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# A Mini Review on Low Carbon Steel in Rapid Cooling Process

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**ABSTRACT**

For heat treatment process on metal that are engaging with the physical and mechanical properties changes such as cooling and heating. The techniques for heat treatment including case hardening, annealing, tempering and precipitation strengthening, quenching and tempering. The mechanical properties like hardness, toughness and ductility can be altered by intense heat treating on steel and cooled it using different methods to produce different mechanical properties. This matters with the low carbon content in low carbon steel such as mildsteel behaviours after the heat treating depending on the thickness of the steel. To change the characteristics of steels is by heat treating whereby altering the diffusion and cooling rate within its microstructure by changing the grain size at different phases and changing the molecular arrangement. The mechanical properties of the steel with different thickness may be different due to the microstructure behaviour after heating and rapid cooling process. Finally, the behaviour of the microstructure of low carbon steel changes with different thickness that is affecting the mechanical properties after heating and quenching process.

***Keywords:***
low carbon steel, thickness, Rapid cooling, hardening, heat treatment



## 1. Introduction

This concise glossary of heat treatment terms has been embraced by the American Foundry Men's Association, the American Society for Metals, and the American Society for Testing and the Society of Automotive Engineers. To change the characteristics of metals and alloys is by heat treatment process whereby controlling the rate of dissemination and cooling within the microstructure to make them suitable for any kind of usage by changing the grain size at different phases and changing the molecular arrangement [1]. For any process that engaged with changes of chemical properties and the physical is a heat treatment process by cooling or heating a metal. The technique for heat treatment includes, case hardening, annealing, tempering and precipitation strengthening, quenching and tempering. The mechanical properties itself can be modified such as hardness, strength, toughness, ductility and corrosion resistance. By intense heat treating on steel to produce different properties of hardness. This matters on the content of carbon in the steel like in Low carbon steel such as mild steel up to 0.4% carbon, in Medium carbon steel up to 0.8% carbon,

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and in High Carbon Steel up to 2% carbon [2]. Low and medium carbon steel have insufficient amount of carbon to change their crystalline structure, as the results, the steel cannot be tempered or hardened. Medium carbon steel become harder regardless of whether it is hard and unfit to cut using a hacksaw. When steel is heated until it blazes with red color and is immersed in clean water immediately, the steel becomes very hard but also brittle. But, for easier to cut, or somewhat soft is the result for the blazing red-hot steel if is allowed to cool slowly [3].

The mechanical properties of any auxiliary metallic material with certain substance composition are elements of its miniaturized scale structure. The objective of heat treatment innovation is the improvement, or to control the mechanical properties by controlling the microstructure to coordinate the necessities constrained on a specific piece, or for a shaping procedure such as forming or machining innovation [4]. The different mechanical properties of carbon steels will be resulted as different microstructures formed during cooling processes. Furthermore, the diffusionless transformations obtain the martensite formation which is the highest hardness in iron-carbon system and from diffusion transformation, lowest hardness is hardness is obtained which cause the ferrite or pearlite formation by a eutectoid reaction. Ferrite and pearlite obtained from austenite during slow cooling near the equilibrium while martensite is obtained during rapid cooling. Therefore, both steel mechanical properties and microstructure are related to steel thermal history [5].

Low carbon steel has low carbon content itself. As this type of materials has been selected in this study is to examine the effect of rapid cooling process on low carbon steel and the mechanical properties after undergo heat treatment processes. Therefore, the present-day work was planned to study the relationship among the microstructure, heat treatment and mechanical properties for rational selection of manufacturing process, properties and application for certain function. Rapid cooling is essential during industrial production processes [6]. A type of heat-treating process, where immerse a work piece in water, or any fluids to acquire certain material properties. This procedure generally to keep up mechanical properties with a crystalline structure and the phase distribution that would lose during slow cooling process. Low carbon steel has been selected as this material is a type metal which has a comparatively low amount carbon which has a carbon content of 0.05% up to 0.25% by weight [7]. Low carbon steel can be classified as hypoeutectoid steel based on its carbon content. This steel also has other elements such as manganese, silicon and small amounts of phosphorous to shield the integrity of the structure of metal iron by avoiding dislocations within the iron crystals [8].

Steel with low carbon steel has same properties as iron, which is easily to be forms and soft. As the carbon goes about as a solidifying agent, the strength of the steel increase by the large increments with the level of carbon contain. This made the metal becomes difficult to weld and less ductile but harder and stronger. Since low carbon steel cannot be strengthened by heat treating which can be only accomplished through cold working [9]. This steel is machine-able and weld-able due to its softer and the outstanding ductility. Low carbon steel is mostly widely used of all steel products because it is cheaper compare to other types of steel. It is desirables properties such as ductility, strength and affordable price range make low carbon steel more likeable by industries. To allows parts to be fabricated in an easily formable soft state, steel can be heat treated. The alloy is hardened to increase wear and impact resistance and its strength, if there is enough carbon steel present [10].

