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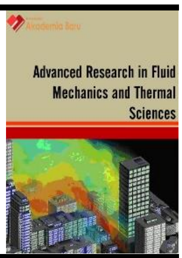

The Influence of Thickness on Low Carbon Steel in Rapid Cooling Process

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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 shows that 2mm specimen is the fastest cooling for both cooling processes compared to 4mm and 6mm specimens. The 2mm specimen of water quench formed a higher percentage of martensite and compactly bonded structure compared to 4mm and 6 mm specimens' structure.

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 [1,2]. 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 [3]. Generally, the applications of metals have been studied a long time ago. Since the Iron Age, metal have been practically used in

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daily life and become very important in the development of industry [4,5]. 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. 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 [6-8]. For every different heat treatment process of low carbon steels, the microstructure of the steel changed. The microstructure is the representation of structural features of steel under microscopic condition. The study of microstructure is also called microscopy or metallography. The various microstructures of carbon steels are often known as cementite, ferrite, pearlite, austenite and martensite. Most of the phase transformations of interest will involve deviations from equilibrium microstructures, resulting in partial transformations and the reaction of mestable phases [9-12]. The microstructure of iron-base alloys is very complicated and diverse, being influenced by chemical composition, material homogeneity, process and section size. Pearlite forms by the solid state transformation front. The ferrite, cementite and austenite can then exist in equilibrium at the eutectoid temperature. In alloy steels as Fe, Mn, and C, three phase equilibrium with austenite. Martensite is a phase when formed by quenching but becomes a constituent after tempering as in decomposes from BCT martensite to BCC ferrite and cementite.

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. 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 has 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 involve the desired mechanical properties processes. 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 [13,14].

The different mechanical properties of carbon steels will be resulted as different microstructures formed during cooling. Furthermore, the diffusion less 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. 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. From the engineering material theory, the required properties of material can be changed by manufacturing process and heat treatment process method [15-18]. 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. This study 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.

2. Methodology

2.1 Materials Preparations

Low carbon steel has been chosen to serve as experimental material because carbon content that ranges between 0.05% and 0.20% and a manganese content that falls between 0.40 and 1.5%. First step was to check the composition of the materials used by using the Arc Spark Spectrometer. Secondly, a steel block of low carbon steel (50 x 50 x 400 mm) was cut into smaller pieces of specimen regarding to the specification of size, thickness and shape required for this project by using EDM Wire Cut. Steel block went through the face milling process to remove the outer coating of the material surface. The cutting tools that should to be used are facing mill and the depth of cut for overall surface is 2.0 mm. The speed of the spindle is 600rpm. Specimens with different thickness, 2mm, 4mm and 6mm were heated to the critical temperature and then allowed to cool with different method. The first method is normalization process which the specimens cool at room temperature after heated. The second method is quenching process where the heat treated specimens are rapidly cooled by immersed into the water bath immediately. Microstructures of each specimen are well observed by using metallurgy microscope.

2.2 Heat Treatment Process

Low carbon steel is primarily heat treated to create matrix microstructures and associated mechanical properties not readily obtained in the as-cast condition. As-cast matrix microstructures usually consist of ferrite or pearlite or combinations of both, depending on cast section size or alloy composition. The specimens heat in the furnace to the temperature of 1000°C. After the heat treatment, the specimens are cut by using the sectional cut off machine. This cutting process is purpose to cut the sectional of specimen for analyzing the internal structure experiment. The black dashed line is the cutting line to be cut while the red circle shows the region of microstructure to be observed. Only one part is taken to do the microstructure test and assuming the microstructure of the other three parts will be the same.

2.3 Microstructure and Composition Analysis

After finishing the etching, the specimen is observed using the microscope to observe the metallurgy in the specimen. During the observation of microstructure of each specimen including untreated specimen, the image was captured by using the Progress Metallurgical Analysis Software through the microscope.

