I / We* admit that had read this dissertation and in my / our*opinion this dissertation is satisfactory in the aspect of scope and quality for the bestowal of Bachelor of Mechanical Engineering (Thermal-Fluid)

Signature : ....

Name of 1st Supervisor :..........................

Date : 13/05/2008

ENCIK MOHD FADZLI B. ABDULLAH
Pensyarah
Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

Signature : ....

Name of 2nd Supervisor :..........................

Date : 13/5/2008

PUAN RAFIDAH BT. HASAN
Pensyarah
Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

EFFECT OF RE-SOLUTION HEAT TREATMENT TIME ON THE IMPACT OF AN ALUMINUM ALLOY FOR AUTOMOTIVE APPLICATION

SARAH NADIAH ABDUL HALIM

This dissertation is submitted as partial
fulfillment of the requirement for the Degree of
Bachelor of Mechanical Engineering (Thermal-Fluid)

Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

MARCH 2008

"I declare that this report is done by my own exclude the citation with the mentioned references for each."

Signature:............................

Author: SARAH NADIAH ABDUL HALIM

Date: 13 MEI 2008

ACKNOWLEDGEMENT

ALHAMDULILLAH, all the praise to Allah The Mighty for giving me a chance to finish my dissertation in order to fulfill the requirement for Bachelor Degree of Mechanical Engineering (Thermal-fluid).

Firstly, I would like to thank the supervisor, Mr. Fadzli Bin Abdollah for every commitment and guidance that really helpful in completing this report and sharing a lot of knowledge in finishing my dissertation.

I would like to express my gratitude to all lecturer and technician of Faculty of Mechanical Engineering especially Mr. Mahader Muhamad (technician of Material Science Laboratory) and the co-supervisor, Mrs. Rafidah Binti Hasan for taking some time of their busy schedule to guide me. Not to be forgotten to my fellow friends, Aishah Mazelan, Asrul Nizam Addrus and Mohd Hafiz Mohd Elias.

Finally, a lot of thanks to all my family and friend for their undivided supports and encouragements.

Thank you.

ABSTRACT

This study presents the effect of re-solution heat treatment of 6061-T6 aluminum alloy. Solution heat treatment was done on the material with different heating time; one to four hour. Then, specimens were quenched in water. All samples were tested with Brinell hardness and Charpy impact test. Brinell hardness test result showed that there was no significant different in the hardness value obtained between each time sample. Compared to the non-heat treated sample, the hardness values for heat treated sample were decreased. Charpy impact test result showed that there was slightly increasing value of toughness for one hour, two hour and three hour sample but then decrease for four hour sample. Compared to the non-heat treated specimen, the impact energy for every sample was increased. Microstructure characterizations that were carried out by optical microscope showed that Θ (Mg_2Si) particles dispersed in the supersaturated solution of α (Al) at room temperature. The result showed that the maximum hardness obtained by sample of 2 hours and maximum impact toughness was obtained by sample of 3 hours.

ABSTRAK

Objektif utama kajian ini ialah mengkaji kesan rawatan haba semula 6061-T6 aluminum aloi. Rawatan haba semula telah dilakukan pada bahan aluminium aloi dengan masa pemanasan berbeza; satu hingga empat jam. Selepas itu, semua spesimen diberi rawatan sepuh-lindap menggunakan medium air. Semua sampel menjalani ujian kekerasan Brinell dan ujian impak Charpy. Hasil ujian kekerasan Brinell menunjukkan bahawa tidak ada perbezaan besar dalam nilai kekerasan yang diperolehi di antara setiap sampel. Berbanding dengan sampel tanpa rawatan haba, nilai-nilai kekerasan untuk sampel rawatan haba semula adalah lebih rendah. Hasil ujian impak Charpy menunjukkan bahawa terdapat penambahan nilai tenaga impak untuk sampel satu jam, dua jam dan tiga jam tetapi menunjukkan pengurangan untuk sampel empat jam. Berbanding dengan spesimen tanpa rawatan haba, tenaga impak untuk setiap sampel adalah bertambah. Gambaran sifat mikrostruktur yang telah dijalankan oleh mikroskop optik menunjukkan bahawa zarah-zarah Θ (Mg2Si) terlarut dalam larutan lampau tepu α (Al) pada suhu bilik. Hasil menunjukkan bahawa kekerasan maksimum diperoleh dari sampel 2 jam dan kekuatan hentaman maksimum diperolehi daripada sampel 3 jam.

