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# A short review on different metal alloys on rapid cooling process

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**Abstract**. This review is being undertaken to compare the effect of rapid cooling process of variation metal alloys and make observation about microstructure and hardness. Types of metal alloys involve in this experiment are mild steel, stainless steel and brass. All of the specimens prepared with same shape and size which is 4mm. Nowadays there are many manufacturing industries that provide their own standard operation procedure (SOP) to create a better quality in producing product, one of the aspect that always be considered is about the strength. To understand the process, concept and mechanical properties about the material used are too important to produce or design the best product. All material have their own identities so we try to use different metal alloys and compare which one will give the best results according to our objective to evaluate based on microstructure and hardness in two different method which are slow cooling and fast cooling. All specimens are setup with our own parameter and heat up until reach certain temperature, and after specimens take it out from furnace we will separately do cooling process in two different method which are quenching and normalizing. As we knows every metal will change their properties by heat, heat treatment and rapid cooling will be the higher contribution to ensure the hardness and microstructure. This research show the results between three specimens ,mild steel have the best option to be selected because tally with our objective and it have a better strength also supported by their microstructure results.

## 1. Introduction

The common metal that always used in manufacturing industries are metal alloys. All of the activities in industry can be enhanced or improved by understanding more about microstructure characteristics. The most important thing to design better product is everybody should expert in selecting material and this will depend more on mechanical properties. Mechanical properties and microstructure study are important because it functions to detect the behaviour of every kinds of metal [1]. In metal alloys there were divided by two categories which is ferrous and non-ferrous. Basically ferrous actually have two categories, steel and cast iron. Steel if we go through and referring from journal it was from ferrous metal which is the metal that contains Fe, they have added smaller quantities of other composition metals or elements to support the properties required. Normally, ferrous metals are known because of magnetic properties and have smaller corrosion resistance [2]. Under steel part, there have high alloy and low alloy, and low alloy also can be divided known as low carbon steel (LCS), medium carbon steel and hi carbon steel which are based on the amount of carbon content. Basically carbon steel is not hard enough to use in certain manufacturing. Therefore, heat treatment will be the important process to improve the mechanical properties of the carbon steel [3]. The common method of heat treatment for steels are normalizing, hardening also annealing. For a non-ferrous are known as metal that do not have any amount of iron(Fe) ,they also do not have any magnetic properties and commonly more resist to corrosion compare ferrous metals. The example of the non-ferrous metal is aluminium which is one of the metal that always used in huge industries.

Copper one of the metal alloys under non-ferrous that always used in wiring production, automobile manufacturing ,piping, and architecture because of their high strength, high ductility, malleability, give the formability , light than other metal and resistance corrosion also easy to joint. This metal also can be processed in many situation hot and cold, can be rolled, stamped and pulled .The price of every categories of copper is depend on the specific blending, where will effects at their endurance and ability. Just because of this metal are commonly used in industries and too famous, this will be a reasons why this metal is selected to complete the experiments to observe about the effect of rapid cooling. Move to next material which is stainless steel, stainless steel is under ferrous metal, for the information under steels there have two branches low alloy and high alloy. Stainless steel categorized under high alloy ,when study about the characteristics this metal are more shine ,magnetic , low weld ability, moderate corrosion resistance and normally not used at low temperature. This metal also famous in manufacturing industries such as for producing home appliance and many else. The strength of every product produced by stainless steel is depend on the heat treatment procedure or process. Next is low carbon steel(LCS), same like stainless steel but this low carbon steel is under low alloy, low carbon means the percentage of the carbon is lower. In carbon steel there have a various microstructure and known as cementite, ferrite, austenite, pearlite and martensite. So, at the eutectoid temperature only cementite, ferrite and austenite form in equilibrium because martensite only form when perform in fast cooling like quenching process and ferrite and pearlite will form in slow cooling [4]. This material have been chosen because this kind of steel is always used to create car bodies, motorcycle parts and other domestic application where it is tally with what manufacturer want and follow all the desired mechanical properties process.

