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QUENCHING-TEMPERING EFFECTS ON HARDNESS AND COMPRESSION STRENGTH OF CARBURIZED LOW CARBON STEEL

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ABSTRACT

Variety of techniques and technologies has been applied in the heat treatment of steels since long time before. The objective of the steel's heat treatment is to alter some of their properties to be fit with the application of the steels. This project studied the hardness and compression strength of heat treated low carbon steels using statistical analysis. The heat treatment that has been carried out on the low carbon steel are carburizing, quenching and tempering. The carburizing process is the pack carburizing with wilcarbo powder as the carburizing agent. Oil quenching and tempering were applied to the low carbon steel after the carburizing process. In order to determine the hardness and compression strength of the treated low carbon steel, Rockwell hardness test and compression test were used. The test results of the mechanical testing of the untreated and heat treated low carbon steel were compared and analysed using hypothesis test .The results of the hardness and compression strength together with the hypothesis test results were discussed and finally the findings of the studies were concluded .

ABSTRAK

Pelbagai teknik dan teknologi telah diaplikasikan di dalam rawatan haba untuk keluli sejak sekian lama. Objektif rawatan haba ke atas keluli adalah untuk memperbaik sesetengah sifat keluli untuk disesuaikan dengan penggunaannya. Tujuan projek ini adalah untuk mengkaji kekerasan dan kekuatan mampatan keluli karbon rendah yang telah diberi rawatan haba dengan analisis statistik. Rawatan haba yang telah dilakukan ke atas keluli karbon rendah adalah penusukkarbonan, sepuh-lindap dan pembajaan. Proses penusukkarbonan yang telah dilakukan adalah menggunakan serbuk wilcarbo sebagai ejen karbon. Setelah penusukkarbonan, keluli karbon rendah itu diberi rawatan sepuh-lindap dan pembajaan. Untuk mengkaji kekerasan dan kekuatan mampatan keluli karbon rendah yang telah diberi rawatan haba, ujian kekerasan Rockwell dan ujian mampatan akan dilakukan. Keputusan ujian mekanikal keluli karbon rendah yang tidak dan telah diberi rawatan haba dibandingkan dan dianalisis dengan menggunakan ujian hipotesis .Keputusan daripada ujian-ujian tersebut dikaji dan dibincangkan dan akhirnya hasil daripada projek dan kajian ini disimpulkan.

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LIST OF ABBREVIATION

1. AISI (The American Iron and Steel Institute)
2. ASTM (American Standard Testing Method)
3. BHN (Brinell Hardness Number)
4. VHN (Vickers Hardness Number)
5. CNC (Computer Numerical Control)
6. HRB (Rockwell B Hardness)
7. HRC (Rockwell C Hardness)
8. UTM (Universal Testing Machine)
9. C (Carbon)
10. CO (Carbon monoxide)
11. CO_2 (Carbon dioxide)
12. LAS (Low alloy steel)
13. LCS (Low carbon steel)

CHAPTER 1

INTRODUCTION

1.1 Overview

Carbon steel is the most common commercial steel alloy. Carbon steel type is widely used for engineering materials such as fabricating structural steel for buildings and automation. This is due to their versatility and low cost. Carbon steel hardenability was adequate enough for many parts application, though less than alloy steels. However, new techniques and refinement in heat treatment method made it possible to obtain higher properties for carbon steels than previously. Furthermore, more new compositions were added to the carbon steel permitting more discriminating selection.

Plain carbon steel which are usually steels with iron less than 1 percent carbon and plus small amounts of manganese, phosphorus , sulfur and silicon. The weldability and other characteristics of these steels are primarily a product of carbon content , although the alloying and residual elements do have a minor influence This plain carbon steel can be categorized into four groups which are low, medium, high and very high carbon steel. Low carbon steel which often called mild steels are most commonly used grades with less than 0.30 percent carbon. This type of carbon steel has almost the same properties as iron , soft but easily formed. Thus it can be machined and welded nicely and also more ductile compared to higher carbon steels. (*Internet reference*, 15 August 2007).

However for some other mean, harder steel is needed and this is done with carburizing. Carburizing can be defined as a process of adding carbon to the surface layer of the steel. Increasing carbon content in steel generally increases hardness and strength thus improves hardenability of the steel. However the higher content of the carbon also increases brittleness and also reduces weldability (*Internet reference*, 15 August 2007).

Therefore, heat treatment such as carburizing need to be done on plain carbon steel according to its application. The purpose of heat treating the plain carbon steel is to change the mechanical properties of steel such as hardness and wear resistance.

In this project, statistical analysis will be done on hardness and compression strength of low carbon steel before and after heat treatment, specifically carburizing , quenching and tempering processes .

