UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY OF SELECTED PROPERTIES OF LOW DENSITY ALLOY AFTER THE HEAT TREATMENT PROCESS

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

by

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APPROVAL

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

………………………………

PN. YUSLIZA BINTI YUSUF

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ABSTRACT

This research is to study the material properties of low density alloy after the heat treatment process. Low density alloy is category of alloy that have densities below that 4.5g/cm³. The alloys consist in this category are magnesium, titanium, beryllium and aluminium. In this study, the alloy used are titanium alloy, Ti6Al4V and magnesium alloy, MgAZ91D. These alloys will undergo the heat treatment process at various different temperature. Heat treatment temperature of Ti6Al4V are 950°C/4H and 900°C/4H. While, for MgAZ91D are 500°C/8H and 450°C/8H. Then, followed by water and air quenching medium and aging treatment at 400°C/4H for Ti6Al4V and 200°C/8H for MgAZ91D. The effect of the heat treatment parameter is documented by compared surface roughness, optical microscope analysis and hardness measurement with as-received materials. The results shows that heat treatment process with water quenching medium help to improve properties of material Ti6Al4V and MgAZ91D in term of grain size of microstructures. Generally, the value of surface roughness and hardness increased after the heat treatment process.

ABSTRAK

Kajian ini adalah untuk mengkaji sifat bahan aloi yang berketumpatan rendah selepas melakukan proses rawatan haba terhadapnya. Aloi berketumpatan rendah adalah aloi yang mempunyai ketumpatan kurang dari $4.5g/cm^3$. Aloi yang dikelaskan dalam kategori ini adalah magnesium, titanium, beryllium dan aluminium. Aloi yang digunakan dalam kajian ini adalah titanium aloi, Ti6Al4V dan magnesium aloi, MgAZ91D. Aloi ini akan menjalani proses rawatan haba pada suhu yang berlainan. Suhu rawatan haba yang digunakan untuk Ti6Al4V adalah 950°C/4J dan 900°C/4J. Manakala, suhu rawatan haba untuk MgAZ91D pula adalah 500°C/8J dan 450°C/8J. Selepas selesai proses rawatan haba, aloi tersebut menjalani proses pelindapkejutan dalam dua medium yang berbeza iaitu air dan udara. Kemudian, proses rawatan penuaan juga dilakukan atas aloi ini pada suhu 400°C/4J untuk Ti6Al4V dan 200°C/8J untuk MgAZ91D. Kesan parameter rawatan haba yang digunakan didokumentasikan dengan melakukan perbandingan kekasaran permukaan, analisis mikroskop optik dan pengukuran kekerasan dengan aloi yang tidak dikenakan proses rawatan haba. Keputusan menunjukkan bahawa proses rawatan haba serta pelindapkejutan dengan menggunakan medium air membantu meningkatkan sifat bahan Ti6Al4V dan MgAZ91D dari segi saiz butiran mikrostruktur. Secara umumnya, nilai kekasaran permukaan dan kekerasan meningkat selepas proses rawatan haba.

DEDICATION

Every challenging work needs self-efforts as well as guidance of elders, especially those who were very close to our heart.

My humble effort I dedicate to my sweet and lovely

Families members

Whose affection, love, encouragement and prayers of day and night make me able to get such success and honour,

Along with all hardworking and respected

Lectures

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This research praises to the Almighty God for giving me the grace, courage and strength to complete it. I am very thankful to my family for their lovely, support and encouragement and for being with me on each and every step of my life.