The significant of conduct this process are to maintain mechanical properties tally with a phase distribution or crystalline structure that will affect during slow cooling [5,6] .These technique or skill is usually applied to steel objects only. Besides, copper materials who needs to transform to become hardened by hammering or others deformation at normal temperatures can be restored to the malleable state by doing heating and quenching process. The purpose of this research is to compare hardness and microstructure effect of three metals alloy mild steel, brass and stainless steel with the same thickness 4mm in rapid cooling process and to understand the behaviour of the metal alloys after done that process. Nowadays, there are many manufacturing industries that provide their own standard operation procedure(SOP) to create a better quality in producing product ,one of the aspect that always be considered is about the strength. These all materials are chosen because it is always used widely in heavy industries Method that used to complete this research are Quenching and Normalizing based on suitable parameter provided. So, it is important to study the variation metal alloys effect on microstructure development.

## 2. Low carbon steel

The most famous metal is known as carbon steel because commonly used in industries. As everybody knows it can be divided into three group low carbon, medium carbon and high carbon based on carbon content. Normally heat treatment that always applied for steel are annealing, normalizing, hardening and tempering. Low carbon steel explained about metal that have an alloy component comprised of low formula of carbon that provided carbon content ranges between 0.05% and 0.20% and a manganese content 0.40 and 1.5%. Low Carbon Steel can be characterized into hypo eutectoid steel dependent on its carbon content range [7]. Mechanical properties of these steels are firmly associated with their microstructures acquired after different thermo-mechanical treatments, in view of controlled cooling after hot deformation [8].

When the carbon content higher the metal automatically become more strong and hard but at the same times it less ductile and hard to be welded. The increases of carbon content will affect at the melting point of that steel where it become lower melting point. When low carbon steel is cooled rapidly from austenite, body centered tetragonal (BCT) structure will occur but for FCC structure it will change to BCC for the carbon to form pearlite [9]. Yield strength of steel also influenced by carbon content because the body centered cubic (BCT) positions of iron molecule fit into the interstices crystal lattice sites. The different mechanical properties of carbon steel directly effect of their microstructure during cooling process. The highest hardness in carbon system is martensite and to achieve that phase, it must go through in fast cooling [10]. In the off chance of carbon available, the compound can be maintained to improve the quality, wear defect, and resistance impacts. Steels are normally created by cool working techniques, which is shaping metal through deformation at a low balance or met a steady temperature.

## 3. Stainless steel

Normal iron, iron alloy and also steel relatively are poor material because of their properties that easy can rusting in air, corrode in acids (all concentration). So because of this situation, there have another group or categories of iron alloys which are iron(Fe)-chromium nickel alloys also known as stainless steel. Stainless steel is one of the ferrous group where in generally it contains amount of iron, it still steel but it category of high alloy. In group of steel, there were divided by two for low alloy and high alloy, what can differentiate between this two alloys are low alloy have different amount of carbon, low carbon, medium carbon and high carbon content. Stainless steel in high alloys have the great abilities where do not rust in salt water and also have ability as resistant to the concentrated acids at normal temperatures up to 1100°C. The endurance of this steel be one of the factor why this stainless steel is widely used in industries and also construction. Their mechanical properties and manufacturing characteristic give a good reason why many designers choose them as the best material to create something but the usage of stainless steel small if want to compare to carbon steel. When talk about cooling rate, actually it give a big impact on the size of particles and on the morphology of the intermetallic phase [11,12]. If the rate of cooling decreased, then the volume of the intermetallic grow with time.

**Table 1.** The composition ranges.

| Steel category | Composition | | | | | Hardenable | Ferro-magnetism |
|---|---|---|---|---|---|---|---|
| | C | Cr | Ni | Mo | Others | | |
| Martensitic | >0.10 | 11-14 | 0-1 | - | V | Hardenable | Magnetic |
| | >0.17 | 16-18 | 0-2 | 0-2 | | | |
| Martensitic-austenitic | <0.10 | 12-18 | 4-6 | 1-2 | | Hardenable | Magnetic |
| Precipitation Hardening | | 15-17 | 7-8 | 0-2 | Al | Hardenable | Magnetic |
| | | 12-17 | 4-8 | 0-2 | Al,Cu,Ti,Nb | | |
| Ferritic | <0.08 | 12-19 | 0-5 | <5 | Ti | Not hardenable | Magnetic |
| | <0.25 | 24-28 | - | - | | | |
| Ferritic-austenitic (duplex) | <0.05 | 18-27 | 4-7 | 1-4 | N, W | Not hardenable | Magnetic |
| Austenitic | <0.08 | 16-30 | 8-35 | 0-7 | N,Cu,Ti,Nb | Not hardenable | Non-magnetic |

