UNIVERSITI TEKNIKAL MALAYSIA MELAKA

HEAT TREATMENT AND MECHANICAL PROPERTY OF Ti6Al4V

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

by

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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 (*Engineering Material*) with Honours. The member of the supervisory committee is as follow:

……………………………..

Dr Zulkifli Mohd Rosli

ABSTRACT

This project investigates the heat treatment and mechanical property of Ti6Al4V titanium alloys. The heat treatment process for Ti6Al4V is follow by ASTM standard procedure. The purpose of this project to carry out heat treatment process for Ti6Al4V, than follow by microstructure observation and oxidation element at Ti6Al4V titanium alloy before and after heat treatment process. Optical microscopy will be use to investigate the microstructure orientation and x-ray diffraction (XRD) will be use to spot oxidation elements from Ti6Al4V titanium alloy. To investigate mechanical property of Ti6Al4V titanium alloy Rockwell Hardness Tester will be by using to test the hardness of Ti6Al4V titanium alloy before and after heat treatment process. It is predicted that the Ti6Al4V titanium alloy heat treatment will be conduct greatly and give good effect for microstructure orientation, oxidation layer and hardness test result at the end of project.

ABSTRAK

Projek ini mengkaji perlakuan panas dan sifat mekanik dari gabungan titanium Ti6Al4V. Perlakuan panas proses untuk Ti6Al4V adalah mengikuti ketetapan ASTM. Tujuan projek ini dilakukan proses perlakuan panas, untuk Ti6Al4V, dan ikuti oleh pengamatan mikro dan unsur pengoksidaan pada gabungan titanium Ti6Al4V sebelum dan selepas proses perlakuan panas. Optik mikroskop akan digunakan untuk mengkaji orientasi mikro dan x-ray pembelauan (XRD) akan digunakan untuk tempat unsur-unsur pengoksidaan dari gabungan titanium Ti6Al4V. Untuk mengetahui sifat mekanik dari gabungan titanium Ti6Al4V Rockwell Hardness Tester akan digunakan dan bagi menguji kekerasan gabungan titanium Ti6Al4V sebelum dan selepas proses perlakuan panas. Sebagai inferens awal bahawa gabungan titanium Ti6Al4V perlakuan panas akan melakukan dan memberikan kesan sangat baik untuk orientasi mikro, kekerasan lapisan pengoksidaan dan hasil ujian pada akhir projek.

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LIST OF ABBREVIATIONS

Al	-	Aluminum
AMS	-	American Society for Testing Standard Material
ASTM	-	American Society for Testing and Material
BTU	-	British Thermal Unit
$FeTiO_3$	-	Ilmenite
Ga	-	Gallium
GPa	-	Giga Pascal
H2O	-	Water
HF	-	Hydrofluoric
HNO_3	-	Nitrid acid
Mo	-	Molybdenum
MPa	-	Mega Pascal
N	-	Nitrogen
O	-	Oxygen
Ta	-	Tantalum
Ti	-	Titanium
TiO_2	-	Rutile
UK	-	United Kingdom
UTeM	-	Universiti Teknikal Malaysia Melaka
V	-	Vanadium
W	-	Tungsten
XRD	-	X-Ray Diffraction
Z	-	Atomic number

LIST OF SYMBOLS

%	-	Percentage
°C	-	Degree Celsius
°F	-	Degree Fahrenheit
ft	-	Feet
HRC	-	Hardness Rockwell scale C
kg	-	Kilogram
kJ	-	Kilo Joule
m/s	-	Meter/second
mm	-	Milimeter
Tg	-	Glass Transition Temperature
α	-	Alpha
β	-	Beta

CHAPTER 1
INTRODUCTION

1.1 Background

Since the introduction of titanium and titanium alloys in the early 1950s, these materials have in a relatively short time become backbone materials for the aerospace, energy, and chemical industries.

The combination of high strength-to-weight ratio, excellent mechanical properties, and corrosion resistance makes titanium the best material choice for many critical applications. Today, titanium alloys are used for demanding applications such as static and rotating gas turbine engine components. Some of the most critical and highly-stressed civilian and military airframe parts are made of these alloys.

