



Faculty of Engineering

**Correlation Study of Relationship Between Hardness and Microstructure  
in Mechanical Properties of Heat Treatable Aluminium Alloys**

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Correlation Study of Relationship Between Hardness and Microstructure in  
Mechanical Properties of Heat Treatable Aluminium Alloys

MELVIN LUAT ANAK AUGUSTINE LUBON

A dissertation submitted in partial fulfilment of the requirement for the degree of  
Bachelor of Engineering with Honours  
(Mechanical and Manufacturing Engineering)

Faculty of Engineering  
Universiti Malaysia Sarawak

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To my beloved family and friends

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# ABSTRACT

This research is to investigate the unknown type of aluminium alloys either they are heat treatable or non-heat treatable alloy by conducting same heat treatment. Three types of aluminium alloys are used to undergo heat treatment; forged aluminium, aluminium from mounting gearbox component and aluminium from roofing component which are denoted as samples A, B, and C, respectively. To indicate whether these aluminium alloys are heat treatable, each of them are evaluated by hardness test. The difference of hardness value between as received, solutionized and precipitation hardened will determine whether the aluminium alloy is heat treatable or not. Therefore, the hardness value is correlated and justified with metallographic examination by observing microstructure under scanning electron microscope. Based on the results obtained, sample A shows an increase of hardness after heat treatment. Therefore, the sample is heat treatable aluminium alloy. On the other hand, sample B and C show no changes of hardness occurred after heat treatment. These samples show a decrease in hardness after solutionizing. Hence, they are denoted as non-heat treatable aluminium alloys. The composition of these alloys studied through EDX analysis also supports the final conclusion.

# ABSTRAK

Kajian ini adalah untuk mengkaji aluminium aloi yang tidak diketahui sama ada aloi tersebut adalah aloi haba terawat atau tidak dengan menjalani ujian rawatan haba yang sama. Aluminium aloi terbahagi kepada dua kategori iaitu haba terawat aluminium aloi dan bukan haba terawat aluminium aloi. Dalam eksperimen ini, terdapat tiga jenis sampel aluminium aloi digunakan untuk menjalani eksperimen rawatan haba iaitu aluminium aloi yang sudah ditempa (A), aluminium aloi daripada kotak gear kereta (B) dan aluminium aloi daripada siling atap (C). Di samping itu, ujian pengerasan menjadi indikasi untuk menilai ketiga-tiga sampel tersebut. Perbezaan kekerasan antara sampel diberi, rawatan haba penyelesaian dan pengerasan mendakan akan menentukan sama ada aluminium aloi tersebut adalah haba terawat atau bukan haba terawat. Oleh itu, kekerasan sampel aluminium aloi akan dikaitkan dengan ujian mikroskopi dimana mikrostruktur akan dikaji dan dikesan dengan menggunakan elektron mikroskop. Rawatan haba yang ideal akan ditentukan melalui pelbagai syarat variasi dan parameter digunakan. Berdasarkan hasil kajian, sampel A menunjukkan perubahan pengerasan semasa rawatan haba terutama sekali semasa pengerasan mendakan manakala sampel B dan C tiada mengalami perubahan dalam pengerasan. Oleh itu, B dan C adalah bukan aluminium aloi haba terawat. Komposisi elemen dalam sampel aloi tersebut akan disokong melalui analisis *Energy Dispersive X-ray (EDX)* pada kesimpulan kajian ini.



