CARBURIZING EFFECT ON IMPACT TOUGHNESS OF LOW CARBON STEEL

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"I verify that this report is my own work except for the citation and quotation that the source has been clarify for each one of them"

Signature: ……………………………….

Name of writer: …………………………

Date: …………………………………….

To my beloved family

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I would like to give my special acknowledgement to my supervisor, Puan Rafidah binti Hasan for supervising me all the way in conducting the research to fulfill my Projek Sarjana Muda course.

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ABSTRAK

Kajian ilmiah kesan-kesan penyusukkarbonan ke atas ketegaran impak keluli karbon rendah ini dilakukan di bawah kursus Projek Sarjana Muda (PSM) untuk Universiti Teknikal Malaysia Melaka. Kajian ini dikendalikan untuk menentukan sama ada peningkatan kekerasan permukaan melalui proses penyusukkarbonan akan memberikan kesan kepada ketegaran impak keluli karbon rendah. Cara pengkajian adalah berdasarkan perbandingan data hasil ujian impak ke atas keluli yang tidak mengalami penyusukkarbonan dan keluli yang menjalani proses penyusukkarbonan. Proses penyusukkarbonan yang telah dijalankan dikendalikan dengan teratur dan sama bagi setiap spesimen untuk memastikan tiada keraguan atau ralat. Ini adalah untuk memastikan bahawa keputusan kajian adalah tepat dan kesan penyusukkarbonan dapat ditentukan sebaik mungkin. Ujian impak yang telah dilakukan menunjukkan bahawa ketegaran impak keluli karbon rendah yang tidak mengalami proses penyusukkarbonan adalah lebih tinggi berbanding keluli yang ditusukkarbon. Keputusan kajian ini telah dibincangkan sebaiknya di dalam bab 5 bagi memastikan kesahihan keputusan yang diperolehi. Rumusan tentang kajian ini juga telah dilakukan dengan sebaiknya berdasarkan keputusan perbincangan yang dibuat.

ABSTRACT

This research on effect of carburizing on impact toughness of low carbon steel is done under the Projek Sarjana Muda (PSM) course for Universiti Teknikal Malaysia Melaka. This research is conducted to determine whether increasing surface hardness of steel by carburizing process can increase the impact toughness of the steel. The method of investigation is based on comparison of carburized and uncarburized steel impact toughness test data. The carburizing process that has been carried out is conducted properly and similar for each specimen to prevent uncertainties or error the specimen. This is to make sure that the results are accurate and the effect of carburizing can be determined properly. The impact test that has been conducted shows that uncarburized low carbon steel has the higher impact toughness compared to carburized steel. The result has been discussed properly in chapter 5 to make sure that the result is acceptable. The final conclusion has also been made properly referring to discussion result.

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CHAPTER I

INTRODUCTION

1.1 General

Low-carbon steels, by definition, contain less carbon than other steels and are inherently easier to cold-form due to their soft and ductile nature. When strength is not a major concern, low-carbon steels are good choices because they are easy to handle such as to draw, bend, punch and swage and also fairly inexpensive. But, the surface hardness of the steel 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 AISI1015, 1018, 1020, and 1117 (*Internet references,* 23/8/2007).

Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures generally between 850 and 950°C, at which austenite, with its high solubility for carbon, is the stable crystal structure. Hardening is accomplished when the high-carbon surface layer is quenched 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. 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 a carbon content can result in retained austenite and brittle martensite (*Internet references*, 23/8/2007).

The method used to initiate the carbon into the steel has been a matter of continuous evolution. By far the most important methods of carburizing fall broadly into three categories that is pack carburizing which uses solid carburizing compounds as the medium for the carbon supply, liquid carburizing which employs molten cyanide for carbon enrichment of the case and gas carburizing which uses hydrocarbon gases at the source of the carburizing medium (Prabhudev, 2000).

For impact toughness test of the carburize steel, the most suitable test is the Charpy impact test. It is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. The apparatus consists of a pendulum hammer swinging at a notched sample of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after a big fracture. The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of a regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain. This difference can greatly affect conclusions made (*Internet reference*, 11/7/2007).

1.2 Objectives

To study and discuss the effects of carburizing on impact toughness of carburized low carbon steel using statistical analysis.

1.3 Problem Statement

Surface treatment on steel relatively increase surface hardness and decreases its strength and ductility which cannot be tolerated in many industrial applications. As many research studies that are found only focusing on surface hardness and morphology, this research about the effects of carburizing on impact toughness of low carbon steel is done to see the suitability of the steel for dynamic application.