The use of titanium has expanded in recent years to include applications in nuclear power plants, food processing plants, oil refinery heat exchangers, marine components and medical prostheses.

The high cost of titanium alloy components may limit their use to applications for which lower-cost alloys, such as aluminum and stainless steels. The relatively high cost is often the result of the intrinsic raw material cost of metal, fabricating costs and the metal removal costs incurred in obtaining the desired final shape.

In this project, we use grade 5 titanium alloy Ti6Al4V that the most common used alloy. From this project we wish to view the process of heat treatment of the alloying, apprehend the microstructure and undertake the hardness test to check the mechanical property of Ti6Al4V.

1.2 Problem statement

There are several studies that concentrated on the heat treatment process for Ti6Al4V alloy following by ASTM standard. Especially after the heat treatment process observation of microstructure, hardness test and viewing oxidation layer for titanium alloy Ti6Al4V will be continue until the end of the project.

1.3 Objectives

1. To study of the effect of heat treatment on Ti6Al4V alloy following ASTM standard.
2. To investigate the layer of oxidation on Ti6Al4V alloy after heat treatment process.
3. To study the hardness of Ti6Al4V alloy before and after heat treatment process
4. To compare the hardness and microstructure of Ti6Al4V alloy before and after heat treatment.

1.4 Research Scope

The sample of Ti6Al4V must be cut into specified size before go through the heat treatment process. The sample size will through the test follows the ASTM standard as reference for heat treatment process. There are five samples to be evaluated with same parameters between each others. Four of sample will go through to heat treatment process and one specimen as a reference. The result obtain is very important to know about the microstructures orientation and the layer of oxidation occurs before and after heat treatment process. X-Ray Diffraction (XRD) is used to investigate the layer of oxidation occurs and optical microscope is used to analysis microstructure orientation for Ti6Al4V before and after heat treatment process. Moreover, Rockwell Hardness Tester is used to measure the hardness of Ti6Al4V before and after heat treatment process.

