UNIVERSITI TEKNIKAL MALAYSIA MELAKA

HEAT TREATMENT STUDIES ON LEAD CASTING

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process) with Honours.

by

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2009

BORANG PENGESAHAN STATUS LAPORAN SARJANA MUDA

TAJUK: **Heat Treatment Studies on Lead Casting**

SESI PENGAJIAN : 2008/09 Semester 2

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honours. The member of the supervisory committee is as follow:

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ABSTRACT

This report focused on the heat treatment operation on lead metal casting and the analysis of the mechanical and microstructure properties. It also includes the casting of the lead metal itself. The casting method used is the basic sand casting. Three methods of heat treatment will be perform in the Material Lab, Fasa-b UTeM. Those are quenching, annealing and normalizing. The analysing will be conducted by testing the hardness, tensile strength and microstructure properties of the heat-treated lead metal. The expected results gain for PSM 2 is the effect of the mechanical and microstructure properties for different type of heat treatment and quenching.

ABSTRAK

Laporan in akan memfokus kepada operasi *heat treatment* ke atas tuangan plumbum dan juga analisis ciri – ciri mekanikal dan struktur mikro. Laporan in juga mengandungi operasi tuangan plumbum itu sendiri. Kaedah tuangan yang akan digunakan adalah dengan cara *sand casting*. Tiga kaedah *heat treatment* akan dilakukan di dalam makmal bahan di Fasa-b, UteM. Kaedah – kaedah itu adalah *quenching, annealing* dan juga *normalizing.* Analisis yang akan dijalankan adalah dengan cara pengujian kekerasan, kekuatan *tensile* dan juga struktur mikro plumbum yang telah menjalani proses *heat treatment* itu. Hasil yang akan dijangka untuk PSM 2 adalah kesan ke atas ciri – ciri mekanikal dan struktur mikro untuk jenis – jenis kaedah *heat treatment* dan *quenching* yang berbeza.

ACKNOWLEDGEMENT

Without involvement of many people, this project would not have been possible to complete. I would like to thank all of you especially to my supervisor, Mr. Sivarao. Thanks for his guidance, advice, trust, sincere helping and excellent supervision in accomplishing this study. He is always willing to help me whenever I approach him.

Besides that, I would like to thank all my lecturers of Manufacturing Engineering Faculty and the lab technicians that provided me with useful information and experience especially in contributing and sharing ideas toward this project.

Furthermore, I would like to extend my thankful to Manufacturing Engineering Laboratory of Universiti Teknikal Malaysia Melaka (UTeM) for providing me the place, time and always show their sincere kindness. Then, I also would like to thank my friend for sharing their time, ideas and comments to help me complete the experiment of this project.

Last but not least, I would like to thank my parents and family members for their love, care, support and understanding to carry out this project to the best of my ability.

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Mm	-	milimeter
Pb	-	Plumbum
PSM	-	Projek Sarjana Muda
UTeM	-	Universiti Teknikal Malaysia Melaka

CHAPTER 1

INTRODUCTION

Heat treatment is a method performed to alter the physical, chemical, and microstructure properties of metals and alloys. It involves heating and cooling, normally in order to achieve desired properties.

It is often associated with the strength of material, but it can also be used to change and modify certain manufacturing objectives to improve machining, and formability. Thus it will improve product performance.

Heat treatment techniques include annealing, normalizing, hardening, tempering, and precipitation hardening. It is noteworthy that while the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes like hot forming or welding.

Metallic materials consist of a microstructure of small crystals called "grains" or crystallites. The nature of the grains determines the overall mechanical behavior of the metal. Heat treatment provides an efficient way to manipulate the properties of the metal and microstructure features by controlling the diffusion rate, and the rate of cooling.

Trophe.M, (2003) has mentioned that 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.

Lead is normally considered to be an unresponsive metal to heat treatment. Yet, some means of strengthening lead and lead alloys may be required for certain applications. Lead alloys for battery components, for example, can benefit from improved creep resistance in order to retain dimensional tolerances for the full service life. Battery grids also require improved hardness to withstand industrial handling purpose.