1.4 Scope of research

The scopes of this research are;

1) To carry out carburizing treatment process on low carbon steel
2) To compare the impact toughness of uncarburize and carburize low carbon steel.
3) To compare and discuss the impact toughness test data using statistical analysis

1.5 Outline of research

The outlines of this research are as follow:

1. Literature review.
   Information gain from many sources is collected as a reference to the project.
2. Specimen preparation.
   Learn on the basis of specimen preparation for impact test.
3. Experimental works.
   Experimental work of carburizing the specimen and carry on impact test to the specimen.
4. Data collection and Analysis.
   Data from impact test will be analyzed using statistical analysis and compared between uncarburized with carburized materials.
5. Discussion.
   Discussions on the analytical result obtain.

CHAPTER II

LITERATURE REVIEW

Literature review is collective of data gather from reading, references and also information from the experts relating to the projects which will be review in this chapter. From here, we will understand the purpose of the project and how we are going to achieve the result. So it is important to review the information gain to make sure it will be useful for this project.

2.1 Steel

Steel is the common name for a large family of iron alloys which are easily malleable after the molten stage. Steels are commonly made from iron ore, coal, and limestone. When these raw materials are put into the blast furnace, the result is a "pig iron" which has a composition of iron, carbon, manganese, sulfur, phosphorus, and silicon. As pig iron is hard and brittle, steelmakers must refine the material by purifying it and then adding other elements to strengthen the material. The steel is next deoxidized by a carbon and oxygen reaction. Strongly deoxidized steel is called killed, and a lesser degrees of deoxidized steels are called semi killed, capped, and rimmed (*Internet references*, 23/8/07).

Steels can either be cast directly to shape, or into ingots which are reheated and hot worked into a wrought shape by forging, extrusion, rolling, or other processes. Wrought steels are the most common engineering material used, and come in a variety of forms with different finishes and properties (*Internet references*, 23/8/2007).

2.1.1 Standard steel

According to the chemical compositions, standard steels can be classified into three major groups of carbon steels, alloy steels, and stainless steels. Table 2.1 shows the composition of each group of steel.

Table 2.1: Steel and its composition (*Internet references*, 23/8/2007).

Steels	**Compositions**
Carbon Steels	Alloying elements do not exceed these limits: 1% carbon, 0.6% copper, 1.65% manganese, 0.4% phosphorus, 0.6% silicon, and 0.05% sulfur.
Alloy Steels	Steels that exceed the element limits for carbon steels. Also includes steels that contain elements not found in carbon steels such as nickel, chromium (up to 3.99%), cobalt, etc.
Stainless Steels	Contains at least 10% chromium, with or without other elements. Based on the structures, stainless steels can be grouped into three grades.

2.1.2 Low Carbon Steel

Low-carbon steels as it were defined contain less carbon than other steels and are naturally easier to cold-form due to their soft and ductile nature. When strength is not a most important apprehension, low-carbon steels are good choices because they are practically low-cost and easy to handle. Surface hardness can be enhanced by a process called carburizing which involves heating the alloys in a carbon-loaded atmosphere (*Internet references*, 23/8/2007).

Low carbon steel or mild steel which has approximately 0.05–0.29% carbon content is the most suitable steel for this project. Low carbon steel has a relatively low tensile strength, but it is cheap and malleable as surface hardness can be increased through carburizing. Low carbon steels which is use as the material are steels whose alloying elements do not exceed the following limits:

Table 2.2: Composition for Low Carbon Steel (*Internet References*, 23/8/2007).

Element	**Max weight %**
C	1.00
Mn	1.65
P	0.40
Si	0.60
S	0.05

Low carbon steels which can successfully undergo heat-treatment have carbon content in the range of 0.30–1.70% by weight. Trace impurities of various other elements can have a significant effect on the quality of the resulting steel. Trace amounts of sulfur in particular make the steel red-short. Manganese is often added to improve the hardenability of low carbon steels. These additions turn the material into low alloy steel by some definitions, but AISI's definition of carbon steel allows up to 1.65% manganese by weight.