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# LIST OF ABBREVIATIONS

Al	—	Aluminium
Cu	-	Copper
Mg	-	Magnesium
O	-	Oxygen
Mn	-	Manganese
Si	-	Silicon
Zn	-	Zinc
Cr	-	Chromium
C	-	Carbon
NaOH	-	Sodium hydroxide
Na <sub>3</sub> AlF <sub>6</sub>	-	Cryolite
FCC	-	Face centre cubic
GP	-	Guinier Preston
SEM	-	Scanning Electron Microscope
EDX	-	Energy Dispersive X-ray
HV	-	Hardness Vickers
ASTM	-	American Society Testing Materials Standard

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction to Aluminium

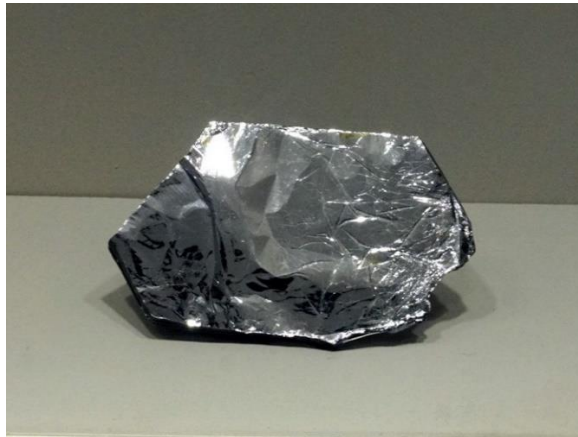
Aluminium is the world's most abundant metal as it is the third most common element comprising 8% of the earth's crust. Aluminium is known to be derived from mineral bauxite. Bauxite is converted to alumina (Aluminium Oxide) via Bayer Process (A.N Bagshaw, 2017). The versatility of aluminium makes it the most widely used metal after steel in engineering materials. Aluminium is a silvery-white metal of atomic number 13 and atomic weight of 26.98 g/mol. Our worldwide demand of usage aluminium approximately 29 million ton per year with 22 million are new aluminium and 7 million ton from recycled aluminium (Azom, 2005). The rapid growth of usage aluminium demand is due to its unique combination of properties which makes it becomes one of the preferable uses for engineering and construction material.

New production of aluminium approximately takes 14000 kWh to produce one tonne of new aluminium. Luckily Malaysia is one of the countries that produce abundant electricity which suitable for manufacture production of pure aluminium. However, people also practically recycled of used aluminium which is economically and environment friendly compared to produce new aluminium. Aluminium is widely used in heavy duty material for large structure although it is soft. Its unique combination of their properties leads to ideal in endless used of application and known its essential parts for modern living. Aluminium is subjected to most common foundry techniques as it is cast in sand, metal, shell or plaster moulds.

Physically, pure aluminium is corrosion resistance, ductile, and possess high electrical conductivity. Usually aluminium is used as a heat trap, such as foil and cable conductor, as a high electric conductivity. In term of corrosion resistance, aluminium even after exposed toward the air, its surface is hard, and the barrier is enough to



prevent deep oxidation process compared to other materials such as low carbon steel. Aluminium is one of the lightest engineering metals that is preferable by engineers in industry with its strength to weight ratio superior to steel. The various combination properties of aluminium are being utilize to its advantageous such as strength, corrosion resistance and electrical conductivity.



**Figure 1.1:** Aluminium (*Minerals.net, Mineral News*, 2016)

## 1.2 Aluminium Alloy Designation

Pure aluminium is very soft and always served as a matrix to combine with other elements as an alloy. The reinforcement of aluminium alloy provides a new character of aluminium which is enhancing their physical and mechanical properties compare to pure aluminium. Aluminium is most commonly alloyed with copper, zinc, magnesium, silicon, manganese and lithium. Therefore, the classification of aluminium alloys is divided into group families for based on the combination of different element. Table 1.1 below shows the wrought composition families of aluminium alloys. The wrought are simplify to four digits to produce a list of wrought composition families as below. Heat treatable aluminium are 2XXX, 6XXX and 7XXX series. Those heat treatable undergo heat treatment which involve phase change that improve mechanical properties and microstructure. For aluminium alloy 1XXX, 3XXX, 4XXX and 8XXX series are non-heat treatable alloy.

