EFFECT OF HEAT TREATMENT OB THE MICROSTRUCTURES AND MECHANICAL PROPERTIES OF COPPER ALLOY

MOHAMAD SYAFIQ BIN MOKHTAR

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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MOHAMAD SYAFIQ BIN MOKHTAR

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Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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SUPERVISOR DECLARATION

"I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure and Materials)."

Signature: ……………………..

Supervisor: Mr. Ridhwan Bin Jumaidin

Date: 29th May 2013

DECLARATION

"I hereby declare that the work in this report s my own except for summaries and quotations which have been duly acknowledged."

Signature: ……………………..

Author: Mohamad Syafiq Bin Mokhtar

Date: 31st May 2013

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ABSTRACT

Copper is an essential element for major industrial metal because of its high ductility, malleability, thermal and electrical conductivity and resistance to corrosion. Copper and its alloy mainly used in wiring production, piping, automotive and architecture. Heat treatment process was applied on copper and copper alloys in order to attain the desired properties for each application. The effect of heat treatment on the microstructures and mechanical properties of copper alloy has been studied with different heat treatment processes which are annealing, water quenched and aging. Tensile test and metallurgical investigation is carried out to achieve the objective. In term of cooling rate, the effect of annealing process and quenching process has been investigated at different temperature. Aging process is studied with different temperature and aging duration. Yield strength and ultimate tensile strength of annealed specimens were decreased on 350^{o}C to 450^{o}C from 204.73MPa to 129.15MPa and 207.66MPa and 135.83MPa respectively. The softening of the specimens was due to the reduction of dislocation density in the structure and the grain growth that leads to the coarsening of the grain. Greater yield strength and ultimate tensile strength has been observed on water quenched specimens at 450^{o}C which record 356.34MPa and 358.89MPa. The hardening of material was due to the finer grain structure obtained by the decreasing of grain size after water quenched. For aging process, peak strength has been obtained by specimen aged for 4 hours at 450^{o}C which recorded 542.38MPa of yield strength and 559.69MPa of ultimate tensile strength. Peak strength was achieved with an increased strain field on the structure produced by coherent precipitates. The finer grain structure is observed on this stage that leads to strain hardening. Lowest strength was recorded on specimen aged for 8 hours at 450^{o}C which recorded 441.66MPa for yield strength and 452.24MPa for ultimate tensile strength. The reduction of strength is caused by overaging. Overaging was occurred by the coarsening grain structure and loss of precipitate coherency. Hence, the mechanical properties and the microstructures are altered accordingly.

ABSTRAK

Tembaga adalah satu elemen penting untuk logam perindustrian utama kerana kemuluran yang tinggi, sifat lunak dan rintangan kakisan. Tembaga dan aloi terutamanya digunakan dalam pengeluaran pendawaian, paip, automotif dan seni bina. Proses rawatan haba telah digunakan pada tembaga dan aloi tembaga untuk mencapai ciri-ciri yang dikehendaki bagi setiap permohonan. Kesan rawatan haba terhadap mikrostruktur dan sifat mekanik aloi tembaga telah dikaji dengan proses rawatan haba yang berbeza. Ujian tegangan dan penyiasatan logam dijalankan untuk mencapai matlamat tersebut. Dari segi kadar penyejukan, kesan proses penyepuhlindapan dan proses pelindapkejutan telah disiasat pada suhu yang berbeza. Proses penuaan dikaji dengan suhu yang berbeza dan tempoh penuaan. Kekuatan alah dan kekuatan tegangan muktamad spesimen anil telah menurun pada 450^{o}C dari 204.73MPa untuk 129.15MPa dan 207.66MPa dan masing-masing 135.83MPa. Penurunan spesimen adalah disebabkan oleh pengurangan ketumpatan kehelan dalam struktur dan pertumbuhan bijian yang membawa kepada pengasaran bijirin. Kekuatan alah yang lebih besar dan kekuatan tegangan muktamad telah diperhatikan pada spesimen direndam air pada 450^{o}C yang mencatakan 356.34MPa dan 358.89MPa. Pengerasan bahan adalah disebabkan oleh struktur bijian yang lebih halus yang diperolehi oleh penurunan saiz butiran selepas air dipadamkan. Untuk proses penuaan, kekuatan puncak telah diperolehi oleh spesimen berusia 4 jam pada 450^{o}C yang mencatatkan 542.38MPa kekuatan alah dan 559.69MPa kekuatan tegangan muktamad. Kekuatan puncak telah dicapai dengan medan tekanan meningkat ke atas struktur yang dihasilkan oleh mendakan koheren. Struktur bijirin halus diperhatikan pada peringkat ini yang membawa kepada ketegangan pengerasan. Kekuatan terendah dicatatkan pada spesimen berusia 8 jam pada 450^{o}C yang mencatatkan 441.66MPa untuk kekuatan hasil dan 452.24MPa untuk kekuatan tegangan muktamad. Pengurangan kekuatan disebabkan oleh overaging yang berlaku oleh struktur bijian pengasaran dan kehilangan pertalian mendakan. Oleh itu, sifat-sifat mekanikal dan mikrostruktur diubah sewajarnya.

