UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY THE PROPERTIES OF Ti-6Al-4V AFTER THE GAS NITRIDING PROCESS

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Engineering Technology Manufacturing (Product Design) (Hons.)

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 degree of Bachelor of Manufacturing Engineering Technology (Product Design) with Honours. The member of the supervisory is as follow:

………………………………

PUAN YUSLIZA BINTI YUSUF

(Project Supervisor)

ABSTRAK

Dalam kajian ini, aloi Ti-6Al-4V akan menjalani proses gas nitriding untuk meningkatkan sifat-sifat permukaannya. Ti-6Al-4V digunakan secara meluas dalam industri kerana sifat-sifatnya yang berfaedah tetapi kegunaannya terhad disebabkan oleh sifat-sifat tribologikal yang lemah. Oleh itu, gas nitriding adalah proses rawatan permukaan yang berkesan untuk meningkatkan ciri-ciri tribologikal Ti-6Al-4V. Dalam proses gas nitriding, suhu proses dan masa adalah parameter penting yang mempengaruhi sifat-sifat permukaan yang dikehendaki. Berdasarkan kajian literatur, kajian ini telah mencadangkan suhu proses iaitu 650 °C, 750 °C dan 850 °C untuk masa proses selama masing-masing 2 dan 4 jam. Selepas proses gas nitriding, analisis sifat-sifat permukaan termasuk analisis mikrostruktur, analisis kekasaran permukaan dan analisis kekerasan telah dijalankan untuk menilai sifat-sifat permukaan sampel nitrat berbanding dengan sampel rujukan yang merujuk kepada Ti-6Al-4V yang tidak dirawat.

ABSTRACT

In this study, the Ti-6Al-4V alloy will be undergo the gas nitriding process in order to enhance its surface properties. Ti-6Al-4V is widely used in industries due to its beneficial properties but its applications is restricted by its poor tribological properties. Hence, the gas nitriding is the most common effective surface treatment process to enhance the tribological properties of Ti-6Al-4V. In gas nitriding process, the process temperature and time are the crucial parameters that may affected the desired surface properties obtained. Based on the literature review, this study has proposed the process temperatures which are 650 °C, 750 °C and 850 ℃ carried out for the process time of 2 and 4 hours respectively. After the gas nitriding process, the surface properties analysis which include microstructure analysis, surface roughness analysis and hardness analysis is conducted to observe the surface properties of the nitrided samples in comparison with the reference sample which refer to the untreated Ti-6Al-4V.

DEDICATION

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

My humble effort I dedicate to my sweet and lovely

Family members

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

Project supervisor, Puan Yusliza Binti Yusuf

Along with all hardworking and respected

Lectures and friends

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Ti	-	Titanium
Al	-	Aluminium
V	-	Vanadium
Sn	-	Tin
Mo	-	Molybdenum
Si	-	Silicon
Zr	-	Zirconium
Bi	-	Bismuth
Cr	-	Chromium
Nb	-	Niobium
C	-	Carbon
N	-	Nitrogen
α	-	Alpha
β	-	Beta
SCFH	-	Standard Cubic Feet per Hour

CHAPTER 1

INTRODUCTION

1.1 Background

Titanium is found as the fourth most in metal and ninth most in earth crust (Pappas and Contributor, 2014). Titanium is a light weight and high strength non-ferrous metal that widely applied in various industries such as marine, aerospace and automotive. Titanium exists in alpha phase which has hexagonal closely packed (HCP) crystal structure and then transforms into body centered cubic (BCC) in beta phase at 882.5 °C. Titanium is strong as steel because of the crystal structures and metallic bonds of the atoms. However, titanium is seldom used commercially and applied for high rigidity structural due to poor corrosion resistance and lack of stiffness (Pattman, 2015). Due to the weaknesses, titanium can be alloyed with other elements such as molybdenum, vanadium, and aluminium in order to enhance the strength. Titanium alloy can be classified as alpha, alpha + beta and beta based on the structural and composition of elements. The alpha stabilizers such as aluminium dissolve in pure titanium and form alpha titanium alloy whereas beta titanium alloy is formed when beta stabilizers such as molybdenum and vanadium is dissolved in pure titanium. The alpha + beta titanium alloy consists of both alpha and beta stabilizers and it is stronger than alpha alloy. Ti-6Al-4V is an example of alpha + beta titanium alloy.