I wish to express my deepest appreciation to my supervisor, Puan Yusliza Binti Yusuf for her ideas, guidance. Motivation and help throughout my research, Study of Selected Properties of Low Density Alloy After The Heat Treatment Process which is part of the Final Year Project required for Bachelor's Degree in Manufacturing Engineering Technology (Process and Technology) with Honours. I feel very thankful for her insightful advice and suggestions. Without her support and guidance, it is impossible for me to complete my research successfully. Special thank also to lab assistant of Engineering Material Lab, Mr. Zuraini for his guidance during lab session and also to my Engineering Material's lecturer Miss Nuzaimah Binti Mustafa for her advice and support to finish my research.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Light alloys is classed of metal whose have densities less than 4.5g/cm³ (Jones, 2013). The materials that listed in light metal group are magnesium, beryllium, aluminium, and titanium. Light metals are commonly applied in aerospace and automotive industries due to their lightest weight. The commonly used in industries are aluminium, titanium and magnesium. The average aluminium content for vehicles manufactures in the United States has risen continuously from about 8 kg in1947 to 35 kg in 1971, 67 kg in 1991 and 90 kg in 1994 (Polmear, 1995). In late 1940s, titanium has been widely used when it relatively low density and high melting point (1670±10°C) made it as a potential replacement for aluminium for the skin and structure of high-speed aircraft subjected to aerodynamic heating. In this study will focused on two materials which are titanium alloy, Ti6Al4V and magnesium alloy, Mg AZ91D. This alloy are chosen due to their widely applications in industries.

Ti6Al4V is composed of Aluminium (6%) Vanadium (4%) and the balance is Titanium (90%). This alloy have a characteristic of light weight, good corrosion resistance, high tensile strength, good creep resistance that offers as an important and valuable materials especially in the construction of aerospace vehicles and engines (Srinivasan, 2010). Besides, in medical application, this material used as orthopaedic implant, bone screws, trauma plates, dental fixtures and surgical instruments.

Mg AZ91D the composition consist of Aluminium (9%) Zinc (0.6%) Manganese (0.4%) and the balance is Magnesium (90%) (Zhou et al. 2010) This alloy has the highest strength among magnesium alloy. The characteristic of this alloy are light weight, good corrosion resistance and easily cast. The common application of Mg AZ91D is in die casting part for cars and hand tools. But the low fatigue strength under service conditions has been an important factor in limiting the use of magnesium alloy in highly stressed design (Bag & Zhou, 2001).

This two alloy have weaknesses in their mechanical properties such as low fatigue strength for Mg AZ91D and low modulus elasticity for Ti6Al4V. Due to their weaknesses, many studies are done by researcher to investigate their solution. The propose solution in this study is to improve their mechanical properties with applying the suitable heat treatment process on this materials. According to (Zhou et al. 2010) Mg AZ91D alloy requires heat treatment process to improve their corrosion resistance behaviour. Meanwhile, tensile strength of Ti6Al4V alloy also can be increased with heat treatment process (Morita & Iizuka, 2005).

Heat treatment is the heating and cooling method applied to metal and alloy in a solid state so as to obtain the desire properties (Srinivasan, 2010). The main purpose of heat treatment are to improve in ductility, relieving internal stresses, refinement of grain size and increase hardness or tensile strength. There are four types of heat treatment process consists of annealing, normalizing, hardening and tempering. Not all heat treatment process are applicable for all materials because normalizing is applicable to ferrous metals only. Based on literature study, the preferred heat treatment process for Ti6Al4V and Mg AZ91D is annealing heat treatment process. Annealing is process to relieve internal stresses, soften, make more ductile, and refine the grain structures of the materials. The process is consists of heating a metal to a specific temperature, holding it at that temperature for a set length of time, and then cooling process. The estimation of the heat treatment temperature and phase obtained is predetermine base on the phase diagram. This materials will quench in two quenching medium air and water. Then will performs the aging process to increase the hardening characteristic.

The microstructure of the materials will be analysed after the heat treatment process to study the structure of the materials and phase transformation occurred. Microstructure cannot seen with naked eyes, so this will be done by using optical microscope.

The mechanical testing will be conducted to see the changes on the mechanical properties of the materials. The testing performed is hardness testing. Compare the value of as received sample with the heat treated samples. Based from data collected, compare untreated and heat treated samples and make an analysis for results and discussion.

