EXPERIMENTAL STUDY OF PACK CARBURIZING OF CARBON STEEL

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JUDUL: A STUDY ON HEAT TREATMENT OF CARBURIZING CARBON STEEL

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Examiner	Signature

EXPERIMENTAL STUDY OF PACK CARBURIZING OF CARBON STEEL

HAZIZI AZRI BIN AHMAD SABRI

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

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MEI 2011

SUPERVISOR'S DECLARATION

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Position: SUPERVISOR
Date: 30 MEI 2011

STUDENT’S DECLARATION

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

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ABSTRACT

The main purpose of this project is experimental study of pack carburizing of carbon steels by using two parameters (holding time and carburizing temperature). This study was conducted by using furnace. This process is carried out at temperatures from 850°C to 950°C (1123 – 1223K) for three various durations time which are 4, 8 and 16 hours. From the experiment, the surface hardness and thickness of carbon layer was different according to the parameters used. The quenching medium that use in this experiment is water. For carburizing temperature at 950°C, the highest of surface hardness value is 395.7 HV that carburized for 16 hours. For carburizing temperature at 900°C, the highest of surface hardness value is 373.4 HV that carburized for 16 hours and for carburizing temperature at 850°C which is the highest of surface hardness value is 345.5 HV. The thickness of carbon layer for 950°C was between 40μm to 120μm. The thickness of carbon layer for 900°C was between 40μm to 80μm and for 850°C was between 20 μm to 60 μm. Activation energy was determined which is 142.55 kJ/mol. The result indicates the carburizing process accelerates the diffusion of carbon atoms into the surface, thus increasing the thickness of carburized layer as well as the surface hardness.

ABSTRAK

Tujuan utama kajian ini adalah untuk mengkaji eksperimen karburisasi baja karbon dengan menggunakan dua (masa penahanan dan suhu karburasi). Kajian ini dijalankan dengan menggunakan kebuk pembakaran. Proses ini dilakukan pada suhu 850°C sehingga 950°C (1123 – 1223K) untuk tiga masa berbeza iaitu 4,8 dan 16 jam. Daripada eksperimen ini, kekerasan permukaan dan ketebalan lapisan karbon berlainan mengikut pembolehubah yang digunakan. Agen pnyejuk yang digunakan dalam eksperimen ini adalah air. Bagi karburasi pada suhu 950°C, nilai kekerasan permukaan yang paling tinggi ialah 395.7 HV yang dikarburasi selama 16 jam. Bagi karburasi pada suhu 900°C, nilai kekerasan permukaan yang paling tinggi ialah 373.4 HV yang dikarburasi selama 16 jam dan bagi karburasi pada suhu 850°C dimana bacaan kekerasan permukaan yang paling tinggi ialah 345.5 HV. Bagi ketebalan lapisan karbon pada suhu 950°C ialah 40µm hingga 120µm. Bagi ketebalan lapisan karbon pada suhu 900°C ialah 40µm hingga 80µm dan bagi suhu 850°C ketebalan lapisan karbonnya antara 20 µm hingga 60 µm. Tenaga pengaktifan dikirakan iaitu 142.55 kJ/mol. Keputusan ini menunjukkan proses karburasi mempercepatkan kemasukan atom karbon ke dalam lapisan lalu meningkatkan ketebalan lapisan karbon begitu juga dengan kekerasan lapisan.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Low-carbon steel used in many mechanical components is tough, but also soft and flexible. There are advantages to its ductility. However its very nature means that the low-carbon steel's surface is susceptible to battering and wear. Generally, surface treatment processes will apply to produce ductile but tough components. After a component has been produced, it may still not have good condition in surface properties (Parrish G, 1999).

Case hardening is ideal for parts that require a wear-resistant surface and must be tough enough internally to withstand heavy loading. Steels best suited for case hardening are the low-carbon and low-alloy series. When high-carbon steels are through hardening, the hardness penetrates the core and causes brittleness. In case hardening, the surface of the metal is change chemically by introducing a high carbide or nitride content. The core remains chemically unaffected. When heat-treated, the high-carbon surface responds to hardening, and the core toughens. Typical applications for case hardening are gear teeth, cams, shaft, bearing, fasteners, pins, automotive clutch plates, tools, and dies (Parrish G, 1999).

Case hardening-also known as "pack carburising"-involves putting carbon (or a combination of carbon and nitrogen) into the surface of the steel to make it a high-carbon steel which can be hardened by heat treatment, just as if it were tool steel or any other high-carbon steel. Only the outer skin of the steel gets hard in case hardening, while the center remains tough and malleable. This makes for a strong part with a very tough, durable surface (Parrish G, 1999).

Carburising is a case-hardening process by which carbon is added to the surface of low-carbon steel. This results in carburized steel that has a high-carbon surface and a low-carbon interior. When the carburized steel is heat-treated, the case becomes hardened and the core remains soft and tough. Two methods are used for carburizing steel. One method consists of heating the steel in a furnace containing a carbon monoxide atmosphere. The other method has the steel placed in a container packed with charcoal or some other carbon rich material and then heated in a furnace.

1.2 PROBLEM STATEMENT

The case depth is controlled by the adjustment of the carburizing time and temperature. There is a limit to which temperature can be increased in case hardening. At high temperatures, the structure of the core can be worse and it can affect the diffusion process. At elevated temperature, the rate at which the diffusing element is deposited on the surface of the specimen is greater than the rate at which it diffuses towards the core of the steel. This leads to uneven distribution of the concentration of the element and a high concentration which may lead to the formation of networks of chemical compounds such as carbides and nitrides, which impacts high brittleness to the surface layer. The yield strength of the core of a carburized component may be exceeded, particularly as the core is in a state of tensile stress. It very difficult to control case depth during carburizing to close tolerances because there have relative with heating and cooling times involved, which make the accurate control of actual carburizing temperature and time difficult.

1.3 RESEARCH OBJECTIVES

The objectives of this study are to:

i. Investigate the influence of time and temperature on pack carburizing
ii. Examine the activation energy on carburized layer based of varying time and temperature.

1.4 SCOPE OF THE RESEARCH

The scopes of this study are:

i. Pack carburizing using commercial grade carbon granule
ii. Using material which is AISI 1045.
iii. Using 3 different temperatures which are 850°C, 900°c and 950°C for carburizing.
iv. Using 3 different times which are 4 hours, 8 hours and 16 hours in carburizing.
v. Using one medium which is water in quenching.
vi. Using Vickers test to determine the hardness of certain part on the carbon steel.
vii. Using optical microscope to determine the thickness of carburizing layer.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Pure iron is not suitable for use as a structural material. It is weak, soft, is very ductile and does not respond to heat treatment to any appreciable degree. Steel, which is basically iron, alloyed with carbon and a few percent to a few tens of percent of other alloying elements can be heat treated to a wide range of strengths, toughnesses and ductilities. Carbon is the most important of these alloying elements in terms of the mechanical properties of steel and most heat treatments of steel are based primarily on controlling the distribution of carbon. Heat treatment is a process to change certain characteristics of metals and alloys like physical properties by either heating or cooling in order to make them more suitable for a particular kind of application. When heat treatment process occurs, the mechanical properties of metal will influence such as strength, hardness, ductility, toughness, and wear resistance.

2. 2 HEAT TREATMENT OF CARBON STEELS

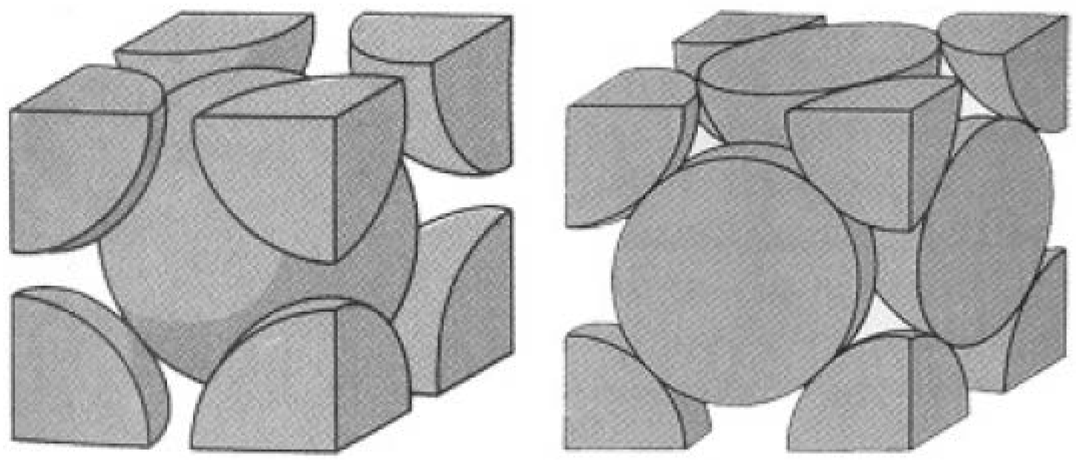
Most carbon steels and carbon alloy steels can be heat treated for the purpose of improving mechanical properties such as hardness, tensile and yield strength. This is happen because heat treatment fundamentally altering the microstructure of the carbon steel (Parrish G, 1999).

Firstly, it must begin with the understanding of the structure and phases of metals. The structure of steel is composed of two variables:

i. Grain Structure - The arrangement of atoms in a metal.
ii. Grain Size - The size of the individual crystals of metal. Large grain size is generally associated with low strength, hardness, and ductility.

The crystals in steel have a defined structure that is determined by the arrangement of the atoms. There are two common crystal structures in iron which are body-centered-cubic (BCC) and face-centered-cubic (FCC). When the iron is arranged in the FCC structure, it is able to absorb higher amounts of carbon than a BCC structure because of an increase in interstitial sites where carbon can sit between the iron atoms. During the alloying process elements, carbons are introduced to the metal that makes crystal structures changing to be more strength. That mean heat treatment makes increasing strength in crystal structure (D. R. Askeland, 1984).

Carbon steel can exist in various phases which are ferrite, austenite, and cementite. Figure 2.2 shows the phase in steel when heat treatment occur. The Y-axis (vertical) is a measurement of temperature while the X-axis (horizontal) is a measurement of the carbon content of the carbon steel. The far left hand side of the X-axis represents the ferrite phase of carbon steel (low carbon content) while the far right hand side represents the cementite phase of steel (high carbon content), which is also known as iron carbide. The austenite phase is located between the phase lines and occurs only above 1333 °F (D. R. Askeland, 1984).



(a)

(b)

Figure 2.1: (a) Body-Centered Cubic (BCC), (b) Face-Centered Cubic (FCC)

Source: William D. Callister Jr., 1994

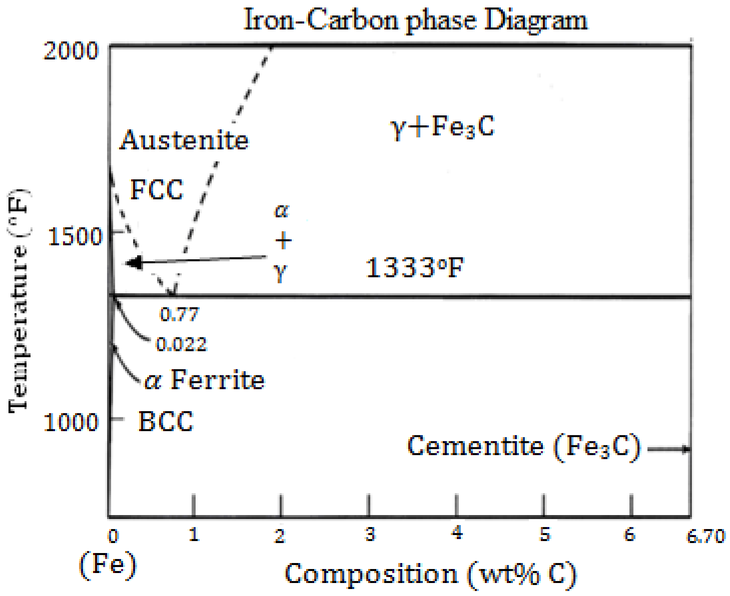


Figure 2.2: Iron-Carbon phase diagram

Source: William D. Callister Jr., 1994

Based Figure 2.2, ferrite is above the lined 1333°F. When ferrite (low carbon steel) is at room temperature, the crystal structure is a body-centered cubic structure, which is can only absorb a low amount of carbon. The un-absorbed carbon separates out of the body centered-cubic structure to form carbides which join together to create small pockets of an extremely hard crystal structure within the ferrite called cementite because of low amount of carbon. When ferrite is heated to a temperature above the transformation line at 1333 ºF (refer Figure 2.2), the body centered-cubic structure changes to a face-centered-cubic structure known as austenite. That mean amount of carbon absorbs in the crystal structure and make arrangement atom

When the carbon steel heat more than 1333 ºF, it in the austenitic phase and all of the cementite dissolves into austenite. If the steel is allowed to cool slowly, the carbon will separate out of the ferrite as the cubic-structure will change from face-centered back to body-centered. Cementite will reform within the ferrite, and the carbon steel will have the same properties that it did before it was heated but when the steel is rapidly cooled, or quenched, in a quenching medium (such as oil, water, or cold air) the carbon does not exit the cubic structure of the ferrite and it becomes bond with the structure. This leads to the formation of martensite which is the microstructure that produces the most sought after mechanical properties in steel fasteners (Parrish G, 1999).

