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Date : May 7, 2007

STUDY ON CARBURIZING AND THE KINETICS OF LOW ALLOY TOOL STEEL

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"I hereby, declare this thesis is the result of my own research except as cited in the references"

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DEDICATION

To my beloved mother and family

ACKNOWLEDGEMENT

Thanks to Allah for giving a good health and mind which enable me to complete this research report.

I would like to express my deepest appreciation to my supervisor, Pn. Rafidah Hasan, who gave me the opportunity to do this research and spent her time and offered for many suggestions during the entire study.

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ABSTRACT

Carburizing is one of heat treatment process for hardening the steel by exposing the part to a Carbon rich atmosphere at an elevated temperature and allows diffusion to transfer the Carbon atoms into steel. The parts were simply placed in a suitable container and covered with a thick layer of carbon powder. Throughout this project, a square bar of 20 x 20 x 20 mm dimension was cut for ten pieces. For the first analysis, one piece of specimen is used for hardness testing and microstructure analysis. The specimen should be grinded, polished and etching for the research. Another nine pieces of specimens are used for carburizing process. It is carburized in three different temperatures; 1073 K, 1123 K and 1173 K and three different times; three hour, six hour and nine hour. The surface hardness value before the carburizing process was ±98.6 HRB and after carburizing process, the result was ±84 HRB to ±100.4 HRB. The result of hardness was increased contributed to the temperature and time of carburizing process. Then, the data obtain from the carburized low alloy tool steel was analyzed and give activation energy value at 264.14 $kJmol^{-1}$ and the pre-exponential constant (K_o) value at 1.03×10^{-10} m^2s^{-1}.

ABSTRAK

Penusukkarbonan adalah satu proses rawatan haba untuk mengeraskan permukaan logam dengan menambah karbon ke dalamnya melalui suhu tinggi yang dikenakan. Melalui projek ini, satu batang logam panjang bersegi empat berukuran 20 x 20 x 20 mm dipotong kepada 10 bahagian. Untuk analisis awal, satu sampel digunakan untuk membuat ujian kekerasan dan analisis terhadap struktur dalam sampel. Sebelum membuat analisis struktur, sampel perlu digosok dan digilap dan disapu asid pada permukaannya. Sembilan sampel yang lain digunakan untuk membuat ujian penusukkarbonan. Ia dibakar dalam tiga suhu yang berbeza iaitu 1073 K, 1123K, 1173 K dan untuk tiga masa yang berbeza iaitu tiga, enam dan sembilan jam.Nilai kekerasan pada sampel sebelum ujian penusukkarbonan dilakukan ialah ± 98.6 HRB dan selepas ujian dilakukan nilai nya adalah antara ± 84 HRB hingga ± 100.4 HRB. Nilai kekerasan sampel bertambah mengikut suhu dan masa ujian penusukkarbonan. Analisis akhir dibuat daripada data ujian penusukkarbonan dan didapati nilai tenaga penggiatan adalah 264.14 $KJmol^{-1}$ dan nilai pemalar adalah $1.03 \times 10^{-3}\ m^2s^{-1}$.

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SYMBOL	DEFINITION
A2	Low alloy tool steel
HRB	Brinnel Hardness Number
CO	Carbon monoxide
C	Carbon
Ea / Q	Activation energy
R	Gas constant (8.314 mol^{-1} K^{-1})
K	Kelvin
T	Absolute temperature in Kelvin
A	Frequency factor
K_o	pre-exponential constant
SEM	Scanning Electron Microscope
μm	micron

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CHAPTER 1

INTRODUCTION

1.1 General

Carburizing is a surface hardened treatment by adding carbon on the surface of specimen. There are three method of carburizing processes which are pack powder carburizing, gas carburizing and liquid carburizing.

In this research, the pack powder carburizing process was chosen because it is easy to handle, not dangerous and suitable for laboratory used. The chosen sample for this study was low alloy tool steel (A2) because it has a low carbon content in AISI series. Pack powder carburizing process were conducted at the temperature of 1073 K, 1123 K and 1173 K for three, six and nine hours holding time.