The most common titanium alloy used is Ti-6Al-4V. The reasons for the success of this alloy is because it has a high specific strength, well in heating and corrosion resistance due to the combination of alpha and beta stabilizers which are aluminium and vanadium respectively (Ge et al. 2013). Based on its mechanical properties, Ti-6Al-4V is able to fulfil the requirements in engineering and industries. However, its application is usually restricted due to its poor tribological properties which are low surface hardness and poor wear resistance (Ge et al. 2013). Due to the limitations of Ti-6Al-4V, a lot of studies have investigated the methods of improving tribological properties. Surface treatment is one of the method to enhance its poor tribological properties and there are various types such as physical vapor deposition (PVD) and nitriding. According to Man, Bai and Cheng (2011), the nitriding is the most suitable and effective method to enhance the tribological properties of Ti-6Al-4V.

Nitriding is a thermochemical reaction which form a nitrided layer on the surface of metals in order to improve surface properties. The nitrogen is introduced into metals' surface and nitrided layer formed is used to harden the surface of metals (Zhecheva et al. 2005). The nitriding process can be classified into three main types which are salt bath nitriding, plasma nitriding and gas nitriding. According to Zhecheva et al. (2005), the gas nitriding is an easy method in forming the nitrided layer and able to reduce the fatigue limit of titanium alloys. Gas nitriding is also a method which is low cost and less variables process parameters. Therefore, gas nitriding is considered as the most suitable method to improve the surface properties of Ti-6Al-4V.

By referring the previous studies, a lot of studies indicate that the crucial parameters which able to affect the nitriding process are process temperature and time. According to Zhecheva et al. (2005), the process temperature and time are able to affect the results of nitrided layer and desirable surface properties of titanium and its alloys. Based on the study by Zhecheva, Malinov, and Sha (2006), the hardness of the materials increases as of the process time is increased. Furthermore, the increasing of process temperature and time are able to cause the surface hardness improvement and thicken the nitrided layer on the surface of materials according to the study of Ge et al. (2013). Thus, in this study will investigate the most suitable process temperature and time for gas nitriding process in order to improve the surface properties of Ti-6Al-4V alloy.

1.2 Problem Statement

Titanium alloys, especially Ti-6Al-4V has been used in many industries such as aerospace applications, medical applications and automotive applications. This is because it has beneficial properties such as low density, high strength to weight ratio and excellent corrosion resistance.

However, Ti-6Al-4V has limited use in mechanical engineering applications due to its poor tribological properties such as low surface hardness and poor wear resistance (Ge et al. 2013). Therefore, much work has been done to improve the wear properties of titanium alloys including surface hardening treatment.

During the past years, various surface treatment processes have been explored to meet the growing requirement in surface properties. The surface treatment can be various types such as surface coating technologies but the nitriding process is the most common effective surface treatment process that used to improve the tribological properties of Ti-6Al-4V (Man, Bai, and Cheng, 2011).

Nevertheless, previous researches is limited to the evaluation of the effect process parameters to the surface properties obtained (Zhecheva, Malinov, and Sha, 2006). Thus, discrepancy study that identify the suitable process parameters which are temperature and time in order to enhance the surface properties of Ti-6Al-4V is evidenced. Therefore, to get a better understanding on how the process temperature and time influencing the surface properties of Ti-6Al-4V is not possible. Hence, in this study, a systematic study consisting the evaluation of nitriding performance on various process temperature and time is conducted to have better understanding on the influence of process temperature and time to the surface properties and to the overall performance of nitrided Ti-6Al-4V surface.

1.3 Objectives

This study consists of two objectives which include:

i. To compare the surface properties (microstructure, roughness and hardness) for different process temperature and time to produce nitrided Ti-6Al-4V in compared to a reference Ti-6Al-4V.
ii. To analyse the suitable process temperature and time for nitriding process of Ti-6Al-4V.