3. Results

3.1 Microstructure and Composition Analysis

Based on Table 1, all six specimens are heated at the same temperature 1000°C measured by using National Instruments data acquisition system. This high temperature of heating is purpose to ensure all of the specimens reach its austenizing temperature which consists of entirely austenite phase on its microstructure [19]. During the heating process, the temperature of specimen reached 1000°C at furnace temperature of 1035°C. It shows the furnace temperature is not equal to temperature of the specimen inside. The temperature difference between a furnace and the specimen is 35°C equivalent to 3.4% reduction of furnace temperature.

Table 1
Several specimens heated at 1000°C

Cooling media	Material thickness (mm)	Heating temperature (°C)
	2	1000
Water Quenched	4	1000
	6	1000
	2	1000
Air Cooled	4	1000
	6	1000

Two types of differential cooling process are involved in this project. Water quenching and air cooling is the cooling method to be studied and compared. According to Figure 1, it shows the result of the temperature history of cooling curve and time taken during water quenching process. Each specimen is heated in the furnace at 1000°C reached its austenizing temperature and immediately quenched into the water bath. From the graph, 2mm specimen is quenched at lowest temperature about 484.96°C and fastest cooling which only takes 6 seconds to reach the constant temperature at 38.33°C. Besides that, for 4mm and 6mm specimens, they were quenched to 593.34°C and 691.06°C respectively and take a larger time to reach the constant temperature compared to 2mm specimen. So, the highest cooling rate lies on 2mm specimen due to its thickness and able to cool rapidly.

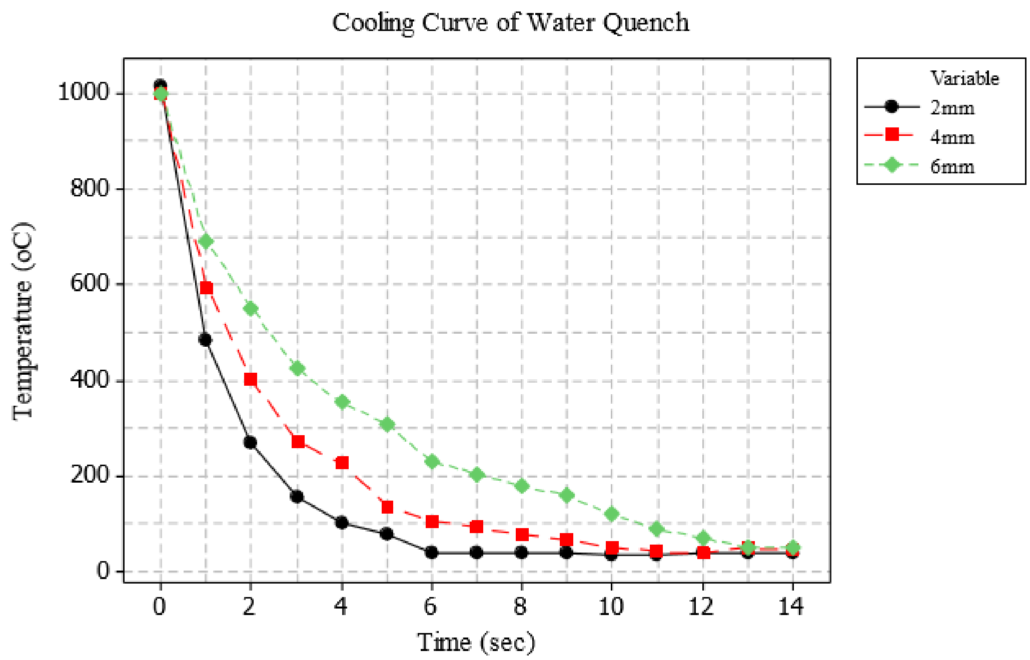


Fig. 1. Cooling curve of water quenching

According to Figure 2, the graphical data show the cooling history of air cooled specimens for 2, 4 and 6mm thicknesses. Specimens are heated at 1000°C and hold at this temperature for a sufficient time around 10 minutes. Then the specimens are taken out from the furnace and it cooled in air at room temperature. The time required of specimens to reach the equilibrium temperature at surrounding temperature is longer than water quenching process. About 33 minutes to finish the cooling process for air cooling. Similar to water quenching process, 2mm specimen is results as the fastest cooling than specimens of 4 and 6mm respectively. From the results, it shows the material thickness affects the time taken to cool. Thinner specimen will release heat faster than thicker specimen.

