EFFECTS OF SOLUTION TREATMENT TEMPERATURE ON THE MECHANICAL PROPERTIES OF COMMERCIAL RECYCLED ALUMINIUM ALLOY CYLINDER HEAD (A319)

By

MURIZAM BIN DARUS
04 30410006

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DECLARATION OF THESIS

Author's full name : MURIZAM BIN DARUS

Date of birth : 8th APRIL 1978

Title : EFFECTS OF SOLUTION TREATMENT TEMPERATURE ON THE MECHANICAL PROPERTIES OF COMMERCIAL RECYCLED ALUMINIUM ALLOY CYLINDER HEAD (A319)

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780408 – 09 – 5075	Prof. Dr Shamsul Baharin Jamaludin
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KESAN SUHU RAWATAN PELARUTAN KE ATAS SIFAT-SIFAT MEKANIKAL KEPALA SILINDER ALOI ALUMINIUM KITAR SEMULA KOMERSIL (A319)

ABSTRAK

Kajian dilakukan untuk meneliti kesan suhu pelarutan yang berbeza-beza ke atas kepala silinder aloi aluminium kitar semula komersil semasa proses penuaan buatan. Set sampel dipotong daripada kepala silinder automotif kitar semula dan dikenakan rawatan haba pelarutan pada setiap suhu 495°C, 510°C dan 525°C untuk jangka masa selama 10 jam. Semua sampel kemudian disejukkan ke dalam air ais pada suhu 0°C dan diikuti dengan proses penuaan buatan untuk tempoh masa sehingga 20 jam. Sifat pemendakan dipantau melalui kaedah pengujian kekerasan mikro Vicker's dan pengukuran kerintangan elektrik. Kewujudan pemendakan dicirikan melalui kaedah analisa terma dan teknik SEM/EDX. Kesan proses-proses rawatan haba diperhatikan melalui teknik metalografi. Diperhatikan bahawa aloi aluminium menunjukkan tindakbalas pengerasan penuaan yang serupa seperti proses penuaan buatan di mana pengerasan puncak telah dipercepatkan apabila suhu pelarutan yang tinggi dikenakan. Kesan pengerasan yang dicapai adalah disebabkan oleh pemendakan fasa-fasa separa stabil θ''/θ', β''/β', and $Q''Q'$ kecuali untuk suhu 495°C dimana partikel-partikel silikon yang kasar turut menyumbang kepada pengerasan puncak. Partikel-partikel silikon telah memecah dan membulat semasa rawatan haba pelarutan pada suhu yang tinggi dan menjadi homogen ke dalam matrik aluminium. Proses penuaan buatan yang lebih lama menyebabkan partikel-partikel aluminium membesar dan mengurangkan tapak-tapak untuk penjanaan fasa-fasa pemendakan, yang seterusnya merendahkan pengerasan aloi aluminium.

EFFECTS OF SOLUTION TREATMENT TEMPERATURE ON THE MECHANICAL PROPERTIES OF COMMERCIAL RECYCLED ALUMINIUM ALLOY CYLINDER HEAD (A319)

ABSTRACT

The present work was performed to investigate the effect of different solution treatment temperature on commercial recycled aluminium alloy cylinder head during artificial ageing process. All samples were sectioned from recycled automotive cylinder head and solution heat treated at 495°C, 510°C and 525°C each for a period of 10 hours. All samples were then quenched into ice water at 0°C and followed by artificial ageing at 180°C for a time up to 20 hours. The precipitation behaviours was monitored by Vicker's microhardness test and electrical resistivity measurement. Precipitation occurrence were characterised by thermal analysis method and SEM/EDX technique on critical sample. The effect of heat treatment processes was observed by metallographic technique.