1.2 Objective

The objective of the project is to study and discuss the effects of quenching-tempering processes on hardness and compression strength of carburized low carbon steel using statistical analysis.

1.3 Scopes

a) To do literature study on carburizing process
b) To carry out carburizing treatment , carburizing-normalizing , carburizing quenching-normalizing , carburizing-quenching-tempering-normalizing on low carbon steel
c) To carry out hardness and compression test on the material, before and after treatments
d) To compare the data using statistical analysis in order to propose a better carburizing treatment process.

1.4 Problem statement

Steel is one of the most common materials in the world and is a major component in buildings, tools, automobiles, and appliances. Modern steel is generally identified by various grades of steel defined by various standards organizations. The usage of steels as major components in different type of field such as in the construction of roads, railways, infrastructure and buildings allows further refinement in the steel industries. Thus, steels are designed and produced according to certain specific, desirable characteristics, including strength, formability, and wear resistance.

Solution heat treatment of steel is done usually to increase the strength of steel. The term heat-treatment embraces many processes employing combinations of heating and cooling operations to the components so as to produce desired mechanical properties, with attendant characteristics related to particular types of in-service applications. Steel are particularly suitable for heat treatment since they respond well to heat treatment and the commercial use of steels exceed that of any other material.

Carburizing effects, as one of the heat treatment process , has been studied on various material such as low carbon steel and low alloy steel. This study on the low carbon steel is done not only to analyse the effects of carburizing itself but also included the quenching and tempering phases to the carburized material which enhanced the previous study of carburized material.

CHAPTER 2

LITERATURE REVIEW

2.1 Carbon steel

Carbon steel is the most important commercial steel alloy. The group of carbon steel type is widely used for engineering material such as for fabricating structural steel. The American Iron and Steel Institute (AISI) defines carbon steel as follows; steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, columbium (niobium), molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 per cent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60(Chapman ,2004).

In other source carbon steel is defined as carbon steel when its alloying elements do not exceed limits 1% carbon, 0.6% copper, 1.65% manganese, 0.4% phosphorus, 0.6% silicon, and 0.05% sulfur (*Internet reference*, 16 August 2007).

The commercial steel group is classified into three groups which are plain carbon steels, low alloy steels and high alloy steels. The plain carbon steels usually are iron with less than 1 percent carbon, plus small amounts of manganese, phosphorus, sulfur, and silicon. The plain carbon steel are further subdivided into four groups which are low, medium, high and very high according to their carbon contents (*Internet reference*, 15 August 2007).

2.1.1 Low carbon steel

Low carbon steel is defined as an iron-carbon alloy containing about 0.05 to 0.25% carbon and up to about 0.7 % manganese (Tomsic and Horder, 2000). Low carbon steels often called mild steels, are the most commonly used grades when strength is not a major concern because it can be machine and weld nicely, more ductile than higher-carbon steels and fairly inexpensive. However, the properties of this low carbon steel can be modify or alter with heat treatment processes to achieve the desirable properties for a specific function. Carburizing is a common treatment applied to the low carbon steel to improve the surface hardness of the steel. Low-carbon steels that are usually carburized are AISI 1015, 1018, 1020, and 1117 (*Internet reference*, 17 August 2007).

2.1.2 Medium carbon steel

Medium-carbon steels have from 0.30 to 0.45 percent carbon. Increased carbon means increased hardness and tensile strength, decreased ductility, and more difficult machining (*Internet reference*, 15 August 2007).

2.1.3 High carbon steel

With 0.45 to 0.75 percent carbon, these steels can be challenging to weld. Preheating, postheating (to control cooling rate), and sometimes even heating during welding become necessary to produce acceptable welds and to control the mechanical properties of the steel after welding (*Internet reference*, 15 August 2007).

2.1.4 Very high carbon steel

With up to 1.50 percent carbon content, very high-carbon steels are used for hard steel products such as metal cutting tools and truck springs. Like high-carbon steels, they require heat treating before, during, and after welding to maintain their mechanical properties (*Internet reference*, 15 August 2007).

2.2 Heat treatment

According to Chapman (2004), heat treatment is the operation or series of operations of heating and cooling a metal or alloy in the solid state to develop specific desired properties or characteristics.

In another source, heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. It is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability and restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics (*Internet reference*, 17August 2007).

Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material. Steels are heat treated for one of the reasons which could be for softening, hardening or material modification. Heat treatment techniques include annealing, surface hardening, precipitation strengthening, tempering, quenching and normalizing (*Internet reference*, 17August 2007).