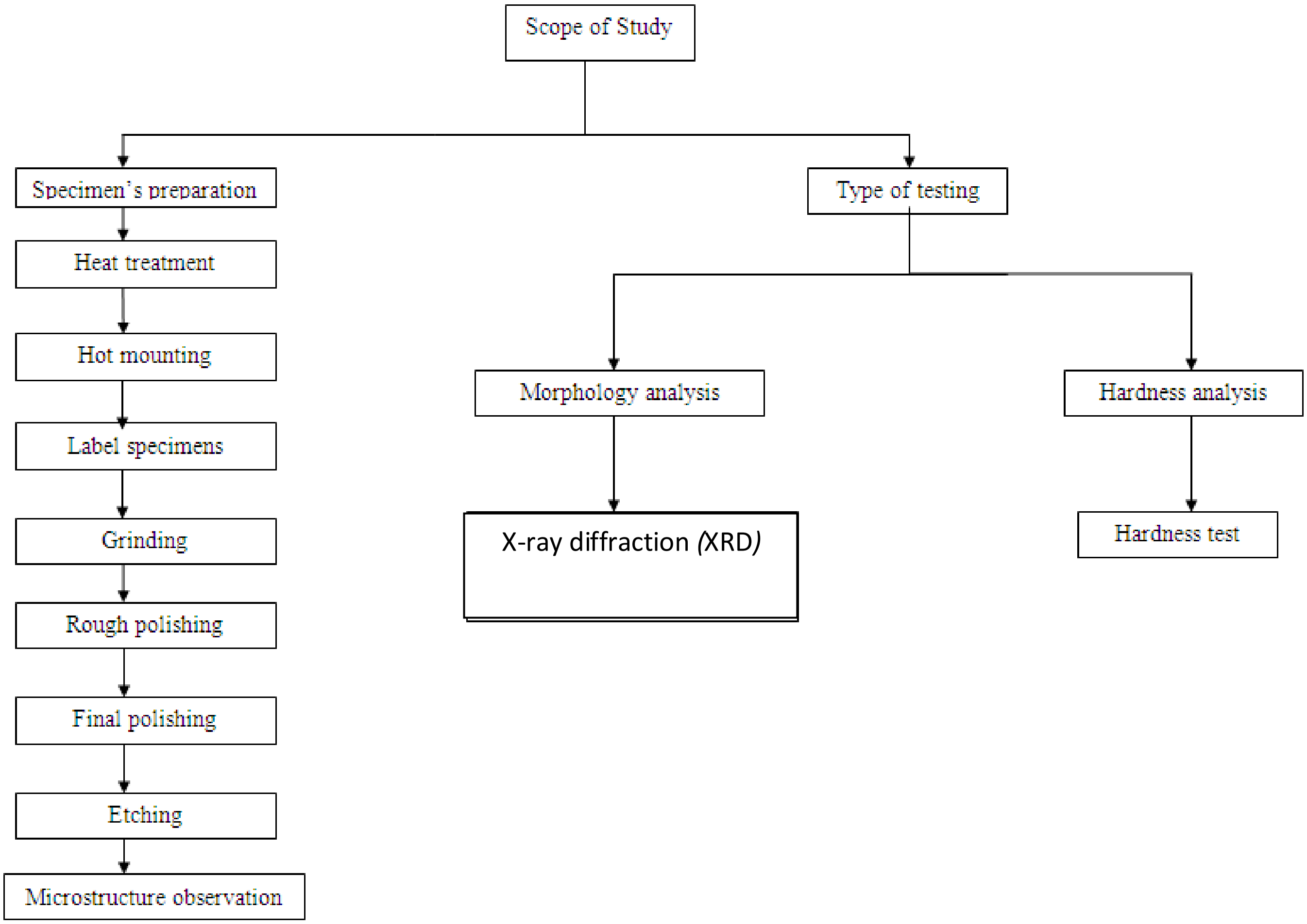

Figure 1.1 Flow chart scope of study

CHAPTER 2

LITERATURE REVIEW

2.1 Titanium

2.1.1 Background of Titanium

Titanium is present in the earth's crust at a level of about 0.6% and is therefore the fourth most abundant structural metal after aluminum, iron and magnesium. The most important mineral sources are ilmenite (FeTiO3) and rutile (TiO2) (Heiderberg, V.B., 2003).

The first suspicion of new, unknown element present in ad dark, magnetic iron-sand (ilmenite) in Cornwall (UK) was expressed in 1791 by Gregor, a clergyman and amateur mineralogist. In 1795, Klaproth, a Germen chemist analyzed rutile from Hungary and identified an oxide of an unknown element, the same as the one reported by Gregor. Klaproth named the element titanium after the Titans, the powerful sons of the earth mythology (Heiderberg, V.B., 2003).

Many attempts were made to isolate the metal from the titanium ore using titanium tetrachloride (TiCl4) as an intermittent step. The production of ductile, high purity titanium still proved to be difficult, because of the strong tendency of this metal to react with oxygen and nitrogen. Early demonstration of reduction of titanium tetrachloride (TiCl4) using either Sodium (Na) or Magnesium (Mg) produce a small quantities of brittle titanium metal. It was not until well into 20^{th} century (1973-1940) that commercially attractive process was developed by Kroll in Luxembourg. This process involved the reduction of titanium tetrachloride ($TiCl_4$) with Magnesium (Mg) in an inert gas atmosphere. The resulting titanium is called "titanium sponge" because of its porous and spongy appearance. This famous Kroll process remained essentially unchanged and is the dominant process for titanium production today (Heiderberg, V.B., 2003).

It is noteworthy that industry capacity of TiCl4 production existed before the interest in metallic titanium developed. This is because TiCl4 is the feed stock for synthetic, high purity TiO2 used in paint. Even today, only 5% of TiCl4 production is used to produce titanium metal (Heiderberg, V.B., 2003).

A more detailed description of the history of titanium can be found in the over-view "Titanium- A Historical Perspective" by Bomberger, Froes, and Morton (Heiderberg, V.B., 2003).