Table 1.1 Designation of Aluminium Alloy (E. Hamed, 2017)

Alloying Element	Wrought
None (99% pure aluminium)	1XXX
Copper (Al-Cu and Al-Cu-Mg alloys)	2XXX
Manganese (Al-Mn and Al-Mn-Mg alloys)	3XXX
Silicon (Al-Si)	4XXX
Magnesium (Al-Mg)	5XXX
Magnesium + Silicon (Al-Mg-Si)	6XXX
Zinc (Al-Zn-Mg and Al-Zn-Mg-Cu alloys)	7XXX
Others (Miscellaneous alloys)	8XXX

Each aluminium alloy series has its own application use. As an example, some applications of aluminium alloy that does not required high strength and use for daily heat insulator such as window house insulator. The designation for non-heat treatable aluminium alloy commonly apply for application that does not require too high strength properties but good formability work. For heat treatable aluminium alloy, they are suitable for heavy and high strength such as body of automobile, aerospace etc (Udomphol, 2007).

### 1.3 Heat Treatment

Heat treatment is defined as the heating and cooling of metals alloys which enhance their mechanical strength without changing its shape. The purpose of heat treatment process is to obtain certain desirable conditions or properties. The application of heat treatment for strengthen metals or alloys could be used to alter some mechanical properties for example improving, formability and machining. The study of heat treatment has many terminologies such as solutionize, quenching, age hardening, annealing, carburizing, decarburizing and tempering. However, different metals or alloys have different condition of heat treatment depends on their physical properties and state.

Besides that, the optimum properties of aluminium are achieved by alloying before heat treatment such as small amount of copper and magnesium is favourable to improve aging in heat treatable aluminium alloys. During the process, aluminium alloy undergoes the hardening when exposed to an evaluated temperature on a long period of time. This promotes the formation of small hard precipitates which interfere with the motion of dislocations and improve its mechanical properties. The age hardening discovered in 1901 by Dr. Alfred Wilm where he developed and patented first age-hardenable based on aluminium copper-manganese magnesium (Kulkarni, 2015).

#### 1.4 Research Gap

The specimens of aluminium alloys will be undergoing heat treatment process with several elevated temperatures applied followed by their accurate steps. The study of heat treatment cycle will be conducted based on the unknown identity's samples of aluminium alloy. The changes in property during heat treatment will be identified whether the alloy is heat treatable or not. Therefore, the study has a relation between the hardness and microstructure of aluminium alloy. At different stages, the result will come out with different microstructure according to the properties of aluminium alloy.

#### 1.5 Problem Statement

Heat treatment would be the last stage process for manufacturing of aluminium alloy in industry. As the process is done, the heat treatment will alter the mechanical properties in desirable condition without changing its shape. However, the main problem statement in this research is to determine the optimum heat treatment condition for aluminium alloys in order to improve their desired properties. To encounter the quality level of aluminium alloy during heat treatment, some problem needs to be resolved especially during solution treatment and precipitation hardening. For common heat treatment, some result does not expect to what desired due to error in deciding what temperature will be used. The temperature is hard to decide due to non-availability of phase diagram as reference since aluminium alloys are unknown identities.

Other issues occur during heat treatment alloys such as overheating and burning. Those temperature exceed the desired temperature above solidus line in phase diagram of the aluminium alloy could destroy the aluminium and other properties of alloy metal. Mechanical deficiency could occur if too much heat applies which contribute to formation of warping. Deterioration occurs in some phases in mechanical properties of aluminium alloy. Although aluminium alloy is known as ductile, uneven hardness could contribute problem during heat treatment. This problem occurs during unstable cooling rate which come out of steam bubble that lead to thermal shock.

Since the grade of aluminium alloys used are unknown identities, it is difficult to decide the phase diagram of the aluminium alloy. The phase diagram leads to the ideal temperature used for heat treatment. Furthermore, long aging time of heat treatment toward aluminium alloy will contribute to overageing and hardness and strength will be decreased along heat treatment. Therefore, this project will determine the change in properties of aluminium alloy based on hardness value compared to before and after heat treatment. Also, hardness value will become an indicator to identify whether the samples of aluminium alloy could be heat-treatable or not.