With every different heat treatment process of steels, the microstructure of steel will change. The study of microstructure also known as metallography or microscopy. The microstructures are the presentation of the structural characteristics of steel under microscopic state. A variety of microstructures of carbon steels are known as ferrite, cementite, pearlite, martensite and austenite [11]. Resulting in partial transformations and the reaction of metastable phases from most of the phase transformations of interest will involve deviations from equilibrium microstructures. Ferrite, cementite and austenite can exist in harmony at the eutectoid temperature while pearlite existed by the solid-state transformation. This three stages, cementite, pearlite and ferrite are in this manner with the foremost constituents of the microstructure of plain carbon steels, if they have been exposed to slow cooling rates and stay away from the arrangement of transient stages [12]. In this way, it is pivotal to watch the development of these stages and the nucleation, and to decide the highlights which control their morphology [13].

**Table 1**
Application of Low Carbon Steel based on carbon content

| Carbon Percentage (%) | Applications |
|---|---|
| 0.08-0.15 | Cold headed fasteners and bolts |
| 0.15-0.30 | Case hardened, shafts, spindles and rods |

## 2. Microstructure Theory

With every different heat treatment process of steels, the microstructure of the steel will change. The study of microstructure also known as metallography or microscopy. The microstructures are the presentation of the structural characteristics of steel under microscopic state. A variety of microstructures of carbon steels are known as ferrite, cementite, pearlite, martensite and austenite. Resulting in partial transformations and the reaction of metastable phases from most of the phase transformations of interest will involve deviations from equilibrium microstructures. Ferrite, cementite and austenite can exist in equilibrium at the eutectoid temperature while pearlite forms by the solid-state transformation [14]. The three stages, cementite, pearlite and ferrite are in this manner the vital constituents of the microstructure of plain carbon steels. To prevent the formation of transient phases, they are put in to slow cooling rates. Therefore, it is important to observe these phases and nucleation development and to decide the features which alter their morphology [15]. Martensite phase generally achieved by rapid cooling, and prior deformation in the austenite region also affects the martensite transformation. The martensitic variants were study using relationship Kurdjumov-Sachs to analyse it and the results show that austenite grain structure effect on the martensitic transformation kinetics and its morphology [16]. Hot working processes applies deformation in the austenite region and the grain size affects the martensitic transformation and it is important to understand the grain size of austenite before and after heat treating. The face centred cubic (FCC) structure of austenite can dissolve more carbon than body centred cubic (BCC) ferrite structure though martensite is a stretched BCC structure because of the confined carbon [17]. The martensite crystals lattice parameters differ with carbon content and temperature. The tetragonality of the martensite crystal is near not exist in low carbon steel with less than 0.6wt% of carbon [18].

## 3. Normalizing Process

Normalizing process is a heat-treating process to make softer material and to adjust desired mechanical properties. To produce a uniform and fine-grained structure is normalising goals. The goals of normalising process are used for grain refinement and to obtain appropriate microstructure and mechanical properties. After heat treating, steels microstructure normally getting unhomogenous consists of unwanted particle and large grains such as bainite or carbides. By austenizing treatments, carbides in the matrix could dissolve completely and form uniform chemical compositions [19]. In normalizing process, complete austenite transformation occurs when steel is uniformly heated to a certain temperature. The result of this process is pearlite or pearlite with left-over ferrite or cementite. There is less of excess ferrite or cementite and the pearlite is finer. Due to the higher cooling rate, the austenite transformation occurs at a very low temperature than in annealing process. The effect of hot forging after normalizing on mechanical properties of steel is by giving better improvement on the toughness and tensile strength by proper normalizing temperature and air cooling after normalizing [20].

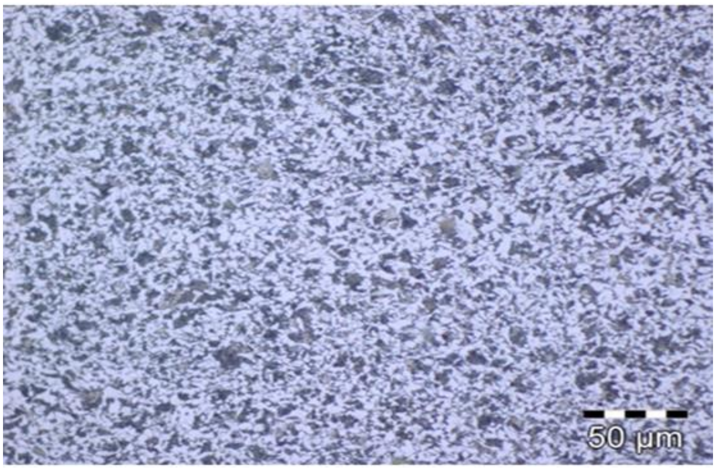

**Fig. 1.** The microstructure of medium carbon steel 35C8 after air cooled. Coarse ferrite and pearlite grains with volume fraction of pearlite content around 40% [2]