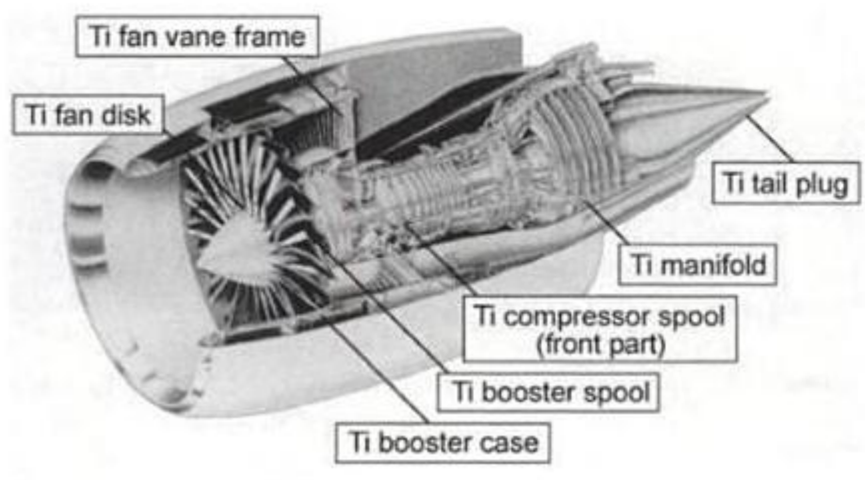

Figure 2.1: Examples of application titanium used in the GE-90 aero-engine (Heiderberg, V.B., 2003).

2.1.2 Definition of Titanium

Titanium is a rather new material and is, probably, the last addition to comparatively small group of structural material for large-capacity constructions. Along with iron, aluminium, magnesium, copper and nickel, it is becomes one of the essential metal materials for modern machine building, as its reserves in the Earth's crust are rather big (Valentin, N.M., 2006).

The advantages of titanium as structural material are well known. The major stimulus for titanium to be used in various engineering fields is its specific strength and high temperature strength with broad temperature strength within a broad temperature range, and also a high corrosion resistance in most aggressive media (Valentin, N.M., 2006).

For the crystal structure of the titanium alloy, the pure titanium exhibits an allotropic phase transformation at 882c, changing from a body- centred cubic crystal structure (β phase) at higher temperature to a hexagonal close –packed crystal structure (α phase) at lower temperature. The exact transformation temperature is strongly influence by interstitial and substitutional elements and therefore depends on the purity of the metal (Heiderberg, V.B., 2003). Figure 2.2 shows that the unit cell of a phase and figure 2.3 shows that unit cell for b phase.

Comparison of titanium with other structural metal shows it be the most refractory and to have lower values of thermal conductivity, electrical resistant and thermal expansion.

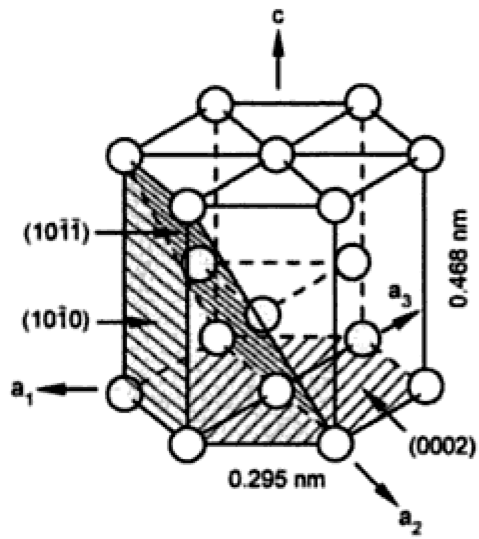

Figure 2.2 Unit cells of α phase titanium (Heiderberg, V.B., 2003).

