‘I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the reward of the Bachelor’s degree of Mechanical Engineering (Structure and Materials)’

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Date : MAY 2007

EFFECTS OF CARBURIZING ON MECHANICAL PROPERTIES OF LOW CARBON STEEL

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Mei 2007

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

Signature : ....

Autjor's Name : NOR AZRIN BINTI NOZMI

Date : MAY 2007

Dedicated to my dear parents and family

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ABSTRACT

Carburizing 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. In this research, studies on the effects of carburizing on mechanical properties of carburized steel were the main objective. Carburizing process was conducted at temperature of 850 °C and time of 6 hours. This research reports the effect of carburizing on mechanical properties, includes the hardness, compression, and tensile strength of low carbon steel. As for comparison data, the surface hardness was in the range of 75.3 HRB to 76.8 HRB. It is however showed significantly higher after carburized with value in the range of 97.2 HRB to 99.3 HRB. The stress determine from tensile test before carburized was found to be higher at 531.07 MPa, compared after carburized at 507.44 MPa, respectively. Fortunately the strength shows increment from 467.72 MPa before carburized to 536.30 MPa after carburized. Carburizing process is then continued by annealing and quenching-tempering process to improve the brittleness of specimen and as a precaution to obtain better result. The overall results from the study show that the carburizing process can significantly improve the mechanical properties of Low Carbon Steel. And for this research, result has shown that carburizing increased the surface hardness of low carbon steel.

ABSTRAK

Penusukkarbonan adalah salah satu proses pengerasan permukaan keluli dimana karbon ditambah ke permukaan keluli berkarbon rendah untuk kegunaan tertentu. Proses ini memberi nilai karbon di bahagian permukaan lebih tinggi daripada bahagian dalam bahan. Atas alasan ini, kajian terhadap kesan penusukkarbonan ke atas sifat mekanikal seperti kekerasan bahan, kemampatan, dan ketegangan keluli berkarbon rendah dilakukan.. Proses penusukkarbonan ini dilakukan pada suhu 850°C selama 6 jam. Sebagai perbandingan data, kekerasan asal permukaan keluli berkarbon rendah ini ialah antara 75.3HRB hingga 76.8HRB. Namun, nilai ini menunjukkan peningkatan selepas menjalani proses penusukkarbonan iaitu diantara 97.2 HRB hingga 99.3 HRB. Bagi sifat kemampatan pula, kekuatan bahan setelah penusukkarbonan adalah 536.30 MPa berbanding sebelumnya iaitu 467.72 MPa manakala bagi sifat ketegangan bahan pula, nilai sebelum ujikaji adalah 531.07 MPa dan berkurang kepada 507.44 MPa selepas proses penusukkarbonan. Proses ini kemudiannya diteruskan dengan proses '*annealing*' iaitu proses penyejukan secara perlahan-lahan selepas dipanaskan untuk ditempa; dan proses '*quenching – tempering*' iaitu penyejukan dengan membenamkan keluli ke dalam minyak dan seterusnya memanaskan semula pada suhu tertentu. Proses ini dilakukan sebagai langkah pindaan terhadap sifat keluli bahan khususnya kerapuhan bagi mendapatkan keputusan yang lebih baik. Secara keseluruhan, proses penusukkarbonan ini menunjukkan peningkatan terhadap sifat mekanikal bahan dan dapat meningkatkan kekerasan permukaan terhadap keluli berkarbon rendah ini.

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LIST OF SYMBOLS

SYMBOL	DEFINITION
σ	Stress
P	Load
A	Area
ε	Strain
L	Length
E	Modulus Elasticity
AISI 1020	Low Carbon Steel
A2	Low Alloy Tool Steel
HRB	Brinell Hardness Number
°C	Degree Celcius
K	Kelvin

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CHAPTER 1

INTRODUCTION

1.1 Background

Carburization is the name of the process by which carbon is introduced into a metal. The carbon diffused into the surface is intended to make the surface harder and more abrasion resistant. (Wikipedia, 15/12/2006). Carburization of steel generally involves a heat treatment of the metallic surface using a gaseous, liquid, and solid or plasma source of carbon. Early carburization used a direct application of charcoal packed onto the metal, but modern techniques apply carbon-bearing gases or plasmas (such as carbon dioxide or methane). The process depends primarily upon ambient gas composition and furnace temperature, which must be carefully controlled, as the heat may also impact the microstructure of the rest of the material. After carburizing, the work is either slow cooled, or quenched directly into various liquid quenches. Quench selection is made to achieve the optimum properties with acceptable levels of dimensional change. Hot oil quenching is preferred for minimal distortion, but may be limited in application by the strength requirements for the product.

