STUDY ON THICKNESS EFFECTS OF LOW CARBON STEEL IN RAPID COOLING PROCESS

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ABSTRACT

Hot stamping is among the latest technology applied in sheet metal manufacturing. It is a combination of a forming and rapid cooling to produce stronger products with the creation of martensite inside the sheet metal components. To cope with a huge range of sheet metal that suitably used for hot forming process, this research investigates microstructure changes during the rapid cooling process of three different sheet metal thicknesses. The Low Carbon Steel specimens of 2, 4 and 6mm thick were heated in a furnace to austenite region before immediately quenched in water and normalized in air. During the process, cooling rates were measured with acquisition system. The quenched specimens were observed using metallurgical microscope. The results show that water quench produced martensite structures while air quench produced pearlite and ferrite structures. The 2mm specimen of water quench formed a higher percentage of martensite and compactly bonded structure compared to 4mm and 6 mm specimens' structure. For the air quench, 2mm specimen formed finely dispersed pearlite and ferrite. However, the microstructure of 4mm and 6mm specimens' shows coarse pearlite and ferrite with lower hardness surface.

ABSTRAK

Proses pembuatan bersuhu panas ke atas logam adalah antara teknologi terkini yang digunakan dalam industri pembuatan. Ia adalah gabungan pembentukan dan proses penyejukan pantas untuk menghasilkan produk lebih kukuh dengan penciptaan martensit di dalam komponen yang dihasilkan dari lembaran logam. Untuk berhadapan dengan pelbagai besar kepingan logam yang sesuai digunakan untuk proses pembentukan panas, kajian ini mengkaji perubahan mikrostruktur semasa proses penyejukan pada tiga kepingan logam yang berlainan ketebalan. Spesimen keluli carbon rendah daripada ketebalan 2, 4 dan 6mm telah dipanaskan dalam relau sehingga mencapai fasa austenit sebelum segera disejukkan dalam media penyejukan iaitu air dan udara. Semasa proses penyejukan, kadar penyejukkan setiap specimen telah diukur dengan sistem pemerolehan data. Mikrostruktur dalam spesimen telah di analisis menggunakan mikroskop metalurgi. Keputusan menunjukkan bahawa air lindap kejut menghasilkan struktur martensit manakala udara lindap kejut menghasilkan struktur pearlit dan ferit. Spesimen berketebalan 2mm pada proses air lindap kejut membentuk peratusan martensit yang lebih tinggi dan struktur yang kemas terikat dengan kekerasan permukaan yang tinggi berbanding mikrostuktur yang dihasilkan oleh specimen 4mm dan 6mm. Bagi lindap kejut udara, spesimen 2mm membentuk taburan halus pearlit dan ferit. Walau bagaimanapun, mikrostruktur 4mm dan 6mm spesimen menghasilkan pearlit dan ferit yang kasar dengan kekerasan permukaan yang lebih rendah.

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LIST OF SYMBOLS

γ	Austenite Phase
α	Ferrite Phase
T_e	Eutectoid Temperature
M_s	Martensite Start
M_f	Martensite Finish
C	Carbon
Fe	Ferrous
Si	Silicon
Mn	Manganese
P	Phosphorus
S	Sulphur
Cr	Chromium
Mo	Molybdenum
Ni	Nickel
Al	Aluminum
Co	Cobalt
Cu	Copper
Nb	Niobium
Ti	Titanium
V	Vanadium
Pb	Plumbum
Sn	Stannum

B	Boron
Ca	Calcium
Zr	Zirconium
As	Arsenic
Bi	Bismuth
Fe_3C	Cementite

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
BCC	Body-centered Cubic
BCT	Body-centered Cubic
CCT	Continuous-cooling Time
EDM	Electric-discharged Machine
FCC	Face-centered Cubic
ISA	Instrument Society of America
NI	National Instrument

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Process of manufacturing activities can be improved by the understanding of microstructure characteristic of the used material. In this case, the most useful material is metals where their material properties are usually determined by tests. As a mechanical engineer, it is necessary to engage in testing work to have a general understanding of the common methods of properties test of metals. From an engineering point of view, the mechanical properties are the most important requirement in selecting material for design purpose. Mechanical properties and microstructure of metals describes their behavior under mechanical and physical usage.

Generally, the applications of metals have been studied a long time ago. Since the Iron Age, metal have been practically used in daily life and become very important in the development of industry. The ability to withstand service for higher loadings without permanently deforms and ruptures. In the other hand, the ability of metal undergoes large permanent deformation, thus permitting the formation of different shapes under the application of proper forces [Izabel, 2005]. Plenty of studies have been done on metal, so the microstructures of most metals are well identified as well as the effects of heat treatment in altering their mechanical properties.