The successful heat treatment of steels to produce a predominantly martensitic microstructure throughout the cross section depends mainly on three factors

i. The composition of the alloy
ii. The type and character of the quenching medium
iii. The size and shape of the specimen

Carbon steel’s ability to transform into martensite with a particular quenching treatment is called hardenability. This is due to the composition of alloy in the carbon steel. Each steel alloy has a specific relationship between its mechanical properties and its cooling rate. It is to be noted that hardenability is not some kind of resistance to indentention but it is actually a hardness measurement which is used to estimate the extent of martensitic transformation inside the material. A steel alloy which formed into martensite has a high ability at the surface and also a large degree throughout the entire interior. In much simply words, hardenability is a measure of the degree to which a specific alloy may be hardened (D. R. Askeland, 1984).

The martensite newly formed is considered as a grain structure and it is very hard and brittle. The steel which has been quenched from austenitizing temperatures requires tempering before it can be placed into service due to the brittleness property in martensite. Tempering is a process of heating the carbon steel to a specific temperature below that of transformation line and the carbon steel is allowed to cool slowly. The slow cooling process will increase the ductility and decrease the hardness to specified level of the crystal structure. Based on the desired results for the steel the specific tempering temperature will be varied (Parrish G, 1999).

2.2.1 Carburizing

The addition of carbon to the surface of low carbon steel at temperature generally 850-950 degree Celsius is called carburization. Carburization is the most widely used method of surface hardening. It consists of enrichment of surface layers of low carbon or mild steel with carbon up to 0.8 % to 1%. This will superimposed the good wear and fatigue resistance on a tough low carbon steel core. It usually has base-carbon contents of about 0.2%, with the carbon content of the carburized layer generally being controlled at between 0.8 and 1% C. However, due to high carbon content it can results in retained austenite and brittle martensite which is the main reason it is often limited to 0.9%.

Carburizing process increases the grains size due to permanence for a long time in the austenitic region of the phase diagram and makes necessary a posterior heat treatment to refine the grains. Classic quenching generates a martensitic hard but brittle material. On the order hand, intercritical quenching transforms the outward carbon-rich solid solution into martensite, while the internal microstructures present a mixture of martensite, producing a less-brittle material (Parrish G, 1999).

The following carburizing processes are commonly used in industrial application:

1. Pack carburizing
2. Gas carburizing
3. Liquid carburizing

2.2.2 Pack Carburizing

Pack carburizing is a process of packing parts in a high carbon medium such as carbon powder or cast iron shavings and heated in a furnace for 12 to 72 hours at 900 ºC (1652 ºF). CO gas is produced at this temperature which is a strong reducing agent. Due to high temperature, carbon is diffused into the surface as the reduction reaction occurs on the surface of the steel. Based on experimental and theoretical calculations on diffusion theory the parts are removed and can be subject to the normal hardening methods when enough carbon is absorbed inside the part (Krauss G, 1991)

During the process the part which needed to be carburized is packed in a steel container and surrounded by granules of charcoal. The charcoal is treated with an activating chemical such as Barium Carbonate ($BaBO_3$) that promotes the formation of Carbon Dioxide (CO_2). CO_2 will then react with the excess carbon in the charcoal to produce carbon monoxide (CO). Next, carbon monoxide will react with low carbon steel surface to form atomic carbon which diffuses into the steel. Carbon gradient supplied by Carbon Monoxide is necessary for diffusion. It is to be noted that, carburizing process does not harden the steel but it just only increases the carbon content to some predetermined depth below the surface to a sufficient level to allow subsequent quench hardening. Figure 2.3 below show that about the carburizing process.

Carbon Monoxide reaction:

$$CO_2 + C \rightarrow 2\,CO$$

Reaction of Cementite to Carbon Monoxide:

$$2\,CO + 3\,Fe \rightarrow Fe_3C + CO_2$$

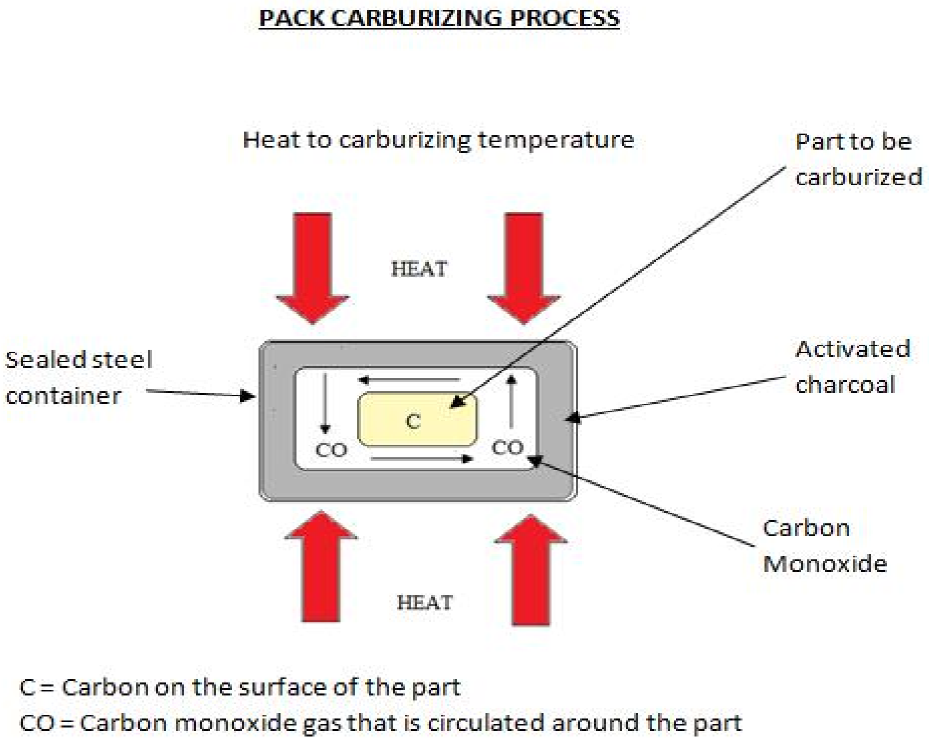


Figure 2.3: Pack carburizing process

Source: Romesh C.Sharma, 2003

2.2.3 Gas Carburizing

Gas carburizing consists of introducing carbon into the ferrous base material by heating in a gaseous atmosphere. Commercial gases, natural and propane, and easily vaporized hydrocarbon liquids are used to supply the desired quantity of carbon.

Batch type furnaces are used in this process. This furnace consists of an inner cylinder, made from noncarburizing alloy steel, and heated-insulated outer cylinder. The parts are placed in the inner cylinder. After that carburizing gas or oil will introduced, circulated by a fan. The furnace is sealed and the parts are soaked at the carburizing temperature for the required time for the depth of case desired. The carburizing temperature required is about 1700°F for case depths of 0.020″ to 0.030″. Longer carburizing periods will produce greater depths.

The parts are then quenched. Finally, they are reheated to a point above the transformation range of the case and quenched (Vijaya and Ranganjaran, 2004).

2.2.4 Liquid Carburizing

Liquid carburizing is a method of case-hardening or carburizing steel in molten baths. The baths are mixtures of cyanides, chlorides, and carbonates. The case that is produced is comparable with one resulting from pack or gas carburizing. The salts produce carbon and nitrogen that penetrate the surface.

The carburizing action depends upon sodium cyanide or barium cyanide, which supplies the carbon and some nitrogen. Non-cyanide carburizing applications are available. They produce excellent results.

Liquid carburizing temperatures usually range from 1500°F to 1750°F. Faster penetration can be obtained if higher temperatures are used. However, this method increases material cost and causes rapid deterioration of equipment. Cases as deep as 0.30″ can be obtained with a cyanide content of 20% using carburizing temperatures from 1550°F to 1650°F (Vijaya and Ranganjaran, 2004).

This advantage of this method can be summarized as follows:

i. Uniform case depth and carbon content
ii. Rapid penetration depth
iii. Rusting, pitting, and corrosion minimized
iv. Reduction of time required for steel to reach carburizing temperature
v. Low installation cost.

2.2.5 Quenching

The process to improve the mechanical properties of steel products, such as hardness, stiffness, and strength, by the means of opportune solid–solid phase changes, induced by a heating, holding, and cooling thermal cycle is called quenching process it is widely used and the main purpose of the heating and the holding stages is to transform starting material structure into a homogeneous austenitic phase. During the process, workpiece is undergoing forced cooling to induce the opportune decomposition of austenite into several microstructures such as martensite, pearlite, ferrite and Fe-carbide that depending on the chemical composition of the processing carbon steel and the local cooling rate. (K.H. Prabudev, 1988).

The timing of each step such as heating, cooling rates and the holding temperature are very important. This is because high heating rates could results to excessive temperature gradients which will then causes internal stresses, deformations or cracks. For non-homogeneous austenite formation, the temperature and duration of the holding stage should be carefully planned to obtain a fully austenitic structure, avoiding excessive grain size, and reducing energy consumption and costs, due to extended holding at relatively high temperature. Finally, in order to induce the austenite decomposition into desired microstructures by reducing residual stresses and part distortions, the choice of cooling medium, cooling temperature and cooling technique is very crucial for the cooling stage. (K.H. Prabudev, 1988).

The most commonly used quenching media are:

1. Water (plain or salt water)

2. Oil

3. Air

After carburizing, carburized components are normally quenched from the austenite temperature range to obtain maximum hardness at the surface. A carburized component may either be quenched directly from carburizing temperature, or reheated (after slow cooling) to appropriate austenitizing temperature and quenched. Mildest possible quench, consistent with desired hardening, is normally used to minimize the possibility of quenching cracks and distortion of the components during quenching. Whenever possible, direct quenching from carburizing temperature is done to minimize operational time and costs. After pack carburizing, direct quenching is not possible, and hence, the components have to be reheated for quench hardening (Romesh C.Sharma, 2003).

Sometimes, even the parts carburized by gas and liquid carburizing are slow cooled to room temperature, and then reheated for quench hardening. This may be done for one or more of the following reasons:

i. Some carburized components ay require some machining before the hardening operation. In such cases, parts are slowly cooled and machined in the soft state, before quench hardening.

ii. When grain coarsening has occurred during carburizing, it is desirable to reheat the components for quench hardening to refine the grain size to some extent.

iii. Surface carbon concentration of pack carburizing components is normally at saturation level, and that may be higher than the desired value. Liquid carburized components may also at the times have higher surface carbon content than desired. Such components, when quenched directly, would have relatively higher retained austenite levels, and consequently lower hardness values, near the surface. Furthermore, high retained austenite levels near the surface lead to problems during the grinding of these components. It may be recalled that retained austenite increases with increasing carbon content. Generally, the retained austenite should be less than 15%. When carburized components are reheated for hardening, carbon gradient near the surface get somewhat moderated by carbon diffusion and the surface carbon concentration is somewhat reduced, leading to reduced retained austenite.

2.3 HARDNESS ANALYSIS

2.3.1 Activation Energy

The activation energy is determined by measuring the effect of temperature on the rate of the reaction. At a higher temperature there is greater proportion of reactants with the required activation energy (E ≥ Ea), increasing the rate of the reaction. However change of temperature does not depend to activation energy. It only changes the frequency of collisions and the proportion of reactants with the kinetic energy, E that is greater than or equal to the activation energy, Ea (E ≥ Ea). Arrhenius proposed an equation to represent the proportion of molecules with E ≥ Ea (John M. Coulson, John Francis Richardson, 1995).

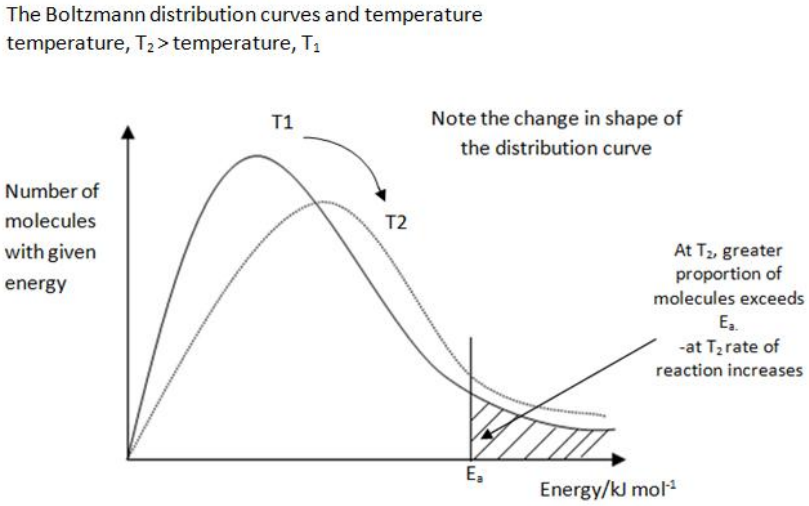


Figure 2.4: Graph number of molecules versus Energy

Figure 2.4 shows the relationship for equation 2.1.

$$Activation\ energy\ = \frac{proportion\ of\ molecules}{total\ area\ under\ curve} = \ e^{\left(\frac{Ea}{RT}\right)} \tag{2.1}$$

This mathematical model developed into now what is called the Arrhenius equation.

$$k \ = Ae^{(\frac{Ea}{RT})} \qquad (2.2)$$

Where;

$A \ =$ the Arrhenius constant or frequency factor. It is related to the collision frequency and the probability that the molecules have the correct orientation/geometry at the point of collision.
$Ea =$ the activation energy in Jmol^{-1}
$R =$ the gas constant (8.314 JK-1mol^{-1})
$T =$ the absolute temperature (K)
$k =$ the rate constant (s^{-1})

From the Arrhenius equation, add natural log and the activation energy can be determined.

$$In\ k = \frac{-Ea}{RT} + In\ A \qquad (2.3)$$

And then plot ln k versus 1/T (called an Arrhenuis plot) a straight line is obtained.

$$slop\ of\ line \ = \frac{\Delta\ \text{In k}}{\Delta 1/T} \qquad (2.4)$$

The activation energy can be determined from the slope/gradient of the line using:

$$slop\ of\ line \ = \frac{-E_a}{R}$$

(2.5)

This is example using Arrhenius equation to determined activation energy in pack carburizing. The activation energy of carburizing process can be determined by using the thickness of carburized layer formed. Figure 2.5 shows the cross-sectional microstructure of superplastically carburized DSS at 1223K with 8 hours carburizing time. From Figure 2.5, the carburizing layer can be observed clearly with dropping hardness value (I. Jauhari, 2007).