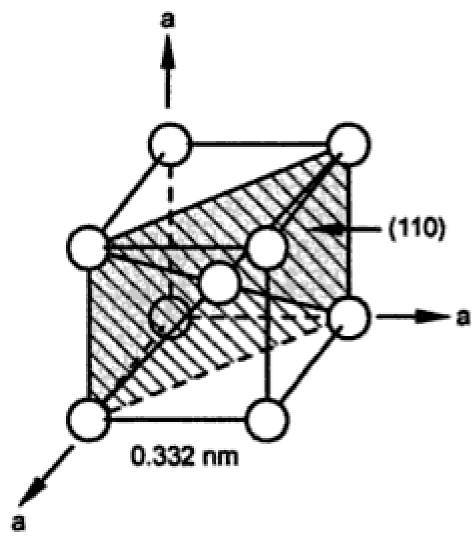

Figure 2.3 Unit cell for β phase titanium (Heiderberg, V.B., 2003).

2.1.3 Classification of Titanium

All titanium alloys are divided into three groups by the type of structure

1. Alloys based on solid α and β solution

2. Alloys based on solid solution with some amount of chemical compound
3. Alloy based on a chemical solution

The most numerous and traditional group are titanium alloys which represent solid solutions. As a rule there are structural alloys with a high ratio of strength and ductility, satisfactory fusion weldability, capability of hardening heat treatment, good thermal stability, and other properties required for modern structural materials. Solid solution titanium alloys retain high strength at temperature 350-450°C (Valentin, N.M., 2006).

Solid-solution titanium alloys with chemical compounds are also widespread. This is a class of titanium alloys based on α -, (α + β), and β -solid solutions with an amount of disperse formations of a chemical compound, which ensure a significant enhancement of strength and high temperature strength. Commercial titanium alloys contain a minor amount of chemical compound or the initial stage of its formation in α - or (α + β) – matrix. Aluminum (Ti_3Al), silicon (Ti_5Si_3), carbon (TiC), boron (TiB), etc., are used as alloying element forming chemical compound in titanium. Other complex chemical compounds can be formed in multicomponent alloys. Development of solid-solution based alloy with chemical compound made it possible to increase the operational temperature up to 500-600°C (Valentin, N.M., 2006).

There are two crystallographic forms of titanium:

1. α-titanium, in which atoms are arranged in hexagonal closest packing (HCP) crystal lattice;
2. β-titanium, in which atoms are arranged in body cubic centered (BCC)crystal lattice;

Pure titanium exists in form of α-phase at temperatures above 1621°F (883°C) and in form of β-phase at temperatures below 1621°F (883°C). The temperature of allotropic transformation of α-titanium to β-titanium is called Beta Transus Temperature. Alloying elements in titanium alloys may stabilize either α-phase or β-phase of the alloy. Aluminum (Al), gallium (Ga), nitrogen (N) and oxygen (O) stabilizes the α-phase. Molybdenum (Mo), vanadium (V), tungsten (W), tantalum (Ta) and silicon (Si) stabilizes the β-phase.

Titanium alloys are classified into four groups according to their phase composition:

1. Commercially pure and low alloyed titanium alloys

Commercially pure titanium consists of grains of α-phase and dispersed spheroid particles of β-phase. Small amounts of iron, present in the alloys, stabilize β-phase. Commercially pure titanium has relatively low mechanical strength and good corrosion resistance.

2. Titanium alpha and near-alpha alloys

α-alloys consist entirely of α-phase. They contain aluminum (Al) as the major alloying element, stabilizing the α-phase. α-alloys have good fracture toughness and creep resistance combined with moderate mechanical strength, which is retained at increased temperatures. They are easily welded, but their workability in hot state is poor. Near α-alloys contain small amount of ductile the β-phase. Besides α-phase stabilizer (aluminum), near α-alloys are alloyed by 1-2% of β-phase stabilizers (molybdenum (Mo), silicon (Si)). Mechanical properties of near α-alloys are similar to those of α-alloys, however due to the presence of β-phase these alloys may be heat-treatable and are forged in hot state (Anonymous, 2009 [2]).

3. Titanium alpha-beta alloys

α-β alloys contain 4-6% of β-phase stabilizers; therefore they consist of a mixture of α and β phases. α-β alloys are heat-treatable. They have high mechanical strength and good hot formability. Creep resistance of the alloys is lower, than that of α- and near α-alloys (Anonymous, 2009 [2]).