TABLE OF CONTENT

	CONTENT	PAGE
	DECLARATION	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENT	vi
	LIST OF TABLE	x
	LIST OF FIGURE	xii
	LIST OF APPENDIX	xiv
CHAPTER 1	**INTRODUCTION**	1
	1.1 Overview	1
	1.2 Objective	2
	1.3 Scope	2
	1.4 Problem Statement	3
CHAPTER 2	**LITERATURE REVIEW**	4
	2.1 Aluminum Alloys	4
	2.1.1 Temper Designation of Aluminum Alloys	7
	2.1.2 6061 Aluminum Alloy	9
	2.1.2.1 Properties of 6061-T6 Aluminum Alloy	9

CONTENT		PAGE

	2.1.3 Application of Aluminum Alloy in Industry	10
	2.2 Heat Treatment of Aluminum Alloy	11
	2.2.1 Heat Treating Process	12
	2.2.1.1 Solution Heat Treatment	13
	2.2.1.2 Precipitation (Age) Hardening	14
	2.2.1.3 Quenching	15
	2.3 Impact Test Theory	16
	2.3.1 Charpy Impact Test	17
	2.3.2 Izod Impact Test	19
	2.3.3 Drop Weight Impact Test	21
	2.4 Hardness Test Theory	22
	2.4.1 Hardness Scales	23
	2.4.2 Brinell Test Method	23
	2.4.3 Knoop Test Method	24
	2.4.4 Rockwell Test	25
	2.4.5 Vickers Test Method	25
	2.5 Microstructure characterization	26
	2.6 Past Researches	27
CHAPTER 3	**METHODOLOGY**	29
	3.1 Process Flow Chart	29
	3.2 Material Preparation	30
	3.2.1 Introduction	30
	3.2.2 Cutting and Notching Procedure	30
	3.3 Heat Treatment Process	31
	3.3.1 Introduction	31
	3.3.2 Heat treatment procedure	31

CONTENT		PAGE

	3.4 Charpy Impact Test	33
	3.4.1 Charpy Test Procedure	34
	3.4.2 Safety Precaution	34
	3.5 Brinell Hardness Test	35
	3.5.3 Brinell Hardness Test Procedure	36
	3.6 Microstructure Characterization	37
	3.6.1 Sample Preparation	37
	3.6.2 Microstructure Analysis	37
CHAPTER 4	**RESULT AND DISCUSSION**	38
	4.1 Hardness Test Result	38
	4.1.1 Discussion of Hardness Test Result	38
	4.2 Impact Test Result	40
	4.2.1 Discussion from Impact Test Result	41
	4.3 Microstructure Characteristics of Heat Treated Aluminum Alloy	44
	4.3.1 Discussion on Microstructure Characterization for Different Heat Treatment Time of Aluminum Alloy	49
	4.3.2 Comparison of Microstructure Characterization	49
CHAPTER 5	**CONCLUSION AND RECOMMENDATION**	51
	5.1 Conclusion	51
	5.2 Recommendation	52
	REFERENCES	53
	BIBLIOGRAPHY	56

CONTENT	PAGE
APPENDIX A	57
APPENDIX B	58
APPENDIX C	60
APPENDIX D	62
APPENDIX E	72

LIST OF TABLE

NO.	TITLE	PAGE
2.1	Properties of Aluminum Alloy. (Source : www.matweb.com and www.efunda.com)	5
2.2	Aluminum Alloy Series and Description. (Source : www.burnsstainless.com and www.weldreality.com)	5
2.3	Basic Temper Designation (Source :William,2004)	7
2.4	Heat-treated Subdivisions (Source : www.efunda.com)	7
2.5	Chemical Composition Limits of 6061 Aluminum Alloy (Source : www.aircraftmaterialsuk.com)	9
2.6	Mechanical Properties of 6061 Aluminum Alloy (Source : www.aircraftmaterialsuk.com)	10
2.7	Grade of Aluminum Alloy and The Application (Source : www.aircraftspruce.com)	10
3.1	Pendulum Impact Test Machine Specification	33
4.1	Hardness Test Result of Heat Treated Aluminum Alloy	38
4.2	Impact Toughness Test Result of Heat Treated Aluminum Alloy	41
4.3	Microstructure of Aluminum Alloy (non-heat treated)	44