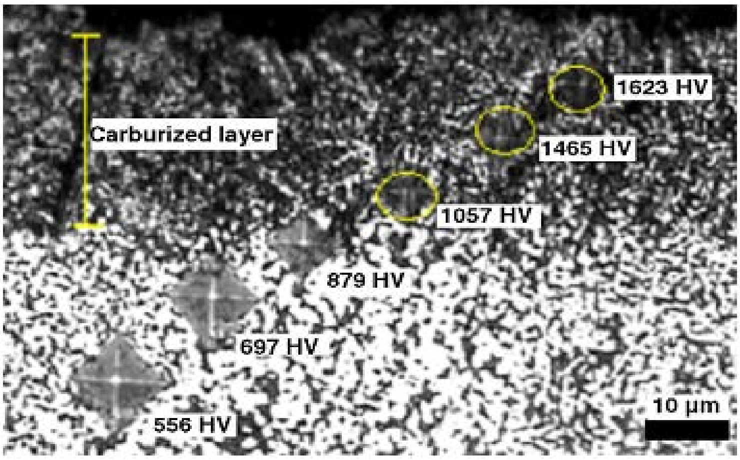


Figure 2.5: Optical micrograph showing the hardness indentation variation from the outer layer to the interior of superplastically carburized DSS at 1223K for 8 h.

From Vickers test, the dropping hardness value can be determined with graph surface hardness (HV) versus distance from surface (µm) that takes from edge to core. It had been shown in Figure 2.6 (I. Jauhari, 2007).

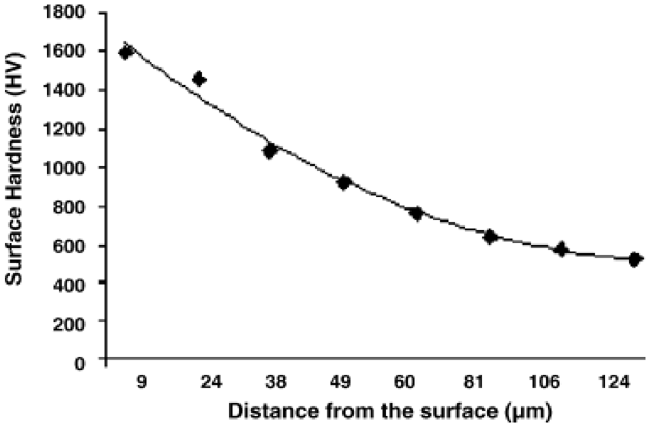


Figure 2.6: Cross-section hardness profiles of super plastically carburized DSS at 1223K for 8 hours.

When the thickness carburizing layer had been found, graph thickness of carbon layer (µm) versus carburizing time (hour) was plotting that shown in Figure 2.7.

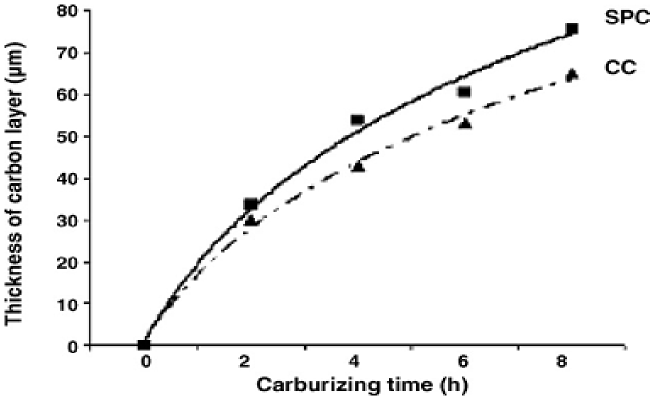


Figure 2.7: The variation of carbon layer thickness with carburizing time at 1223K.

The thickness of carbon layer from the graph increasing with increasing time and follows parabolic law as below:

$$d^2 = Kt \tag{2.6}$$

Where;

d= the carbon layer thickness (µm)

K= carbon growth rate constant

t= carburizing time (s)

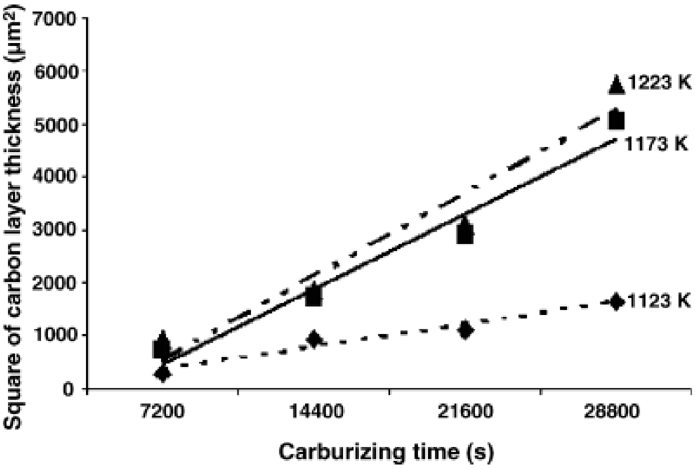


Figure 2.8: Square of carbon layer thickness of superplastically carburized DSS vs. carburizing time.

Figure 2.8 shows the square of carbon layer thickness superplastically carburized DSS changes linearly with time that comes from Figure 2.6 and using parabolic law to make the graph linear. Therefore, the relationship between the diffusion coefficient, K (m^2s^{-1}), activation energy, Q($Jmol^{-1}$) and carburizing temperature, T (K) can be expressed by Arrhenius equation as follow:

$$K = K_0 e^{-(\frac{Q}{RT})} \tag{2.7}$$

Where;

K_0= pre-exponential constant

R = 8.314 $Jmol^{-1}\ K^{-1}$

T = temperature (K)

Q= activation energy

Taking the natural logarithm of equation 2.7, equation 2.8 can be derived as follow:

$$In\, K = In\, K_0 + \ (-QR^{-1})(T^{-1}) \tag{2.8}$$

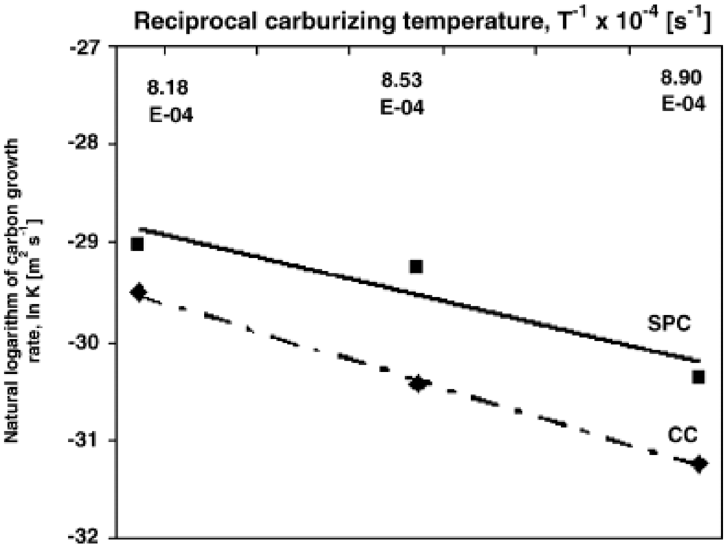


Figure 2.9: Natural logarithm of carbon growth rate (ln K) vs. reciprocal carburizing temperature (T−1) for superplastically and conventionally carburized DSS.

Figure 2.9 shows the plot of natural logarithm of carbon growth rate (ln K) versus reciprocal of carburizing temperature (T−1) for both SPC and CC processes is linear. Thus, the slope of the straight line will determine the activation energy (Q) of each carburizing process (I. Jauhari, 2007).

2.3.2 Diffusion Energy

Diffusion is the process by which atoms move in a material. Many reactions in solids and liquids are diffusion dependent. Structural control in a solid to achieve the optimum properties is also dependent on the rate of diffusion. Diffusion can be defined as the mass flow process in which atoms change their positions relative to neighbors in a given phase under the influence of thermal and a gradient. The gradient can be a compositional gradient, an electric or magnetic gradient, or stress gradient (Vijaya and Ranganjaran, 2004).

Diffusion processes can be either steady-state or non-steady-state that are distinguished by use of a parameter called flux. It is defined as net number of atoms crossing a unit area perpendicular to a given direction per unit time. For steady-state diffusion, flux is constant with time and for non-steady-state diffusion, flux varies with time. The graph of concentration gradient with distance for both steady-state and non-steady-state diffusion processes are shown in Figure 2.10 (Vijaya and Ranganjaran, 2004).

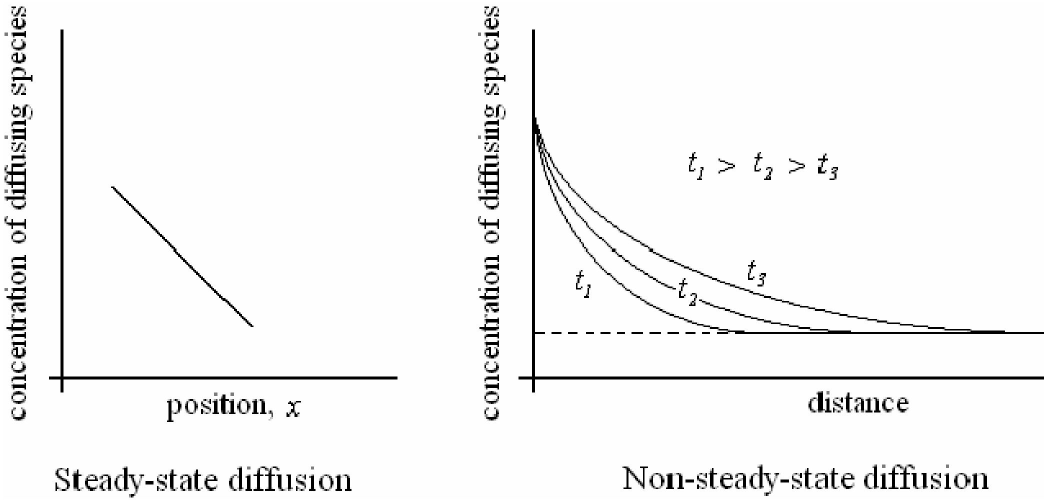


Figure 2.10: Steady-state and Non-steady-state diffusion processes.

Steady-state diffusion is described by Fick's first law which states that fluxes (J), is proportional to the concentration gradient. The constant of proportionality is called diffusion coefficient, D (cm2/sec). Diffusivity is characteristic of the system that depends on the nature of the diffusing species and the temperature at which diffusion occurs. Anyway, when the flux is independent of time and remains the same at any cross-sectional plane along the diffusion direction that is under steady-state flow. For the one-dimensional case, Fick's first law is given by

$$J_x = -D\frac{dc}{dx} = \frac{1}{A}\frac{dn}{dt} \qquad (2.9)$$

And

$$J_x \neq f(x,t) \tag{2.10}$$

Where;

D= the diffusion constant

$\frac{dc}{dx}$= the gradient of the concentration c

$\frac{dn}{dt}$= the number atoms crossing per unit time a cross-sectional plane of area A

For non-steady-state processes there are concentrating to the position changes with time and make the flux changes with time too. This is because of diffusion flux were depends on time which means that a type of atoms accumulates in a region or depleted from a region that may cause them to accumulate in another region. For this process, the Fick's law had been introduced, which is expressed by

$$\frac{dc}{dt} = -\frac{dJ}{dx} = \frac{d}{dx}\left(D\frac{dc}{dx}\right) \tag{2.11}$$

Where;

$\frac{dc}{dt}$= the time rate of change of concentration at a particular position x

If D is assumed to be a constant

$$\frac{dc}{dt} = D\frac{d^2c}{dx^2} \tag{2.12}$$

During carburizing, temperature has a most profound influence on the diffusivity and diffusion rates. It is known that there is a restriction to diffusion created by atoms those need to move to let the diffusing atom pass. Therefore, the temperature makes the atomic vibrations for assist diffusion. Empirical analysis of the system resulted in an Arrhenius type of relationship between diffusivity and temperature (Vijaya and Ranganjaran, 2004).

$$D = D_0 e^{\left(-\frac{Q}{RT}\right)} \tag{2.13}$$

Where;

D_0= Temperature-independent pre exponential (m^2s^{-1})

Q= the activation energy for diffusion ($Jmol^{-1}$)

R= the gas constant (8.31 $Jmol^{-1}$-K^{-1})

T= absolute temperature (K)

Taking the natural logarithm of equation 2.13, equation 2.14 can be derived as follow;

$$In\ D = In\ D_0 + \ (-QR^{-1})(T^{-1}) \tag{2.14}$$

From this equation, the graph In D versus T^{-1} will plot to find the activation energy which is from the gradients that shows in Figure 2.11.

