UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Effect of Heat Treatment Conditions on Aluminum Alloy 6061

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

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DECLARATION

I hereby, declared this report entitled “Effect of Heat Treatment Conditions on Aluninum Alloy 6061” is the results of my own research except as cited in references.

Signature	:	…….
Author’s Name	:	……
Date	:	……

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 (Process) (Hons.). The member of the supervisory is as follow:

……

(Project Supervisor)

ABSTRAK

Laporan yang dibentangkan merupakan satu kajian eksperimen mengenai pemendakan aloi aluninum 6061 untuk mengkaji kesan penuaan masa dan suhu terhadap sifat mekanikal dan mikrostruktur. Rawatan haba telah digunakan untuk spesimen aluminium yang terdiri daripada proses rawatan haba pada 530 ˚ C diikuti oleh pelindapkejutan air dan akhirnya proses penuaan tiruan. Kajian eksperimen tertumpu kepada penuaan tiruan di mana suhu penuaan yang berbeza-beza antara 150 ˚ C hingga 200 ˚ C pada lima kali penuaan yang berbeza. Vickers ujian kekerasan dan tegangan ujian adalah untuk menilai ukuran kekerasan dan kekuatan tegangan untuk AA6061 masing-masing dan juga analisis mikrostruktur selepas proses penuaan. Pelbagai suhu penuaan dan masa penuaan menunjukkan perbezaan yang luar biasa dalam sifat mekanik dan pemerhatian mikroskopik. Masa penuaan optimum dan suhu telah ditentukan pada akhir eksperimen ini. Kajian ini membawa kepada kesimpulan bahawa optimum telah dicapai antara 150 ˚ C hingga 200 ˚ C dengan 2 hingga 6 jam penuaan masa. Kesan rawatan haba ke atas kekuatan dan kekerasan telah dikenalpastikan. Mikrostruktur analisis evolusi terhadap AA6061 juga dibincangkan dalam laporan ini.

ABSTRACT

The report presented an experimental study on the precipitation of aluninum alloy 6061 to investigate the effect of aging time and temperatures on the mechanical properties and microstructure. Thermal treatment was applied to the aluminum specimens that included of heat treatment process at 530˚C; followed by water quenching and finally the artificial aging process. This experimental study was focused on the artificial aging upon which the aging temperature is varying between 150˚C to 200˚C at five different aging times. The Vickers hardness test and tensile test were applied to evaluate the hardness measurements and tensile strength for AA6061 respectively as well as the microstructure analysis after the aging process. Various aging temperature and aging times indicated remarkable difference in the mechanical properties and microscopic observation. The optimum aging time and temperature was determined at the end of this experiment. The study brought to the conclusion that the optimum aged was achieved between 150˚C to 200˚C with 2 to 6 hours of aging time. The effect of heat treatment on the strength and hardness were been investigated. Microstructure evolution analysis was also done to the AA6061.

DEDICATION

To my beloved father Mr. Lee Hong Seng and mother Mdm. Christina Kueh, my beloved eldest sister Ms. Lee Mei Fung, my beloved younger sister Ms. Lee Mei Ing, my beloved younger brother Mr. Lee Yong Kiat and my respected Dr. Nur Izan Syahriah Hussein.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURES

Al	-	Aluminum
AA6061	-	Aluminum Alloy 6061
AA	-	Aluminum Association
ASM	-	American Society for Metal
SHT	-	Solution Heat Treatment
WQ	-	Water Quenching
TEM	-	Transmission Electron Microscopy
APFIM	-	Atom Probe Field Ion Microscopy
DOE	-	Design of Experiment
RSM	-	Respond Surface Methodology
UTM	-	Universal Testing Machine
ASTM	-	American Society of Testing and Material
GP	-	Guinier-Preston
SSS	-	Supersaturated Solid Solution
Mg_2Si	-	Magnesium Silicide
Mg	-	Magnesium
Si	-	Silicon
EDX	-	Energy Dispersive X-ray Spectroscopy

CHAPTER 1

INTRODUCTION

This report described the study on the effect of heat treatment on Aluminum Alloy 6061. Besides, factors that give impact on the heat treatment such as the temperature and time approaching the testing specimens were discussed in this report. The research background and problem statements were briefed in this chapter. Furthermore, the objectives as well as the scope for the study are elaborated.

