described as a framework of the research that contains the elements of work based on the scope and the objectives. Frameworks also use to facilitate the supervisor to view the overall process of the research. Any mistaken or default can be correcting and adding the elements which lacking in the research.

3.2 FLOW CHART

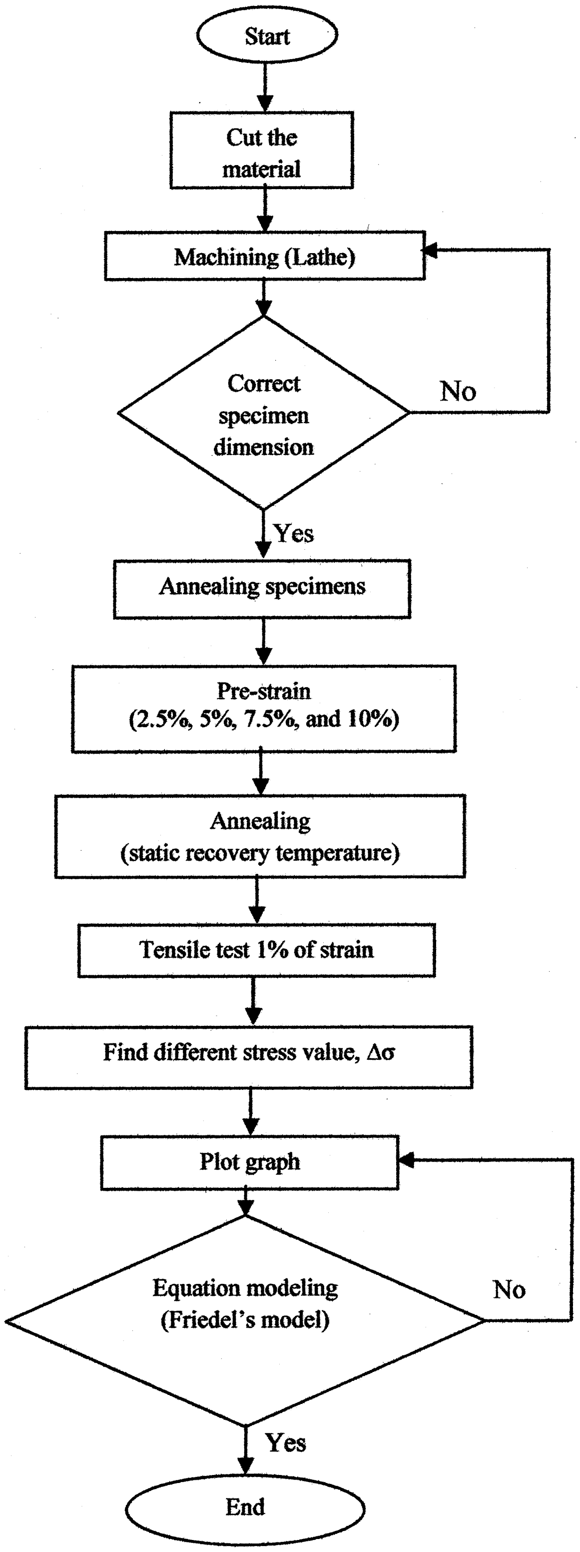


Figure 3.1: Flow Chart

3.3 MACHINING

For the first step the material need to cut from the larger stock. The specimen that use for this project is aluminium-cooper alloy. The raw material came out with dimension 13mm of diameter. The rod of aluminium-copper alloy must be cut from larger stock into 36 pieces with dimension 160mm of length. This process is using band saw machine (Figure 3.2). In this process the cutting speed and feed rate must be set depends on the material.

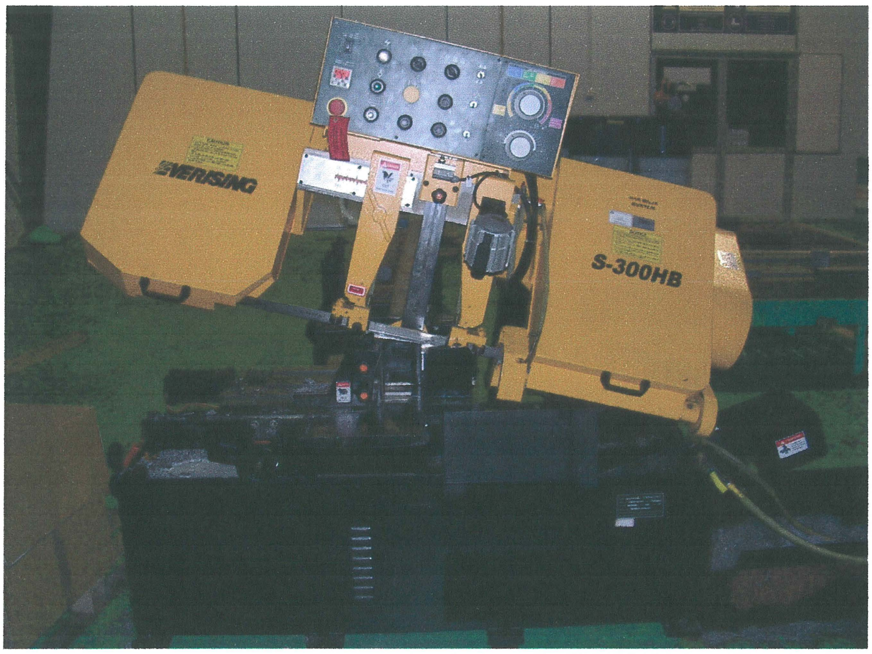


Figure 3.2 Band saw machine

After cut the material the next step is to make the specimen into dog-bone shape with the code of ASTM E8. Figure 3.2 show the dimension of the specimens.

