"I hereby declare that I have read this thesis and this thesis is sufficient in term of scope and quality for the reward of the Bachelor's degree of Mechanical Engineering (Structure and Material)"

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Date : 6 MAY 2007

EFFECTS OF CARBURIZING ON MECHANICAL PROPERTIES OF LOW ALLOY 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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ABSTRACT

The report will cover research on of hardness, tensile and compression test before carburizing (Phase 1), carburizing-annealing (Phase 2), and carburizing-quenching-tempering (Phase 3) processes. Estimated better mechanical properties result of carburized specimens was expected compare to uncarburized specimens. The effect of carburizing on the mechanical properties of steel is important in terms of use.

The carburizing treatment on low alloy steel shows brittle behavior. According to compressive results, percentage difference in compressive strength values are – 7.3% (from Phase 1 and Phase 2) and 26.41 % (from Phase 1 and Phase 3) meanwhile, the maximum load differs by -22.41% (from Phase 1 and Phase 2)

This carburizing method more suitable for low carbon steel compared to low alloy steel. According to compressive test result for low carbon steel, the maximum load increase about 30.78% (Phase 1 and Phase 2) and + 33.32% (Phase 1 and Phase 3). And compressive strength value decreases to 14.66% (Phase 1 and Phase 2), 41% (Phase 1 and Phase 3).

ABSTRAK

Kajian projek yang dijalankan adalah merangkumi ujikaji-ujikaji terhadap kekerasan, ketegangan dan pemampatan sebelum penusuk-karbonan (Fasa 1), penusuk-karbonan-'annealing'(Fasa 2), penusuk-karbonan-'quenching'-'tempering' (Fasa 3) proses. Adalah dianggap bahawa keadaan sifat mekanikal selepas proses penusuk-karbonan adalah lebih baik berbanding sebelum proses penusuk-karbonan. Kesan-kesan penusuk-karbonan terhadap sifat mekanikal adalah penting dalam ujikaji ini.

Rawatan penusuk-karbonan terhadap keluli rendah aloi adalah bersifat rapuh. Berdasarkan kepada keputusan pemampatan, data bagi kekuatan mampatan ialah -7.3%MPa (Fasa 1 dan Fasa 2) dan daya maksimum ialah -22.41% kN dan kekuatan mampatan ialah -26%MPa (Fasa 1 dan Fasa 3).

Kaedah penusuk-karbonan adalah lebih sesuai dijalankan terhadap keluli rendah karbon berbanding keluli rendah aloi. Berdasarkan keputusan ujian mampatan bagi keluli rendah karbon, nilai daya maksimum ialah bertambah sebanyak 30.78% kN(Fasa 1 dan Fasa 2) dan 33.32% kN(Fasa 1 dan Fasa 3). Dan nilai kekuatan mampatan berkurangan kepada 14.66%MPa (Fasa 1 dan Fasa 2), 41%MPa(Fasa 1 dan Fasa 3).

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SYMBOL	DEFINITION
A2	Low alloy steel
HRB	Brinell Hardness Number
CO	Carbon monoxide
C	Carbon
Fe	Ferum
$BaBO_3$	Barium Carbonate
K	Kelvin
σ	Stress
ε	Strain
δ	Ferrite
E	Modulus young

CHAPTER 1

INTRODUCTION

1.1 General

Title: Effects of Carburizing on Mechanical Properties of Low Alloy Tool Steel

Steels that contain specified amounts of alloying elements, other than carbon and the commonly accepted amounts of manganese, copper, silicon, sulfur, and phosphorus are known as alloy steels. Alloying elements are added to change mechanical or physical properties. A steel is considered to be an alloy when the maximum of the range given for the content of alloying elements exceeds one or more of these limits: 1.65% Mn, 0.60% Si, or 0.60% Cu; Technically, the term alloy steel is reserved for those steels that contain a modest amount of alloying elements and that usually depend on thermal treatment to develop specific properties' tool and stainless steels are alloy steels. With proper heat treatment, the value of mechanical properties such as tensile strength can be increase.

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. If, 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.

In this research, the material used for heat treatment is low alloy tool steel. The heat treatment will be carried out through pack carburizing process at 850 degree Celsius within 6hours, water quenching, annealing and tempering at 200 to 500 degree Celsius for an hour. The effects of mechanical properties before and after heat treatment would be analyzed through hardness, tensile and compressive experimental.