There are many grade of stainless steel because of the development increase rapidly year by year. So the group of stainless steel are divided into six group which are martensitic, martensitic-austenitic, austenitic and precipitation hardening steels. To be more clearly the name of the first five if referring the chart is the dominant or major components of the microstructure in different steels categories. Same goes to the last group refer on how these steel is hardened by a special method involving the orientation or formation and microstructure.

Besides, activities cooling in different environment can causes formation of precipitates because have different morphologies and size like cluster, precipitates that will form lamellar band at the end. Alloy that have different properties obtained by different heat treatment cannot be related to the ferrite ratio stated by previous researcher [13]. The effect of different cooling rates can change properties of alloy but it's still depend on cooling environment. [13] claim that slow cooling will give high strength and toughness for all type of stainless steel.

## 4. Brass

Brass is a metal alloys and can be classified from non-ferrous group where if referring to journal it was metal that did not have any iron presence. This metal is normally used in our daily live, it provide excellent electrical and thermal conductivities, resistance to corrosion and fatigue, also good formability and strength. Copper nickel, copper and certain brass are used widely for heat exchanger, automotive radiator, solar collector, home heating systems and other manufacturing. These kind of copper also used in piping industries because of their abilities to withstand corrosion. In fact, why the copper alloy are too important in manufacturing because it can minimize the bacteria limit and it also have ability to kill 99.9 percent around 2 hour and this fact are strong supported by public health registration by the United State Environmental Protection Agency (EPA). EPA already do a research on 280 copper alloy sample. Based on periodic table, Copper has 29 atomic number and 63.54(weight), exhibits a FCC crystal structure. Copper also known as transitional element and in a noble metal group, which same as silver and gold based on inherent properties. Besides that, copper also provided best of malleability, conductivity, corrosion resistance and bio functionality stem from copper's elemental origins. In fact copper has high solubility compared to others elements such as nickel, zinc,tin and aluminium [6].

## 5. Heat treatment

Enhancing the physical and mechanical properties are the most important factors to ensure that the metal alloys are ready to work as well. Heat treatment is the combination of cooling operation and times heating are applied to the metal alloys. This method is always used extremely to change or remain the microstructure positions and properties of the specimen. Commonly all kinds of heat-treating process are same because all of this involve cooling and heating to metal alloys. However, what can be differentiate and give the impact to the results is the rates of cooling and heating temperature used. The final results normally have a different reading because of the method used. Normal process involve in ferrous metal are tempering, hardening, normalizing, and annealing but for non-ferrous metals it also can be annealed exactly same with ferrous but still have a different where it cannot be normalized, tempered or case-hardened. Previous studies have explained that heat treatment is defined as the operation where to control the effect of heating changes in their characteristic or mechanical properties [14]. The process heat treatment material by remaining some certain manufacturability objects that was done by major stresses like welding and forging. Their properties of metal actually were strongly bonded to their microstructure where can perform to reach the best hardened and tensile strength. Moreover, heat treatment can be heated at difference temperature to ensure metal properties can be improved [8].

## 6. Internal structure of mild steel

In plain carbon steel it is obtained by quenching from above upper critical temperature (martensite phase).It is the hardest constituent obtained in given steel. It shows a fine needle-like microstructure. Its hardness is about 700 B.H.N stated by previous study [3]. It is unstable and disappears on reheating the steel. It is magnetic and less tough than austenite [3]. It is considered to be highly stressed α-iron supersaturated with carbon.

## 7. Internal structure of stainless steel

The microscopic structure of stainless steel ,from high volume of crystal (Grain) to original size occur because of heating upper than critical temperature and followed by very slow cooling ,to complete it the material need to left inside the furnace until it equilibrium to room temperature [12]. Actually this process do not lead to improve the mechanical properties for stainless steel due to deposition of carbides which occurs at a temperature(400-800) °C [12].