It is seen that the aluminium alloy exhibit age hardening response similar to artificial ageing where as the the peak-age hardening accelerated when higher solution temperature applied. The hardening effect achieved was due to precipitation of metastable phases of θ″/θ′, β″/β′, and Q″Q′ except for 495°C where the coarser silicon particles contributes to the peak-aged hardening. Silicon particle were fragmentised and spherodised during high temperature solution treatment and homogenised into the aluminium matrix. Prolonged artificial ageing resulting the silicon particles to growth and reduces the nucleation site for phases precipitation, thus reduce the aluminium alloy hardening.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Aluminium has become a preferred material in an automotive industry since it's interception in 1970's. This material offered a good strength-to-weight ratio as compared to steel materials which were the only metal used in the early generation of automobiles. Due to the oil crisis in the 70's, all carmakers are forced to produce a lighter car with lower fuel consumption. In 1976, the average North American passenger car contained 40 kg of aluminium, while today's car has close to 115 kg. The amount of aluminium used in cars is growing rapidly in line with the development and complexity of car design. This level is expected to grow to more than 170 kg in 2005 for average passenger car, and to 410 kg for aluminium intensive vehicle (Gesing and Wolanski, 2001).

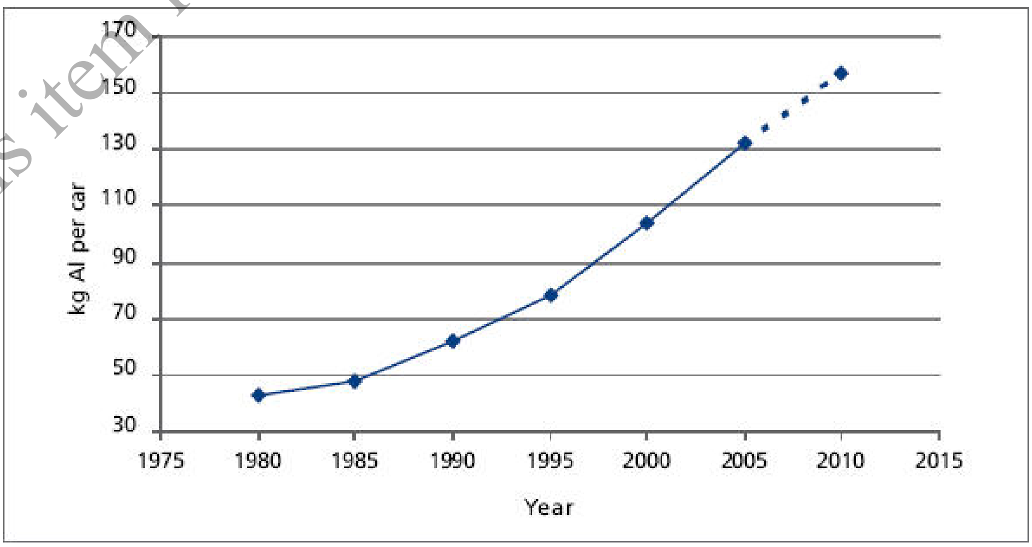


Figure 1.1 Evolution of aluminium contents in European cars (Gesing and Wolanski, 2001).

European Aluminium Association reported in Autoroadmap, (1999) that the enviromental concerned among world population regarding the climate changed and green house gases (GHG) emission have forcing automotive industry to further reduced the vehicle weight in 1990's. Transportation is claimed as a major contributor for CO_2 emissions which result in warmer weather on planet earth. Therefore, the automotive producers have chosen lighweighting as a reliable and most effective tools to reduce CO_2 emissions. A study carried out by European Aluminium Association had found that a 100kg saved on a mass of a car is equivalent to a reduction of 9 grams of CO_2 per kilometre. The weight saving acheived through a lower density of aluminium materials which is about one-third to steel but provide a greater strength-to-weight ratio (Autoroadmap, 1999).

There are two key obstacles that limiting the substitution of aluminium for steel. First the price of prime aluminium is very high as compared to steel and secondly the manufacturing cost for aluminium components contributes to an expensive production cost. The automotive industry is demanding new materials that are stronger, lighter, more reliable, more manufacturable and lower in cost (Autoroadmap, 1999).
Some of the focus areas are as listed below;

i. develop processes and technologies to reduce the cost of ingot;
ii. improve understanding of the relationship of aluminum alloy composition and processing and its effect on microstructure and properties;
iii. develop improved casting processes (including continuous casting) to produce low-cost, defect-free sheet;

iv. establish alloy and testing commonisation, i.e., reduce the number of alloy variants and test practices; and

v. develop advanced methods for integrating product design and the material and processing

Aluminium engine blocks are expected to increase by the year 2000 to about 50% of all cars. Aluminium castings find the most widespread use in automobile. In automotive power train, aluminium castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission. The other aluminium components include rear axle, differential housings and drive shafts etc (Miller et al. 2000). These scenarios provide abundance sources for recycling aluminium programme at the end-of-life of vehicles estimated in 20 years.