1.1 Background

Nowadays, companies have to face competition that becomes harder and severe especially in the manufacturing industries. All industries are continuously striving to establish the new goals in order to enhance their process organization and management efficiency. In this competitive environment, industries have to identify the best solution to fulfill their customers' demands and satisfaction. Throughout the industrial revolution era, heat treatment is one of the most innovative concept represent a significant opportunity in today manufacturing industry for better mechanical properties and microstructure evolution of the metals. The main function of this heat treatment is to alter the physical and chemical properties by controlled the heating as well as the cooling of the metals without the interrupt of product shape. Heat treatment is an extraordinary step in the process of manufacturing that the end results can be different by altering the procedure involved in the process or the type of heat treatment. Essentially the properties of all materials can be enhanced through heat treatment.

The 6000 series group contains magnesium and silicon as major addition elements. Due to the technological importance, the 6061 Al alloy has been studied extensively. 6061Al alloy mostly used as extruded products, construction and automotive industries (Mohammad, 2011). This alloy can be easily shaped; its good density, corrosion and surface properties as well as the better weldability are the outstanding factors that along with economical price make this alloy highly demanded (Evren et al., 2011: Mapellia et al., 2011).

1.2 Problem Statement

Heat treatment is the process involving controlled heating and cooling operations towards materials in a way as to bring about a desired change in specific condition or properties. There are some reasons for heat treating such as to remove stresses, to refine the grain structure and other purposes as well. Even though heat treatment is a useful technology which has been used widely but there are some disadvantages which could lead to the imperfection of producing the products. Rajan (2012) mentioned that oxidation, corrosion, fatigue and fracture are examples for the metallurgical phenomena where imperfections take place. Variance conditions of heat treatment such that the temperature, time and cooling method gives different effect to the mechanical properties and microstructure evolution of the specific material. Study of the effect of heat treatment on Aluminum Alloy 6061 using furnace was carried out to determine the effect of the different conditions of heat treatment in the respective of the temperature, time, and also the method of cooling on Aluminum Alloy 6061. In addition, the result of the study was analyzed to verify the differences between the constraints on the mechanical properties and microstructure evolution of the Aluminum Alloy 6061.

1.3 Objective of Study

The objectives of the study are to:

i. Study the heat treatment condition for AA6061.
ii. Study the effect of heat treatment condition to the microstructure, strength and hardness of the AA6061.
iii. Propose the optimum heat treatment condition for AA6061 to achieve ideal strength and hardness.

1.4 Scope of Study

The scope of this work is to perform review of the temperature and time for the heat treatment of AA6061. The study was more focus on the parameters that contribute to the effect of heat treatment towards the aluminum alloy properties. To accomplish this project and the technical report, the work planning was organized in respective chapters.

Maisonnette et al. (2011) mentioned that 6061 aluminum was introduced to fulfill the necessity for medium-strength heat-treatable aluminum which is tough but easily welded and joined or anodized. It is the most versatile and least costing of heat-treatable aluminum alloy and is applicable in which appearance and moderate strength are required. Altering the mechanical properties by heat treatment, specific mechanical strength was achieved. Aluminum alloys gain strength from the process of solution heat-treating and aging.

1.5 Activity Planning

The activity planning throughout the weeks in these two semesters were summarized in the form of Gantt chart in Appendix A and Appendix B.

CHAPTER 2
LITERATURE REVIEW

This chapter demonstrated the theoretical concepts and information in engineering field which are related to this study. Types of Aluminum Alloy, heat treatment and microstructure investigation were described in this chapter. Besides, the type of cooling method for the heat treatment was explained. Next, the parameters that give impact on the AA6061 series were discussed. Consequently, the mechanical testing for the Aluminum Alloy after the heat treatment was presented. Last but not least, this chapter ended with a brief summary.