## 8. Internal structure of copper

The phase content and characterization in brass is always be considered before move to the next step of apply processes. Brass have different crystal structures even in general microstructure, because brass can have several mixed crystal structure which are represent phase of themselves [5]. There are many alloys of copper and zinc that will produced brasses and the reason small amount was added just to enhanced some property. Red brass normally have 16% zinc, 84% copper and the intermediate Cu –Zn alloys up to 31% zinc are single phase with a face centered cubic (FCC) crystal structure. Red brass usually have 84% of copper, 16% of zinc and Cu-Zn up to 31% are single phase with FCC. The characteristic of alpha brass is ductile at room temperature and also have capabilities of severe cold working without have any fracture [6]. Next, brass alloys who have content more 35% of zinc have a combination of the alpha (FCC) and beta (BCC) body centered cubic structure. Brass with higher combination beta (BCC) content has good hot working properties and will allow it to be extruded into variety complex shapes also easy to perform forging [5].

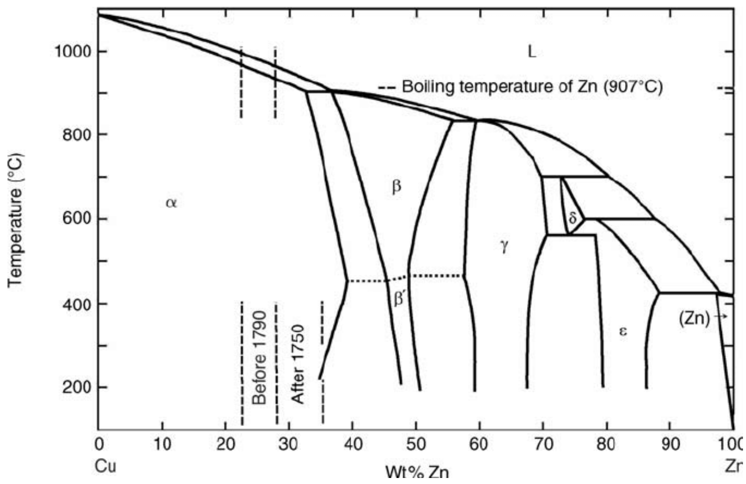


**Figure 1.** Phase diagram Copper-(Zn).

Brass who have higher beta (BCC) content is less ductile and it is not suitable to do cold working process such as thread rolling, knurling or staking. As stated to the phase diagram above, the beta phase (BCC) content in the brass is function to know their composition and temperature range, so alloys quenched from high temperature in the 35-40% zinc range will have higher beta content and suffer some defect of BCC structure at room temperature. When less ductile, the beta(BCC) phase produces finer chips when machined than alpha that will produce long chip [5]. Besides, Alpha (FCC) and Beta (BCC) phases in brass are easily differentiate under metallographic inspection by the shape of the crystal and colour. Metallography is commonly used to determine the % beta phase in alpha- beta brass and some applications can specify maximum or minimum beta phase content.

## 9. Normalizing process

Normalizing process known as one of heat treatment process to create material to become softer but still do not produce same material properties as produced by annealing process and others. Adjusting mechanical properties by following the desired requirements or try to suit the service conditions. The others goal of the normalizing explained as to remove the internal stresses, to repair grain structure and to increase the machinability and heating process will be conducted to 50ºC above the upper critical temperature, (for hypo-eutectoid steel) and to 50ºC above the lower critical temperature for hyper eutectoid steel). In order to avoid grain growth, temperature was hold for a certain time and finally let it cool in air but with adequate time to ease the temperature to be equalized through the section. The outcome of normalizing was the structure was same as annealing process but still have a difference between that two kind of process, due to more quickly of air cooling which cooling in furnace. Therefore, the result produced by normalized have a different if compared with annealing because normalize can produce fine grain. The structure of normalize of low alloy steel contain fine pearlite and ferrite. The impact of results by normalizing process was influenced by adding the rate of cooling with high hardness and low ductility than annealed steel. As stated by previous study, increase in cooling rate will effect to a higher strength due to local strain effect [14]. Slowly cooling rate by normalizing will effect in the lowest tensile strength of 136 MPa. Microstructure investigation emphasizing that normalizing specimen produced coarse austenitic structure with larger grain size. The observation from previous researcher stated that the grain size of the normalizing specimen was increased with soaking temperature Figure 2.