The most popular metal is known as carbon steel. Carbon steel is being divided as low carbon steel, medium carbon steel and high carbon steel which based on the carbon content. Normally carbon steel is not enough hard to use in certain manufacturing. Therefore heat treatment is important process to improve the mechanical properties of the carbon steel. The common forms of heat treatment for steels are hardening, tempering, annealing, normalizing and case hardening [Krauss, 1989].

The different mechanical properties of carbon steels will be resulted as different microstructures formed during cooling. Furthermore, the diffusionless transformations obtain the martensite formation which is the highest hardness in iron-carbon system and the lowest hardness is obtained due to a diffusion transformation, which cause the ferrite and/or pearlite formation by a eutectoid reaction. Martensite is obtained during rapid cooling while ferrite and pearlite obtained from austenite during slow cooling near the equilibrium. Therefore, both steel microstructure and mechanical properties are related to steel thermal history [W. Wen, 2005]. Pressure also has an influence on stability of phase of equilibrium. However, this parameter is not usually taken in account, mainly in solid state reaction. It is because the influence of pressure is limited [Jokhio *et al.,* 2000].

Low carbon steel as one of engineering material that has been selected in this project is to investigate the comparison of the effects on thickness of material of rapid cooling process and develop a mechanical data of low carbon steel after the heat treatment. This material have been chosen because this type of steel is mostly used for deep drawing of motor car bodies, motor cycle parts, and other domestic applications where it is must involved the desired mechanical properties processes.

From the engineering material theory, the required properties of material can be changed by manufacturing process and heat treatment process method. Therefore the present work was planned to investigate the relationship between thickness, microstructure, mechanical properties, and heat treatment for intelligent selection of manufacturing process, properties, and application for particular purpose [Sim *et al,*. 2004].

1.2 PROBLEM STATEMENT

This project is being undertaken to compare microstructure effects of different thickness on metal in rapid cooling process. In present day, new approaches of manufacturing process have been introduced. For example, the application of hot stamping technique is used to form many types of car component. This process involves thermo mechanical effects where the sheet metal parts are quenched after forming process to improve the mechanical properties. It is important to investigate the thickness effects on microstructure development.

1.3 OBJECTIVES

The aim of this research is to understand the mechanism of investigation microstructures changes during rapid cooling process of different sheet metal thicknesses. In order to achieve the objectives, the approach to the research has been determined as listed below:

1) To conduct experiment of rapid cooling process on low carbon steel
2) To identify the material composition of low carbon steel
3) To investigate the microstructure effect after water quenching and air cooling process with different thickness
4) To determine the effect of material thickness on surface hardness

1.4 PROJECT BACKGROUND

Quenching is common process to harden the steel. This process are widely used in industry which to obtain the required properties of any application. From this study, the mechanical properties of the specimen from in-received after quenching process with different material thickness can be differentiate. The formation of martensite and pearlite can be analyzed and the investigation of influences of thickness effecting the microstructure and hardness of material.

1.5 PROJECT SCOPE

1.5.1 Literature Reviews

i. Researching and surveying on the paper work that have been made by the previous researcher.
ii. Collect the information related to the project's objectives.

1.5.2 Experiment

i. Planning the methodology flow of experiment.
ii. Specimen preparation of experiment.
iii. Do the experiment to compares the effects of different thickness in two types of different process which are normalizing and quenching
iv. Apply two types of test on the low carbon steel after heat treatment (Microstructure test and Rockwell hardness test).

1.5.3 Analysis of the Experiment

i. Analyze the experiments result and do a comparison related of the experiment.
ii. Summarize the assumption from the research.

1.5.4 Thesis Writing

i. Transfer all the experiment data and results into a form of thesis report including the conclusion of project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Rapid cooling is a process purpose to harden the metals by immersion in oil or water, of a metal object from the high temperature at which it has been shaped. This usually is undertaken to maintain mechanical properties associated with a crystalline structure or phase distribution that would be lost upon slow cooling. The technique is commonly applied to steel objects, to which it imparts hardness. On the other hand, copper objects that have become hardened by hammering or other deformation at ordinary temperatures can be restored to the malleable state by heating and quenching.