4.4	Microstructure of Aluminum Alloy (1 hour heat treatment time)	45
4.5	Microstructure of Aluminum Alloy (2 hour heat treatment time)	46
4.6	Microstructure of Aluminum Alloy (3 hour heat treatment time)	47
4.7	Microstructure of Aluminum Alloy (4 hour heat treatment time)	48
4.8	Comparison of Microstructure Characterization	50

LIST OF FIGURE

NO.	TITLE	PAGE
2.1	Pseudo-binary phase diagram for Al-Mg_2Si (Source:www.me.uh.edu/ceramics/3445LabManual)	13
2.2	Heat treatment diagram for Al-Mg_2Si (Source: http://info.lu.farmingdale.edu)	14
2.3	Schematic aging curve (strength of hardness versus time) at a particular temperature for a precipitation-hardenable alloy. (Source : William, F. S., 2004)	15
2.4	Dimensions for Impact Energy Calculation (source : ASTM E23-02a, 2003)	17
2.5	Charpy V-notch Specimen (source : Anderson, 1988)	18
2.6	Charpy Keyhole Specimen (source : Anderson, 1988)	18
2.7	Charpy U-notch Specimen (source : Anderson, 1988)	18
2.8	Configuration of Charpy Test Specimen (source : Anderson, 1988)	19
2.9	Izod Specimen (source : Anderson, 1988)	20
2.10	Specimen for Izod Testing (source : Anderson, 1988)	20
2.11	Drop Weight Impact Test Apparatus (Source : www.instron.us)	21
2.12	The Brinell hardness indentation (Source : www.instron.us)	24

2.13	The indenter used in Knoop hardness test (Source : www.instron.us)	24
2.14	All Vickers ranges use a 136° pyramidal diamond indenter that forms a square indent. (Source : www.instron.us)	26
2.15	Scanning Electron Microscope (Source : www.mos.org)	26
2.16	The changes in microstructure of an aluminum alloy (Source: http://info.lu.farmingdale.edu)	27
3.1	Bandsaw	30
3.2	Specimen's Dimension (source : Anderson, 1988)	31
3.3	Graph of temperature,T (°C) versus time,t (hour) for heat treatment of aluminum alloy.	32
3.4	Specimens are inserted into the furnace	32
3.5	Pendulum Impact Test Machine	33
3.6	Specimen is placed on the anvil	34
3.7	Hardness Test Machine	35
3.8	The specimen is placed on the anvil	36
3.9	Optical Microscope with Image Analyzer	37
4.1	Hardness for Heat Treated Aluminum Alloy	39
4.2	Hardness for Heat treated and Non-heat treated Aluminum Alloy	40
4.3	Impact Energy for Heat Treated Aluminum Alloy	41
4.4	Impact Energy for Heat treated and Non-heat treated Aluminum Alloy	42

LIST OF APPENDIX

NO.	TITLE	PAGE
A	General Characteristic of Hardness Testing and Formulas for Calculating Hardness (Source : Kalpakjian, S. & Schmid, S., 2004)	57
B	Analysis of Impact Test Result	58
C	Analysis of Hardness Test Result	60
D	Standard Test Methods for Notched Bar Impact Testing of Metallic Materials (Source : ASTM E23-02a, 2003)	62
E	Standard Test Methods for Brinell Hardness of Metallic Materials (Source : ASTM E10-01, 2003)	72

CHAPTER 1

INTRODUCTION

1.1 Overview

Aluminum alloys are widely uses in industry such as in containers and packaging, buildings, transportation, automobiles and electrical application. 6061-T6 aluminum alloy is commonly used for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft. This is due to its characteristics; high strength-to-weight ratio, high thermal and electrical conductivity, resistance to corrosion by many chemicals, ease of formability and machinability.