1.2 Objectives:

The objectives of this research are:

- To study the effects of carburizing on mechanical properties of carburized low alloy tool steel.

1.3 Scope

The scopes of this research are:

- To do literature study on carburizing and related mechanical testing.
- To perform carburizing treatment on low alloy tool steel.
- To carry out mechanical testing such as tensile test and compression test on the material before and after carburizing treatment.
- To compare and discuss the data of carburized low alloy tool steel with the uncarburized one.
- To compare and discuss the mechanical properties of carburize low alloy tool steel with that of carburized low carbon steel.

The research has been carried out in three phases as will be described below:

1.3.1 Phase one: *Mechanical properties before carburizing*

Hardness, tensile and compressive test before heat treatment process were conducted using two types of materials; low alloy steel (A2) and low carbon steel. The results were compared and analyzed to each other.

1.3.2 Phase two: *Carburizing, Annealing and Mechanical properties after carburizing*

Specimens were carburized using pack carburizing method at 850 degree Celsius for 6hours. Annealing process was carried out after carburized and mechanical testing such as tensile and compressive was done on the specimens. The data were analyzed and process modification was suggested and carried out as in third phase.

1.3.3 Phase three: *Carburizing, Quenching, Tempering and Mechanical properties after carburizing*

Specimens were carburized by using pack carburizing method at 850 degree Celsius for 6hours. Quenching and tempering process were carried out after carburizing. Mechanical testing was done on the specimen and the data were analyzed.

1.4 Outline of Research

The research outlines are as follows:

1. Literature review

The theories, concept and reference standard of carburizing, annealing, quenching, tempering and mechanical properties of material were studied from various source such as text books, journals, articles, and world wide web. The literature was presented in Chapter 2.

2. Experimental works

The experimental works were divided into three phases as in section 1.3. This involved Carburizing process, annealing process, quenching process, and tempering process, hardness, tensile and compressive experiments. These experimental works were described in Chapter 3.

3. Data collection and data analysis

Data from all phases were discussed. Hardness, tensile and compressive experiments data before and after heat treatment process were compared and discussed in chapter 4

4. Discussion

All of the results obtained in the research were compiled and discussed in Chapter 5. Conclusion and recommendation for future research were presented in Chapter 6 and 7.

CHAPTER 2

LITERATURE REVIEW

2.1 Alloy tool steel

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive toughness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperature.

Tool steels are made to a number of grades for different applications. Choice of grade depends on, among other things, whether a keen cutting edge is necessary, as in stamping dies, or whether the tool has to withstand impact loading and service conditions encountered with such hand tools as axes, pickaxes, and quarrying implements. In general, the edge temperature under expected use is an important determinant of both composition and required heat treatment. The higher carbon grades are typically used for such applications as stamping dies, metal cutting tools and etc. (internet reference,23/10/2006)

A typical composition is:

Carbon (C)	0.95%
Phosphorus (P)	0.04%
Manganese (Mn)	0.3%
Sulphur (S)	0.04%
Silicon (Si)	0.25%

Table 2.1: A typical composition

TOOL STEEL ALLOY / SPECIFICATION	ANNEALED	HARDENED	CHARACTERISTICS
A-2 / CA-2	20 Rc	47-60 Rc	Medium machinability, toughness & wear resistance
D-2 / CD-2	35 Rc	50-59 Rc	Very good wear resistance / Lower machinability & toughness
H-13 / CH-13	100 Rb	45-53 Rc	Medium machinability & wear resistant

Table 2.2: Tool steel application and characteristic

In general, wear resistance can be improved by increasing the hardness of an alloy, by specifying an alloy with greater carbon content (without increasing hardness), or by both. The surface of flame-hardened, medium-carbon steel, for example, is likely to have poorer wear resistance than the carbon-rich case of a carburized steel of equal hardness. Fully hardened-and-tempered, low-carbon (0.10 to 0.30% C) alloy steels have a good combination of strength and toughness, both at room and low temperature. Care must be taken in heat treatment of certain alloy-steel grades, however, because toughness may be decreased substantially by temper brittleness; a form of brittlement developed by slow cooling through the range of 900 to 600, or by holding or tempering in this range. (Internet reference,23/10/2006)