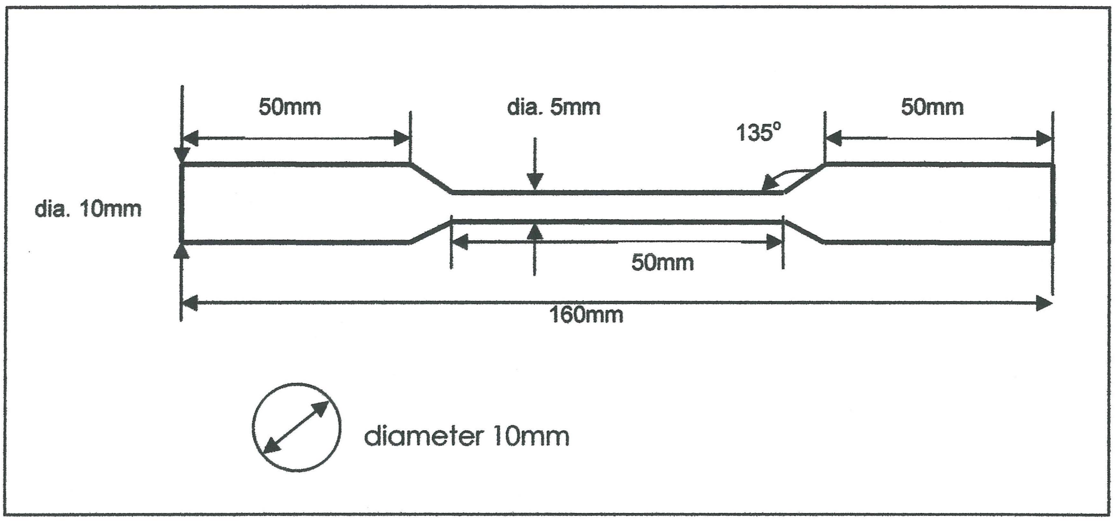


Figure 3.2 Dimension of specimen

The specimens will machine using lathe machine (Figure 3.4). There are many step involve for this process. First of all the edge of the rod must be facing to remove the burr. The next process is roughing the surface of the aluminium-cooper alloy rod to the dimension 10mm of diameter. The speed that use for this process is 1305 rpm.

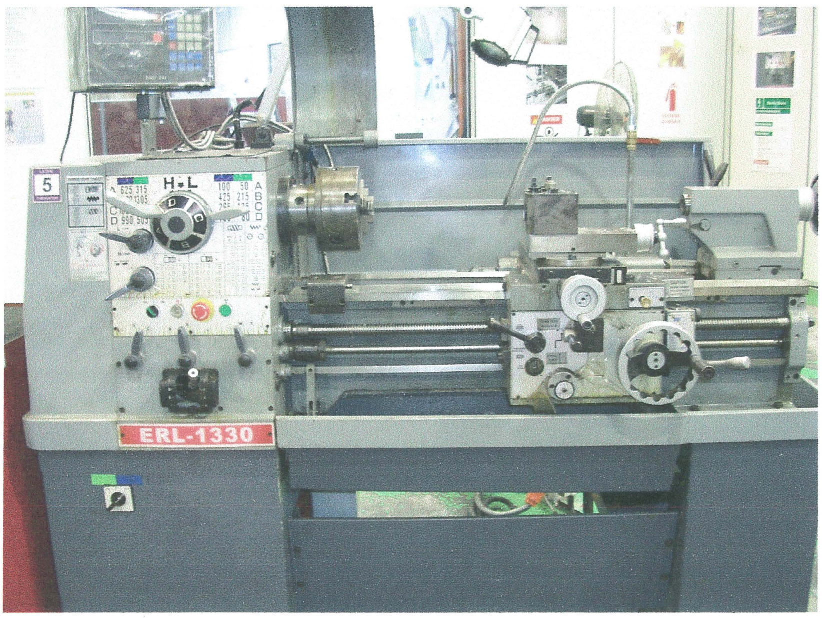


Figure 3.4 Lathe machine

After completing the roughing process the next step is to make an angle with the gauge length 50mm and 5mm of diameter. For this process the angle that use is 30 degree (Figure 3.5). The cutting tool table must be adjusting to 30 degree to feed the specimen.