This study presents an experiment of re-solution heat treatment on 6061-T6 aluminum alloy due to several heating time at constant temperature. The re-solution heat treatment process involves solution heat treatment, quenching and precipitation hardening. Consequently, the heat treated aluminum alloy specimen will be tested to determine the effect on its microstructure using SEM or optical microscope. The changes on its mechanical properties such as hardness and impact toughness are also to be determined.

Impact test is performed to determine the energy dissipated in the material. A typical impact test consists of placing a notched specimen in an impact tester and breaking it with a swinging pendulum. From the amount of the swinging pendulum, the energy dissipated in breaking the specimen can be obtained; this energy is the impact toughness of the material.

Hardness is commonly used property to gives a general indication of the strength of the material and of its resistance to scratching and wears. It is usually defined as resistance to permanent indentation. However, hardness is not a fundamental property, because the resistance to indentation depends on the shape of the indenter and on the load applied.

1.2 Objectives

The objectives of this dissertation are:

(a) to study the effect of re-solution heat treatment time on the impact energy of an aluminum alloy.

(b) to study the microstructure characterization of re-solution heat treatment aluminum alloy.

1.3 Scopes

The scopes of this dissertation are:

(a) to study the parts of automotive that used aluminum alloy

(b) to carry out impact and hardness testing on aluminum alloy before and after re-solution heat treatment

(c) to study the microstructure characterization of re-solution heat treated aluminum alloy using SEM or optical microscope

1.4 Problem Statement

(a) Conventional vehicles are heavier, thus require more usage of fuel due to power to weight ratio.

(b) To produce lighter vehicle, aluminum alloy are proposed to be used as its component. However, it requires good strength for safety.

(c) Thus, heat treatment is suggested to be a better way on increasing the strength and hardness of aluminum alloy.

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminum Alloys

Commercial purity of aluminum is 99.5 to 99.79%, but pure aluminum is too soft to be of structural value. It has a low tensile strength, but when combined with thermo-mechanical processing, aluminum alloys display a marked improvement in mechanical properties, especially when tempered. Almost all bulk metal materials that are referred to loosely as "aluminum", be actually alloys. For example, the common aluminum foils are alloys of 92% to 99% aluminum. Aluminum is approximately 1/3 the weight of steel, yet some aluminum alloys exhibit tensile strengths greater than some low carbon steels. (www.burnsstainless.com)

There is a variety of wrought and cast alloys available for use by the manufacturer. Adding alloying elements to enhance the physical properties of aluminum for specific purposes creates these alloys. Table 2.1 shows the properties of aluminum alloy generally. The primary reason for alloying aluminum is to increase strength without significantly increasing weight. Other reasons are to improve machinability, weldability, surface appearance and corrosion resistance. (www.pennaluminum.com)

CHAPTER 2

LITERATURE REVIEW

2.1 Aluminum Alloys

Commercial purity of aluminum is 99.5 to 99.79%, but pure aluminum is too soft to be of structural value. It has a low tensile strength, but when combined with thermo-mechanical processing, aluminum alloys display a marked improvement in mechanical properties, especially when tempered. Almost all bulk metal materials that are referred to loosely as "aluminum", be actually alloys. For example, the common aluminum foils are alloys of 92% to 99% aluminum. Aluminum is approximately 1/3 the weight of steel, yet some aluminum alloys exhibit tensile strengths greater than some low carbon steels. (www.burnsstainless.com)

There is a variety of wrought and cast alloys available for use by the manufacturer. Adding alloying elements to enhance the physical properties of aluminum for specific purposes creates these alloys. Table 2.1 shows the properties of aluminum alloy generally. The primary reason for alloying aluminum is to increase strength without significantly increasing weight. Other reasons are to improve machinability, weldability, surface appearance and corrosion resistance. (www.pennaluminum.com)

Table 2.1: Properties of Aluminum Alloy. (Source : www.matweb.com and www.efunda.com)

Physical Properties	**Metric**
Density	2600-2800 kg/m^3
Mechanical Properties	
Modulus of Elasticity	70-79 GPa
Poisson's Ratio	0.33
Shear Modulus	26 Gpa
Tensile Strength	230-570 MPa
Yield Strength	215-505 MPa
Thermal Properties	
Heat of Fusion	390 J/g
Specific Heat Capacity	0.88 J/g.°C
Thermal Conductivity	190 W/m.K
Melting Point	620 - 650 °C
Solidus	620 °C
Liquidus	650 °C

Wrought aluminum alloys are designated using a four-digit system, with the first digit specifying the alloying element. Table 2.2 lists the major series of aluminum alloy includes the alloying elements, heat treatability and general properties and uses.