Most of the researches done related to carburizing were focused on the metal used such as plain carbon steel, alloy steels, etc. Some are focused on the phenomenon studies. But in this research, the effect of carburizing on mechanical properties, specifically hardness, tensile and compression test is studied. Notice earlier, that there are no researches provides for tensile and compression test results for carburizing before. So it is become an advantage for this research.

From the experimental point of view, the process set up for carburizing is seen to be much easier and safer because using carbon powder pack. In this research, the material used was low carbon steel. Low carbon steel has the same properties as iron, less strong but cheap and easy to shape. The properties of the steel depend on the microstructure. Decreasing the size of the grains and decreasing the amount of pearlite improves the strength, ductility and toughness of the steel. The inclusions can also affect the toughness. Due to this characteristic, surface hardness is perfectly can be performed through carburizing. Table 1.1 below shows the simplification of characteristic of carburizing process with its applications. Carburized of low carbon steel will purposely enrich data on previous experiment as well as expand the application of mechanical properties of carburized low carbon steel in industries. Therefore, the findings of this research will be beneficial in both carburizing process and surface engineering areas.

Table 1.1: Characteristic of carburizing

Process	**Case Characteristics**	**Suitable Steels**	**Applications**
Carburizing	Medium to deep case. Oil quenches to harden case. Surface hardness 675-820 HV (57-62 HRC) after tempering.	Mild, low carbon and low alloy steels.	High surface stress conditions. Mild steels small sections <12mm. Alloy steels large sections

1.2 Objectives

The objective of this research is:

i. To study the effects of carburizing on mechanical properties of carburized low carbon steel.

1.3 Scope

i. To do literature study on carburizing and related mechanical testing.
ii. To do carburizing treatment on low carbon steel AISI 1020.
iii. To carry out tensile test, compression test and other suitable test on the material before and after carburizing treatment.
iv. To compare and discuss the data of carburized and uncarburized carbon steel.
v. To compare and discuss the effects of carburizing on mechanical properties of carburized low carbon steel and low alloy tool steel.

1.4 Outline of Research

The research outlines are as follows:

a) Literature review

The theories and concept of carburizing, carburizing treatment, and related mechanical testing were reviewed from various sources such as journals, text books, World Wide Web, and conferences proceeding. Summary of literatures was presented in Chapter 2.0

b) Experimental works

Experimental works were divided in three categories. This includes testing before, after carburize, and after quenching – annealing process using low carbon steel. The experimental procedures for these categories are described in Chapter 3.0.

c) Methods and Testing

Mechanical testing before and after carburize were measured include quenching - annealing method. This includes hardness test, compression test, and tensile test. The methods or characterization techniques were also described in Chapter 3.2.

d) Data Evaluation and Data Analysis

Testing result were presented and comparisons between before and after carburize were evaluated and the result were discuss in Chapter 4.0.

e) Discussion

All the results obtained in this research work were compiled and discussed in Chapter 5.0 and followed by conclusion of present study and recommendation for future research were presented in Chapter 6 and Chapter 7 each.

CHAPTER 2

LITERATURE REVIEW

2.1 Definition of Carburizing

Carburization or often referred to as carburizing is the name of the process by which carbon is introduced into a metal. The carbon diffused into the surface is intended to make the surface harder and more abrasion resistant. (Wikipedia, 15/12/2006). Carburizing working as the addition of carbon to the surface of low carbon steels at temperatures generally between 850 and 950°C (1560 and 1740°F), at which austenite, with its high solubility for carbon, is a stable crystal structure (Key-to-Steel, 14/08/2006). Hardening is accomplished when the high-carbon surface layer is quenched or tempered to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low carbon steel core. Figure 2.1 shows the carburizing of low carbon steel to produce a high – carbon, wear resistant surface. Carburizing steels for case hardening usually have 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, surface carbon is often limited to 0.9% because too high carbon content can result in retained austenite and brittle martensite. The lower the carbon content in the steel, the more readily it will absorb carbon during the carburizing process (Key to Steel, 14/12/2006). 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 (Aviation, 16/12/2006). 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. The differential between specimens before and after carburized is shown in Figure 2.2.