2.2 Carburizing

Carburizing is a heat treatment process to increase the surface hardness and wear resistance of components which are vital to acquire fairly good impact strength and resistance to wear in service. This is why it is commonly used in surface hardening process of general engineering. A precise method for hardening metallic files, as given by Theophilus Prebyster in the ninth century is a mixture of three parts of horn meal and one part of salt was used on the surface of a heated file which was subsequently reheated and water quenched. (Prabudhev, 2000)

Also stated by Prabhudev (2000), carburizing increases the surface carbon content of low carbon steel (0.1-0.2%C) by 0.7-1% in a carbon medium. This medium can be solid (charcoal), molten salt (cyanide), a gaseous or plasma medium. At low temperatures, carbon will not diffuse into steel. Both the steel and carburizing material must be heated during carburizing to an elevated temperature. In practice, carburizing is done at temperatures between 900^{o}C and 950^{o}C. After carburizing, the components are usually quenched directly or cooled, reheated, and then quenched in oil or in a warm bath, depending on the alloy content of the steel, to get the martensitic water structure. The hardness obtained after carburizing depends on the type of steel used. The hardness value obtained by carburizing usually ranges from 700-900 VHN.

Pack carburizing process consist of packing the component in solid carburizing compound in a suitable box and heating it slowly in a furnace to attain a temperature of about 900^{o}C to 950^{o}C. At this temperature, the oxygen in the air reacts with the carbon present in the carburizing compound to produce carbon monoxide dissociates as given in the following equation:

$$2CO \rightarrow CO_2 + C \text{ (atomic)}$$

The atomic carbon thus formed diffuses into the steel and forms the required case. In order to keep the gas generated by the compound in contact with the steel, it is necessary to pack the parts and the compound in gas-tight containers (*Internet reference*, 23/8/2007).

2.2.1 Theory of carburizing

Carburizing is usually done at an elevated temperature with a chemical agent such as solid or molten salt, gaseous medium, which can supply an adequate quantity of atomic carbon for absorption and diffusion into the steel. This is achieved by heating both the component and the carburizing medium to a pre-determined temperature, usually in the range of 900-950^{o}C. The diffusion of carbon on to the surface layer of steel takes place in its atomic state (Prabhudev K H, 2000).

Prabhudev (2000) in his book stated that during carburizing, three important changes take place. First, the atomic carbon is liberated from the carbonaceous medium. This take place due to the decomposition of carbon monoxide into carbon dioxide and atomic carbon as given below:

$$2CO \rightarrow CO_2 + C_{at}$$

Secondly, the carbon atom from the carburizing agent is transferred to the surface of the steel. Thirdly, the carbon so absorbed by the surface of steel is diffused deep into it. The steel changes its structure fro a body-centered cubic lattice (ferrite) to a face-centered cubic lattice(austenite) at about 720^{o}C.Austenite is capable of dissolving carbon. The longer the time or the higher the temperature, the deeper is the carbon diffusion. At a temperature of 720^{o}C the diffusion of carbon in ferrite (Alpha iron) will be 0.02% and in austenite (gamma iron) it is about 0.8%. With a further rise in temperature to 1130^{o}C, the solubility of carbon will be 2%.

In practice, steel is carburized at 900-950^{o}C, and it is held for several hours to diffuse the carbon into steel. The carbon concentration on the surface layer does not exceed 0.8 to 1 %. The carburized steel consists of three structural zones:

i) Hypereutectoid.
ii) Eutectoid zone.
iii) Hypoeutectoid zone

2.2.2 Characteristic of carburizing

In general, with pack carburizing methods, carbon monoxide breaks down at the steel surface by given equation of:

$$2CO \leftrightarrow CO_2 + C \qquad (2.1)$$

The liberated carbon is readily dissolved by the austenite phase and diffuses into the body of the steel. For some process methods, the carbon dioxide produced may react with the carbon atmosphere or pack charcoal to produce new carbon monoxide by the reverse reaction (*Internet reference*, 23/8/2007).

The theory of pack carburizing as stated by Prabhudev (2000) is at lower temperatures, the atmospheric oxygen combines with the carbon in the carburizing box will produces carbon dioxides. As the temperature is increased, the equilibrium of the reaction is displaced to the right, resulting in a progressive enrichment of the carbon monoxide. Carbon monoxides break at the surface of the steel to produce carbon dioxide and atomic carbon as follows:

$$2CO \rightarrow CO_2 + C \qquad (2.2)$$

The atomic carbon, thus produced, readily dissolves in the austenitic phase of steel, and diffuses into the body of steel. The carbon dioxide formed, in addition to the atomic carbon, reacts again with the carburizing compound. This cycle of reaction is repeated.