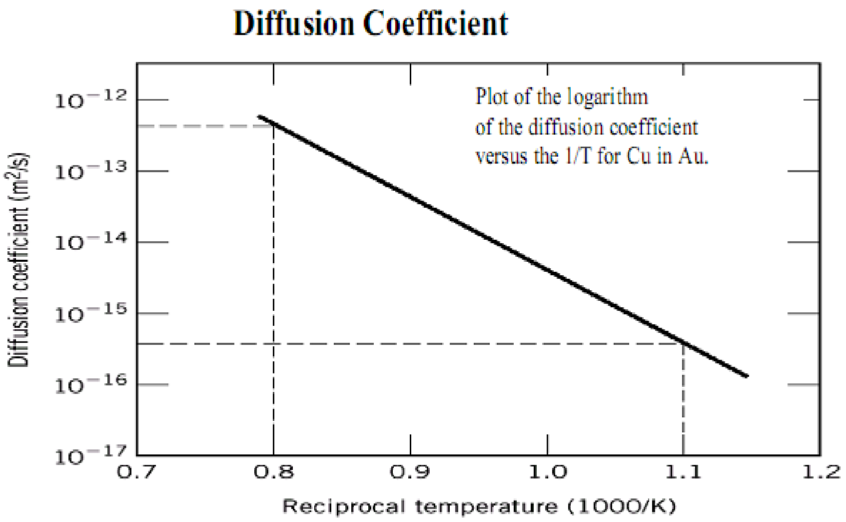


Figure 2.11: In D versus T^{-1}

This is example using diffusion energy to determined activation energy in pack carburizing. The carbon profiles along with case depth of the pack carburizing will derive by using Fick's second law. A two-step optimization procedure will develop in order to compute the optimum values of the activation parameters (activation energy for diffusion and diffusivity coefficient) of carbon in austenite as well as carbon potential that is form at the surface of the carburizing specimen under different conditions of temperature, time and coke-catalysts mixtures. This experiment will use SAE 8620 H steel and three different mixtures that will use for agent carbon in pack carburizing. Table 2.1 shows the mixture that use in this experiment

Table 2.1: Composition of the pack carburizing mixtures

Composition	Mixture A	Mixture B	Mixture C
Coke	90	100	85
$BaCO_3$	5	-	10
$NaCO_3$	5	-	5

The carbon profile after carburizing was determined from chips obtained at 0.1 mm intervals from the outer face of the samples until the chemical analysis was found close to the carbon composition of the base steel. The machining process was carried out carefully without lubrication. The determination of the carbon content of the case layer was conducted in a Leco CS-46 analyzer, taking the mean of three samples and the value obtained was then reported in relation to the midpoint of the cemented case, according to the ASTM standard G79-C. The carbon profile of the cemented case was also evaluated by means of SEM techniques (Phillips 505) employing a WDX analyzer (Microspec WDX-2A). In this case, the change in carbon content was evaluated linearly from the outer surface to the center of the samples (H. Jiminez, 1999).

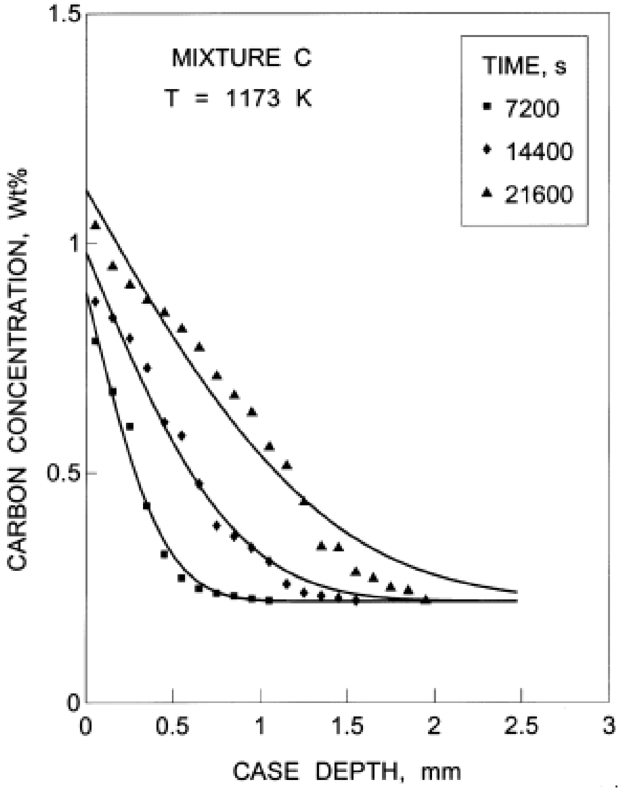


Figure 2.12: Carbon concentration profile obtained with the carburizing compound designated as mixture C, at 1173 K. The solid curve represents the theoretical description obtained by optimization of the parameters CS and D.

The Figure 2.12 shows the amount of carbon after pack carburizing in mixture C for example. The carbon profiles determined by means of chemical analysis of the chips machined from the specimens, after carburizing at 1173 K for 4 hours with mixtures C employed. The carbon concentration is observed to decrease smoothly from the surface to the interior of the work- piece, with the trend to achieve asymptotically the carbon content of the steel. The solid lines shown in these figures correspond to the theoretical description of the experimental data by means of the classical expression determined from the solution of Fick’s second law, of the form:

$$\hat{C}(x,t) = C_o + (C_S + C_O)\left\{1 - \frac{2}{\sqrt{\pi}} \int_0^{x/(\sqrt[2]{Dt})} e^{-y^2} dy\right\} \tag{2.15}$$

Where:

$\hat{C}(x,t)$ =The carbon content at any distance from the outer surface of the carburizing sample

C_s =The carbon concentration or carbon potential at the surface

C_o =The carbon concentration of the steel

In this experiment the equation 2.15 will fit to determine the value of the constants C_S and D that minimize the function:

$$\varphi = \sum_{i=1}^{N} \left\{C(x,t)_i - \hat{C}(x,t)\right\}^2 \tag{2.16}$$

This represents the quadratic mean difference between the experimental values of the carbon concentration profiles and those predicted from the solution of Fick’s second law. The optimization of the parameters C_S and D has been conducted by means of the Newton–Gauss method, which involves the expansion of Equation 2.15 in terms of a series of two variables, of the form:

$$\hat{C}(x,t) = \left[\hat{C}(x,t)_0\right] + \left[\frac{\partial \hat{C}(x,t)}{\partial C_s}\right](C_s - C_{so}) + \left[\frac{\partial \hat{C}(x,t)}{\partial D}\right](D - D_o) \tag{2.17}$$

The square brackets and the subscript zero imply the evaluation of the parameters C_S and D at some initial value reasonably close to the optimum solution. The iterative procedure for determining the optimum values of C_S and D involves the computation of the these parameters by means of linear regression analysis applied to the above expanded equation and to employ the values obtained as the initial approximation for the next iteration until convergence is achieved (H. Jiminez, 1999).

Table 2.2 presents the results of the computation of both D and C_S for the different conditions of carburizing temperature and exposure time.

Table 2.2: Optimized values of carbon diffusivity and carbon potential at the surface computed for different carburizing temperatures and exposures times

Diffusivity x 10^6 (mm^2s^{-1})	**Carbon potential (wt %)**	**Temperature (K)**	**Time (s)**
1.70	1.00	1123	7200
7.26	0.97	1123	14400
9.50	1.12	1123	21600
8.33	0.84	1173	7200
8.37	1.01	1173	14400
14.9	1.12	1173	21600
14.5	0.80	1123	7200
10.5	0.98	1123	14400
14.5	1.16	1123	21600
0.92	0.57	1123	7200

Thus, once the values of D have been determined from the experimental data at different carburizing times and temperatures for the different mixtures, it is possible to compute both the diffusivity coefficient and the activation energy for the diffusion of carbon in austenite, by means of Equation 2.14.

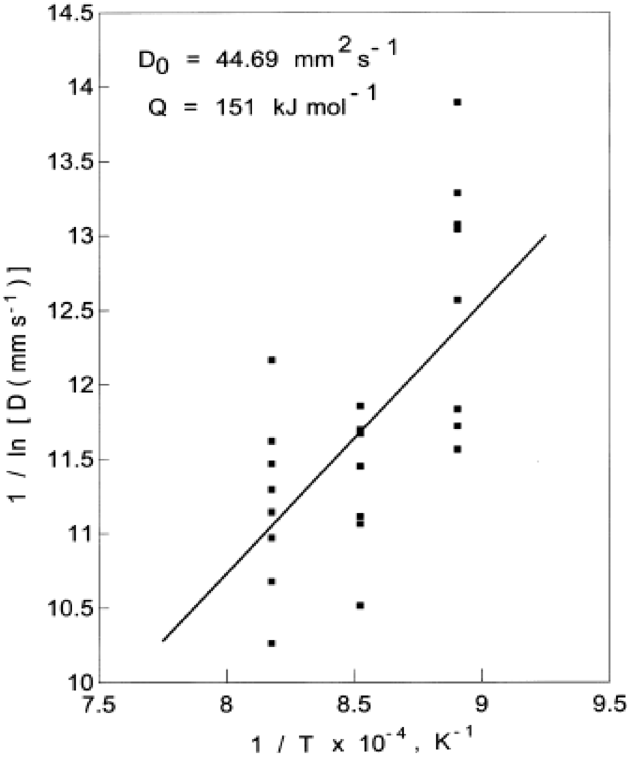


Figure 2.13: Arrhenius plot of the inverse of the logarithm of the diffusion coefficient versus inverse of the absolute carburizing temperature.

From the equation 2.14, the graph will plot that shows in Figure 2.13. The slope from the straight line can determine the activation energy (Q) of each carburizing process.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

A successful experiment comes from the systematic plan that followed during running the experiment. The structure of the research is an important thing that should be considered in order to make sure the experiment that conducted is running smoothly and gives the best result. Besides, the experiment with the plan can be conduct with the guideline based on the objective that had been started earlier.

In this chapter, the methodology of this study had been clearly elaborate and discussed. The methodology included in this study sample preparation for heating process, grinding sample, polishing sample, Vickers test, etching sample and surface analysis by using optical microscope.

3.1.1 General Experiment Procedure

Figure 3.1 shows that experiment procedure for this project which was to study about experimental study of pack carburizing of carbon steel.

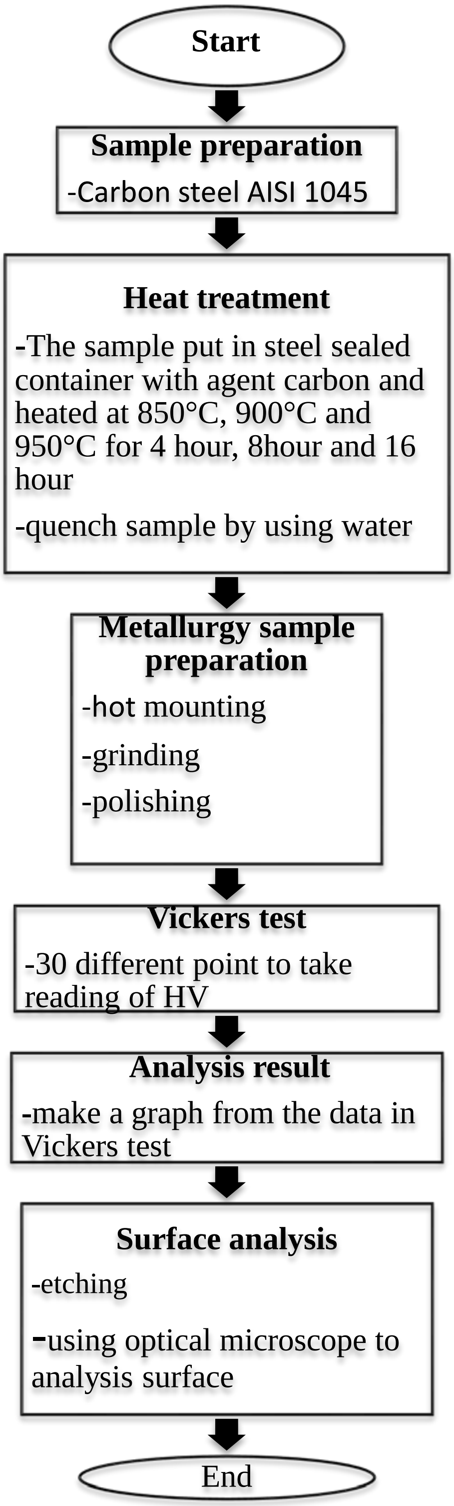


Figure 3.1 Experimental procedure

3.2 SAMPLE PREPARATION

In this project, AISI1045 was used to study about experimental study of pack carburizing of carbon steel. All the samples had been prepared from raw material. The AISI1045 were cut into nine pieces and sizes of each specimen are 5cm diameter and 1cm length using band saw.