Hardening of steels is done to increase the strength and wear properties. One of the pre-requisites for hardening is sufficient carbon and alloy content. If there is sufficient carbon content then the steel can be directly hardened. Otherwise the surface of the part has to be carbon enriched using some diffusion treatment hardening techniques. In the case of low carbon steel which the carbon content is less than 0.25 %, the alternate means exists is to increase the carbon content of the surface. However, important to note that this method will only allow hardening on the surface but not in the core, because the high carbon content is only on the surface (*Internet reference*, 17August 2007).

Rajput (2000), cited that heat treatments is generally employed for following purposes :

a) To improve machinability.
b) To change or refine grain size.
c) To relieve the stresses of the metal induced during cold or hot working.
d) To improve mechanical properties such as tensile strength, hardness, ductility, and shock resistance to corrosion.
e) To improve mechanical and electrical properties.
f) To increase resistance to wear, heat and corrosion.
g) To produce a hard surface on a ductile interior.

2.2.1 Surface hardening

Horath (2001), declared that for many engineering purpose it is desirable for parts to have a hard surface to resist wear and abrasion and the inner portion remains soft and tough to sustain impact loading. This depth of the hardened surface is normally from 0.0001 mm to a few mm depending on applications. Surface hardening is used on parts such as gear teeth, cutting wheels and tools. There are four different methods of surface hardening which are carburizing, nitriding, cyaniding and carbonitriding.

Surface hardening is the most common form of heat treatment because heating can be localized to the areas where the metallurgical changes are desired. This process is a complex combination of electromagnetic, heat transfer and metallurgical phenomena that occur when a workpiece is heated rapidly to a temperature above that required to form a phase transformation and then rapidly quenched. The goal of case surface hardening is to increase hardness and wear resistance on the certain areas while allowing the remainder of the part to be unaffected by the process (Totten, 2007). In conjunction with that, Tiemens (2006), stated that by only hardening the outer surface, overall toughness and impact resistance can be maintained through the softer core while the hardened case resists contact fatigue and general wear.

2.2.2 Tempering

Tomsic and Horder (2000), defines tempering as reheating a quench-hardened or normalized ferrous alloy to a temperature below the transformation range and then cooling at any desired rate. The tempering process takes place after steel is hardened, but is no less important in metal heat treatment. Tempering temperatures are usually below the lower transformation temperature.

Totten (2007) stated that the main purpose of tempering is to increase the steel's toughness, yield strength and ductility, to relieve internal stresses, to improve homogenization, and to eliminate brittleness. As discussed before, in surface hardening, only a thin surface layer of workpiece is heated. The surface is raised to a relatively high temperature and this significant surface-to-core temperature difference and steel transformation phenomena results in the buildup of internal stresses. Reheating the steel for tempering after hardening and quenching leads to a decrease or relaxation of these internal stresses. In other words, because of tempering it is possible to improve the mechanical properties of the workpiece and to reduce the stresses caused by the previous heat treatment stage without losing too much of the achieved hardness.

There is a misconception that tempering removes all the internal stresses. It does not, but tempering significantly decreases stresses. Tempering makes the steel softer and reduces the chance of distortion and the possibility of cracking. If tempering has been done correctly, there will be only a slight loss in hardness. The benefits obtained, such as internal stress relieved, the creation of the required ductility or toughness, shifting of the dangerous maximum of tensile stresses, which is located under the hardened surface layer further down toward the core of the workpiece, and improvement in the machinability of the steel , will offset the slight reduction in hardness (Totten, 2007).

2.2.3 Quenching

Quenching usually thought to mean cooling from an elevated temperature more rapidly than would occur in still air (Tomsic and Horder, 2000). Totten, 2007 cited in his book that quenching is one of the most critical processes in the overall heat treatment operation. It is essential to achieve the necessary heat transfer rates and optimal uniformity of the heat transfer process if the desired steel transformation is to be obtained.

Quenching is rapid cooling from a high temperature by immersion in a liquid bath of oil or water. Metals are quenched using air, water, oil, or liquid polymers to obtain certain hardness and mechanical properties requirements. Quenching is generally done by cooling at a sufficiently high rate to avoid undesirable internal microstructure as well as to ensure uniform mechanical properties, minimize residual stresses, and avoid warpage. The main challenges face by the industry is to maintain a uniform quench rate together with a required agitation near all the surfaces of all the parts. Non-uniform cooling would lead to residual stresses and then to warpage of the parts (*Internet reference*, 12 September 2007).

Oil usually is used to quench high-speed and oil-hardened steels and is preferred for all other steels provided that the required hardness can be obtained.. Oil is classed as an intermediate quench. It has a slower cooling rate than brine or water