In a carburizing box, the amount of atmospheric oxygen can vary, and may be insufficient to produce the carburizing gas. Therefore, in practice, barium carbonate, sodium carbonate and calcium carbonate are added as energizers.

The addition of sodium carbonate as a catalyst to the carburizing compound accelerates the rate of carburization as follows. When the carburizing compound is heated up and held at the carburizing temperature, sodium carbonate reacts with carbon although the temperature may be below the minimum temperature at which direct dissociation into sodium oxide and carbon dioxide can occur.

$$Na_2CO_3 + 2C \rightarrow 2Na + 3CO \qquad (2.3)$$

The sodium vapor generated by the reaction also exerts an important influence because of the marked affinity for carbon dioxide:

$$CO_2 + 2Na \rightarrow Na_2O + CO \qquad (2.4)$$

The sodium oxide thus formed will also tend to absorb carbon dioxide because of the low dissociation pressure of sodium carbonate in relation to the equilibrium pressure of carbon dioxide at the gas-steel interface.

$$Na_2O + CO_2 \rightarrow Na_2CO_3$$

(2.5)

Na_2CO_3, thus formed, is free to reacts with carbon, and the cycle will be repeated indefinitely. Addition of barium carbonate will lead to:

$$BaCO_3 + C \rightarrow BaO + 2CO \qquad (2.6)$$

The carbon monoxide thus formed speeds up the carburization for the same reason as mentioned for sodium carbonate. The carbon-dioxide released during carburization is removed at a faster rate mainly because of the low dissociation pressure of barium carbonate when it reacts with carbon dioxide.

$$BaO + CO_2 \rightarrow BaCO_3$$

(2.7)

The foregoing cycle can be maintained indefinitely. Again, after the carburization temperature has been maintained for a short period of time, a condition of dynamic balance will be established with the reaction occurring simultaneously and continuously.

The action of catalyst such as barium carbonate is due to its dissociation into metallic oxide and carbon dioxide according to the following reaction:

$$BaCO_3 \rightarrow BaO + CO_2 \qquad (2.8)$$

The carbon dioxide, thus released, reacts with the nascent carbon to form carbon monoxide.

$$C + CO_2 \rightarrow 2CO \qquad (2.9)$$

The carbon monoxide formed by the foregoing reaction will react with the steel, resulting in the absorption of carbon by austenite, and by forming carbon dioxide as a byproduct (Prabhudev, 2000).

$$2CO \rightarrow CO_2 + C \text{ (in austenite)} \qquad (2.10)$$

2.2.3 Mechanism of Carburizing

2.2.3.1 Compound

Carburizing compounds used for pack carburizing should be in the form of solids. These compounds are mixtures of materials which, when heated, will generate a gas to give its carbon to the steel. The process of carbon transfer from the carburizing compound to the steel surface takes place at different speeds depending on the composition and structure of the carburizing compound. The compounds usually consist of a carbon carrier (carburizers), an energizer or activator, and a binding agent. The popular carburizers used are activated charcoal, coal, semicoke and peak coke. Powdered coke may be added to the charcoal to the extent of about 20% of the total volume. The advantages of using coke-based compound are its higher heat conductivity and low dusting losses as compared to a pure charcoal-based compound.

Energizers used in carburizing compounds consist either uniquely of a carbonate or admixture of various carbonate. Carbonates of barium, sodium, and calcium are used in a definite proportion. Barium carbonate, for example, is usually compounded with carbon by mixing the whole mass with a suitable binder, whereas sodium carbonate may be applied to carbon as an aqueous solution following by drying. Compounds made using tar or molasses as energizers to bind energizers are more defective (Prabudhev, 2000).

2.2.3.2 Carburizing Containers

Containers used for pack carburizing are made of heat resistant steel or plain structural carbon or aluminum-coated carbon steels. It is now a general practice to employs such alloys either in the cast form or as welded pressings with suitable ribs. The containers made of heat resisting materials are most economical in the long run for a large number of part having similar shapes. The containers made of carbon steels will develop scales during carburizing and will have shorter life, but there are more economical for processing odd lots and unusual shapes (Prabhudev, 2000).

2.2.3.3 Furnaces

The furnaces used for pack carburizing can be either batch type furnaces such as muffle furnace or continuous type furnace. The continuous type furnaces may have pre-heating, carburizing and a post-carburizing zone permits the carbon to diffuse in the case and the temperature of the parts to be reduced before final treatment. The most essential requirement of pack carburizing furnaces is their ability to supply a steady and uniform temperature (Prabhudev, 2000).