Figure 3.1: Cutting machine band saw

3.3 HEAT TREATMENT (PACK CARBURIZING)

Carburizing is a process of adding Carbon to the surface. This is done by exposing the part to a Carbon rich atmosphere at an elevated temperature and allows diffusion to transfer the Carbon atoms into steel. This diffusion will work only if the steel has low carbon content, because diffusion works on the differential of concentration principle.

3.3.1 Carburizing Process

Each specimen was placed in steel container together with carbon powder. Then, preheat the furnace until 800 °C and put the specimens in the furnace at 850°C, 900°C and 950°C. The specimens were heated at three different periods which are 4 hours, 8 hours and 16 hours. Figure 3.2 shows the process of pack carburizing. After the heating finished, the specimens was quench in water medium quench for 3 minutes.

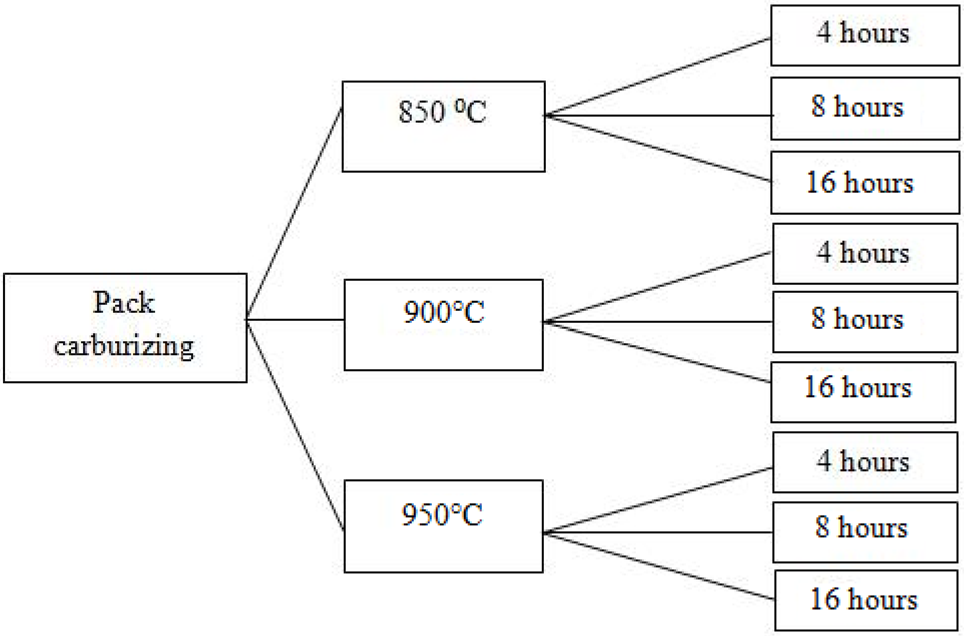


Figure 3.2: Pack carburizing process configuration

Figure 3.3: Electric Furnace

Figure 3.4: Steel Container

3.4 METALLURGY SAMPLE PREPARATION

3.4.1 Mounting

Hot mounting uses a thermosetting compound, cured in amounting press which exerts both heat and high pressure. This mounting method produces hard mounts in a short space of time. However the heating (generally in the order of 120 °C) and considerable pressure applied may be unsuitable for delicate, soft or low melting point specimens (P.M.Unterweiser et.al. 1982).

Figure 3.5: Mounting Machine

Firstly, put the samples in a mounting mould then filled one of half scoop of mounting powder and press button down. After that, close the mounting mould. With the controlled application of pressure and heat, the mounting powder are melted and cured to fill in the cavities of the specimen and mould. Then the sample is cooled under pressure with water to prevent cracking and shrinkage. The sample is then ready for grinding and polishing.

3.4.2 Grinding

Surface layers damaged by cutting must be removed by grinding. Mounted specimens are ground with rotating discs of abrasive paper, for example wet silicon carbide paper. The grinding procedure involves several stages, using a finer paper (higher number) each time. Each grinding stage removes the scratches from the previous coarser paper. This can be easily achieved by orienting the specimen perpendicular to the previous scratches. Between each grade the specimen is washed thoroughly with soapy water to prevent contamination from coarser grit present on the specimen surface.

Figure 3.6: Grinding machine

For this step, the sample had been grinding to get smooth surface and remove the damaged surface that caused by cutting. The surface of the papers was flushed by a current of water, which serves not only as a lubricant in grinding, but also carries away coarse emery particles, which might otherwise scratch the surface of the specimen. The silicon carbide papers used in achieving the proper grinding of the specimen were in the following grades 120, 240, 320 and 400 grits, grinding respectively in that order of grades.

3.4.3 Polishing

Polishing discs are covered with soft cloth impregnated with abrasive diamond particles and an oily lubricant or water lubricant. Particles of two different grades had been used to polish the material. A coarser polish typically with diamond particles 6 microns (polycrystalline Diamond) in diameter which should remove the scratches produced from the finest grinding stage and a finer polish typically with diamond particles 1 micron (Nanopolish Alumina) in diameter, to produce a smooth surface. After the polishing, the sample had been cleaned by using distilled water then drying by using cold air drier.

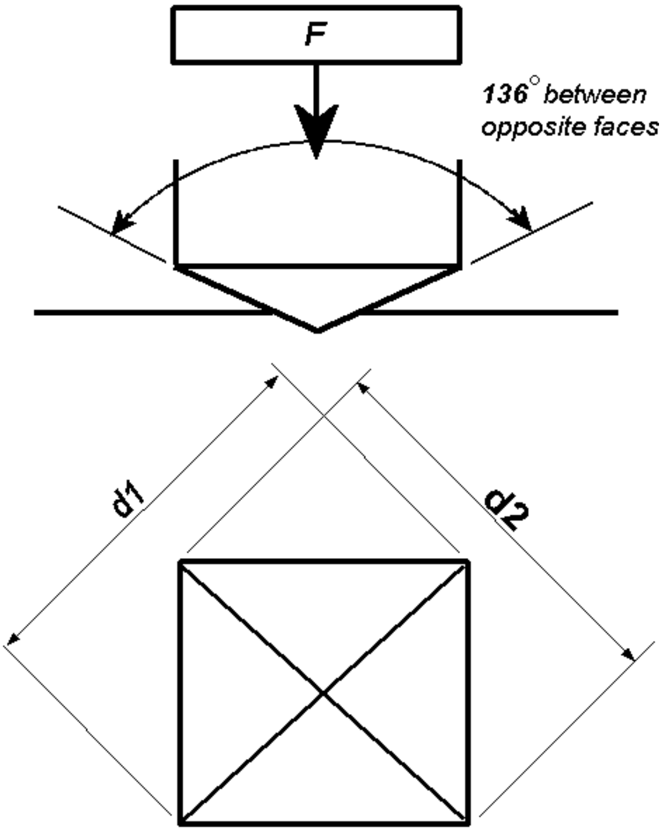
Figure 3.7: Polishing machine

3.5 Hardness Test

The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression which are Brinell, Vickers, and Rockwell (Ray PK et. al 2003). For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

3.5.1 Vickers Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136° between opposite faces subjected. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kg load by the square mm area of indentation (Ray PK et. al 2003).



$$HV = \frac{1.854F}{L^2}$$

Where:

L = mean of the two diagonals, *D1* and *D2* in mm

=

F = Load in kg

For this experiment, the location need to be observed for the indenter to be pressed and make sure the surface of the specimen is flat (refer figure 3.21). Then the indenter is being press into the specimen by an accurately controlled test force about 500g load. The force has been maintained for about 10 seconds to get the specific dwell time. The indenter is removed after the dwell time is complete and leaving an indent on the specimen surface with the shape of square. The size of the indent has been measure by get the diagonal measurement of the indent. Thirty hardness readings were performed per sample and they were averaged. The distance between each point is 20µm.

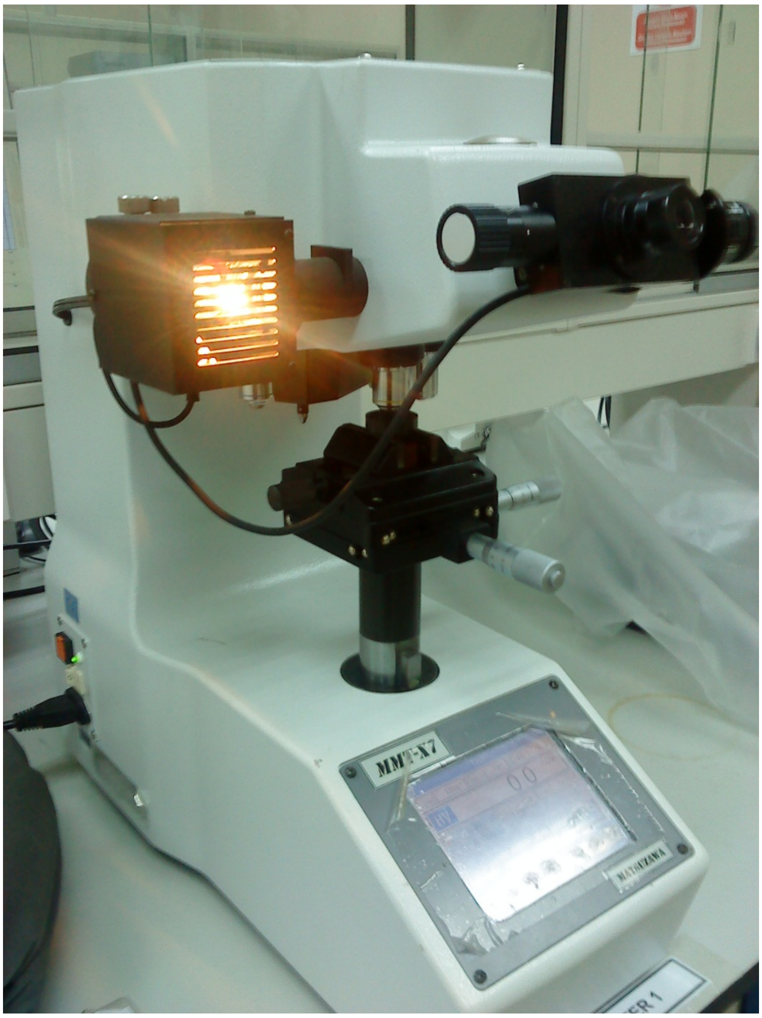


Figure 3.8: Diamond Indenter

3.6 SURFACE ANALYSIS

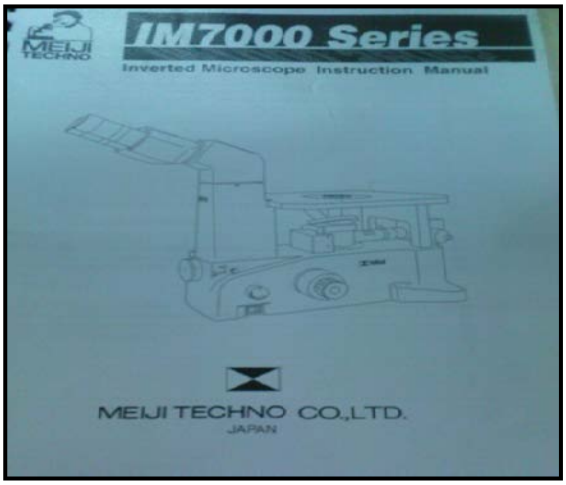
3.6.1 Etching

Etching is used to reveal the microstructure of the metal through selective chemical attack. In alloys with more than one phase etching creates contrast between different regions through differences in topography or the reflectivity of the different phases. The rate of etching is affected by crystallographic orientation, so contrast is formed between grains, for example in pure metals. The reagent will also preferentially etch high energy sites such as grain boundaries [J. Will et al.1998]. This results in a surface relief that enables different crystal orientations, grain boundaries, phases and precipitates to be easily distinguished.

The microstructure of the sample of stainless steel had been revealed by etching with mixing solution. The specimen had been etched by nital 2%. To etch these specimens, they were washed free of any adhering polishing compound and plunged into the etching solution, agitated vigorously for 3 minutes. The specimens were then very quickly transferred to running water, in order to wash away the etchant as rapidly as possible.

3.6.2 Material Characterization

Surface visualization had been carried out the etching process. Observations on the material microstructure of the sam ples for determine the carburizing layer had been observed by using inverted microscope (IM7000 series) in the UMP mechanical laboratory at campus Pekan.



MEIJI TECHNO

IM7000 Series

Inverted Microscope Instruction Manual

MEIJI TECHNO CO.,LTD.
JAPAN

Figure 3.9: Inverted microscope (IM7000 Series)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter describes the results and discussion based on the experiment conducted. The experimental results will be presented in the table to facilitate the process of analyzing those results. Then the experimental results will be analyzed. Recommendation will be given for future improvements. Surface of specimen will be measure using Vickers hardness to get hardness value (HV). The ability of carburizing operation is base on many factors which are carburizing time, carburizing temperature, and quenching time that make the different value of hardness of specimen.

4.2 HARDNESS PROFILE

4.2.1 Vickers hardness results for carburizing

After all experiment had been conducted, the results for carburizing at 850°C (1123K), 900°C (1173K), 950°C (1223K) for water quench are shown in Table 4.1, Table 4.2 and Table 4.3. Each table shows the results for carburizing time which are 8 hours, 10 hours and 12 hours and quenching medium which is water. There are 30 readings for each table that to measure the surface hardness where the reading will begin from edge to centre of specimens. From the table, the cross-section hardness profiles can be determined.