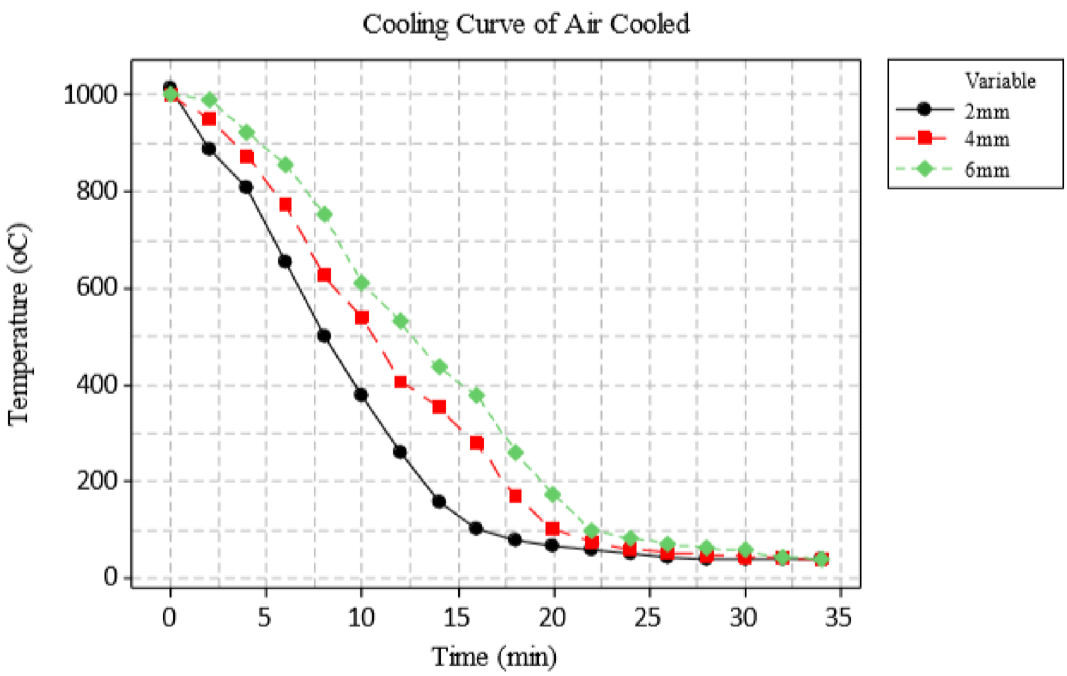


Fig. 2. Cooling curve for air cooling specimen

3.2 Microstructure Analysis

After going through the cooling process of Water Quenching and Air Cooling, the internal microstructure of treated specimen with different thicknesses are investigated by microstructure test. Therefore, the cross section of each specimen including untreated specimen is cut by using Sectional Cutting Machine at the desired cutting line on the surface to observe the microstructure of internal surface of specimens as represented in the Figure 3. The specimens are then going through the specimen preparation for microstructure test. The metallography's investigation was also carried out on specimens using metallurgical microscope.

Figure 4 represents the captured images of microstructure resulted from the observation for water quenched and air cooled specimens. The microstructures are compared to each other and found that the formation of pearlite resulting in air cooling process and the water quenching process produces the needle-like phase structure of martensite. Small changes in thickness of material give different effects depending on structure formation [20-22].