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CHAPTER 1

INTRODUCTION

Heat treatment is described as the controlled heating and cooling methods performed on a material in a solid state in order to alter the characteristic of microstructure and its properties. Heat treatment can be applied to ingots, castings, semi-finished products, welded joints and various elements of machines and instruments. Basically, heat treatment can be operated with various methods. Common heat treatment is including annealing, normalizing, stress relief treating, hardening, quenching, and tempering. The cold treatment for each treatment is different based on the heating methods used. (Kakani, 2004)

Heat treatment are done on material to achieve different results such as softening the material for improved workability, increase the strength or hardness of material, increase the toughness or resistance to fracture of the material, stabilize mechanical or physical properties against changes that might occur during exposure to service environments, to insure part dimensional stability, to harden non-ferrous metals and alloys like copper and aluminum and relieve undesirable residual stresses induced during part fabrication. (Kakani, 2004)

Based on the characteristic of material, each metal has a specific chemical composition. Thus, the changes in physical and structural properties take place at different critical temperatures. As a result of heat treatment, the microstructure of a metal will change due to movement of dislocations, changes in the solubility of atoms, increasing of grain size, new grains formation at same phase or different phase, a change in crystal structure and others mechanisms.

When an alloy or pure metal is heated, the molecules in the metal will become mobile and subjected to vibrating. Once the metal is allowed to cool, the molecules in the metal will reform into a solid mass and will crystallize into distinct structures. Hardness is directly linked to the crystalline structure. (Trophe.M, 2003)

In this study, copper alloy will be to undergone various type of heat treatment in order to identify the effects on microstructure and mechanical properties. Copper alloy is chosen in order because the effect of heat treatment on its mechanical properties.

1.1 Objective

i. To identify the effect of heat treatment process on copper alloy.
ii. To observe the change of microstructure before and after heat treatment process.
iii. To compare tensile strength of copper alloy before and after heat treatment.

1.2 Problem Statement

Copper is an essential element for major industrial metal because of its high ductility, malleability, thermal and electrical conductivity and resistance to corrosion. Copper and its alloy mainly used in wiring production, piping, automotive and architecture. Unfortunately, some copper and copper alloys needs to undergone heat treatment process in order to attain the desired properties for each application.

1.3 Scope of Study

The main scope of the study is:

i. To conduct heat treatment process on copper alloy.
ii. To conduct tensile test of copper alloy before and after heat treatment.
iii. Metallurgical investigation and material characterization before and after heat treatment on copper alloy.

CHAPTER 2

LITERATURE REVIEW

Based on previous study, the researchers were mainly focused on the heat treatment of pure copper and copper alloy by using certain methods. As a result of heat treatment, the microstructure features are modified and the mechanical properties like hardness and tensile strength is altered. Thus, the findings can be used as a guidance and reference for this study.

2.1 Background of copper

Copper is known as non-ferrous metal. Copper also is one of basic chemical elements which have atomic number of 29 and atomic weight of 63.55. It consists of two stable isotopes, of mass number 63 and 65. Copper is located in group 11 of the periodic table. The symbol for copper is Cu. (Kakani, 2004)

In its nearly pure state, copper is reddish-orange metal known for its high thermal and electrical conductivity. Basically, pure copper is usually combined with other chemicals in the form of copper ores that are obtained from the mines as sulfides which contain zinc, lead and other sulfur. Others are known as oxide ores, carbonate ores, or mixed ores depending on the chemical presents. Most of copper ores also contain significant quantities of commercially useless material. Contains of the copper ores mined in the pure copper is only about 1.2-1.6% of copper weight. (Kakani, 2004)

Recently, copper is mainly used in industry. The capability of copper to be made into alloys makes the copper become popular in industry. This means copper can be combined with other metals to make new alloys. There are variable types of metals are used to produce copper alloys such as brass, nickel, lead, magnesium and others. The alloying elements make the parents or base copper become stronger in variable aspects like become harder, tougher and more corrosion resistant than pure copper. (S. Nagarjuna, 2000)

2.1.1 Properties of copper

2.1.1.1 Physical properties

Table 2.1: Physical properties of copper (T J. Miller, 2000)

Physical properties	**Value**
Boiling point	2567^oC
Density@ 20^oC	8.96 g/cm^3
Melting point	1081.9^oC

2.1.1.2 Mechanical properties

Table 2.2: Mechanical properties of copper (T J. Miller, 2000)