Table 4.1: Carburizing for 850 °C (1123K)

POSITION (µm)	HV(4 hours)	HV(8 hours)	HV(16 hours)
0	310.7	331.2	345.5
20	308.7	329.7	344.4
40	300.4	327.5	344.1
60	293.7	319.5	342.1
80	285	310.1	333.5
100	279.4	301.3	327.1
120	274.2	292.5	323.8
140	270.2	285.4	319.7
160	267.2	279.4	315.3
180	264.5	272.8	311.8
200	259.3	270.3	306.5
220	255.8	265.1	303
240	249.6	262.7	298.8
260	245.3	260.7	295.2
280	242.1	257.9	291.3
300	238.2	255.6	285.7
320	235.7	252.2	281.9
340	232.8	248.7	277.3
360	227.2	243.5	273
380	225.6	240.4	266.6
400	219.2	237.6	260.2
420	218.1	235.1	255.8
440	215.6	232	249.5
460	210.7	229.7	246.5
480	208.7	226.9	244.7
500	206.3	223.9	243.5
520	205.4	223.9	242.6
540	205.4	223.9	242.6
560	205.4	223.9	242.6
580	205.4	223.9	242.6
600	205.4	223.9	242.6

Table 4.1 shows the position of carburizing layer for three different time of carburizing. Each position gives different value of Vickers hardness. From 0 µm to 600 µm position, the HV were decrease and reach the same value of hardness.

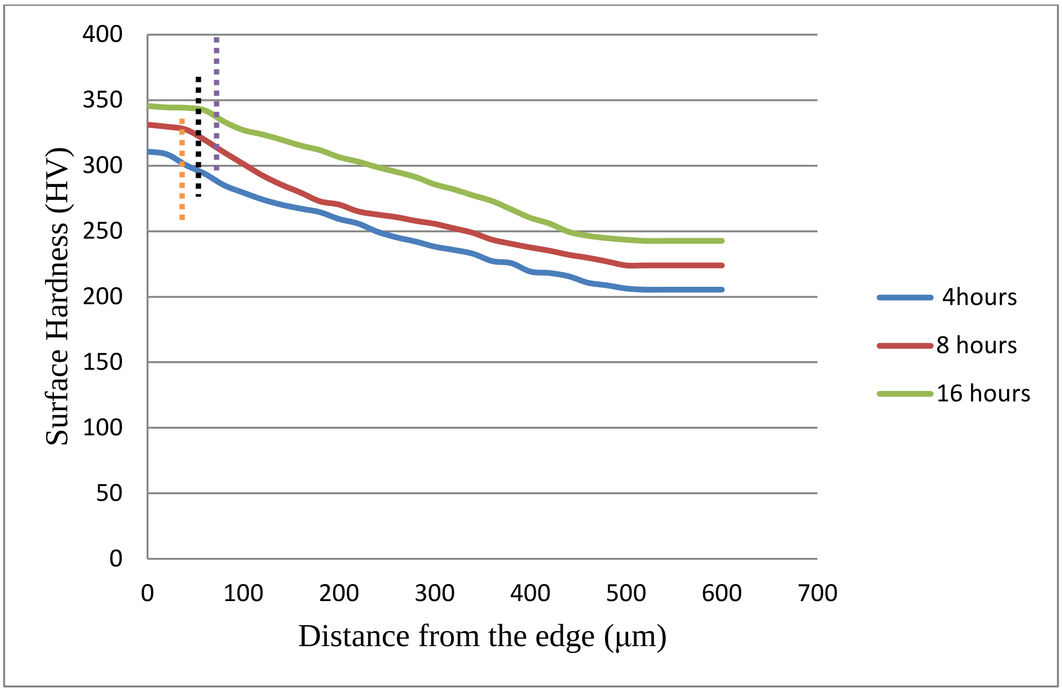


Figure 4.1: Graph of surface hardness vs. distance from the edge (cross-section hardness profiles)

Figure 4.1 showed that the highest HV value is 16 hours which is 345.5 but it kept decreasing until 242.6 as the distance from the edge increases. The second line which present the 8 hours experiment give the highest HV value of 331.2 but it also kept decreasing until 223.9 as the distance from the edge increases. The third line which is 4 hours experiment showed the lowest HV value of 310.7 however it also kept decreasing until 205.4. From the graph, the thickness of carburizing layer can be determined from the starting point of the lines until the point before the value of surface hardness start to drop and the dash line shows when its drop. The purple dash line is referring to 16 hours while the black dash line is referring to 8 hours. The last line which is orange dash line is referring to 4 hours.

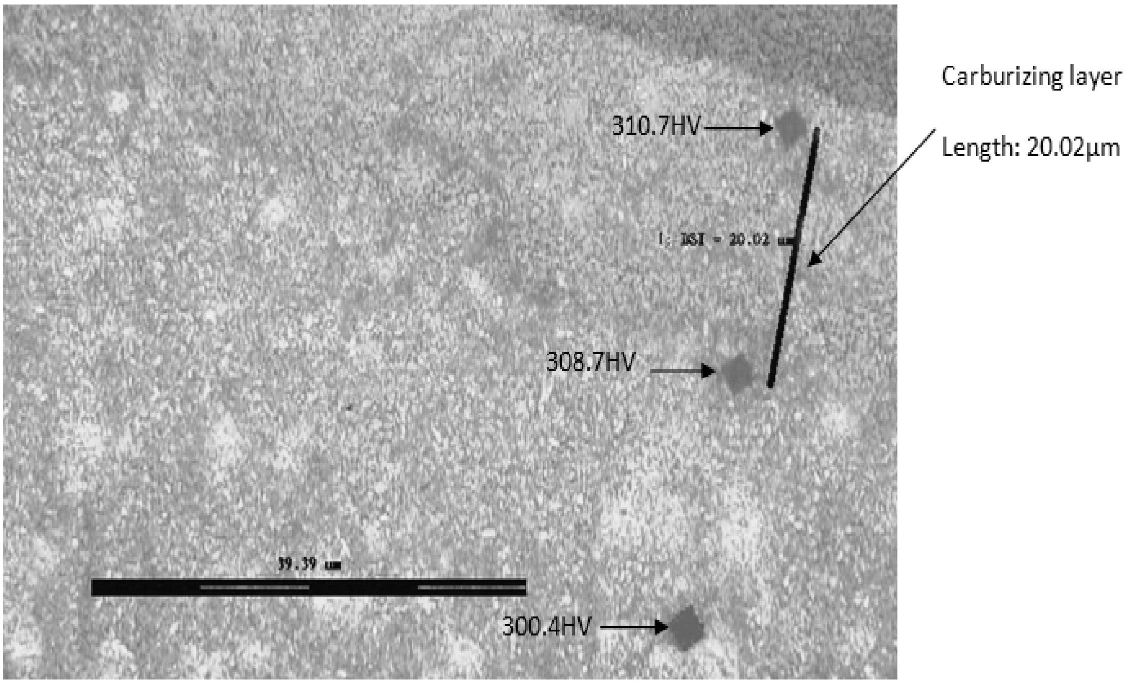


Figure 4.2: Optical micrograph showing the thickness layer of carburizing at 850°C for 4 hours.

Figure 4.2 shows that the cross-sectional microstructure of specimen at 850°C with 4 hours carburizing time. From this figure, the carburizing layer can be observed clearly with dropping hardness value.

Table 4.2: Carburizing for 900°C (1173K)

POSITION (μm)	**HV(4 hours)**	**HV(8 hours)**	**HV(16 hours)**
0	320.1	361.2	373.4
20	319.7	359.5	371.5
40	317.5	358.1	369.9
60	306.4	355.4	368.6
80	297.5	342.5	366.5
100	293	337.6	353.8
120	290	330.2	346.1
140	285.6	327.4	337.9
160	283.1	322.3	332.3
180	279.6	314.5	329.2
200	275.1	310.9	325.1
220	272.2	305	320
240	266.2	298.8	316
260	260.3	292.8	311.3
280	255.4	286.5	307.4
300	249.1	277.9	301.1
320	245.6	271.1	296.8
340	238.5	267.4	290.1
360	234.7	261.4	287.5
380	229.3	257	285.6
400	227.6	254.5	281.4
420	225.1	250.9	278.2
440	223.9	248.1	276.9
460	222.1	245.7	276.3
480	221.5	244.1	275.4
500	221.3	242.9	274.9
520	220.9	241.7	274
540	220.7	241.7	272.3
560	220.7	239.5	272.3
580	220.7	239.5	272.3
600	220.7	239.5	272.3

Table 4.2 shows the position of carburizing layer for three different time of carburizing. Each position gives different value of Vickers hardness. From 0 μm to 600 μm position, the HV were decrease and reach the same value of hardness.

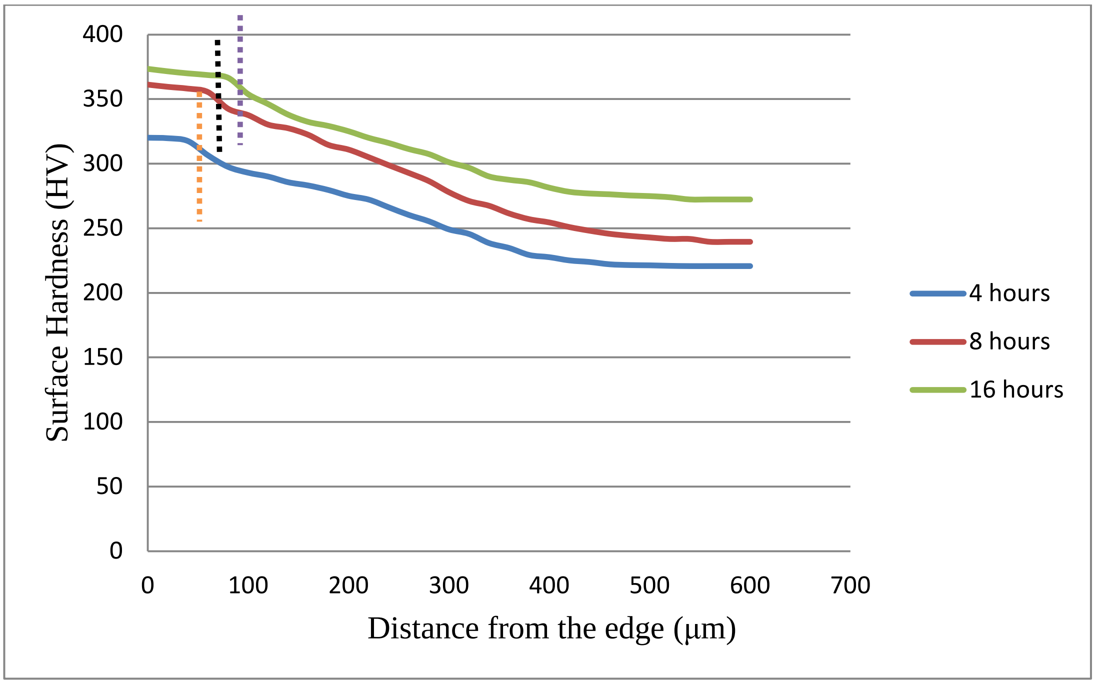


Figure 4.3: Graph of surface hardness vs. distance from the edge (cross-section hardness profiles)

Figure 4.3 showed that the highest HV value is 16 hours which is 373.4 but it kept decreasing until 272.3 as the distance from the edge increases. The second line which present the 8 hours experiment give the highest HV value of 361.2 but it also kept decreasing until 239.5 as the distance from the edge increases. The third line which is 4 hours experiment showed the lowest HV value of 320.1 however it also kept decreasing until 220.7. From the graph, the thickness of carburizing layer can be determined from the starting point of the lines until the point before the value of surface hardness start to drop and the dash line shows when its drop. The purple dash line is referring to 16 hours while the black dash line is referring to 8 hours. The last line which is orange dash line is referring to 4 hours.

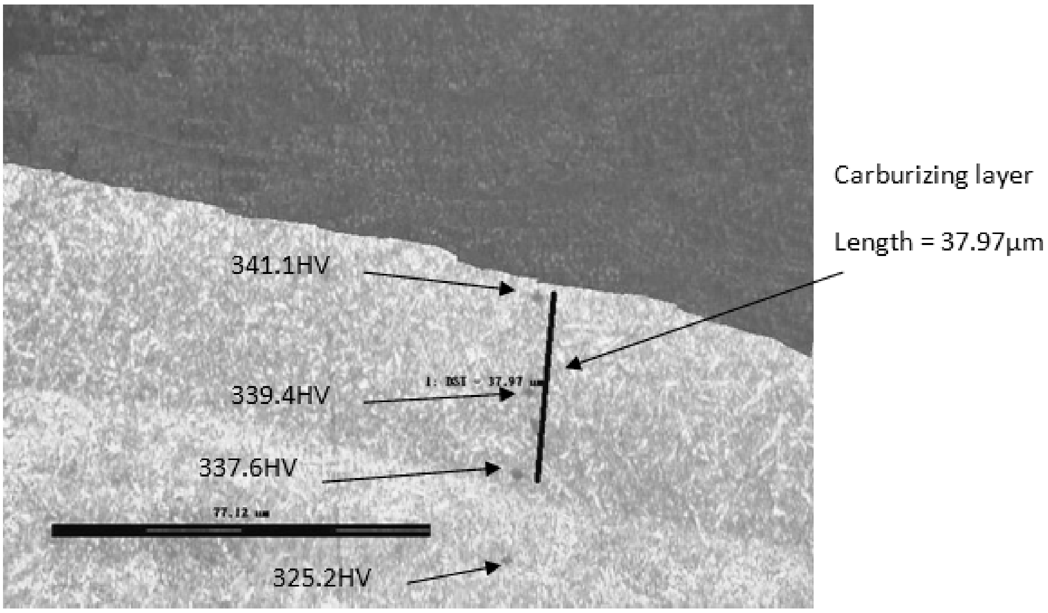


Figure 4.4: Optical micrograph showing the thickness layer of carburizing at 900°C for 4 hours.