Table 2.2 : Aluminum Alloy Series and Description. (Source : www.burnsstainless.com and www.weldreality.com)

Aluminum Alloy Series	**Major Alloying Elements**	**General Properties**	**General Uses**	**Heat Treatable**
1XXX	None (> 99% Aluminum)	Excellent corrosion resistance, high thermal and electrical conductivities, low mechanical	Chemical Equipment, reflectors, heat exchangers, electrical	×

		properties, excellent workability	conductors	
2XXX	Copper	High strength to weight ratio, limited corrosion resistance, limited weldabilty	Truck wheels, truck suspension components, aircraft fuselage	√
3XXX	Manganese	Moderate strength without heat treating	Beverage cans, cooking utensils, heat exchangers, storage tanks	×
4XXX	Silicon	Low thermal expansion, high wear resistance	Forged engine pistons, welding rod, brazing alloys, architectural products	×
5XXX	Magnesium	Good weldability, good corrosion resistance	Ornamental trim, cans, household appliances, boats and ships	×
6XXX	Magnesium and Silicon	Good formability, moderate-strength, good weldability, good machinability, good corrosion resistance	Architectural applications, bridge railings, welded structures, racecar components	√
7XXX	Zinc	Moderate to very high strength	Airframe structures, high-strength forgings	√

2.1.1 Temper Designation of Aluminum Alloys

Temper designation for wrought aluminum alloys are used to represent the type of heating process that have been applied to it. The physical properties exhibited by aluminum alloys are significantly influenced by the treatment of the sample. A standardized system has been developed to designate these treatments. Table 2.3 shows the basic temper designation used for aluminum alloy.

Table 2.3 : Basic Temper Designation (Source : William,2004)

Designation	Description
F	As fabricated. No control over the amount of strain hardening, no mechanical property limits.
O	Annealed and recrystallized. Temper with the lowest strength and highest ductility.
H	Strain-hardened.
T	Heat-treated to produces stable tempers other than F or O.

T designation is used for thermally treated aluminum alloy to produce stable tempers other than F, O or H type. It is applies to products which are thermally treated, with or without additional strain-hardening, to produce stable tempers. The following Table 2.4 lists the heat treated subdivisions for T series aluminum alloy and its application.

Table 2.4 : Heat-treated Subdivisions (Source : www.efunda.com)

Designation	Description
T1	Naturally aged to a substantially stable condition. Applies to alloys which are not cold worked after cooling from a high temperature shaping process, or in which the effect of cold working in flattening or straightening may not be significant in mechanical property limits.
T2	Annealed. Applies to alloys which are cold worked to improve strength after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening is significant in mechanical property limits.

T3	Solution heat-treated and then cold worked. Applies to alloys which are cold worked to improve strength after solution heat treatment, or in which the effect of cold work in flattening or straightening is significant in mechanical property limits.
T4	Solution heat-treated and naturally aged to a substantially stable condition. Applies to alloys which are not cold worked after solution heat treatment, or in which the effect of cold work in flattening or straightening may not be significant in mechanical property limits.
T5	Artificially aged only. Applies to alloys which are not cold worked after cooling from an elevated temperature shaping process, or in which the effect of cold work in flattening or straightening may not be significant in mechanical property limits.
T6	Solution heat-treated and then artificially aged. Applies to alloys which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be significant in mechanical property limits.
T7	Solution heat-treated and then stabilized. Applies to products which are stabilized after solution heat-treatment to carry them beyond the point of maximum strength to provide control of some special property.
T8	Solution heat-treated, cold worked, and then artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is significant in mechanical property limits.
T9	Solution heat-treated, artificially aged, and then cold worked. Applies to alloys which are cold worked to improve strength.
T10	Artificially aged and then cold worked. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is significant in mechanical property limits.