1.2 Problem statement of study

Every material have their advantages and disadvantages, but their disadvantages can be improved by several method such as heat treatment and surface treatment. Ti6Al4V has a potential to improve its strength through tailoring microstructure. Many studies have investigate for heat treatment to obtain various microstructure and their effect on the mechanical properties (Pinke, et al., 2005). Since, the low fatigue strength of Mg AZ91D has limited usage in industries, many research have make to establish some microstructure-property relationship for AZ91D (Zhou et al. 2010).

The heat treatment process is applied in this study because the purpose of this study to improves the mechanical properties of the materials like hardness, impact and tensile and study the microstructures of the materials. The other method are not suitable because it limited to apply at surface of the material to identify like surface roughness and crack. It may not be affected at all to the interior part of material such as microstructure tensile, impact and hardness. The heat treatment process will go through the whole inside and outside part of the materials. So heat treatment process is most suitable method to analyse the microstructure changes of materials Ti6Al4V and Mg AZ91D and their mechanical properties whether it increase or decrease after the heat treatment process. Microstructural analysis of Ti6Al4V and Mg AZ91D remains important in better understanding the way in which physical properties and microstructure are related.

1.3 Objective of study

The objectives of this study are;

i) To identify the suitable heat treatment for Ti6Al4V and Mg AZ91D.
ii) To perform the heat treatment process.
iii) To study the properties in terms of microstructure, hardness and surface roughness for sample heat treatment process in comparison with the pure one.

1.4 Scope of study

This study will focused on two materials which are Ti6Al4V and Mg AZ91D. These material will go through the annealing heat treatment process at required parameter of heat treatment process. The study also focus on the microstructure changes on materials. Moreover, study the effect of the heat treatment on the mechanical properties of material. This study will applied the mechanical testing on Rockwell hardness test and determine surface roughness measurement in comparison with pure one. Gant chart of this study is attached on appendix 1.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Low Density Alloy

Low density alloy is group of alloy that have density less than 4.5g/cm3. The materials listed in this group are magnesium, beryllium, aluminium, and titanium. These four alloy classified as light alloy because of their frequently used to reduce weight of component and structure (Polmear, 1995). These four alloy have relative densities from 1.7(magnesium) to 4.5(titanium). The densities and elastic modulus of this four metal are shown in Table 2.1. Application of low densities alloy commonly used for transportation and aerospace industries, which have provided great stimulus to the development of light alloys during last 50 years (Polmear, 1995). Light alloys have a strong demand in industries due to their lightweight and high-strength characteristic (Reardon, 2012).

Table 2.1: Properties of Low Density Alloy

Metal	Density (g/cm^3)	Modulus of elasticity (GPa)
Magnesium	1.74	44.8
Beryllium	1.85	303
Aluminium	2.71	71.0
Titanium	4.5	115.8

This study will focused on two materials which are titanium alloy Ti6Al4V and magnesium alloy Mg AZ91D. This alloy are chosen due to their widely applications in automotive and aerospace industries. So, many research have been develop a study on how to improve their properties and microstructure as this material is high demand in industries.

2.2 Titanium Alloy, Ti6Al4V

2.2.1 Introduction

Titanium has being discovered well over 100 years previously. In 1910, titanium was isolated by Matthew Albert Hunter with heating titanium tetrachloride ($TiCl_4$) with sodium. Later, in 1932, Wilhelm Justin Kroll was the first to produce significant quantities of titanium by combining $TiCl_4$ with calcium (Clinning, 2012). The properties of titanium alloy is describe in table 2.2 below.