All the data of the carburized layer was discussed and compared to each other. According to the experiment, the activation energy of carbon atom was determined to compare the value between low alloy tool steel and low carbon steel.

1.2 Objectives

The purpose of this work is to study the effects of time and temperature on hardness and microstructure of carburized layer in low alloy tool steel.

1.3 Scope of Research

1) To do literature study on carburizing and kinetics of atom for thermal diffusion process.
2) To carry out carburizing treatment on low alloy tool steel.
3) To determine the kinetics of carbon atom diffusion in low alloy tool steel.
4) To compare and discuss the data obtain from carburized of low alloy tool steel with low carbon steel.

1.4 Outline of Research

The research outlines are as follows:

1. Literature Review

   The theory of carburizing was reviewed from various sources such as journals, text books, previous dissertation reports and the World Wide Web. Summary of literatures was presented in Chapter 2.

2. Experimental works

   The experiments of pack carburizing were done in variable times and temperatures. The experimental procedures were described in Chapter 3.

3. Characterization

   Hardness before and after carburizing were measured at specimens' surface using Rockwell hardness tester. Thickness measurement and microstructure evaluation were done using optical microscopy. The characterization techniques were also described in Chapter 3.

4. Data collection and data analysis

   Data from characterization process were presented according to the experiment works. The data were also analyzed to obtain the kinetics of carburizing process. Data for comparisons between low alloy tool steel and low carbon steel were done and the results were discussed in Chapter 4.

5. Discussion

   All the results obtained in this research work were compiled and discussed in Chapter 5. Conclusions of present study for future research were presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 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 process 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. For example, the steel had high carbon content to begin with, and is heated in a carbon free furnace, such as air, the carbon will tend to diffuse out of the steel resulting in decarburization (*Internet source*: 5/11/2006).

There are three methods of carburizing in heat treatment. These methods introduce carbon by the use of solid compounds (pack carburizing), gas (atmospheric-gas, plasma, and vacuum carburizing) and liquids (salt bath carburizing).

Pack Carburizing is a process in which carbon monoxide derived from a solid compound decomposes at the metal surface into nascent carbon and carbon dioxide. The nascent carbon is absorbed into the metal, and the carbon dioxide immediately reacts with carbonaceous material present in the solid carburizing compound to produce fresh carbon monoxide. The formation of carbon monoxide is enhanced by energizers or catalysts, such as barium carbonate ($BaCO_3$), Calcium carbonate ($CaCO_3$), potassium carbonate (K_2CO_3) and sodium carbonate (Na_2CO_3) that are present in the carburizing compound. These energizers facilitate the reduction of carbon dioxide with carbon to form carbon monoxide.

Pack carburizing is no longer a major commercial process. This has been mainly due to replacement by more controllable and less labor-intensive gas and liquid carburizing process. However, any labor cost advantage gas carburizing or liquid carburizing may have over pack carburizing can be negated should work pieces require additional steps such as cleaning and the application of protective coating in carburizing stop off operation.

Gas Carburizing is conceptually the same as pack carburizing, except that Carbon Monoxide (CO) gas is supplied to a heated furnace and the reduction reaction of deposition of carbon takes place on the surface of the part. This process overcomes most of the problems of pack carburizing. The temperature diffusion is as good as it can be with a furnace. The only concern is to safely contain the CO gas. A variation of gas carburizing is when alcohol is dripped into the furnace and it volatilizes readily to provide the reducing reaction for the deposition of the carbon.

In gas carburizing, the parts are surrounded by a carbon-bearing atmosphere that can be continuously replenished so that a high carbon potential can be maintained. While the rate of carburizing is substantially increased in the gaseous atmosphere, the method requires the use of a multicomponent atmosphere whose composition must be very closely controlled to avoid deleterious side effects, for example, surface and grain-boundary oxides. In addition, a separate piece of equipment is required to generate the atmosphere and control its composition. Despite this increased complexity, gas carburizing has become the most effective and widely used method for carburizing steel parts in large quantities.