1.4 Work Scope

Ti-6Al-4V is used as the material that will be nitrided by using nitrogen gas. This study will focus on the nitriding process temperature and process time that required to complete the gas nitriding process in order to improve the surface properties of Ti-6Al-4V. For other process parameters such as pressure and gas flow rate will remain by referring to the journals and articles. Besides that, this study will also compare the surface properties which include microstructure, roughness and hardness of the nitrided Ti-6Al-4V and reference Ti-6Al-4V.

CHAPTER 2

LITERATURE REVIEW

2.1 Titanium and Its Alloys

Titanium is discovered by a British priest who named as William Gregor in 1791 and then Martin Heinrich Klaproth, a German chemist named it as titanium (Pappas and Contributor, 2014). Titanium is first discovered in the minerals rutile which is TiO_2 and ilmenite which is $FeTiO_3$. In 1910, an American metallurgist who named as Matthew A. Hunter was extracted the pure titanium (Pappas and Contributor, 2014). Titanium is a silver colour and light weight non-ferrous metal. Titanium can be represented with the symbol of “Ti” and it locates in group IV and period 4 of the chemical periodic table. The atomic number of titanium is 22 and atomic weight is 47.9. Titanium is a transition element which incompletely filled “3d” shell in the electron configuration. It is the fourth most in abundance of metal and the ninth most in abundance of the earth crust (Pappas and Contributor, 2014).

Titanium can be mixed with other elements such as aluminium, vanadium, nickel, and molybdenum to produce the titanium alloys. The titanium alloys are able to improve the strength compared to the pure titanium and has widely spread its applications in the industries and other fields such as aerospace and dental implants. Titanium normally can be classified as three types which are alpha, beta and alpha + beta due to the structural types and the composition of other elements (Smith, 2013). There are different properties and applications for the titanium alloys and then will be explained in the next subtopics.

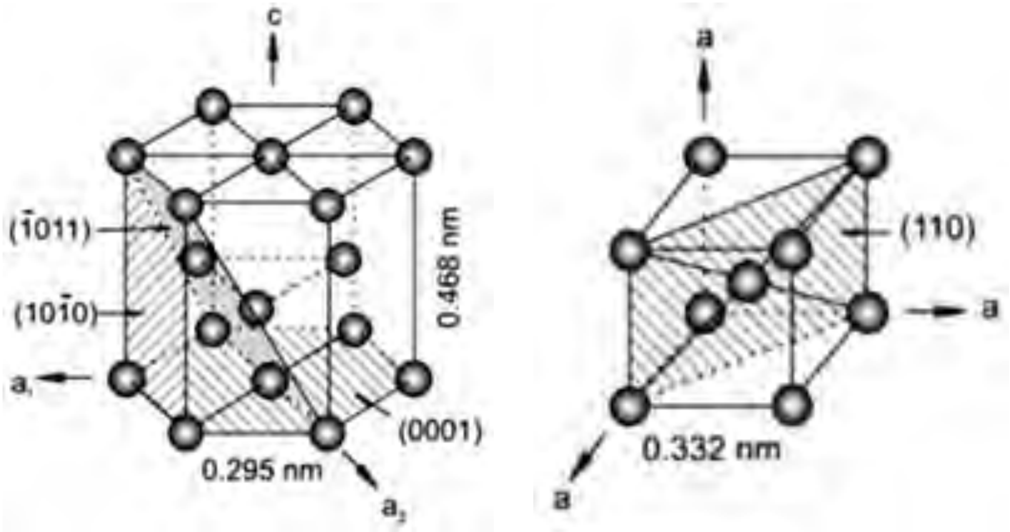
2.1.1 Titanium and Its Alloys Properties

Titanium is harder than steel and low density which is 4.5 g cm^{-3} non-ferrous metal. The weight of titanium is only 60 percent of the weight of aluminium. Titanium has a high melting point of 1668 °C but low electrical and thermal conductivity. Besides that, it is also well in resisting in the acids and alkalis environment. Table 2.1 shows the physical properties of titanium (Pattman, 2015).