Recycled aluminium alloy is less expensive than a prime aluminium because the secondary remelting of scrap aluminium alloy consumes only 5% of total energy compared to the production processes for prime aluminium. Scrap quality can be detrimental to aluminium secondary remelting due to contamination and aluminium-iron phase. In order to increase the molten aluminium up to standard alloy, virgin aluminium or alloying element must be added to the melt which result to a cost increment (Hoyle, 1995). A good scrap sorting which classified the incoming aluminium scrap according to the alloy series may reduces the scrap quality issue.

The European Aluminium Association also spesifically highlighted the important of heat treatment process to produced alloys with characteristic key to automotive application such as higher strength and higher ductility. Reducing the number of alloy variant for automotive usage and optimising the heat treatment processes will further benefit the cost saving to the industry. None of the research work focused on heat treatment on recycled automotive cylinder head alloy.

1.2 Problem Statement

Currently, recycled automotive cylinder heads are used as scraps for secondary melting to produce new similar cast products. It is necessary to explore the use of recycled automotive cylinder for more than only as a scrap material. Heat treatment process is one of efficient methods to achieve the beneath objectives. Alloy strengthening mechanism on heat treatment of recycled aluminium alloy can be evaluated and compared to commercial alloys as studied in previous literature.

1.3 **Research Objectives**

The objectives of this research are:

- To investigate the effect of different solution treatment temperatures on aging response of recycled aluminium cylinder head alloy.
- To study the effect of different solution treatment temperature on the precipitation sequence during ageing.
- To investigate the hardening mechanism in aluminium cylinder head alloy after heat treatment through microstructure observation.

CHAPTER 2

LITERATURE REVIEW

This chapter reviews a metallurgical concept that is relevant to a heat treatment of aluminium alloy. The solution heat treatment and precipitation hardening mechanism were described. Relation between alloy properties such as microstructure, mechanical, thermal and electrical properties were then reviewed.

2.1 Aluminium alloys

Pure aluminium alloy is easily recognised in silvery-white colour. Pure aluminium is a soft metal with low tensile strength of 40 – 50 MPa in annealed condition. Aluminium becomes a preferred materals in engineering application because of it's lightweight and lower processing temperature. However it must be strengthened first by applying several processes such as alloying, cold working and heat treatment.

Alloying elements are added into base metal to produce an aluminium alloy with greater strength and stiffness. These alloying elements are classified as main alloying element, impurities / additions and trace elements. Table 2.1 shows the alloying elements of an aluminium alloy.

Table 2.1 : Alloying elements of an aluminium alloy

Type of alloying elements	Elements
Main	- Copper (Cu), Silicon (Si), Magnesium (Mg), Zinc (Zc) and Manganese (Mn)
Addition / impurities	- Iiron (Fe), Chromium (Cr), Titanium (Ti), Nickel (Ni), Cobalt (Co), Silver (Ag), Lithium (Li), Vanadium (V), Zirconium (Zr), Tin (Sn), Lead (Pb) and Bismuth (Bi)
Trace	- Beryllium (Be), Boron (B), Sodium (Na), Strontium (Sr) and Antimony (Sb)

2.2 Classification of Aluminium Alloys

Aluminium alloy is generally classified into two main groups;

i. Wrought aluminium alloy

ii. Cast aluminium alloy

This classification is done based on the alloying elements composition, processing routes and product application. Figure 2.1 summarised the wide range of wrought and cast aluminium alloys that are available for use.