The absolute melting point of lead is 327.4°C. Therefore, for applications where lead to be used, recovery, recrystallization processes and creep properties have great significance. Attempts to strengthen the metal by reducing the grain size or by cold working (strain hardening) have proved unsuccessful. For example, lead-tin alloys may recrystallize immediately and completely at room temperature. Lead-silver alloys respond in the same manner within two weeks. Transformations that are induced in steel by heat treatment do not occur in lead alloys

Despite these obstacles, however, attempts to strengthen lead have had some success.

1.1 Objective

The main objective of this project is to study the effect of heat treatment on lead metal castings, to analyze and compare the properties of the lead castings. Besides, to study the mechanical properties and microstructure features of lead castings.

1.2 Importance of the Study

The importance of this study is to identify the difference between the usage of different type of quenching medium, the effect of the quenching medium, the structure and properties of lead castings, and the result of using different type of heat treatment to the lead castings.

1.3 Problem statement

Deciding the way to cast the lead casting and the pattern shape of the sample.

Determining the result of heat treating on lead castings by annealing, normalizing and quenching using three different type of medium that is normal water, salt water and oil by using hardness test, tensile test and the microstructure features.

Comparison between non-heat treated to the heat treated lead casting.

1.4 Scope of the Study

The main scope of this study is to perform the heat treatment operation and the lead casting experiment and:

i. To determine and analyse the mechanical properties and microstructure of the lead cast
ii. To analyse the effect of heat treatment to the lead castings based on the mechanical properties and microstructure studies.

CHAPTER 2

LITERATURE REVIEW

From the previous literature, the researchers were mainly focused on the heat treatment of lead cast bullet and an attempt to strengthen the lead and modify the microstructure features of a corrosion resistant lead alloys, for use in pressure cast battery grids so this can be used as a guidance and base for this project.

2.1 Heat treatment

Klinger. C, (2002) has mentioned that heat treatment is a 'black art' before which many items are actually sent to a separate vendor for heat treating to be applied after the items have been made to get the benefit of an expert's judgment. In practice, each item requiring heat treatment brings a host of variables to the process, some of which are difficult to quantify - such as residual stress, variation of alloy chemistry and grain size. Further, there are different heat treatments for different types of metal and alloys.

He also added that metallurgical knowledge has underpinned all the great advanced civilizations including the one in which we reside -- and labour. Although the fundamental mechanisms that make heat treatment valuable have only been discovered and investigated in recent centuries. The resultant knowledge has spawned whole new classes of materials and industries to manufacture them.

Moreover, the value of heat treatment resides in the control of material properties. Let us consider all of the different items manufactured from steel. We expect some of them to be very hard and resistant to wear such as a wood or metal file, others applications demand impact resistance, such as the head of a sledgehammer. It is likely that these items would be made of different kinds of steel. But by manipulating the microstructure of the metal after it is partially or wholly formed into a tool, properties such as hardness, wear resistance and toughness can be further enhanced in the final product. This manipulation of the microstructure is accomplished by changes in part temperature, and is commonly referred to as 'heat treating' or 'heat treatment'.

2.1.1 Quenching

Klinger. C, (2002) said that the most widely used and the oldest heat treatment process is quenching. Quenching involves heating the metal part above a temperature, which causes a change in microstructure, and then rapid cooling to force an unusual change in the microstructure which not formed on slow cooling. 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.

In steels, this process manipulates the location of carbon in the microstructure. At high temperature steel possesses a crystal structure called 'austenite'. Austenite can hold a larger amount of carbon than the room temperature crystal structure called 'ferrite'. Rapid cooling of the steel from temperature conducive to austenite (the 'transformation temperature') will produce a new different crystal structure called 'martensite'. Martensite crystals are longer in one dimension than the other two. In severe cases, cracking may occur. The benefits to the material properties of the part are a higher yield strength and higher hardness, typical transformation temperatures for steel depend heavily on the specific alloying elements used. For carbon steel of 0.77% carbon content, the austenite transformation temperature is 1341^{o} F (727^{o} C).