## 1.6 Research Hypothesis

The proper selection of temperature and time for heat treatment is applicable to different type and quality or grades of aluminium alloy. Therefore, the enhancement throughout precipitation hardening during heat treatment will identify whether the aluminium alloy samples is heat treatable or non-heat treatable alloy.

## 1.7 Objectives of The Project

The objectives of this research to be achieved:

1. To study the changes of properties by comparison of hardness and microstructure during heat treatment in order to verify whether the aluminium alloy samples is heat treatable or non-heat treatable.
2. To identify the composition of different type of as-received aluminium alloy samples after undergoing heat treatment.

## 1.8 Scope of The Report

This project consists of five main chapter excluding acknowledgement, abstract and references. The chapters including introduction, literature review, methodology, result and discussion and finally conclusion. All these chapters will explain about the study of hardness and correlation of heat treatable aluminium alloys.

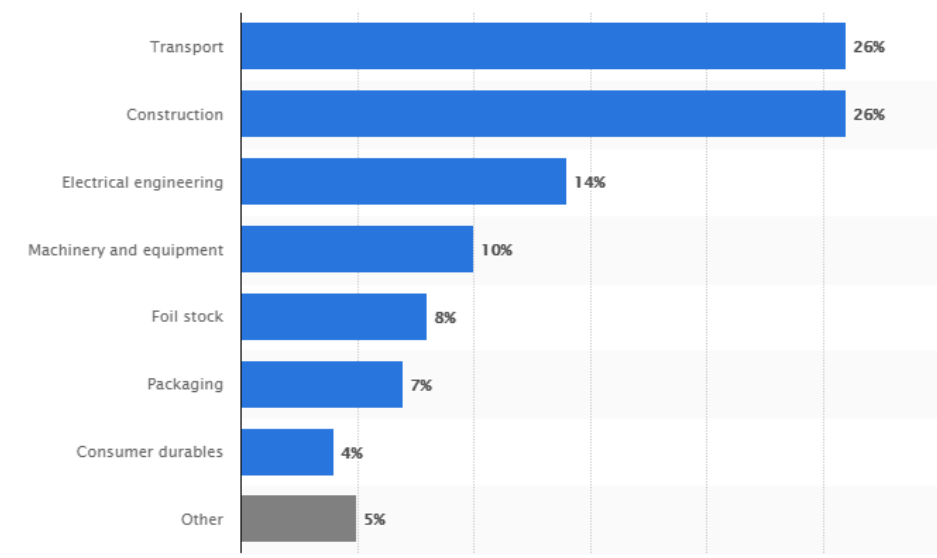
- Chapter 1 is basically introduction toward the concept of aluminium production and heat treatment by point out the problem during conducting the thesis.
- Chapter 2 is focused on the study of journal of other research whom did the similar research for guidance this project. This would help to gain information to complete the thesis.
- Chapter 3 contains the research methodologies used to solve problem outcome of the project. All the procedures and steps during experimental were documented in this chapter in which to achieve the objectives of the study.
- Chapter 4 is about the result of the project. All data collection will be included from the result of experimental lab especially the hardness and microstructure. The data obtain comes with the description based on the results and represent by tables and graphs.
- Chapter 5 concludes all the results outcomes from the studies with recommendation for further research.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Production of Aluminium

The study of aluminium is crucial to determine the process of aluminium production. Basically, aluminium has been widely used in industry as its various applications are useful for engineering mankind. In global demand, the application of aluminium products is categorized in different sectors such as transport, construction, electrical energy, machinery and equipment, foil stock, packaging, consumer durables and others. Figure 2.1 will show the statically worldwide demand for aluminium in 2017 with breakdown sector. Construction and transport sector accounted for around 26% of worldwide consumption of aluminium.