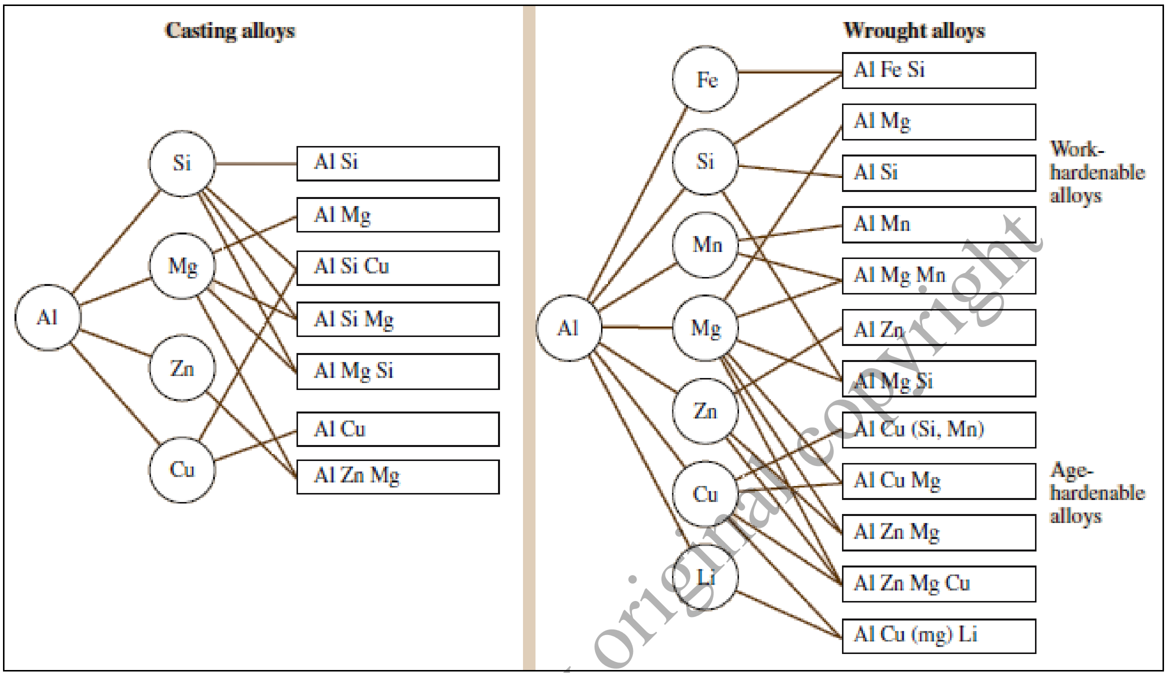


Figure 2.1 : Schematic array of cast and wrought aluminium alloys (Martienssen, 2005)

Both groups of aluminium alloys are differentiated by the percentage of alloying elements. The alloying content for wrought alloy is 1 – 2%, while for cast alloy this content is about 10 – 12%. A higher percentage of alloying content in cast alloy allowing a better melt flow for casting process which result in good quality of cast product such as strength, ductility and corrosion resistance.

The American Society for Testing and Materials (ASTM) have adopted a three-digit (plus decimal) system to indicate aluminium casting alloys. The number series used are ranging from 1xx.x to 9xx.x. These series are arranged according to major alloying elements and certain combination of elements, as shown by Table 2.2 below;

Table 2.2 : Classification of aluminium casting alloy

Series	Alloy family
1xx.x	99.0% min Al
Aluminium alloy grouped by major alloying elements:	
2xx.x	Copper
3xx.x	Silicon, with added copper and/or magnesium
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other elements

2.2.1 Aluminium-Silicon Casting Alloy

Aluminium-silicon (Al-Si) cast alloys are the most important alloy in casting industries. About 80% of cast products are produced from an Al-Si cast alloy. Figure 2.2 indicates the phase diagram for Al-Si alloy system. Addition of silicon provides an excellent casting characteristic to the alloy. Increased fluidity of the liquid metal allows the melts to flow through a mould without premature solidifying. Al-Si alloys combine the advantages of high corrosion resistance, good weldability and low specific gravity, which makes them the very important materials that are used in automotive applications. The application of some of the automotive components require the materials to exhibit consistent strength-ductility properties throughout the casting. They are engine block, cylinder head and wheel as the examples (Ossama, 2006).