2.2 General Mechanical properties of steel

The mechanical properties of metals determine the range of usefulness of the metal and establish the service that can be expected. Mechanical properties are also used to help specify and identify the metals. The most common mechanical properties considered are strength, hardness, ductility, and impact resistance. The following table lists the typical properties of steels at room temperature (25°C). The wide ranges of ultimate tensile strength, yield strength, and hardness are largely due to different heat treatment conditions. (Internet reference,23/10/2006)

Properties	Carbon Steels	Alloy Steels	Stainless Steels	Tool Steels
Density (1000 kg/m^3)	7.85	7.85	7.75-8.1	7.72-8.0
Elastic Modulus (GPa)	190-210	190-210	190-210	190-210
Poisson's Ratio	0.27-0.3	0.27-0.3	0.27-0.3	0.27-0.3
Thermal Expansion (10^{-6}/K)	11-16.6	9.0-15	9.0-20.7	9.4-15.1
Melting Point (°C)			1371-1454	
Thermal Conductivity (W/m-K)	24.3-65.2	26-48.6	11.2-36.7	19.9-48.3
Specific Heat (J/kg-K)	450-2081	452-1499	420-500	
Electrical Resistivity (10^{-9}W-m)	130-1250	210-1251	75.7-1020	
Tensile Strength (MPa)	276-1882	758-1882	515-827	640-2000
Yield Strength (MPa)	186-758	366-1793	207-552	380-440
Percent Elongation (%)	10-32	4-31	12-40	5-25
Hardness (Brinell 3000kg)	86-388	149-627	137-595	210-620

Table 2.3: Properties of materials

An understanding of tool material properties, combined with an understanding of which factors limit tool life for a particular tool (breakage, wear, deformation, etc.), will allow tool users to specify the best performing grade for nearly any application. Tool users can examine failed tools to determine which properties may have been lacking in a tool, which properties should be improved and which other properties must be considered in alternate materials.

2.2.1 Tensile Strength

Tensile strength is defined as the maximum load in tension a material will withstand before fracturing, or the ability of a material to resist being pulled apart by opposing forces. Also known as ultimate strength, it is the maximum strength developed in a metal in a tension test. (*ASM Handbook, Vol. 8, Mechanical Testing and Evaluation)*

2.2.2 Compressive strength

Compressive strength is the maximum load in compression a material will withstand before a predetermined amount of deformation, or the ability of a material to withstand pressures acting in a given plane. The compressive strength of both cast iron and concrete are greater than their tensile strength. *(ASM Handbook, Vol. 8, Mechanical Testing and Evaluation)*

2.2.3 Elasticity and modulus elasticity

Elasticity is the ability of metal to return to its original size, shape, and dimensions after being deformed, stretched, or pulled out of shape. The elastic limit is the point at which permanent damage starts. The yield point is the point at which definite damage occurs with little or no increase in load. *(ASM Handbook, Vol. 8, Mechanical Testing and Evaluation)*

2.2.4 Ductility

The ductility of a metal is that property which allows it to be stretched or otherwise changed in shape without breaking, and to retain the changed shape after the load has been removed. It is the ability of a material, such as copper, to be drawn or stretched permanently without fracture. The ductility of a metal can be determined by the tensile test by determining the percentage of elongation. The lack of ductility is brittleness or the lack of showing any permanent damage before the metal cracks or breaks. *(ASM Handbook, Vol. 8, Mechanical Testing and Evaluation)*

2.2.5 Hardness

Hardness is the ability of a metal to resist penetration and wear by another metal or material. It takes a combination of hardness and toughness to withstand heavy loading. The hardness of a metal limits the ease with which it can be machined, since toughness decreases as hardness increases. *(ASM Handbook, Vol. 8, Mechanical Testing and Evaluation)*

2.3 Heat Treatment

The processes of surface treatments, more formally surface engineering, tailor the surfaces of engineering materials to:

- control friction and wear,
- improve corrosion resistance,
- change physical property, *e.g., conductivity, and reflection,*
- alter dimension,
- vary appearance, *e.g., color and roughness,*
- Reduce cost.

Ultimately, the functions and/or service lives of the materials can be improved. Common surface treatments can be divided into two major categories: treatments that cover the surfaces and treatments that alter the surfaces.

2.3.1 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 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. If, 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 reference,11/1/2006)

Carburizing methods include:

- Gas carburizing
- Vacuum carburizing
- Plasma carburizing
- Salt bath carburizing
- Pack carburizing