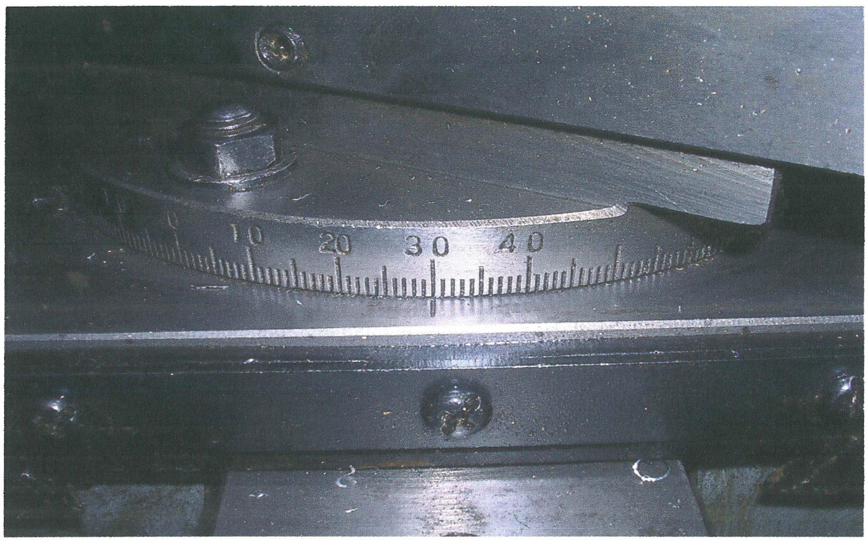


Figure 3.5 Angle setting of lathe machine

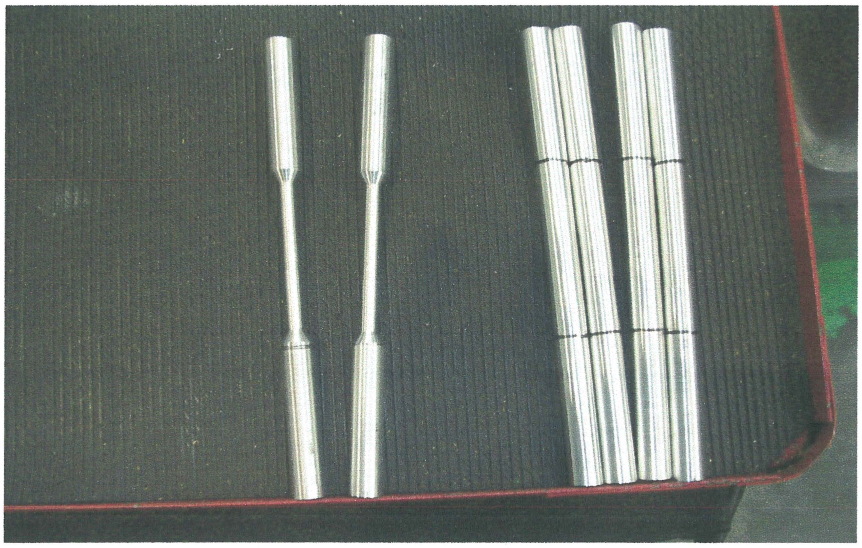


Figure 3.6 Specimens

3.4 ANNEALING

Annealing is a softening process where the material is heated to the annealing temperatures and then slowly cooled. The annealing processes carry out using box furnace (Figure 3.7). The temperature of aluminium-copper alloy that use for annealing process is 413 degree. The process of annealing that use for this experiment is full annealing which the specimen is keep in the furnace while it cool down to the normal temperature.

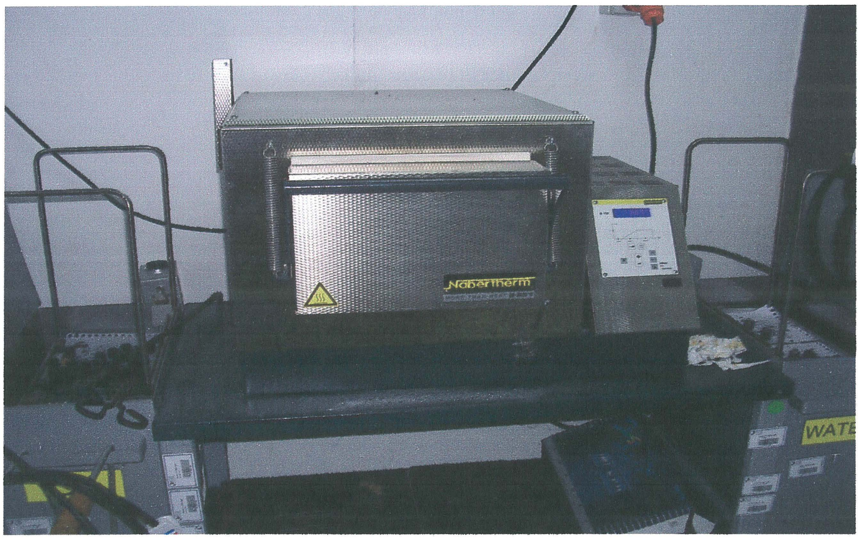


Figure 3.7 Box furnace

In this process temperature must be set and the rate of increasing temperature must be calculated. The rate of increasing of the temperature is 5 degree per minute. After reach the annealing temperature it will hold at that temperature in 1 hour before it cool down to the normal temperature.

3.5 PRE-STRAIN

Pre-strain is a process of tensile that is below the point of elongation. Using tensile test machine (Figure 3.8) In this experiment the value of pre-strain that use is

2.5%, 5%, 7.5% and 10 %. The process of pre-strain is using tensile machine. The load that use for the tensile test machine is 50kN.

Figure 3.8 Tensile test machine

3.6 STATIC RECOVERY

Recovery is the reduction of residual stresses in a cold-worked that is affected by holding the specimen at an elevated temperature. The process of static recovery is heated the specimen using box furnace with the temperature below recrystallization temperature. In this process the material is holding at certain time and temperature to reduce residual stresses and cooling it in the oven to minimize the development of new residual stresses. In this process, the specimens will heat at different time and temperature. For the variable time, the times that use to heat the specimens are one hour, two hour, three hour and four hour. These specimens will heat at 150 °C. For the variable temperature, the specimens will heat at 100 °C, 150 °C, 200 °C and 250

°C in one hour. For the different pre-strain, the specimens will heat at 205 °C at one hour with the pre-strain at 2.5%, 5%, 7.5% and 10%.

3.7 TENSILE TEST

After heated the specimen at static recovery temperature, the specimen must redo the pre-strain using tensile test machine. The specimens will test at pre-strain 1%. The purpose of this process is to find the yield stress of recovery material.

3.8 EQUATION MODELLING

From the data gather of pre-strain using tensile test machine, the degree of recovery can be find using equation 2.1. By using the equation of 2.1 the graph of degree of recovery versus time and temperature can be plot. From this graph the value of linear line equation can be find. Then using Friedel's model equation (eq. 2.2) the value of activation energy (Q) of aluminium-copper alloy at different time and temperature can be calculate.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

Aluminium-copper alloy is the material that use in this research. The objective of the research is to validate Friedel's model of static recovery using tensile test machine at different time and temperature of aluminium-copper alloy.