Table 2.2: Properties of titanium alloy

Property	**Typical value**
Density g/cm3 (lb/ cu in)	4.42 (0.159)
Melting Range °C ±15°C (°F)	1649 (3000)
Specific Heat J/kg.°C (BTU/lb/°F)	560 (0.134)
Volume Electrical Resistivity ohm.cm (ohm.in)	170 (67)
Thermal Conductivity W/m.K (BTU/ft.h.°F)	7.2 (67)

Titanium is low-density element that approximately 60% of the density of steel that can be readily strengthened by alloying and deformation processing. Titanium exists in two crystallographic forms. At the room temperature, unalloyed (commercially pure) titanium has a hexagonal closed-packed (HCP) crystal structure referred to as alpha (α) phase as shown in Figure 2.1. At 883 °C, this transforms to a body-centered cubic (BCC) structure known as beta (ß) phase as shown in Figure 2.2. (Clinning, 2012)

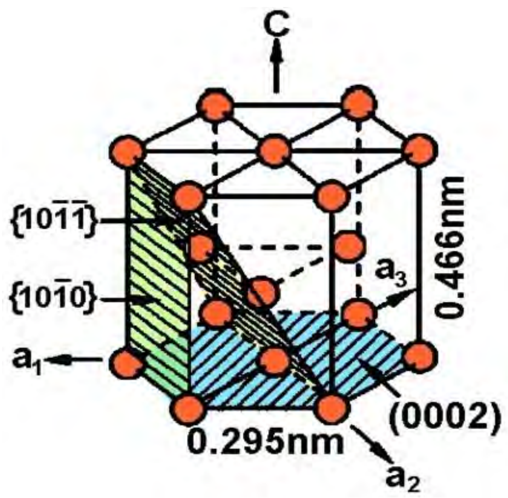

Figure 2.1: Unit cells of α phase titanium

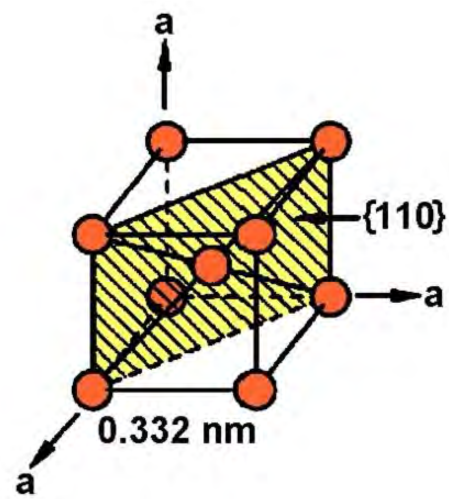

Figure 2.2: Unit cells of ß phase titanium

Titanium alloys can be classified into four categories. First categories is α alloys. Titanium α alloys is commercially pure grades of Ti, it containing well defined amounts of oxygen, and Ti-2.5Cu and Ti-5Al-2.5Sn. Second category is near- α alloys, it contain only a small amount of ß phase. They are stronger than α alloys and heat treatable. Early examples are Ti-6Al-2Sn-4Zr-2Mo and Ti-8Al-1Mo-1V. More complex alloys have been developed for improved creep resistance. These include TiAlZrMoSiFe and TiAlZrSnNb(Mo,Si) alloys. Next category is titanium α – ß alloys. These category contain limited amounts of ß -stabilizers, the majority of which cannot strengthen the α phase. Hence a-stabilizers are also added. The mechanical properties depend on the relative amounts and distribution of the α and ß phases. These variables are controlled by processing and heat treatment. Examples are Ti-6Al-4V and Ti-6Al-

2Sn-4Zr-6Mo. Last category of titanium alloy is ß alloys. Titanium in this category have sufficiently high ß-stabilizer contents that commercially useful microstructures are predominantly b phase. They have been developed mainly because of excellent formability (e.g. cold-rolling) and very good response to heat treatment. Examples are Ti-15Mo-3Nb-3Al-0.2Si and Ti-10V-2Fe-3Al.

Significant change has occurred in the use of titanium and titanium alloys and the number of new titanium materials and product forms the medical device designer has from which to select. Since the early 1990s, several new ASTM standards for titanium-base alloy biomaterials have been developed by the "Metallurgical Materials" Subcommittee, ASTM F-04.12 (Jablokov, 2008). These consensus standards, listed in Table 2.3.