Quenching can also harden several non-ferrous metal and alloys that leads to a similar set of micro-structural changes occurs, though the metallurgical terminology changes. Some of these alloys include aluminium bronzes, nickel aluminium bronzes, and certain brasses.

2.2 Lead (Plumbum)

Anonymous (2008) explained that lead is a main group element with a symbol Pb (Plumbum). It has the highest atomic number of 82 among metals. It is a soft, malleable, and also considered to be one of the heavy metals. The original colour of lead is bluish white when freshly cut, but changes to a dull grayish color when it is exposed to air and change again to a shiny chrome silver when melted into a liquid. Lead is used in building constructions, lead-acid batteries, bullets and shots, weights, and is one of the part of solder, pewter, and fusible alloys. Because of the high density, it is used as a shielding material against X-ray and gamma-ray radiation and is used in X-ray machines and nuclear reactors. Like mercury, lead is known as a potent neurotoxin that accumulates in soft tissues and bone over time and hazardous to environment especially to humans and animals.

Lead is a dull lustrous metal and it is a dense, ductile, soft, highly malleable, and bluish-white metal that has poor electrical conductivity. It is a ture metal that is highly resistant to corrosion, and because of this, it is used to contain corrosive liquids like acids. It can be toughened by adding a small amount of antimony to it. It is a common misconception that lead has a zero Thomson effect. All lead, except 204Pb, is the end product of a complex radioactive decay.

Lead has been commonly used for thousands of years because it is widespread, easy to extract and easy to work with. It is highly malleable and ductile as well as easy to smelt. Metallic lead beads have been found in Çatalhöyük dating back to 6400 B.C. In the early Bronze Age, lead was used with antimony and arsenic. The ancient Romans used lead to make water pipes, some of which are still in use today

2.3 New standard for quenched and tempered metals

According to **Dr.-Ing. Peter Sommer (2007)**, the new standard for quenched and tempered steels was published, and the contents of which are discussed here from the point of view of steel users and heat treatment specialists. The historic development for this group of steels since 1969 is traced below:

- DIN 17200:1969-12: Quenched and tempered steels; quality specifications.
- DIN 17200:1984-11: Quenched and tempered steels; technical delivery conditions.
- DIN EN 10083-1:1991-02: Quenched and tempered steels; technical delivery conditions for special steels.
- DIN EN 10083-1:1996-08+A1:1996: Quenched and tempered steels; technical delivery conditions for special steels +amendment A1:1996.
- DIN EN 10083-2:1991-10: Quenched and tempered steels; technical delivery conditions for unalloyed quality steels.
- DIN EN 10083-2:1991-10+A1:1996: Quenched and tempered steels; technical delivery conditions for unalloyed quality steels+ amendment A1:1996.
- DIN EN 10083-3:1995-02: Quenched and tempered steels; technical delivery conditions for boron steels.
- DIN EN 10083-1:2006-10: Quenched and tempered steels; general technical delivery conditions.
- DIN EN 10083-2:2006-10: Quenched and tempered steels; technical delivery conditions for unalloyed steels.
- DIN EN 10083-3:2006-10: Quenched and tempered steels; technical delivery conditions for alloyed steels.

2.3.1 Harden ability of quenched and tempered steels

Dr.-Ing. Peter Sommer (2007) has stated that harden ability is an important evaluation criterion for quenched and tempered steels to obtain their characteristics through a selective heat treatment. The determination of harden ability is usually done by means of the standardized Jominy test according to EN ISO 642. The regression formulae for the calculation of the harden ability of steels and their analysis, published by VDEh, have been available since 1990.

2.3.2 Heat treatment specifications

From **Dr.-Ing. Peter Sommer (2007)** research, as it is indicated by the name of the material group alone, heat treatment is of particular importance for the group of quenched and tempered steels.