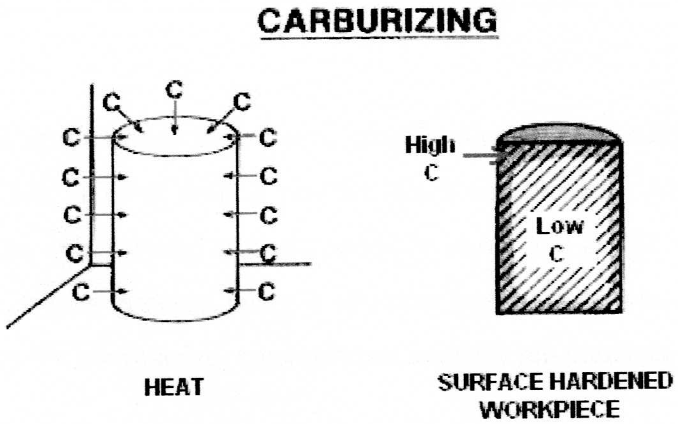

Figure2.1: Carburizing of low carbon steel to produce a high-carbon, wear resistant surface. (Robert H. Todd)

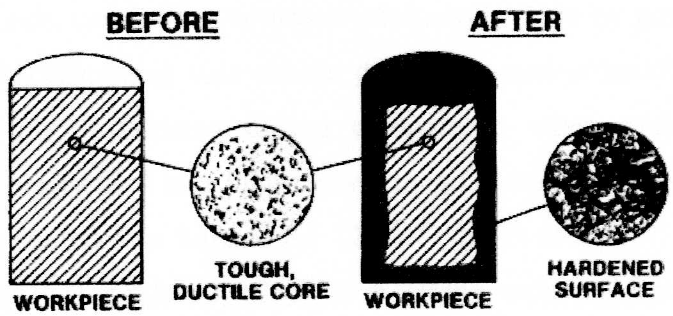

Figure 2.2: Specimen before and after carburized.

2.2 Conventional Carburizing

Two methods are used for carburizing steel. One method consists of heating the steel in a furnace containing a carbon monoxide (CO) atmosphere. The other method has the steel placed in a container packed with charcoal or some other carbon-rich compound and then heated in a furnace. To cool the parts, container may leave in the furnace or remove it and let it air cool. In both cases, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period.

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 (Key to Steel, 15/12/2006). To summarize, conventional carburizing methods include:

- Gas carburizing
- Liquid carburizing
- Pack carburizing

With today's methods, carburizing is almost exclusively done by gas atmospheres. For this research, pack carburizing was chosen due to the easiest handling and the safest method to carry out carburizing testing compare to other method. As for pack carburizing, parts are packed 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 °C (1652 °F). 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 subjected to the normal hardening methods. Some of the problems with pack carburizing are that the process is difficult to control as far as temperature uniformity is concerned, and the heating is inefficient.

2.3 Carburizing Material

Surface hardness can be improved by a process called carburizing which involves heating the alloys in a carbon-rich atmosphere. Low-carbon steels that are usually carburized are AISI 1015, 1018, 1020, and 1117. Low-carbon steels (AISI 1005-1026, 1108-1119, 1211-1215, and 1513-1527), by definition, contains less carbon than other steels and are inherently easier to cold-form due to their soft and ductile nature (eFunda, 18/12/2006). For this research, the selection for low carbon steel AISI 1020 were made. This is due to the composition of carbon that approximately 0.05% to 0.26% carbon content which is lower than other types of carbon steel. Table 2.1 and Table 2.2 present the composition and mechanical properties of low carbon steel AISI 1020.

Table 2.1: Composition of Low Carbon Steel

Element	Weight %
C	0.18 – 0.23
Mn	0.30 – 0.60
P	0.04 (Max)
S	0.05 (Max)

Table 2.2: Mechanical Properties of Low Carbon Steel

Properties		Condition	
		T (°C)	Treatment
Density (x1000 kg/m3)	7.7 – 8.03	25	
Poisson's Ratio	0.27 – 0.30	25	
Elastic Modulus (GPa)	190 - 210	25	
Tensile Strength (Mpa)	394.7	25	(annealed at 870°C more)
Yield Strength (Mpa)	294.8		
Elongation (%)	36.5		
Reduction in Area (%)	66.0		
Hardness (HB)	111	25	(annealed at 870°C more)
Impact Strength (J) (Izod)	123.4	25	(annealed at 870°C more)

Figure 2.3 shows micrograph of low carbon steel. It contains about 0.1% C by weight, alloyed with iron. The steel has two major constituents, which are ferrite and pearlite. The light coloured region of the microstructure is the ferrite. The grain boundaries between the ferrite grains can be seen quite clearly. The dark regions are the pearlite. It is made up from a fine mixture of ferrite and iron carbide, which can be seen as a "wormy" texture. The small spots within the ferrite grains are inclusions or impurities such as oxides and sulphides.

Carbon steel is a very versatile and useful material. It can be machined and worked into complex shapes, has low cost and good mechanical properties. The properties of the steel depend on the microstructure. Decreasing the size of the grains and decreasing the amount of pearlite improves the strength, ductility and toughness of the steel. The inclusions can also affect the toughness. For example, they can encourage ductile fracture. Typical uses are in automobile body panels, tin plate, and wire products.