In this chapter the result from the testing using tensile test machine will be assessed and also tensile properties of the specimen from the different type of pre-strain, temperature and time will be study. From the data the degree of recovery will be determined.

The result of tensile test from the different type of pre-strain, temperature and time will be shown in figure below. The result from the testing will be use to calculate activation energy to compared with the result from the literature review.

4.1.1 Result of Tensile Test at Different Pre-strain

Table 4.1 show the result for the yield stress at different pre-strain of the aluminium-copper alloy. For the tensile test using different pre-strain, the specimens were tested at variable prestrain. The values of pre-strain are 2.5%, 5%, 7.5% and 10%.

Table 4.1: Yield stress at different pre-strain

Pre-strain	σ_m	σ_r	σ_o
2.5%	92.85	70.66	54.22
	88.38	70.17	47.41
	95.34	64.93	55.15
5%	103.3	83.02	50.32
	104.0	82.03	51.94
	104.3	81.12	50.80
7.5%	107.0	87.71	49.78
	109.7	83.94	50.39
	108.0	92.77	50.01
10%	109.3	93.22	50.51
	108.9	96.94	48.54
	112.6	94.83	50.72

Table 4.1 shows the data of tensile test with different of pre-strain that heated at 205 degree Celsius in 1 hour .Three specimen for each pre-strain was tested using tensile testing machine. From the table, we can see the value of σ_m (yield stress of deformed

material), σ_r (yield stress of recover material) and σ_o (yield stress of undeformed material).

Sample calculation of degree of recovery (X_{rec}):

Pre-strain at 2.5%

$\sigma_m = 92.85$

$\sigma_r = 70.66$

$\sigma_o = 54.22$

Equation of degree of recovery:

$$X_{rec} = \frac{\sigma_m - \sigma_r}{\sigma_m - \sigma_o}$$

Substitute the value yield stress into the equation:

$$X_{rec} = \frac{92.85 - 70.66}{92.85 - 54.22}$$

$$X_{rec} = 0.5744$$

Table 4.2: Degree of recovery at different pre-strain

Pre-strain	σ_m-σ_r	σ_m-σ_o	X_{rec}
2.5%	22.19	38.63	0.5744
	18.21	40.97	0.4445
	30.41	40.19	0.7568
5%	20.28	52.98	0.3828
	21.97	52.06	0.4218
	23.18	53.5	0.4333
7.5%	19.29	57.22	0.3371
	25.76	59.31	0.4343

	15.23	57.99	0.2626
10%	16.08	58.79	0.2735
	11.96	60.36	0.1981
	17.77	61.88	0.2877

Using equation of 2.1 the value of degree of recovery can be calculate using data from table 4.1.Table 4.2 show the value of degree recovery at difference pre-strain of aluminium-copper alloy. From the table 4.2, the graph of degree of recovery (X_{rec}) respect to pre-strain can be plot.

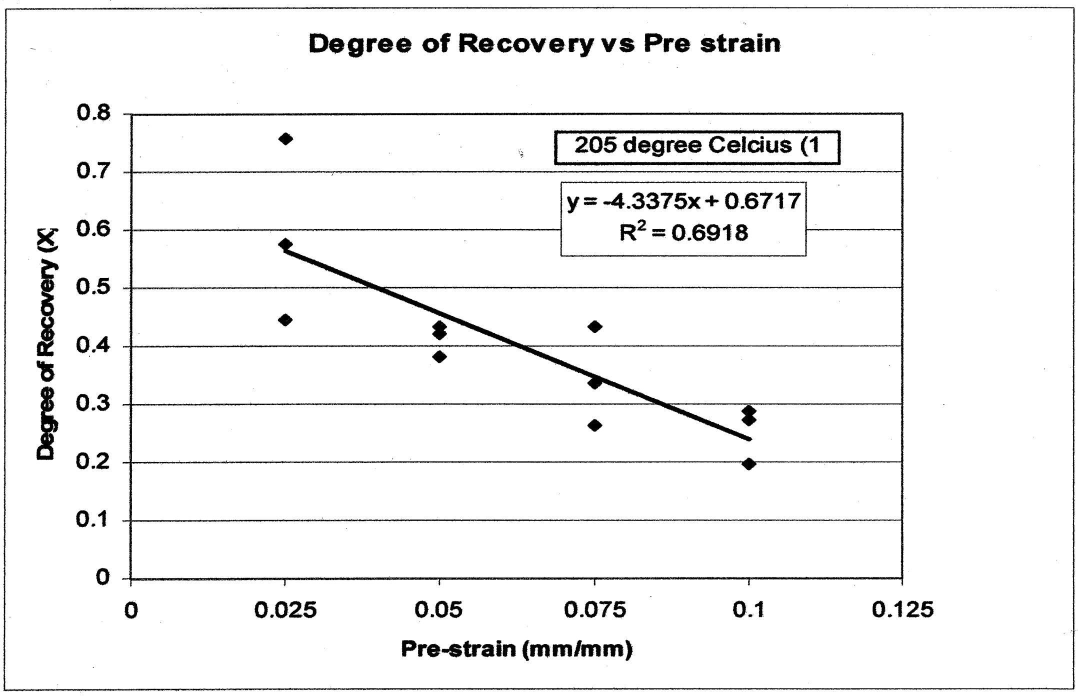


Figure 4.1 Degree recovery versus Pre-strain

Figure 4.1 show the degree recovery (X_{rec}) versus pre-strain (mm/mm) of specimen. The data are getting from the specimen of aluminium-copper alloy with different pre-strain. From the journal of Recovery Revisited, (E.Nes, 1994) said that the value of degree recovery will decrease due to the increasing of pre-strain.