2.1 Aluminum Alloy

An alloy is the combination of two or more metals which consists of specific desirable characteristics that include the corrosion resistance, strength and formability (Aluminum Association 2009). Aluminum (Al) acts as the predominant metal in aluminum alloys. Copper, magnesium, zinc, silicon and manganese are the typical alloying elements in aluminum alloys. Aluminum alloys are widely used in daily lives either in products or applications, from the small size aluminum can for beverages to the huge structure of the aircraft. Aluminum alloys are broadly used in engineering components and structures in which the characteristic of corrosion resistance or light weight is required.

2.1.1 Aluminum Alloy Designation

Basically, aluminum alloys are categorized into two major types that are cast alloys and wrought alloys. The Aluminum Association designates three-digit system for cast alloys which followed by a decimal value and four-digit system for wrought alloys. Cast alloys are the aluminum alloys that are poured as a liquid into a mold and cooled into a solid shape. In Aluminum Association (AA), the minimum percentage of aluminum is reveal by the second two digits. The main alloying elements in the AA system are described in Table 2.1.

Table 2.1: Aluminum Alloy Designation for Cast Alloy (Aluminum Association Inc, 2009)

Designation	Major alloying
1xx.x	Minimum 99% aluminum
2xx.x	Copper
3xx.x	Silicon, copper and/or magnesium
4xx.x	Silicon
5xx.x	Magnesium
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other elements
6xx.x	Unused series

The identification system of wrought alloys consists of four digit numbers which the first number represents the type of alloy, the second number represents the control over impurities, and the last two numbers normally represents the specific alloys. This aluminum alloys can be classified into two principle groups that is non-heat treatable alloys and heat-treatable alloys. Alloys of 1xxx, 3xxx, 4xxx and 5xxx series

are the non-heat treatable alloys that cannot be strengthened through heat treatment. The alloys from this group are ductile and moderately strong that depend on the alloying element concentration. Heat-treatable alloys included the series of 2xxx, 6xxx and 7xxx which can be strengthened by heat treatment.

Table 2.2: Aluminum Alloy Designation for Wrought Alloy (Aluminum Association Inc, 2009)

Series	**Major alloying elements**	**Atomic symbols**
1xxx	Aluminum at least 99% pure	Al
2xxx	Aluminum-Copper-Magnesium	Al-Cu(-Mg)
3xxx	Aluminum-Manganese	Al-Mn(-Mg)
4xxx	Aluminum-Silicon	Al-Si
5xxx	Aluminum-Magnesium	Al-Mg
6xxx	Aluminum-Magnesium and silicon	Al-Mg-Si
7xxx	Aluminum-Zinc	Al-Zn-Mg(-Cu)
8xxx	Aluminum-Tin-some Lithium characterizing miscellaneous compositions.	Al-Li- other elements
9xxx	Unused series	

For either cast or wrought alloys, they are known as heat treatable, in which an approach is taken to dissolve the alloying elements, and then quench to achieve super saturation and finally age hardening to precipitate solute atoms either at room temperature or at elevated temperature.

2.1.2 Aluminum Alloy 6061

Aluminum alloy 6000 series is an aluminum alloy that majorly consists of alloying elements of magnesium and silicon. AA6061 is the least costly and most versatile among the heat-treatable aluminum alloys. This alloy has the most of the good quality of aluminum which it offers a range of superior mechanical properties and good corrosion resistance. As one of the most generally used heat-treatable aluminum alloys, 6061 is available in various range of structural shapes, and also sheet and plate products. AA6061 is widely used in variety of products and applications from truck bodies and frames to screw machine parts and structural components. Table 2.3 shows the nominal composition for AA6061.

Table 2.3: Nominal Composition of AA6061 (Aluminum Association Inc, 2009)

Alloying Element	**Compositions**
Magnesium (Mg)	0.8 – 1.2
Silicon (Si)	0.4 – 0.8
Iron (Fe)	0.7 max
Chromium (Cr)	0.04 – 0.35
Copper (Cu)	0.15 – 0.4
Zinc (Zn)	0.25 max
Manganese (Mn)	0.15 max

Table 2.4: Mechanical properties of AA 6061 (Source Aluminum Association Inc, 2000)

Hardness Brinell	95
Ultimate Tensile Strength	310MPa
Tensile Yield Strength	276MPa
Elongation at break	12%
Modulus of Elasticity	68.9GPa
Notched Tensile Strength	324MPa
Ultimate Bearing Strength	607MPa
Bearing Yield Strength	386MPa
Poisson's Ratio	0.33
Fatigue Strength	96.5MPa
Fracture Toughness	29MPA/m^2
Shear Modulus	26GPa
Shear Strength	207MPa

Melting point is important in order to make the study safe and success. Heating the material without knowing its melting point may cause the specimen melts or no effect at all. AA6061 has the melting point in the range of 582-652˚C (Aluminum Association Inc, 2006).