## 4. Quenching

Quenching is hardening processes of steel that defined as a rapid cooling process from the austenite phase to formation of martensite. Rapid cooling results in lowering temperature required to transform austenite into ferrite, which promotes ferrite nucleation at the austenite grain and grain boundaries. Quenching undergo by immersing the steel in water, oil and any liquid substance to obtain desired material properties, increase strength, hardness and wear resistance. During quenching process, the outer surface of the steel cool at faster rate than the internal area. Since not all austenite is transformed into martensite, the untransformed austenite called as retained austenite. The formation of pearlite, ferrite and bainite may occur before martensite forming completely, if the cooling rate is low. The cooling rate affects the transformation of austenite into various microstructural components that specify the final mechanical properties [18]. The mechanical properties of steels such as strength increase, when the concentration of carbon dissolved in austenite during heating which is because of transformation of austenite into martensite. Therefore, mechanical strength can be improved by quenching in right medium, type of heat treatment, the composition of steel, duration the steel immersed in according to [3].

## 5. Hardness Test

A resistance to indentation, abrasion or cutting are the definition of hardness. Hardness is not a property based on physical but a characteristic of a material which are the results of measuring the depth of the dent. More simply put, the softer the material, the bigger indentation left by the indenter based on its force. By measuring the depth and size of dent obtained using different test methods, the indentation hardness value can be obtained [6]. It is generally known that the hardness of metal alloys is greater than the hardness of its individual components. The hardness of a metal depending on the grain size of the microstructure of steel, the smaller the grain size, and the hardest the steel. This is because the bonding forces between molecules that differ from each other are larger than between molecules that are similar to each other. This is why, with the addition of foreign substance to a metal increase their hardness. [8]. Heat treatment and alloying are the other methods used to increase the hardness and strength of the material. Hardness measurements provide a quick and easy ways to check the given strength has been obtained through some particular methods.

## 6. Rockwell Hardness Test

Comparing different types of hardness testing methods, Rockwell hardness test is much easy process and provide more accurate result results. This approach is used on all metals, except in condition where the dent produce would be too big where the test metal structure or surface conditions would introduce too much variation. Permanent intensity of indentation produced by a pressure on indenter may be measured by this test. First, a sample has applied with a force (preload/minor load) using a diamond or ball indenter. Preload breaks through the surface to lessen the surface finish affects. The baseline depth of indentation is measured after retaining the preliminary test force for a certain time. Then, major load is applied on the surface to get the total required test load where this pressure or force is held for a certain time to allow elastic recovery and major load is released. The final depth is measured and the difference between baseline and final depth measurement is the result derived for Rockwell hardness value. The accuracy of the value is depending on the indentation on a smooth flat surface [21].

## 7. Heat Treatment and the Formation in the Microstructure

Table 1 shows the percentages of phases obtain by using the optical microstructure photograph of steel after undergo heat treatment process. In this table we can observe that the pearlite and ferrite percentages changes with carbon content and cooling rate. In contrast, to reach a martensitic state, higher cooling rate can be used [10]. It can be said that the carbon content and cooling rate effect on the microstructure of the steels. When the carbon is immediately cooled to room temperature, carbon can spread quite further and the space of the rich carbon phase, pearlite is greater. The product of pearlite is called as coarse pearlite. For the faster rate of cooling, it produces fine pearlite in carbon steels. The carbon content and cooling rate effects on the microhardness of steels as the microhardness increases when the cooling rate and the carbon content are higher [22]. In addition, the increasing of the pearlite percentage also results on the higher microhardness of the steel. On the other hand, the microhardness also increases rapidly when the martensite percentage is increasing. This is because strengthening phases in steel occurs in martensite phases [23].

**Table 2**
The percentage of phases after heat treatment of AISI 1060, high carbon steels Adnan C [10]

| Heat Treatment | Ferrite (%) | Pearlite (%) | Martensite (%) | Retained austenite (%) |
|---|---|---|---|---|
| Water-quenched | 5 | 60 | 30 | 5 |
| Air-cooled | 30 | 65 | 5 | - |
| Furnace-cooled | 50 | 50 | - | - |

## 3. Conclusion

Transformation of austenite to martensite only takes place during higher cooling rates which is quenching process. The percentage of martensite forms on the austenite boundaries depends on the time taken the steel to cool. The faster the cooling rate of steel, the more percentage of martensite forms. Formation of pearlite rather than martensite occurs in air normalising process where the cooling rate is lower. Since the cooling rate is depending on the thickness of the steel, the thinner the steel, the faster it takes to cool into equilibrium temperature with high martensite or lower pearlite area formation. The microstructure development after heat treatment affects the mechanical properties of the steel [24-25]. The hardness of the steel was mainly influenced by the grain development. However, the thickness also playing a main role in controlling the growth of the grain. Distribution of pearlite grain increase with the lower thickness of steel, whereas the hardness of the steel increase with the decreasing of its thickness. As the cooling rate of water quenching is higher than normalising, the hardness of water quenched was higher than normalising. On the other hand, the thinner the thickness of the steel, the more hardens the steel will be after rapid cooling process. It can be concluded that, the thickness of a low carbon steel can influence the microstructure growth and mechanical properties by using proper rapid cooling process.

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