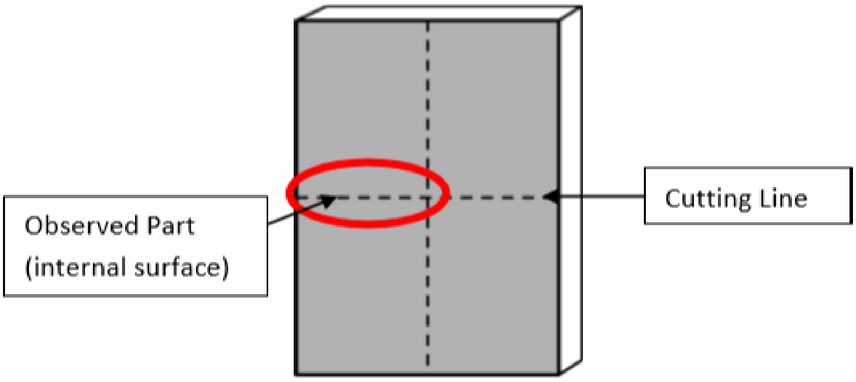


Fig. 3. Specific part of specimen for microstructure analysis

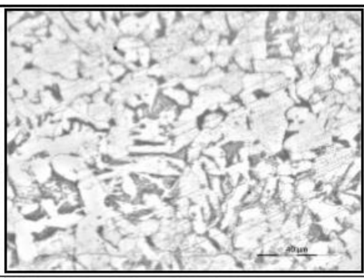
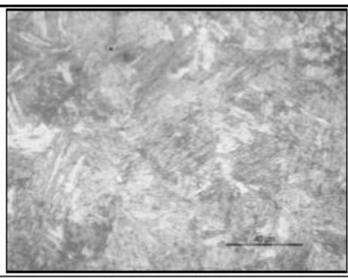
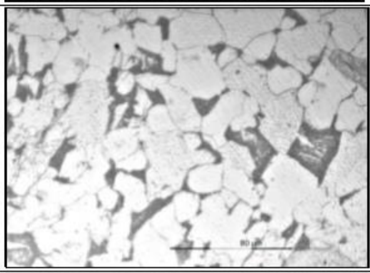
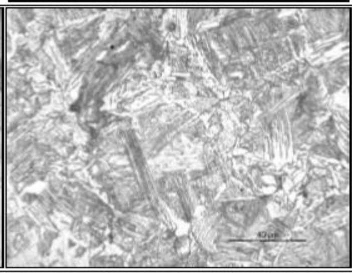
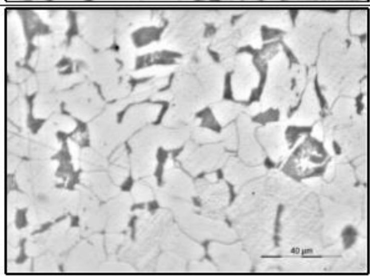
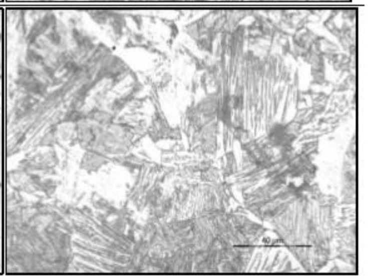
Specimen Thickness	Air Cooled Microstructure (50X)	Water Quenched Microstructure (50X)
2mm		
4mm		
6mm		

Fig. 4. Microstructures of air cooled and water quenched specimens

4. Conclusions

From the results achieved, thickness of material gave an impact to its microstructure development after heat treatment since the cooling time for each different thickness is different. Water quenching produces rapid cooling compared to air cooling process. 2mm specimen is the fastest cooling for both cooling processes compared to 4mm and 6mm specimens. Transformation of martensite is more in a fast cooling and as a result, 2mm from quenching process having a higher surface hardness. From the experiments, it was also observed that the water quenched specimen had higher surface hardness compared to the air cooled specimen.

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