2.2 Heat Treatment in Aluminum Alloy

Heat treatment is a combination or any one of the series of operations that including both the heating and cooling of alloys in the solid state. Commercial alloys able to

alter their mechanical properties from the specification of strength and hardness can be obviously raised by heat treatment. Most of the heat-treatable alloys contain the combinations of magnesium with either one or more of the elements zinc, copper and silicon (ASM Handbook, 1996). The heat treatment process for 6000 series, although not as strong as the 2000 series and 7000 series but it has good weldability, formability and machinability and corrosion resistance, with medium strength (ASM Handbook, 1996).

Heat treatment of aluminum alloys is three successive steps:

i. Solution heat treatment : dissolution of soluble phases
ii. Quenching : development of supersaturation
iii. Age hardening : precipitation of solute atoms either in room temperature (nature aging) or at elevated temperature up to 200˚C (artificial aging or precipitation heat treatment)

2.2.1 Solution Heat Treatment

Solution heat treatment is the ability to heat the alloy to a temperature range in which the solute is totally dissolved (Chandler, 1996). It is compulsory to produce a solid solution in order to take advantage of the precipitation hardening reaction. The purpose of this process is to take into solid solution the maximum practical amounts of the soluble hardening elements on the alloy. Figure 2.1 demonstrates the phase diagram of temperature against alloy content. All of the alloys of the constituents are in solid solution at the temperature, T_{SHT} which means the alloy is 100%, α.

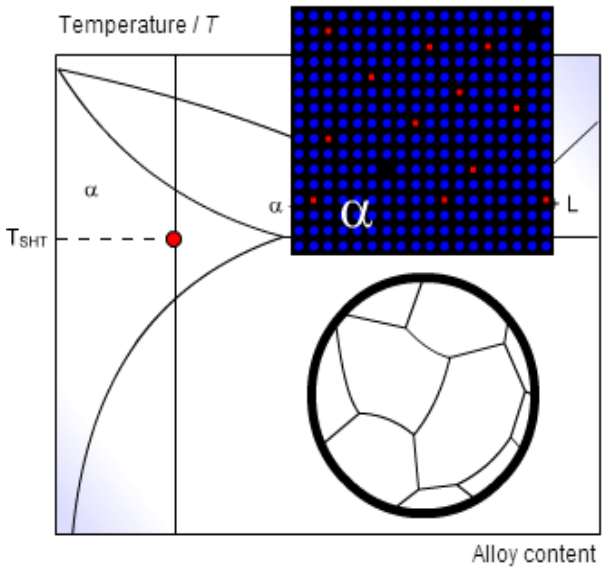

Figure 2.1: Phase Diagram of Alloy (Aluminum Matter Inc, 2010)

In order to achieve a nearly homogeneous solid solution, the soaking process of alloy is done at a sufficiently high temperature and for a long time. Air is the usual heating medium; however, molten salt baths or fluidized beds are outstanding in providing more rapid heating.

This process is carried out under controlled conditions that to avoid exceeding the eutectic melting temperature. Overheating in solution heat treatment may degrade the properties such as fracture toughness, tensile and ductility. When the underheating occurs in the alloy that being heat treated are obviously below the normal range, solution is somehow incomplete and the strength lower than normal is expected (ASM Handbook ,1996).

The soaking time is vital for a satisfactory degree of solution of the undissolved or precipitated soluble phase constituents and to obtain good homogeneity of the solid solution (Evran 2003). Time required for solution heat treatment comply with the product type, alloy, prior history and section thickness. Heating time is controlled by the section thickness. The time consumed to heat a load to the treatment temperature in furnace heat treatment increases together along with the section thickness and, therefore, the total cycle time increases.