4.1.2 Result of Tensile Test at Different Temperature of Annealing

The specimens were tested at different temperature of annealing process. The temperature must be below the recrystallization temperature. For the different temperature, specimens were tested at temperature 100 °C, 150°C, 200 °C and 250 °C. Table 4.3 shows the value of yield stress at difference temperature.

Table 4.3: Yield stress at different temperature

Temp.	σ_m	σ_r	σ_o
100 °C	104.5	97.84	51.62
	103.5	100.5	49.06
	103.9	96.90	50.23
150°C	101.5	84.92	48.73
	98.73	88.77	47.81
	102.6	94.28	49.86
200 °C	102.4	76.56	48.53
	102.0	71.56	48.42
	98.96	74.83	46.89
250 °C	102.6	62.86	49.46
	103.1	69.96	50.01
	101.7	69.23	50.19

Table 4.3 shows the data of tensile test with different of temperature that pre-strain at 5% in 1 hour .Three specimen for each temperature was tested using tensile testing machine. From the table, we can see the value of σ_m (yield stress of deformed material), σ_r (yield stress of recover material) and σ_o (yield stress of undeformed material.

Sample calculation of degree of recovery (X_{rec}):

Temperature at 100 °C

$\sigma_m = 104.5$

$\sigma_r = 97.84$

$\sigma_o = 51.62$

Equation of degree of recovery:

$$X_{rec} = \frac{\sigma_m - \sigma_r}{\sigma_m - \sigma_o}$$

Substitute the value yield stress into the equation:

$$X_{rec} = \frac{104.5 - 97.84}{104.5 - 51.62}$$

$$X_{rec} = 0.1259$$

Table 4.4: Degree of recovery at different temperature

Temp.	σm-σr	σm-σo	1/T	X_{rec}
373 K	6.660	52.88	0.002680965	0.1259
	3.000	54.44		0.0551
	7.000	53.67		0.1304
423 K	16.58	52.77	0.002364066	0.3142
	9.960	50.92		0.1956

	8.320	52.74		0.1577
473 K	25.84	53.87	0.002114165	0.4797
	30.44	53.58		0.5627
	24.13	52.07		0.4634
523 K	39.74	53.14	0.001912046	0.7478
	33.14	53.09		0.6242
	32.47	51.51		0.6304

Using the equation 2.1 the value of degree of recovery can be calculate using the data from table 4.3.Table 4.4 show the value of degree of recovery (X_{rec}) at different temperature. From the data from table 4.4 plot the graph of degree recovery (X_{rec}) with respect to 1/Temperature.

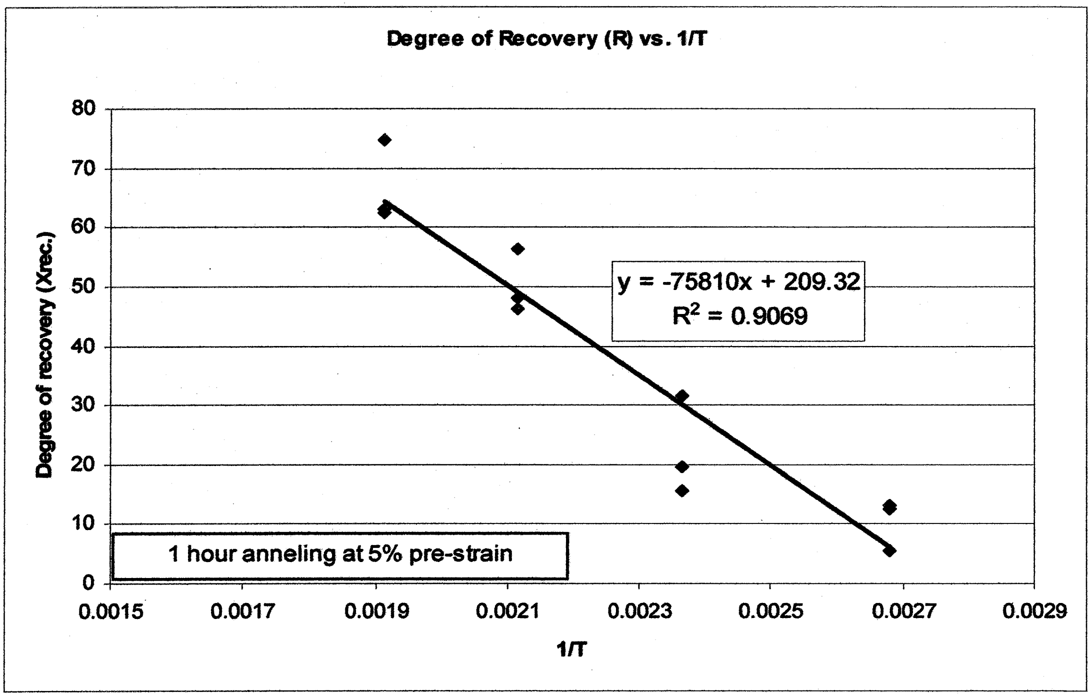


Figure 4.2 Degree recovery versus 1/T

Figure 4.2 show the degree recovery (X_{rec}) versus 1/Temperature of specimen. The data are getting from the specimen of aluminium-copper alloy with different temperature. From the graph, the value of linear line equation can be determined. From the equation the value of activation energy of aluminium-copper alloy at constant time with different temperature can be calculate using equation 2.2. The calculation of activation energy show below:

Linear line equation:

$$y = -75810\ x + 209.32$$

Friedel's model:

$$X_{rec.} = c_1 \ln t - \frac{Q}{RT}$$

Gas constant $(R) = 8.31432 \dfrac{J}{mol}$

Equalize equation of linear line and Fridel's model:

$$-75810 = -\frac{Q}{R}$$

Calculate activation energy

$$Q = 75810 \times 8.31432 \frac{J}{mol}$$

$$Q = 630 \frac{kJ}{mol}$$

4.1.3 Result of Tensile Test at Different Time of Annealing

The specimens were tested at different time of annealing process. The times that have been selected were one hour, two hour, three hour and four hour. Table 4.5 show the value of yield stress at different time.