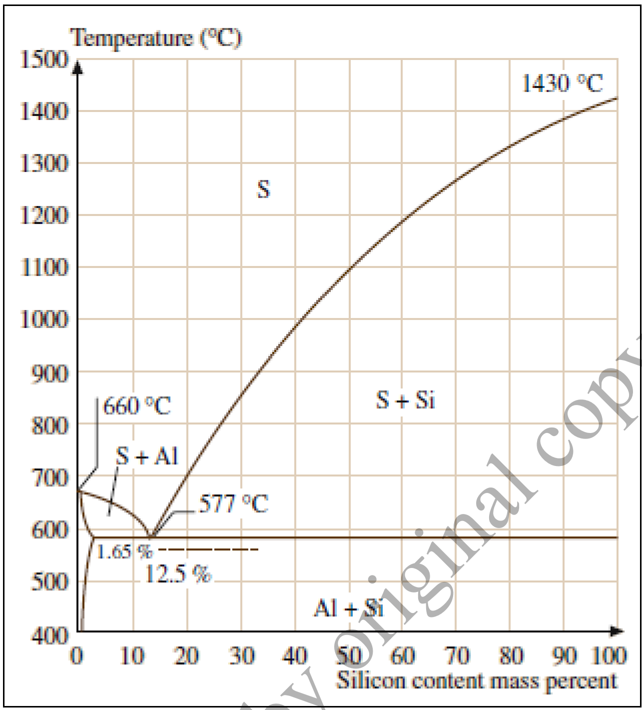


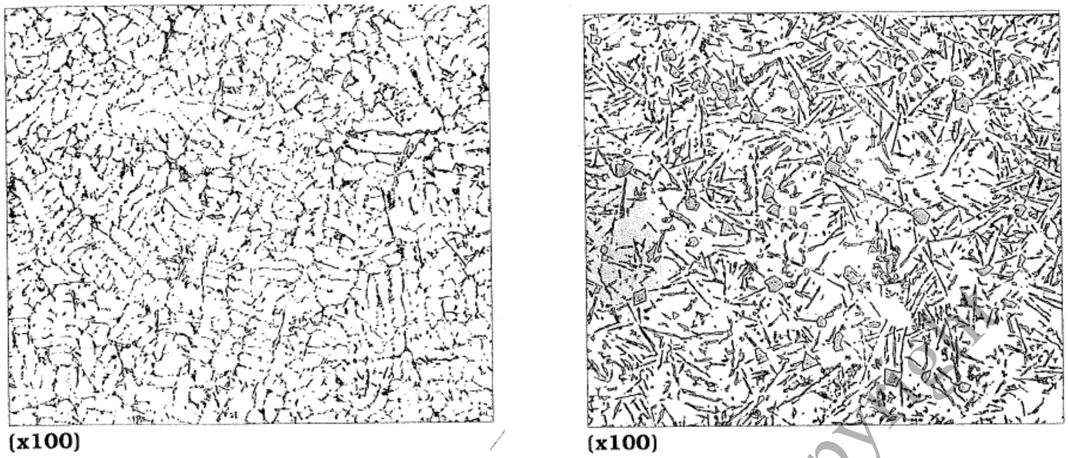
Figure 2.2 : Phase diagram of Al-Si alloy system (Martienssen, 2005)

Al-Si casting alloy are classified into three groups depending on the amount of silicon in the alloy. The microstructure of the Al-Si groups are shown in Figure 2.3 and their description are as follow (González, 2006);

i. Hypoeutectic alloys (5-11% Si), in which the aluminium solidifies forming dendritic net and the eutectic Al-Si precipitates interdendritically.

ii. Eutectic alloys (11-13% Si) in which the final structure is completely eutectic.

iii. Hypereutectic alloys (13-20% Si), in which primary solidification reaction involves the precipitation of primary Si particles until the eutectic temperature is reached, the remaining solidify as eutectic.



(a) **(b)**

Figure 2.3 : Microstructure of Al-Si alloy; (a) hypoeutectic alloy, and (b) hyperuetectic alloy

Haque (2007) reported that the structure and properties of aluminium-silicon alloys are very much dependent upon the composition, cooling rate, modification and heat treatment. During solidification, aluminium and silicon experienced different cooling rates. This has caused both material phases segregated when freezing. Slow cooling rate may result the formation of large and fragile silicon particles and iron intermetallic between aluminium matrix.

The mechanical properties of cast aluminium alloy component are determined largely by the shape and distribution of these silicon particles in the matrix. The alloy properties such as tensile, impact and fatigue are optimised when there are small, spherical and evenly distributed particles throughout the aluminium matrix. Silicon particles are also imparts heat treating ability to the casting through the formation of compounds with magnesium, Mg (Garcia, 2005).

The cast microstructure of these alloys consists of a primary phase, aluminium or silicon and a eutectic mixture of these two elements. Varying amounts of impurities such as iron, manganese, zinc and titanium are added into aluminium alloy to improved the