Figure 4.4 shows that the cross-sectional microstructure of specimen at 900°C with 16 hours carburizing time. From this figure, the carburizing layer can be observed clearly with dropping hardness value.

Table 4.3: Carburizing for 950°C (1223K)

POSITION (µm)	**HV(4 hours)**	**HV(8 hours)**	**HV(16 hours)**
0	341.1	386.3	395.7
20	339.4	386.3	394.9
40	337.6	385.6	394.2
60	331.2	384.2	393.2
80	325.2	382.1	391.9
100	317.6	372.1	389.5
120	312.1	365.2	387.5
140	308.1	359.2	376.1
160	305.9	350.6	367.5
180	300.1	343.5	360.3
200	295.5	337.2	353.4
220	290.1	329.8	346
240	288.4	321.3	342.1
260	283.8	314.6	335.2
280	278.1	305.9	331.6
300	272.7	299.4	327.5
320	267.3	291	324.3
340	263.3	285.4	319.1
360	260.4	278.8	315.4
380	257.1	277.5	311.1
400	255.1	276	308.7
420	248.2	273.1	304.4
440	245.2	270.5	302.7
460	243.3	268.9	301.5
480	239.7	264.5	301.2
500	236.7	262.7	300.5
520	236.7	261.3	299.3
540	236.7	261.3	299.3
560	236.7	261.3	299.3
580	236.7	261.3	299.3
600	236.7	260.4	299.3

Table 4.3 shows the position of carburizing layer for three different time of carburizing. Each position gives different value of Vickers hardness. From 0 µm to 600 µm position, the HV were decrease and reach the same value of hardness.

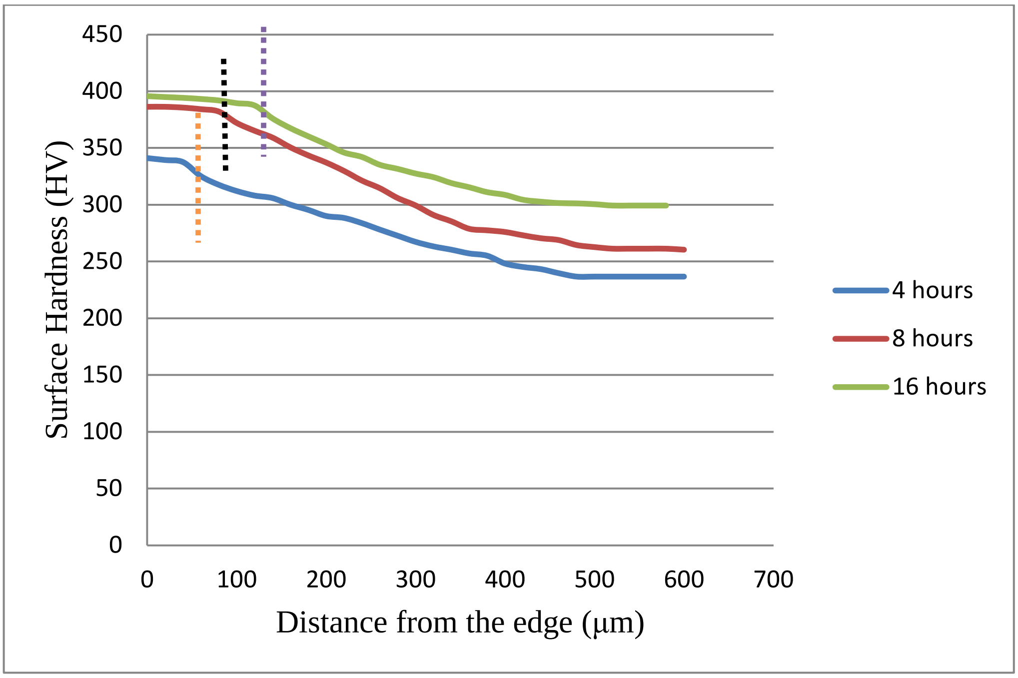


Figure 4.5: Graph of surface hardness vs. distance from the edge (cross-section hardness profiles)

Figure 4.5 showed that the highest HV value is 16 hours which is 395.7 but it kept decreasing until 299.3 as the distance from the edge increases. The second line which present the 8 hours experiment give the highest HV value of 386.3 but it also kept decreasing until 260.4 as the distance from the edge increases. The third line which is 4 hours experiment showed the lowest HV value of 341.1however it also kept decreasing until 236.7. From the graph, the thickness of carburizing layer can be determined from the starting point of the lines until the point before the value of surface hardness start to drop and the dash line shows when its drop. The purple dash line is referring to 16 hours while the black dash line is referring to 8 hours. The last line which is orange dash line is referring to 4 hours.

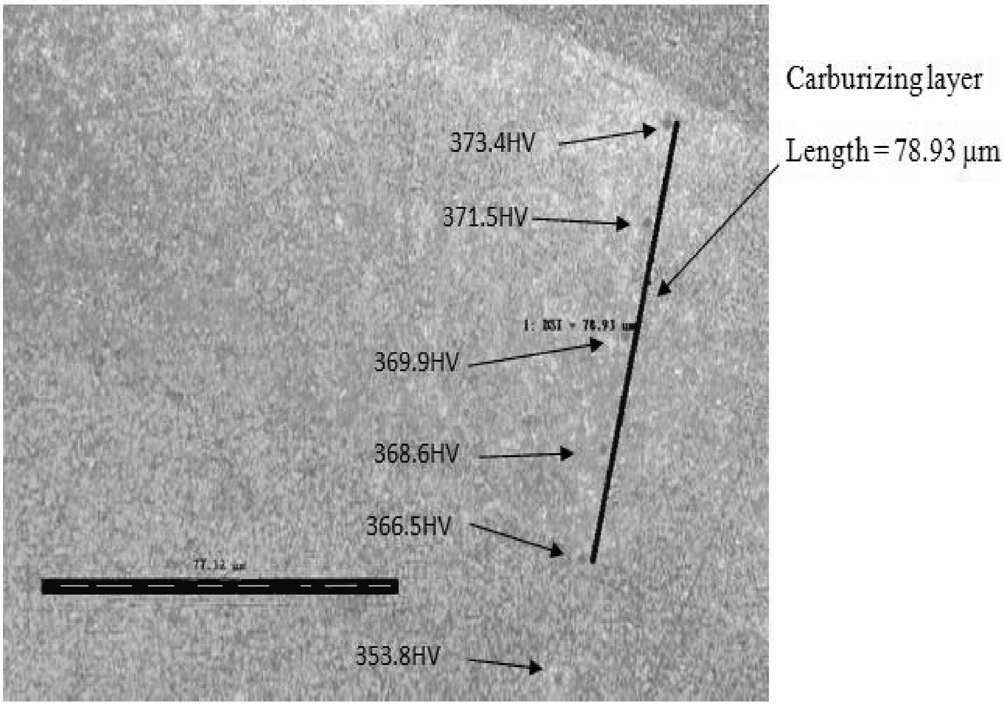


Figure 4.6: Optical micrograph showing the thickness layer of carburizing at 950°C for 8 hours.

Figure 4.6 shows that the cross-sectional microstructure of specimen at 950°C with 4 hours carburizing time. From this figure, the dropping value hardness value and carburizing layer can be observed clearly.

For all carburizing time, using 950°C as carburizing temperature shows the highest value of HV but it depends on time carburizing. When time carburizing is long, the thickness of carburizing layer will increase. It is due to when ferrite is heated to a temperature above the transformation line (723ºC), the body-centered-cubic (BCC) structure changes to face-centered-cubic (FCC) structure known as austenite which is allowing the absorption of the carbon into the crystal structure, thus increasing the structures strength.

Based on the figure above, the thickness of carburizing layer can be determined from the starting point of the lines until the point before the value of surface hardness start to drop.

Table 4.4: Thickness of carbon layer for 850°C, 900°C and 950°C

Carburizing time (h)	**Position/850°C (µm)**	**Position/900°C (µm)**	**Position/950°C (µm)**
0	0	0	0
4	20	40	40
8	40	60	80
16	60	80	120

Table 4.4 shows the thickness of carbon layer for 850°C, 900°C and 950°C at four different carburizing times and the position from the edge.

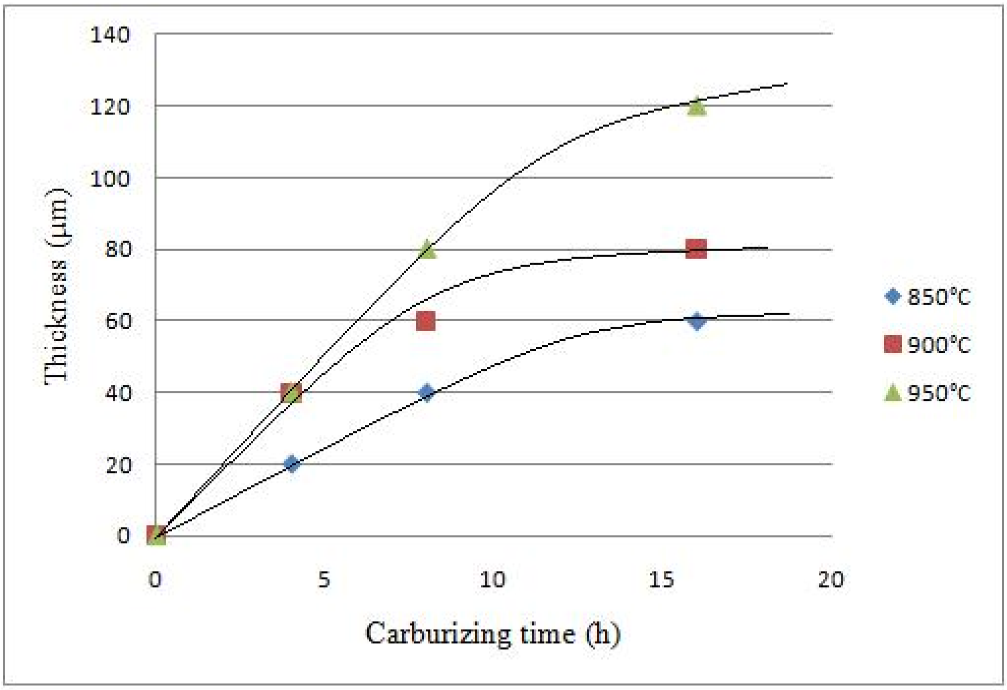


Figure 4.7: Graph of thickness of carbon layer vs. carburizing time

From Figure 4.7, it is observed that the temperature 950°C (1223K) give the highest value of thickness of carbon layer compared to other carburizing time which are 4,8 and 16 hours. The carbon layer for temperature 950°C in 16 hours carburizing time is 120µm, for 8 hours carburizing time is 80µm and 40µm for 4 hours. For temperature 900°C, it gives 80µm for 16 hours carburizing time, 60µm for 8 hours carburizing time and 40µm for 4 hours carburizing time. For temperature 850°C, it gives 60µm for 16 hours carburizing time, 40µm for 8 hours carburizing time and 20µm for 4 hours carburizing time.

4.3 ACTIVATION ENERGY

The thickness of carburized layer is mainly depends on the diffusion of carbon atoms into the substrate material. Thus, the activation energy can be determined by using the thickness of carburized formed. The Arrhenius equation is suitable to determine the activation energy which is measuring the effect of temperature on the rate of the reaction.

Based on Figure 4.7 and microstructure of specimens, the value of diffusion coefficients, K ($m^2 s^{-1}$) can be estimated by making use of the thickness values.