He has also added that the selection of quenching media today has been expanded by a large variety of polymers and in part by high-pressure gas quenching. Therefore, the actual heat treatment conditions of a concrete treatment batch would probably conform to the basic conditions of tempering diagrams in rare cases only. Thus, heat treatment shops will not be able to avoid running tests of the required tempering temperature.

2.4 Effect of heat treatment on lead casting

Kelter. R(unknown year) has said that in most lead alloys, heat treating and rapid cooling or quenching result in a breakdown of the supersaturated solution during storage or aging effect. Although this breakdown produces coarse structures in lead alloys. In alloys of the lead-tin system, the initial hardening produced by alloying is quickly followed by softening as the coarse structure is formed.

The rate of cooling depends on the medium; therefore, the choice of a cooling medium has an important influence on the properties desired.

Heat treating and rapid quenching can result into aging to enhance these effects. Water quenching (dropping the lead casting straight from the mould into a bucket of water) will harden the lead casting. **Trophe. M, (2003)** also said that the hardening process starts as soon as the product from the casting are immersed in the water. After being removed from the water, the hardening process continues for a period of two days, by which time the product have reached their maximum hardness.

According to **George W. M (1971**), by heat treating at a elevated temperature of approximately 500° F, it has been found that the hardness loss is only about 10 percent, while heating at temperatures of only 300° F. to 400° F. the hardness loss is approximately 30 percent to 40 percent.

Trophe. M, (2003) has said that after quenching, the part will be harden at room temperature. That is, for a period of time, the metal will continue to get harder. In industrial situations, metal can be age hardened faster by keeping it at a heated temperature (much lower than the quenching temperature) for a period of time. However, the product can be heat treated for an hour and then immediately plunged into water to quench cool them. This will produce harder lead casting product than quench cooling directly from the mold, **Anonymous, (2008)**.

The heat-treating and quenching of the lead casting product greatly reduces the exterior grain boundary area by producing a surface layer of grains that are thinner, larger, and longer than the matrix of grains on the interior. This type of surface layer is referred to as a "monograin" surface layer or a "monocrystalline" surface layer because the thickness of the layer is only one grain. The reduction of the surface grain boundary area reduces significantly the susceptibility to corrosion which occurs at grain boundaries to thereby produce a product having enhanced corrosion resistance with little sacrifice of grid strength, **George W. M (1971**).

G. Corson, (1928) has proposed that in order to harden lead, it needs to be add an optimum amount 2.5% of antimony making it an alloy and further subjected to heat treatment at 240° C for about 30 minutes and then followed by quenching. This is based on the assumption that 2.5% antimony stays in solid solution in lead at the temperature of the heat treatment remains even after quenching and it is precipitated in an ultra-microscopic form during aging.

According to him, some problems are encounter in this alloy and are listed below:

- The eutectic point of antimony-lead alloy is located at 243° C and thus this alloy can't be heat treated at a higher temperature.
- The formation of the ultra-microscopic particles of antimony requires only the coming together in no definite proportion of the individual atoms of antimony, and the growth of these particles by the addition of other antimony atoms takes place whenever any of such atoms and particles come together. Therefore, a further growth of these particles is continuously going on and both hardness and strength drop significantly in a period of time.

To solve this, **G. Corson, (1928)** by substituting for the elementary antimony one of its metallic compounds, the second metal of this compound is also capable of being soluble to a substantial degree in solid lead:

- The eutectic point would raised to a point where it will permit heat treatment at higher temperature.
- Since the particles that are needed to be precipitated in a lead alloy contained antimony and the second metal would consist of antimony atoms and atoms of the second metal in a definite proportion corresponding to the atomic proportions of such metals in their metallic compound, the particles will grow only when they happened to come together with antimony atoms and atoms of the second metal present in the solid solution of the lead in exactly the proportions such atoms bear towards one another in their metallic compound. It's extremely improbable that atoms of the two metals will come together in precisely the