Table 4.5: Yield stress at different time

Time (hour)	σ_m	σ_r	σ_o
1	101.1	94.48	49.69
	106.1	96.87	50.55
	104.2	98.49	50.85
2	100.2	79.08	48.50
	103.5	92.86	50.20
	103.1	90.38	49.24
3	101.3	85.64	47.84
	106.2	94.64	50.71
	100.2	85.50	48.28
4	101.2	85.14	48.30
	100.2	88.00	47.23
	99.30	88.28	46.89

Table 4.5 shows the data of tensile test with different of time that pre-strain at 5% and heated at 150 degree Celsius. Three specimens for each time were tested using tensile testing machine. From the table, we can see the value of σ_m (yield stress of deformed material), σ_r (yield stress of recover material), σ_o (yield stress of undeformed material) and X_{rec} (degree of recovery).

Sample calculation of degree of recovery (X_{rec}):

When time at 1hour

$\sigma_m = 101.1$

$\sigma_r = 94.48$

$\sigma_o = 49.69$

Equation of degree of recovery:

$$X_{rec} = \frac{\sigma_m - \sigma_r}{\sigma_m - \sigma_o}$$

Substitute the value yield stress into the equation:

$$X_{rec} = \frac{101.1 - 94.48}{101.1 - 49.69}$$

$$X_{rec} = 0.1288$$

Table 4.6: Degree of recovery at different time

Time (second)	σm-σr	σm-σo	ln(t)	X_{rec}
3600	6.62	51.41	8.188689124	0.1288
	9.23	55.55		0.1662
	5.71	53.35		0.1070
7200	21.12	51.7	8.881836305	0.4085
	10.64	53.3		0.1996
	12.72	53.86		0.2362
10800	15.66	53.46	9.287301413	0.2929
	11.56	55.49		0.2083
	14.7	51.92		0.2831
144000	16.06	52.9	9.574983486	0.3036
	12.2	52.97		0.2303
	11.02	52.41		0.2103

Using the equation 2.1 the value of degree of recovery can be calculate using the data from table 4.5.Table 4.6 show the value of degree of recovery (X_{rec}) at different temperature. From the data from table 4.6 plot the graph of degree recovery (X_{rec}) with respect to 1/Temperature.

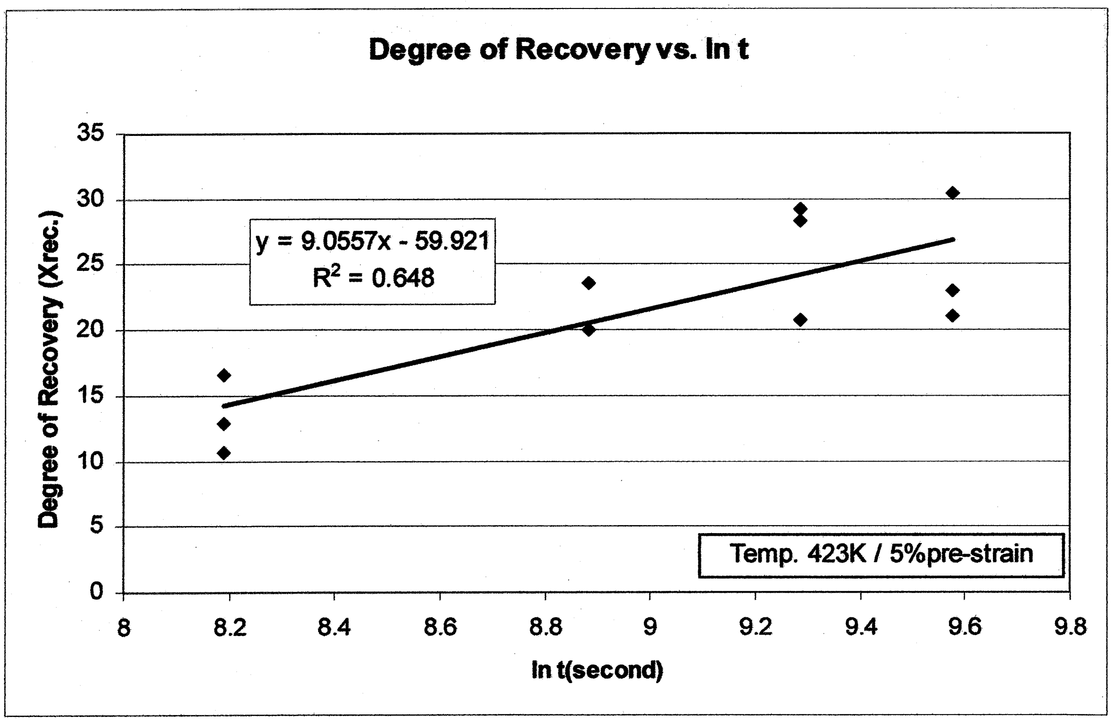


Figure 4.3 Degree recovery versus ln t

Figure 4.3 show the degree recovery (X_{rec}) versus ln t (second) of specimen. The data are getting from the specimen of aluminium-copper alloy with different temperature.

Linear line equation:

$$y = 9.0557\ x - 59.921$$

Friedel's model:

$$X_{rec.} = c_1 \ln t - \frac{Q}{RT}$$

Gas constant $(R) = 8.31432\dfrac{J}{mol}$

Equalize equation of linear line and Fridel's model:

$$-59.921 = -\frac{Q}{RT}$$

Calculate activation energy

$$Q = 59.92 \times \left(8.3144\frac{\mathrm{J}}{\mathrm{mol.K}} \times 423K\right)$$

$$Q = 211\frac{kJ}{mol}$$

4.2 DISCUSSION

The value of activation energy of aluminium-copper alloy can be determined from the data that get from the result of tensile test with different temperature and time. The value of activation energy can be compare with the value that gets from journal. The value of activation energy at different temperature was compare with the journal from Recovery Revisited, (E.Nes, 1994) [8].While, the value of activation energy at difference time was compare with the journal from Subgrain Growth in Heavily Deformed Experimental Investigation and Modelling Treatment.(Furu, 1994).

Table 4.7: Comparison of activation energy for both variables

Variable	Activation energy (Q) kJ/mol	
	Experimental	Journal
Temperature	630kJ/mol	521kJ/mol (E.Nes,Recovery Revisited,1994)
Time	211kJ/mol	175kJ/mol (Furu, Subgrain Growth in Heavily Deformed Experimental Investigation and Modelling Treatment.Pergamon 1994)

Percentage of different the value of activation energy between the experimental and journal was calculated to determine whether the value is validate or not.

Variable temperature:

$$\%\ different = \frac{630-521}{521} \times 100 = 20.92\%$$

Variable time:

$$\%\ different = \frac{211-175}{175} \times 100 = 20.57\%$$

From the data above the value activation energy of experimental can be validate using Friedel's model equation because the percentage of different not exceed 50% of the value.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

The main objective of this study is to determine the activation energy of aluminium-copper alloy by using tensile test machine. Variable pre-strain,temperature and time was selected to do the testing.

The specimens were tested using tensile test machine to find the value of yield stress of undeformed material, deformed and at static recovery condition. The value of yield stress is depending to the condition of the annealing process. From the data the graph of degree of recovery versus temperature, time and pre-strain can be plot. By using linear line equation of the graph, the activation energy can be calculated.

From the data of the research it can be use to validate the equation of Friedel's model. By using Fridel's model equation, the value of activation energy for variable temperature is 630kJ/mol while the value of activation energy for variable time is 211kJ/mol. So, from comparison with the journal, the values of activation energy were validated.

5. 2 RECOMMENDATION

To get the accurate result of the activation energy of aluminium-copper alloy some improvement need to be done. The recommendations to get more precise of the result for the experiments are:

(i) Use the CNC lathe machine to machining the specimens to get accurate dimension.

(ii) For the annealing process, the box furnace that use must be automatic controller with high precision of degree accuracy and have very slow rate of cooling time.

(iii) The tensile test machine must be calibrated to get the accurate of the value.

(iv) To get the more accurate value for the activation energy of the variable temperature, the test must do at the different time.

(v) For the value of activation energy of the variable time, the test must do at difference temperature.

References:

[1] Kenneth G. Budinski, Michael K.Budinski, 2005, *Engineering Materials Properties and Selection* 8th edition. Pearson Prentice Hall.

[2] John A. Schey, 2000, *Introduction to Manufacturing Process* 3rd edition. Mc Graw Hill.

[3] Micheal F Ashby, David R H Jones, 2005, *Engineering Material 1-An Introduction to Properties, Applications and Design* 3rd edition. Elsevier Butterworth Heinemann.

[4] M. Philip, W. Bolton, 2002, *Technology of Engineering Materials*. Butterworth Heinemann.

[5] James F. Shackelford, 2005, Introduction *to Materials Science for Engineers* 6th edition. Pearson Prentice Hall.

[6] William F.Smith, 2004, Foundations of Materials Sciene and Engineering 3rd edition. Mc Graw Hill.

[7] SubsTech, "http://www.substech.com/dokuwiki/doku.php ?id=wrought_aluminium-copper_alloys_2xxx " Access date:7 April 2008.

[8] Pat L. Mangomon, 1999, *The Principles of Materials Selection for Engineering* Design. Prentice Hall