2.2 MATERIAL

In this project, low carbon steel has been chosen to serve as experimental material. Low carbon steel is a type of metal that has an alloying element made up of a relatively low amount of carbon. Typically, it has a carbon content that ranges between 0.05% and 0.20% and a manganese content that falls between 0.40 and 1.5%. According to Figure 2.1, Low Carbon Steel can be classified into hypoeutectoid steel based on its carbon content range.

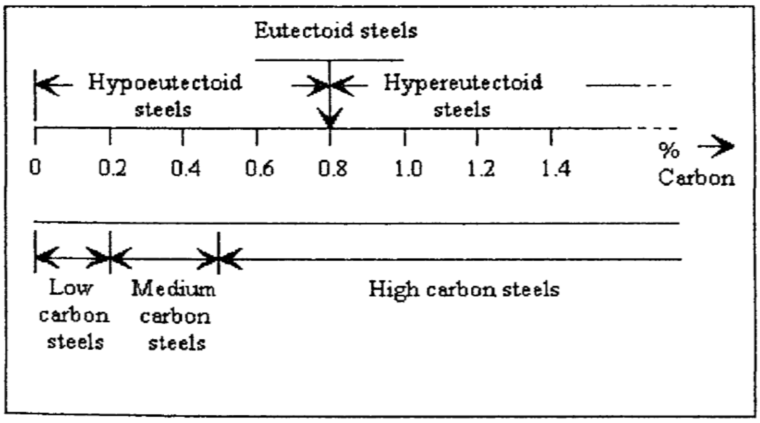

Figure 2.1: Carbon Steel Classification

Source: Ginzel (1995)

Low carbon steel is known as low carbon steel is one of the most common types of steel used for general purposes, in part because it is often less expensive than other types of steel. While the steel contains properties that work well in manufacturing a variety of goods, it is most frequently made into flat-rolled sheet or strips of steel.

Steel with low carbon content has the same properties as iron, soft but easily formed. As carbon content rises the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers steel's melting point and its temperature resistance in general. Carbon content influences the yield strength of steel because they fit into the interstices crystal lattice sites of the body-centered cubic (BCT) arrangement of the iron molecules [Merbaki *et al.,* 2004].

Steel can be heat-treated which allows parts to be fabricated in an easily formable soft state. If enough carbon is present, the alloy can be hardened to increase strength, wear, and impact resistance. Steels are often wrought by cold-working methods, which is the shaping of metal through deformation at a low equilibrium or met a stable temperature.

Table 2.1: Application of Low Carbon Steel based on carbon contain

Carbon Percentage (%)	Applications
0.1-0.2	Chain, stamps, rivets, nails, wire, pipe and where very soft, plastic steel is needed
0.2 – 0.3	Structural steels, machine parts, soft and tough steels and use of case hardened machine part and screw

2.3 HEAT TREATMENT

A combination of times heating and cooling operations which applied to the solid state metal or alloy is called as heat treatment. This method is often used to modify or alter the microstructure and properties of steels. The various types of heat-treating processes are similar because they all involve the heating and cooling of metals. However, they differ in the heating temperatures and the cooling rates used. The final results of each method are different. The usual methods of heat-treating ferrous metals (metals with iron) are annealing, normalizing, hardening, and tempering. Most nonferrous metals can be annealed, but never tempered, normalized, or case-hardened.

According to [Jokio *et al.,* 2005], heat treatment is defined as physical process which entails the controlled heating and cooling of material, such as metal or alloys to obtain desired properties. Heat treating is an energy intensive process that is carried out in different furnaces such as electric and gas. Shortening heat treatment cycles can provide great environment and financial benefits through energy saving. Many texture detail furnace equipment and its design but little to no literature can be found in furnace temperature method [Qiao *et al.,* 2009].

2.4 INTERNAL STRUCTURE AFTER HEAT TREATMENT

2.4.1 Austenite

This phase is only possible in carbon steel at high temperature. It has a Face Center Cubic (FCC) atomic structure which can contain up to 2% carbon in solution.

2.4.2 Ferrite

This phase has a Body Centre Cubic structure (BCC) which can hold very little carbon. Typically 0.0001% at room temperature and can exist as either alpha or delta ferrite.

2.4.3 Carbon

A very small interstitial atom that tends to fit into a cluster of iron atoms. It strengthens steel and gives it the ability to harden by treatment.

2.4.4 Cementite

A very hard intermetallic compound which consisting of 6.7% carbon and the remainder iron. Its chemical symbol is Fe_3C. However, when it is mixed with soft ferrite layers, the average hardness is reduced considerably. Slow cooling gives course pearlite; soft and easy to machine but poor toughness. Faster cooling gives very fine layers of ferrite and cementite which is harder and tougher.