Liquid carburizing parts are immersed in a molten carbon rich bath. Carburizing salt contains cyanide compounds such as sodium cyanide (NaCN). Cycle times for liquid cyaniding is much shorter (1 to 4 hours) than gas and pack carburizing processes. Disadvantage is the disposal of salt. (Environmental problems) and cost (safe disposal is very expensive) (Internet source: 5/11/2006).

2.2 Powder Pack Carburizing

Pack Carburizing parts are packed in a high carbon medium such as carbon powder or cast iron shavings and heated in a furnace for 3 to 72 hours at 1173 K. At this temperature CO gas is produced which is a strong reducing agent. The reduction reaction occurs on the surface of the steel releasing carbon, which is then diffused into the surface due to the high temperature. When enough Carbon is absorbed inside the part (based on experience and theoretical calculations based on diffusion theory), the parts are removed and can be subject to the normal hardening methods.

While the basic principle of carburizing has remained unchanged since carburizing was first employed, the method used to introduce the carbon into the steel has been a matter of continuous evolution. In its earliest application, parts were simply placed in a suitable container and covered with a thick layer of carbon powder (pack carburizing). Although effective in introducing carbon, this method was exceedingly slow, and as the demand for greater production grew, a new process using a gaseous atmosphere was developed.

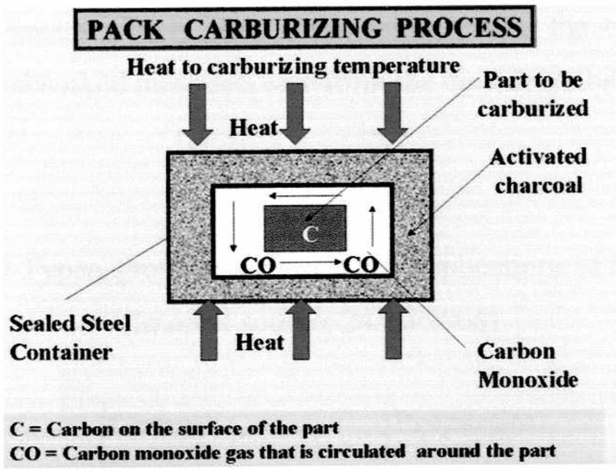

Figure 2.1: Pack Carburizing Process (Internet source: 7/10/2006)

After carburizing, the container should be removed and allowed to cool in the air, or the parts removed from the carburizing compound and quenched in oil or water. The air coding, although slow, reduces warpage, and is advisable in many cases.

2.3 Carburized Material

The carburizing process should be applied to low alloy tool steel which provided within the low-carbon range. Specifically, the carburizing steels are those that contain no more than 0.20 percent carbon. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process. The amount of carbon absorbed and the thickness of the case obtained increase with time; however, the carburization progresses more slowly as the carbon content increases during the process.

The length of time required to produce the desired degree of carburization and depth of the case depend upon the composition of the metal, the kind of carburization material used, and the temperature to which the metal is subjected. It is apparent that in carburizing, carbon travels slowly from the outside toward the center; therefore, the proportion of carbon absorbed must decrease from the outside to the center.

Table 2.1: Types, groups, properties and applications of tool steels
(Internet source: 24/10/2006)

Category	**Type**	**Group**	**Properties**	**Applications**
Tungsten	T	High hardenability, high hardness	Cutting tools, high-temperature structural components	
Molybdenum	M	High hardenability, high hardness	Cutting tools	
Hot Work	Chromium, Tungsten, Molybdenum	H	Good resistance to softening at elevated temperatures, good toughness	High stressed components, hot extrusion dies
High carbon, high chromium	D	High hardness, excellent wear resistance	Long run dies, brick molds	
Medium alloy, air hardening	A	Minimum distortion and cracking on quenching	Dies, punches, forming rolls	
Oil hardening	O	Wear resistant to moderate temperatures	Dies, punches	
Low alloy	L	High toughness, good strength	Arbors, cams, chucks	

Mold	P	Low hardness and low resistance to work hardening	Dies, molds	
Water hardening	W	Tough core, hard and wear resistant surface	Cutlery, forging dies, hammers	

The contributions of each element on the properties of low alloy tool steel are as explained below (Smith, RP,1953).