**Figure 2.1:** Global Demand of Aluminium Products in 2017 (*Global end use of aluminum by sector, 2017*)

The production of aluminium begins in France in the year 1855, H. Sainte-Claire Deville first reduced aluminium chloride with sodium. In 1885, Karl Josef Bayer is the person who patented the Bayer process which digesting the crushed bauxite toward high concentration sodium hydroxide solution. Then, the Germany scientist, Hall Héroult introduced the Hall-Héroult process by dissolving alumina in molten cryolite,  $\text{Na}_3\text{AlF}_6$ . In the United States 1976, Alcoa commence a chloride-based smelting process using alumina combined with chloride (Udomphol, 2007). The extraction of aluminium required high electricity consumption. Malaysia is one of the countries that supply abundant electricity at low cost and inexpensive. Due to the high cost of electric supplied on other countries, foreign countries preferable Malaysia to open plant production of aluminium. Based on Table 1.2, aluminium can be extracted from Bauxite, Kaolinite and Nepheline.

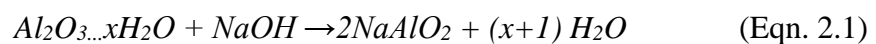
Table 2.1 Classification Extraction Process Aluminium from Minerals  
(Udomphol, 2007)

Minerals	Extraction Process
Bauxite	30-50% Alumina ( $\text{Al}_2\text{O}_3$ )
	3-13% Silica ( $\text{SiO}_2$ )
	10-18% Titanium oxide ( $\text{TiO}_2$ )
	Balanced water ( $\text{H}_2\text{O}$ )
Kaolinite	30-32% Alumina ( $\text{Al}_2\text{O}_3$ )
	Balanced Silica ( $\text{SiO}_2$ ) and water ( $\text{H}_2\text{O}$ )
Nepheline	30% Alumina ( $\text{Al}_2\text{O}_3$ )
	40% Silica ( $\text{SiO}_2$ )
	20% $\text{Na}_2\text{O} + \text{K}_2\text{O}$

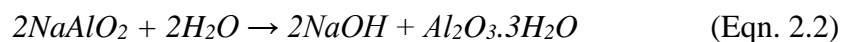
### 2.1.1 Bayer Process

As studied by Tsamo, Kofa and Kamga (2017), the process extraction of metals from the ores comes out with two type processing route which is hydrometallurgical and pyrometallurgical. Both processes are option depends on the condition but sometimes two combination process can be applied. The hydrometallurgical process defines as selective metal that dissolves in liquid which usually water based. The pyrometallurgical process is heat applied and metal would be in molten form. For the production of aluminium, alumina ( $Al_2O_3$ ); intermediate aluminium which smelted subsequently via the pyrometallurgical process. The whole schematic process of alumina by Bayer process is represented in Figure 2.2.

As bauxite been treated to hydrometallurgical process with an acidic solution, there will be a significant number of other elements instead of aluminium dissolve in the ore. Therefore, this would cause aluminium to be selected extract from complex dissolve bauxite. Aluminium is known to be amphoteric metal as it dissolves either acidic or alkaline solution. Hence, when bauxite is treated with caustic substance (alkaline) resulting aluminium is most dissolve in solution. However, other elements also represent especially iron would be insoluble. (A N Bagshaw, 2017). Commonly bauxite been dissolved with strong sodium hydroxide (NaOH) solution with higher temperature over  $240^{\circ}C$ . Then, the residual insoluble or known as red mud are remove by filtration. The red mud consists of iron and silica.



Next step is to decompose sodium aluminium oxide into ( $NaAlO_2$ ) alumina by temperature over  $50^{\circ}C$ . By adding crystal of trihydrate  $Al_2O_3 \cdot 3H_2O$  (seeding agent), the reverse reaction is achieved to promotes fine precipitation of the compound.



The water been removed by calcining product to high temperature. Usually temperature range  $400-600^{\circ}C$ , chemical alumina produces while temperature above  $1200^{\circ}C$ , inert alumina produced.