Table 2. 1: Physical Properties of Titanium

Physical Properties	
Phase	Solid
Density	4.506 $g.cm^{-3}$
Liquid Density	4.11 $g.cm^{-3}$
Melting Point	1941 K, 1668 °C, 3034 °F
Boiling Point	3560 K, 3287 °C, 5949 °F
Heat of Fusion	14.15 $kJ.mol^{-1}$
Heat of Vaporization	425 $kJ.mol^{-1}$
Specific Heat Capacity	(25 °C) 25.060 $J.mol^{-1}.K^{-1}$

Titanium exists as the hexagonal closely packed (HCP) crystal structure in alpha phase and then transforms into body centered cubic (BCC) structure in beta phase at the transformation temperature, 882.5 °C as shown in the Figure 2.2. The crystal structures of titanium are presented in the Figure 2.1 while Figure 2.2 shows the phase diagram of titanium (Trinkle, 2015). Due to the crystal structure and metallic bonds of the atoms, titanium is strong as steel and requires a large amount of energy to break the atomic bonds. However, the application of titanium is limited because of its poor tribology properties and low surface hardness (Ge et al. 2013). Titanium will be oxidized easily at a lower temperature compared to its melting point, so it needs to be melted in a vacuum situation. Besides that, it is poor in corrosion resistance and lack of stiffness which means does not require a lot of force to bend it. Based on these reasons, titanium is seldom to use commercially and apply for the structural that require high rigidity (Pattman, 2015). The weakness of the titanium can be improved by alloying with other elements such as aluminium, vanadium and chromium.



(a) (b)

Figure 2. 1: (a) Hexagonal Closely Packed (HCP) Crystal Structure of Alpha Phase Titanium and (b) Body Centered Cubic (BCC) Structure of Beta Phase Titanium

(Source: < http://dtrinkle.matse.illinois.edu/dokuwiki/doku.php?id=research:ti > 22 April 2016)

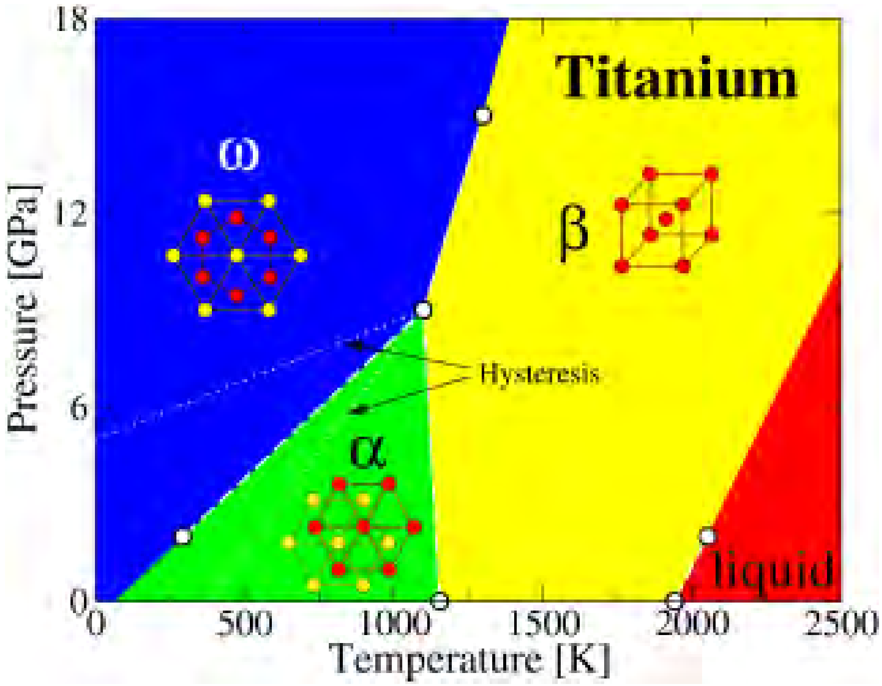


Figure 2. 2: Phase Diagram of Titanium

(Source: < http://dtrinkle.matse.illinois.edu/dokuwiki/doku.php?id=research:ti > 22 April 2016)

Titanium alloys are high specific strength and perform well in corrosion resistance. However, the properties and applications of the titanium alloys are dependence on the composition of elements. The composition of titanium alloys is based on the weight percentage of the elements. The composition, introduction years, and maximum working temperatures of titanium alloys are showed in the Table 2.2 (Zhecheva et al. 2005).