Table 4.5: Square of carbon layer thickness (μm^2)

Carburizing time (s)	Temperature		
	1123 K (μm^2)	1173 K (μm^2)	1223 K (μm^2)
14400	400	1600	1600
28800	1600	3600	6400
57600	3600	6400	14400

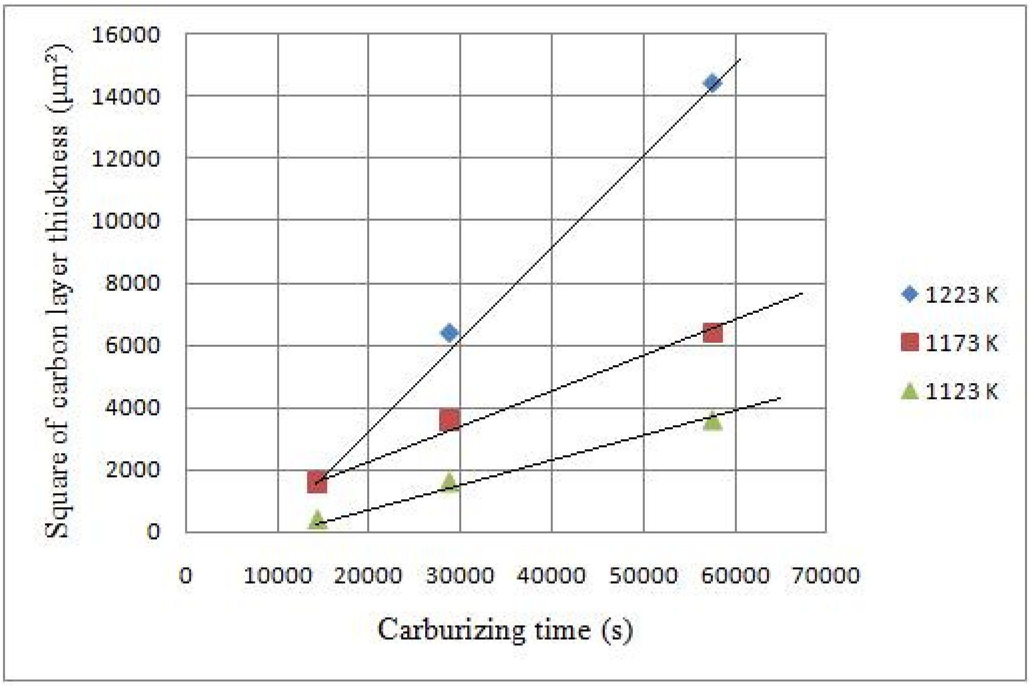


Figure 4.8: Square of carbon layer thickness vs. carburizing time

Figure 4.8 shows that the square of carbon layer thickness is directly proportional with carburizing time. From the slope of Figure 4.8, the diffusion coefficients, K (m^2s^{-1}), can be determine for each carburizing temperature. The data are listed in the table below:

Table 4.6: Value of K and ln K for each carburizing temperature

$K \times 10^{-13}$ [m^2s^{-1}]	$T \times 10^{-4}$ [s^{-1}]	ln K [m^2s^{-1}]
2.92	8.18	-28.86
1.18	8.53	-29.76
0.83	8.9	-30.12

Based on Table 4.5, a graph Natural logarithm of carbon growth rate (ln K) versus reciprocal carburizing temperature (T^{-1}) is drawn using equation

$$In\ K = In\ K_0 + (-QR^{-1})(T^{-1}) \qquad (8)$$

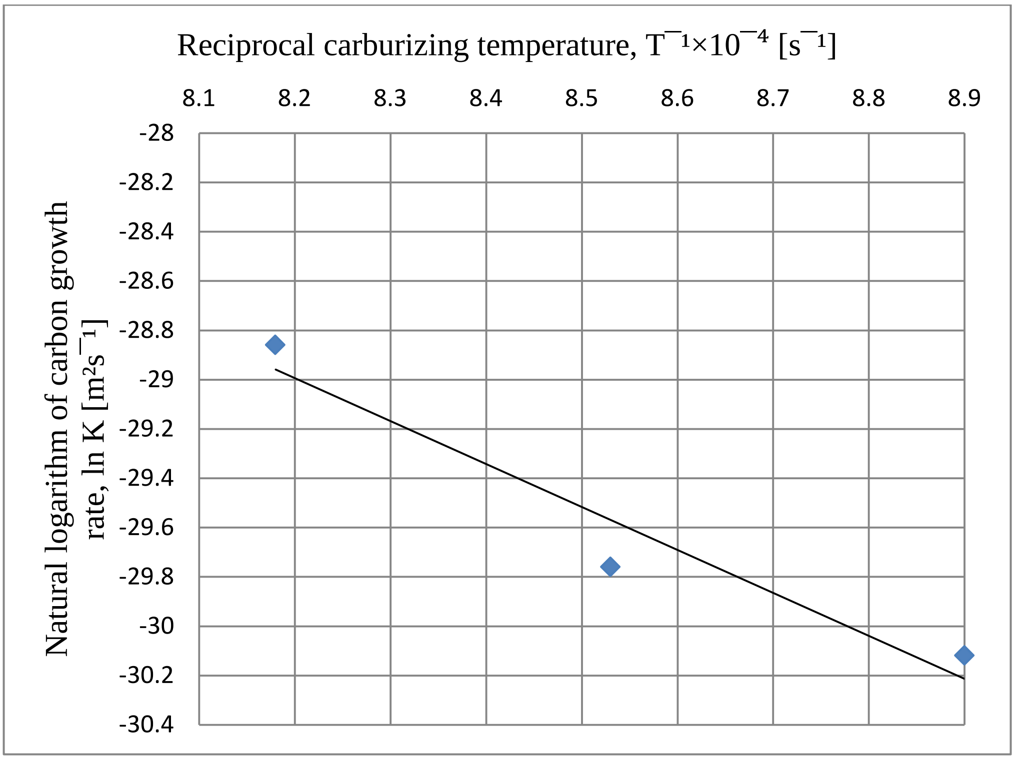


Figure 4.9: Natural logarithm of carbon growth rate (ln K) vs. reciprocal carburizing temperature (T^{-1})

From Figure 4.9, the gradient from the line will determine the activation energy of carburizing process. Based on calculation the activation energy, Q is 142.55 kJ/mol. This result indicates the carburizing process accelerates the diffusion of carbon atoms into the surface, thus increasing the thickness of carburized layer as well as the surface hardness.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

In this chapter, all about the whole research has been summarized. The observation, results analysis and discussion from the experiment are concluded. Besides that, recommendations also have given in this chapter for the future improvement.

5.2 CONCLUSION

The following conclusions can be drawn from this study

i. The different of temperature of pack carburizing make an impact of surface hardness which is when the temperature is increase the surface hardness will increase.
ii. The different of time during pack carburizing were less influence of surface hardness because it depends on temperature. If temperature is high, the time is increase it makes surface hardness increasing too.
iii. In the terms of process kinetics, the activation energy was determined by 142.55 kJ/mol

5.3 RECOMMENDATIONS

For every studies and researches that has been done, there is always room for further improvements. From this experiment, there are several suggestions that could be implanted for improvements when running this research next time.

i. The material that suitable in this experiment is low carbon steel (0.02 wt. %) because the less carbon in a material, the easier carbon agent to penetrate into the material.
ii. Water is the quenching medium that makes specimen more hardness than oil and air but it has disadvantages such as corrosion. This medium quench not very suitable for industries.

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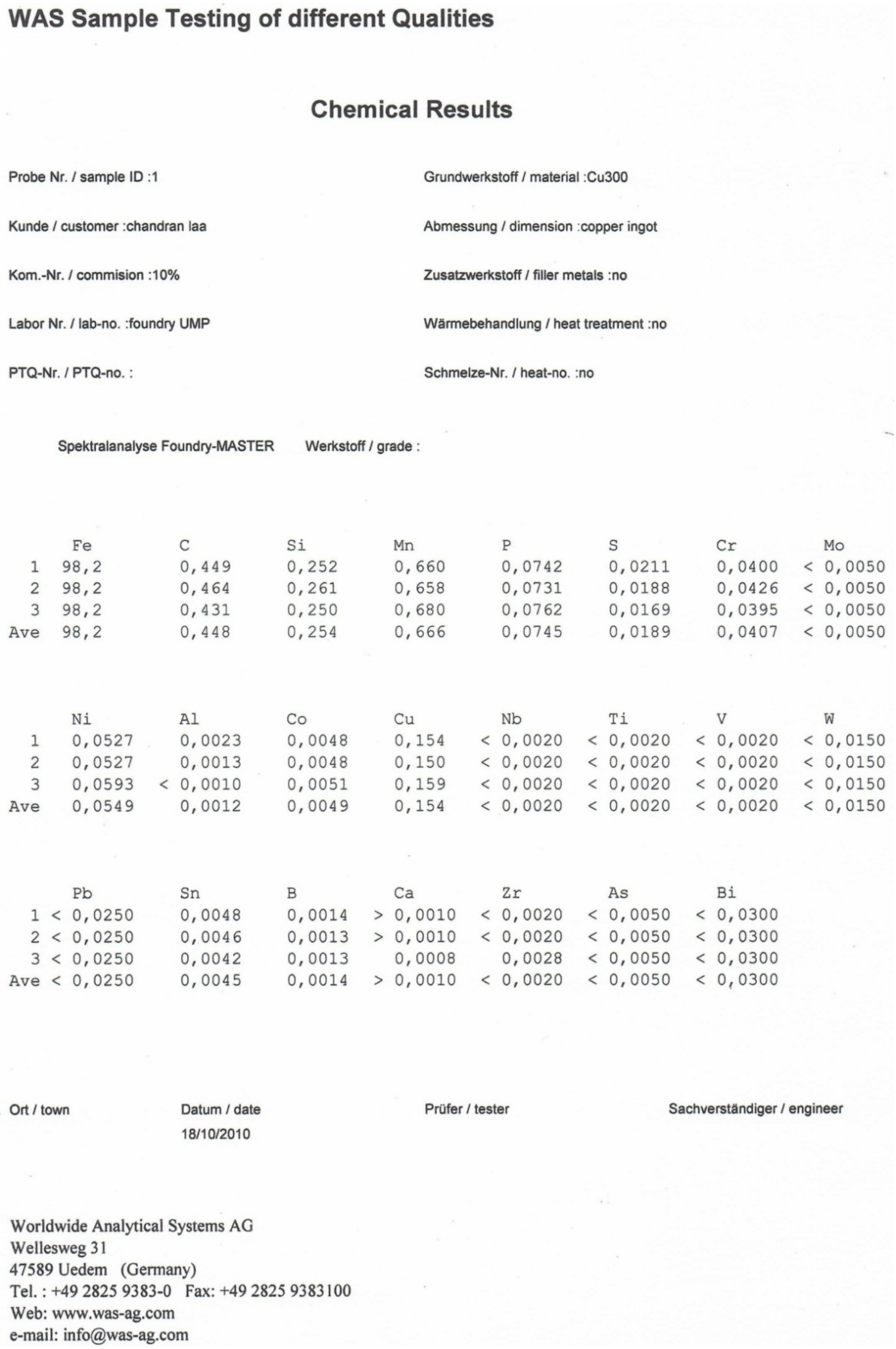
APPENDIX A

Table of chemical composition results



WAS Sample Testing of different Qualities

Chemical Results

Probe Nr. / sample ID :1

Kunde / customer :chandran laa

Kom.-Nr. / commision :10%

Labor Nr. / lab-no. :foundry UMP

PTQ-Nr. / PTQ-no. :

Grundwerkstoff / material :Cu300

Abmessung / dimension :copper ingot

Zusatzwerkstoff / filler metals :no

Wärmebehandlung / heat treatment :no

Schmelze-Nr. / heat-no. :no

Spektralanalyse Foundry-MASTER   Werkstoff / grade :

```
      Fe          C          Si         Mn         P          S          Cr         Mo
  1  98,2        0,449      0,252      0,660      0,0742     0,0211     0,0400   < 0,0050
  2  98,2        0,464      0,261      0,658      0,0731     0,0188     0,0426   < 0,0050
  3  98,2        0,431      0,250      0,680      0,0762     0,0169     0,0395   < 0,0050
Ave  98,2        0,448      0,254      0,666      0,0745     0,0189     0,0407   < 0,0050


      Ni          Al         Co         Cu         Nb         Ti         V          W
  1   0,0527      0,0023     0,0048     0,154    < 0,0020   < 0,0020   < 0,0020   < 0,0150
  2   0,0527      0,0013     0,0048     0,150    < 0,0020   < 0,0020   < 0,0020   < 0,0150
  3   0,0593    < 0,0010     0,0051     0,159    < 0,0020   < 0,0020   < 0,0020   < 0,0150
Ave   0,0549      0,0012     0,0049     0,154    < 0,0020   < 0,0020   < 0,0020   < 0,0150


      Pb          Sn         B          Ca         Zr         As         Bi
  1 < 0,0250      0,0048     0,0014   > 0,0010   < 0,0020   < 0,0050   < 0,0300
  2 < 0,0250      0,0046     0,0013   > 0,0010   < 0,0020   < 0,0050   < 0,0300
  3 < 0,0250      0,0042     0,0013     0,0008     0,0028   < 0,0050   < 0,0300
Ave < 0,0250      0,0045     0,0014   > 0,0010   < 0,0020   < 0,0050   < 0,0300
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Ort / town	Datum / date	Prüfer / tester	Sachverständiger / engineer
	18/10/2010		

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APPENDIX B1

Gantt Chart for
Final Year Project 1

Project Activities	JANUARY				FEBRUARY				MARCH				APRIL			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Title distribution	■															
Meet Supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Brainstorming		■	■													
Identify problems statements			■													
Determine objectives & scope				■	■											
Submit draft proposal						■						■				
Literature Review						■	■	■	■							
Methodology										■	■	■	■			
Log book submission													■	■		
Submit full proposal & presentation													■	■	■	

APPENDIX B2

Gantt Chart for
Final Year Project 2

Project Activities	**JUNE**				**JULY**				**AUGUST**				**SEPTEMBER**				**OCTOBER**				**NOVEMBER**				**DISEMBER**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Study experiment procedure	■	■	■	■																								
Specimen preparation					■	■	■	■																				
Run the experiment					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
Finish the experiment																■	■	■	■									
Collecting data																	■	■	■									
Analyze data collection																		■	■									
Results and conclusion																		■	■	■								
Submit draft 1 report to supervisor																			■	■								
Submit full thesis to faculty																					■							
Collect back full thesis and make correction																						■	■					
Final presentation on FYP 2																								■	■			
Submit final full thesis to faculty																									■			