Table 2.2: Chemical Composition of Low Alloy Tool Steel

Chemical Composition (%)						
C	Si	Mn	Cr	Mo	W	V
1	0.3	0.9	5.25	1.15	0	0.3

Carbon (C): The presence of carbon, usually in excess of 1.0% for non alloyed types, is essential for rising the ability hardens of steels to the levels needed for tools. Raising the carbon content by different amounts up to a maximum of about 1.3 per cent increases the hardness slightly and the wear resistance considerably. The amount of carbon in tool steels is designed to attain certain properties (such as in the water-hardening category where higher carbon content may be chosen to improve wear resistance, although to the detriment of toughness) or, in the alloyed types of tool steels, in conformance with the other constituents to produce well-balanced metallurgical and performance properties.

Silicon (Si): In itself, silicon may not be considered an alloying element of tool steels, but it is needed as a deoxidizer and improves the hot-forming properties of the steel. In combination with certain alloying elements, the silicon content is sometimes raised to about 2 per cent to increase the strength and toughness of steels used for tools that have to sustain shock loads.

Manganese (Mn): In small amounts, to about 0.90%, manganese is added to reduce brittleness and to improve forgeability. Larger amounts of manganese improve hardenability, permitting oil quenching for non alloyed carbon steels, thus reducing deformation, although with regard to several other properties, manganese is not an equivalent replacement for the regular alloying elements.

Chromium (Cr): This element is added in amounts of several per cent to high-alloy tool steels, and up to 12 per cent to types in which chromium is the major alloying element. Chromium improves hardenability and, together with high carbon, provides both wear resistance and toughness, a combination valuable in certain tool applications. However, high chromium raises the hardening temperature of the tool steel, and thus can make it prone to hardening deformations. A high percentage of chromium also affects the grindability of the tool steel.

Molybdenum (Mo): In small amounts, molybdenum improves certain metallurgical properties of alloy steels such as deep hardening and toughness. It is used often in larger amounts in certain high-speed tool steels to replace tungsten, primarily for economic reasons, often with nearly equivalent results.

Tungsten (W): Tungsten is one of the important alloying elements of tool steels, particularly because of two valuable properties: it improves "hot hardness," that is, the resistance of the steel to the softening effect of elevated temperature, and it forms hard, abrasion-resistant carbides, thus improving the wear properties of tool steels.

Vanadium (V): Vanadium contributes to the refinement of the carbide structure and thus improves the forgeability of alloy tool steels. Vanadium has a very strong tendency to form hard carbide, which improves both the hardness and the wear properties of tool steels. However, a large amount of vanadium carbide makes the grinding of the tool very difficult (causing low grindability).

Very important elements for alloy steels are manganese, nickel, chromium, molybdenum, vanadium, tungsten, silicon, copper, cobalt and boron. All commercial steels contain 0.3-0.8% manganese, to reduce oxides and to counteract the harmful influence of iron sulphide. There is a tendency nowadays to increase the manganese content and reduce the carbon content in order to get steel with an equal tensile strength but improved ductility. Nickel and manganese are very similar in behavior and both lower the eutectoid temperature. Nickel steels are noted for their strength, ductility and toughness, while chromium steels are characterized by their hardness and resistance to wear. Chromium can dissolve in either alpha- or gama-iron, but, in the presence of carbon, the carbides formed are cementite (FeCr)3C in which chromium may rise to more than 15%; chromium carbides (CrFe)3C2 (CrFe)7C3 (CrFe)4C, in which chromium may be replaced by a few per cent, by a maximum of 55% and by 25% respectively. The chrome steels are used wherever extreme hardness is required, such as in dies, ball bearings, plates for safes, rolls, files and tools. The combination of nickel and chromium produces steels having all these properties, some intensified, without the disadvantages associated with the simple alloys. Molybdenum dissolves in both alpha- or gama-iron and in the presence of carbon forms complex carbides (FeMo)6C, Fe21Mo2C6, Mo2C. Molybdenum is also a constituent in some high-speed steels, magnet alloys, heat-resisting and corrosion-resisting steels.