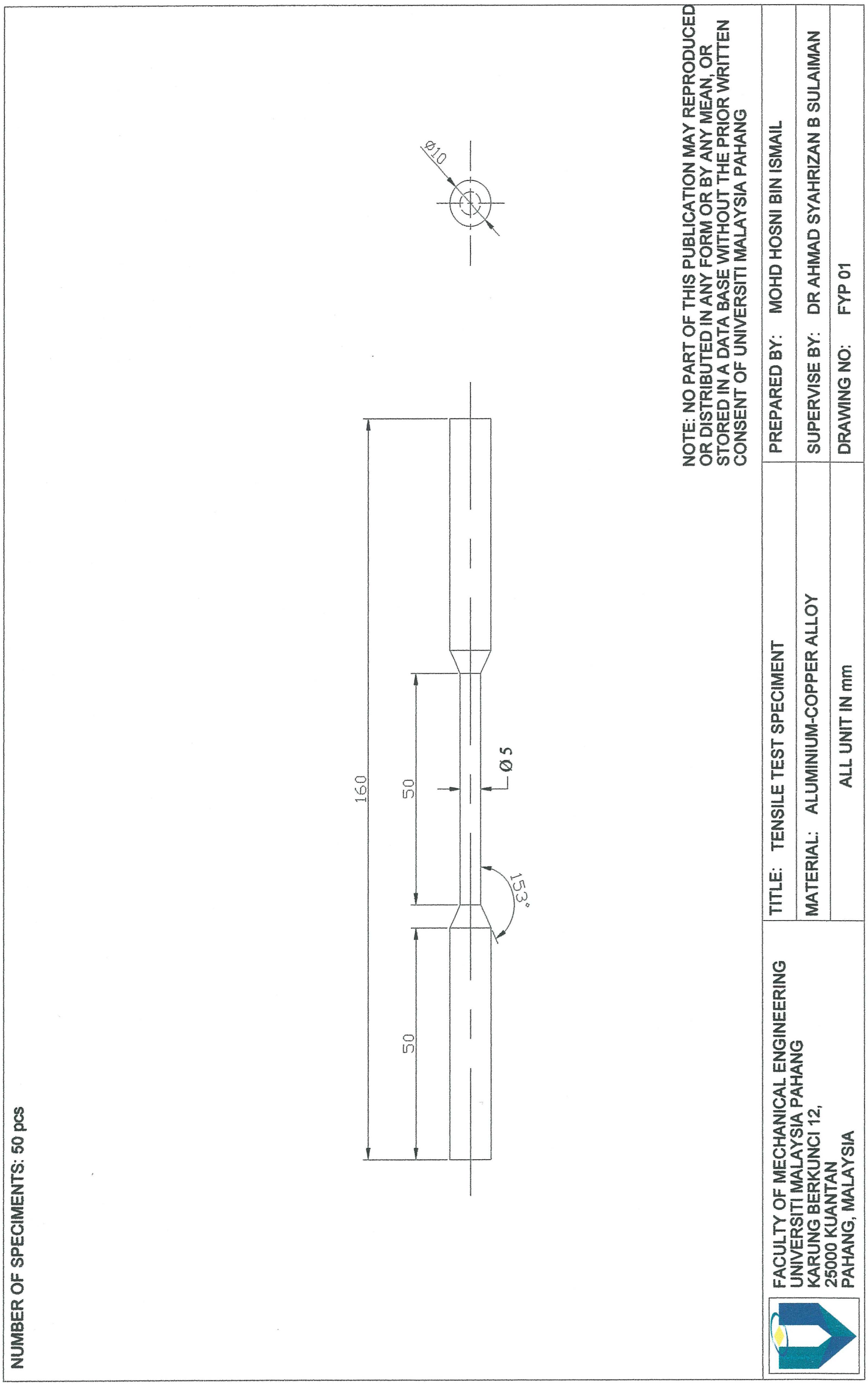
[9] E.Nes,1994, Recovery Revisited. Pegamon

[10] F.J.Humphreys, M.Hatherly, 2004, Recrystallization and Related Annealing Phenomena, 2nd edition,Elsevier.

[11] T.Furu, R. Orsund, E.Nes,1994, Subgrain Growth in Heavily Deformed Experimental Investigation and Modelling Treatment.Pergamon

APPENDIX A

2D drawing of tensile test specimen



APPENDIX B

Data collected from E.Nes journal [9]

Temperature (°C)	Degree of recovery, X_{rec}	$1\text{-}X_{rec}$	Temperature (K)	1/T
100	95.18519	4.814815	373	0.002681
200	66.85185	33.14815	473	0.002114
250	53.33333	46.66667	523	0.001912
300	40.55556	59.44444	573	0.001745
400	19.25926	80.74074	673	0.001486

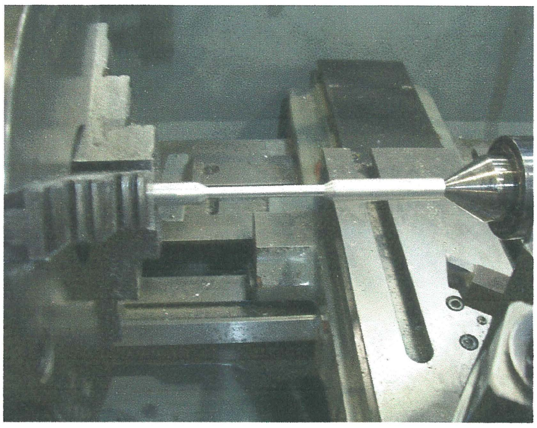
APPENDIX C

Data for time and temperature at different strain hardening [9]

Strain hardening					
0.65		0.6		0.4	
Time (min)	Temperature (°C)	Time (min)	Temperature (°C)	Time (min)	Temperature (°C)
100	200	593.6893204	200	820.8737864	250
3.268292683	250	7.980295567	250	7.044334975	300
Time (sec)	Temperature(K)	Time (sec)	Temperature(K)	Time (sec)	Temperature(K)
6000	473	35621.35922	473	49252.42718	523
196.097561	523	478.817734	523	422.6600985	573
ln Time	1/Temperature	ln Time	1/Temperature	ln Time	1/Temperature
8.699514748	0.002114165	10.48070072	0.002114165	10.80471393	0.001912046
5.278612295	0.001912046	6.171320011	0.001912046	6.046568306	0.001745201

APPENDIX D

Picture during final year project



APPENDIX E

Gantt chart Final Year Project Two

Project Activities	WEEK																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Machining (Lathe)	■	■	■	■	■													
Annealing						■	■											
Pre-strain								■	■									
Static recovery										■								
Tensile test											■							
Plot graph												■	■					
Equation modeling (Fridel's model)														■				
Writing Final Year Project report												■	■	■	■			
Submit FYP 2 report																■		
Preparation Presentation																	■	
Presentation																		■