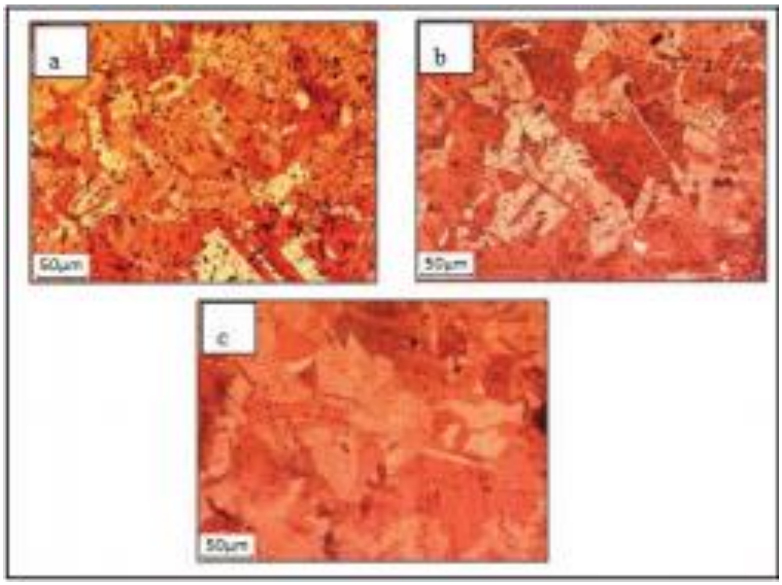


**Figure 2.** Grain image (Normalizing process) [1].

In term of microstructure, the observation by normalizing specimen shown grain growth increases in soaking temperature due to dissolution of pinning particles from grain boundary.

## 10. Quenching

Quenching is a process where the metal need to heated until it reach to the suitable temperature and then that metal need to be quenched in water or oil to increase metal hardness follow the desired requirement according to the kind of steels. Quenching also known as hardening process but still can be defined as rapid cooling process. In fact,the phase of rapid cooling steel from austenite will change the formation or orientation of meta-stable phase and called martensite [3]. Normally, steel have been heated above

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the critical temperature, then cooled by immersing in liquid bath such oil or water in order to obtain martensite or bainite. This process also can be used to obtain a suitable microstructure. Martensitic stainless steel has best hardenability because of their high alloy content(ingredient). Air cooling from the austenitizing temperature is usually sufficient to produce full hardness final product, but larger sections will use oil quenching. Parts have to be tempered once they have reached ambient temperature to avoid delayed cracking if oil quenching is used. Embrittlement can be prevented when tempering at temperatures above 510ºC was in rapid cooling to below 400ºC. Heat treatments which more complex was acquired by some precipitation-hardening stainless steel than standard martensitic types. Besides that, martensitic precipitation-hardening types often require nothing more than a simple aging cure. All alloys can be cooled by air or by quenching in specific oil and water or other liquids. Hardened materials are tempered to increase their dimensional stability and toughness.

## 11. Conclusion

The scope of manufacturing knowledge are too bigger to be explored, but in order to improve the technology of the manufacturing process the requirement to do research for every kind of the material are needed by doing some testing process and consider about microstructure. By doing this activities the result can be improved and quality also can be guaranteed. Based on three specimens mild steel shown the better hardness compare to another two specimens brass and stainless steel. The method that achieve our objective is gained from quenching fast cooling because it directly form martensite phase for mild steel. Microstructure captured also shown that fast cooling will produce small grain compare to slow cooling. As a mechanical engineer, it is necessary to carry out tests in order to understand the common methods of metal property testing. Mechanical properties are the most important requirement to be considered in the selection of materials for design purposes. The mechanical and physical properties also microstructure of metals describe their behaviour.

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