Table 2.3: ASTM standard for Titanium Alloy

Common Name	**ASTM/ISO**	**Microstructure**	**UNS Number**
Ti-5Al-2.5Fe (“Tikrutan”)	ISO 5832-10	α + ß	unsigned
Ti-6Al-7Nb Alloy (“TAN”)	ASTM F 1295, ISO 5832-11	α + ß	R56700
Ti-6Al-4V Alloy	ASTM F 1472, ISO 5832-3	α + ß	R56400
Ti-13Nb-13Zr Alloy	ASTM F 1713	Metastable ß	R58130
Ti-12Mo-6Zr-2Fe Alloy (“TMZF”)	ASTM F 1813	Metastable ß	R58120
Ti-15Mo Alloy	ASTM F 2066	Metastable ß	R58150
Ti-3Al-2.5V Alloy (tubing only)	ASTM F 2146	α + ß	R56320
Ti-35Nb-7Zr-5Ta Alloy “TiOsteum”	Sub. F-04.12.23	Metastable ß	R58350

By far the most popular and widely used titanium alloy is the α – ß alloy, Ti6Al4V which consists of 6% (by weight) aluminium, 4% vanadium and the balance titanium (Morita & Iizuka, 2005). Ti6Al4V, also known as grade 5, Ti-6Al-4V or Ti 6-4. This alloy alone accounts for more than 50% of all the titanium usage worldwide. The phase diagram of Ti6Al4V is shown in Figure 2.3. As Ti6Al4V is an α – ß alloy, at temperatures below the ß -transus temperature, the alloy exists as a mixture of both α and ß phases. Because vanadium has a greater solubility in the BCC ß phase of titanium while aluminium is more soluble in the HCP α phase, elemental partitioning exists between equilibrium α and ß phases in Ti6Al4V, meaning that the ß phase will be vanadium rich, while the α phase will be depleted in vanadium as compared to the bulk composition of the alloy.

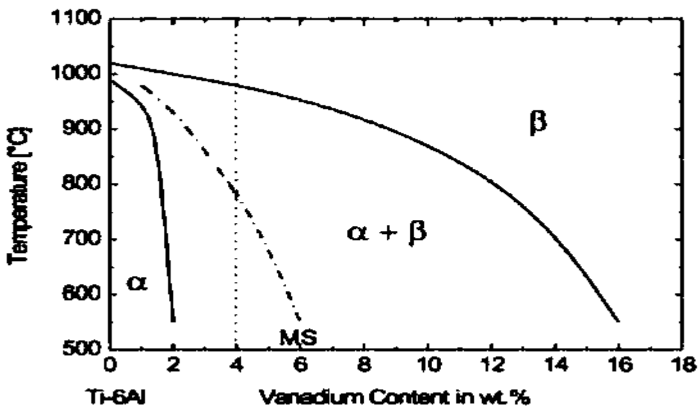

Figure 2.3: Phase diagram of Ti6Al4V

2.2.2 Application of Ti6Al4V

Titanium alloy have been used instead of iron or nickel alloys in aerospace applications because titanium saves weight in highly loaded component that operate at low to moderately elevated temperatures (Reardon, 2012). The Ti6Al4V alloy offers the best all-round performance for a variety of weight reduction applications in aerospace, automotive and marine equipment.

Ti6Al4V alloy has been widely used for lightweight parts and members in a variety of industrial products since its first production in 1954. At the present time, this typical α – ß alloys covers 56% of the titanium market in the USA. The widespread application of Ti6Al4V alloy results from its light weight, good corrosion resistance and excellent combination of static strength and ductility (Morita & Iizuka, 2005). The demand for the use of titanium and its alloys in many areas of applications has increased over the past years by the necessity for weight reductions that enhance the efficiency