2.4.5 Pearlite

Pearlite is a mixture of alternate strips of ferrite and cementite in single grain. The distance between the plates and their thickness is depending on the cooling rate of the material. Fast cooling will creates thin plates that are close together and slow cooling creates a much coarser structure possessing less toughness. A fully pearlitic structure occurs at 0.8% carbon. Further increases in carbon will create cementite at the grain boundaries, which will start to weaken the steel.

2.4.6 Martensite

Body centered tetragonal (BCT) structure occur when steel is cooled rapidly from austenite, the FCC structure rapidly changes to BCC leaving insufficient time for the carbon to form pearlite. This results in a distorted structure that has the appearance of fine needles. There is no partial transformation associated with martensite, it either form or it doesn’t. However, only the part of the section that cool fast enough will form martensite. In the thick section it will only form to a certain depth, and if the shape is complex it may only form in small pockets. The hardness of martensite is solely dependent on carbon content; it is normally very high, unless the carbon content is exceptionally low.

2.5 NORMALIZING PROCESS

This process can be done by heating the steel to austenite phase and cooling it in the air. In industry, normalizing is applied to eliminate coarse-grained structures obtained in previous working operations such as rolling and forging. Besides, normalizing is purpose to modify and improve the cast dendritic structures and reduce segregation by homogenizing the microstructure. The desired microstructure and mechanical properties can be obtain and improve the machinability of low carbon steel.

In normalizing steel is uniformly heated to a temperature which causes complete transformation to austenite. The steel is held at this temperature for sufficient time for the formation of homogeneous structure throughout its mass. Then, it is allowed to cool in air. Furthermore, normalizing results in the formation of ferrite, cementite and lamellar pearlite. Due to the higher cooling rate in this process, the transformation of austenite is occurring at a lower temperature than in annealing process. Therefore, the transformation of pearlite is finer where having lower interlamellar spacing between the two neighboring of cementite plates compared to anneled steel compared to coarse pearlite [Izabel, 2005].

The amount of pearlite will affect the hardness and strength of steel. The normalized steels are harder and stronger than annealed steels due to the amount of pearlite in normalized steel is more despite having the same carbon content [Saquet *et al.,* 1999]. This differences value of pearlite occurs due to the shifting of eutectoid composition to a lower value. The microstructure of 0.2% carbon steel in normalized condition is shown in Figure 2.2 refers to the researched of *the Effect of Cooling Rate on Hardness and Microstructure of AISI 1020 Steels* [Adnan C., 2009].

In normalizing, the mass of metal has an influence on the cooling rate and on the resulting structure. Thin pieces cool faster and are harder after normalizing than thick ones. In annealing (furnace cooling), the hardness of the two are about the same [Holzcr *et al.*, 1991].

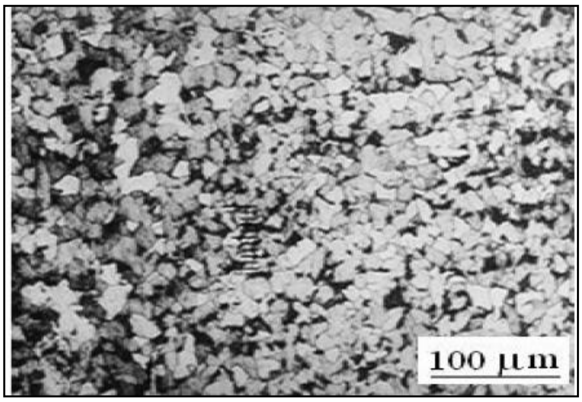

Figure 2.2: The microstructure of 0.2% carbon steel after air cooled. Fine dispersed pearlite (black) and ferrite (white)

Source: Adnan C. (2009)

Since normalizing is a much more economical process, this type of method is extensively used in industry as cooling take place in the air. Some typical examples of normalizing in commercial practice are homogenization of cast and wrought structures, improvement of machinability, grain size refinement of cast structures and stress relieving of castings [Monsanto, 1992].

2.6 QUENCHING PROCESS

Quenching is one of the hardening processes of steel that may be defined as rapid cooling from the austenite phase. The rapid cooling is obtained by immersion of steel in a liquid bath such as water or oil. The rapid cooling of steel from austenite phase results in the formation of meta-stable phase called martensite. The main objective of this process is to increase hardness, strength and wear resistance. Besides,