Properties	**Material Condition**		
	Soft	Hard	Polycrystalline
Hardness-Vickers	49	87	137.8
Tensile Strength (MPa)	224	314	-

2.1.2 Application of copper

Main uses of copper can be seen in electrical applications, construction, transports, and architecture. Approximately 65% of copper produced is used for electrical applications due to the highest electrical conductivity of any metal. This is leading for applications in power generation and transmission like generators, transformers and cables. For electrical equipment, the copper is provided for circuitry, wiring and contacts for electronic devices. Copper has a key role to play in energy efficiency. Besides that, 25% of all copper produced is used in buildings especially in plumbing, roofing and cladding. For application of copper on transports, the high purity copper wire harness system carries the current from battery throughout the vehicle to equipment such as lights, central locking and satellite navigation system. Copper also is used in production of coins, musical instruments and cookware.

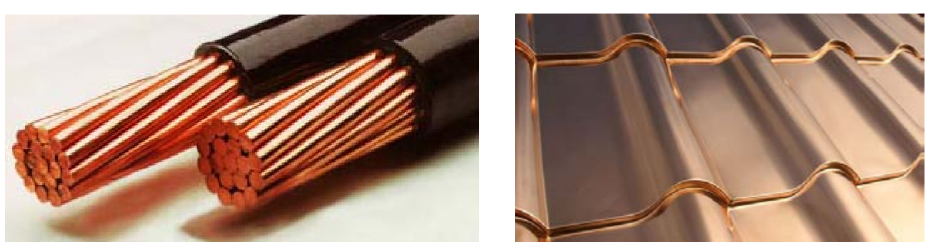

Figure 2.1: Application of copper in wire and cables and roofing for construction

2.1.3 Phase Diagram and Microstructure of copper

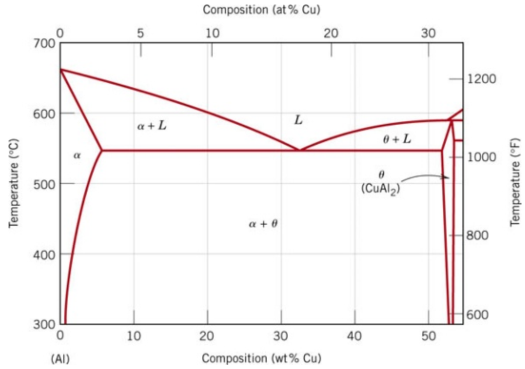

Figure 2.2: Phase diagram of copper alloy, CuAl [Source: Hosford, 2005]

Figure 2.3: Austenite microstructure of copper alloy
[Source: Hosford, 2005]

2.2 Heat treatment

Heat treatment is defined as physical process which entails the controlled heating and cooling of material which is metal or alloy to obtain desired properties. Heat treatment also is considered as a sequence of heating and cooling designed of steel after heat treatment are due to the phase transformations and structural changes that occur during heat treatment. The factors which determine and control the structural changes are called the principles of heat treatment.

The important principles of heat treatment are as follows;

i. Phase transformation during heating.

ii. Effect of cooling rate on structural changes during cooling.

iii. Effect of carbon content and alloying elements.

For copper alloy, the heat treatment processes available are annealing, quenching, and age-hardening.

2.2.1 Cooling Stage

After a metal has been soaked, it must be returned to room temperature to complete the heat-treating process. To cool the metal, you can place it in direct contact with a cooling medium composed of a gas, liquid, solid, or combination of these. The rate at which the metal is cooled depends on the metal and the properties desired. The rate of cooling depends on the medium. Therefore, the choice of a cooling medium has an important influence on the properties desired. (Zhang, 2002)

Quenching is the procedure used for cooling metal rapidly in oil, water, brine, or some other medium. Because most metals are cooled rapidly during the hardening process, quenching is usually associated with hardening; however, quenching does not always result in an increase in hardness. For example, to anneal copper, usually quench it in water. Other metals, such as air-hardened steels, are cooled at a relatively slow rate for hardening. Some metals crack easily or warp during quenching, and others suffer no ill effects. Therefore, the quenching medium must be chosen to fit the metal. Brine or water is used for metals that require a rapid cooling rate, and oil mixtures are more suitable for metals need a slower rate of cooling. (Zhang, 2002)

2.2.1.1 Effect of cooling rate on the microstructure and microhardness on copper alloy

Regarding to the study on the effect of microstructure and microhardness of CuZrAgAl alloy by Liu (2012), an alloy with a composition of $Cu_{40}Zr_{44}Ag_8Al_8$ (at.%) was prepared by casting in copper moulds and were melted in a cold crucible in an argon atmosphere and injected under pressure into water-cooled copper mold. The alloy was solidified under various shapes to be use as sample which are: