INFLUENCE OF HEAT TREATMENT CONDITIONS ON THE WEAR RESISTANCE AND HOT TENSILE PROPERTIES OF THE Ti-6Al-4V ALLOY

By

Manar Nady Abd EL-Ghany Mansour

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
In
Metallurgical Engineering

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Title of Thesis:

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Key Words: titanium alloys; heat treatment; wear resistance; hot tensile.

Summary:

In the current work, several heat treatments were carried out below and above the beta transus temperature of the Ti-6Al-4V alloy. The resultant microstructures and their effects on hardness, wear resistance and hot tensile properties of the Ti-6Al-4V alloy were examined. The results showed that solution treatment of Ti-6Al-4V samples followed by water quenching from β and α/β fields raised the alloy hardness from 380 to 575 and 656 HV respectively while no remarkable changes were observed after aging. Hot tensile strength of the as-forged sample increased from 671 to 756 MPa after water quenching from the β-phase field, while the air cooling decreased the tensile strength 644 MPa. The fracture mode of the tensile samples was more ductile in case of the solution treated samples compared to the as forged samples. A subsurface layer was formed due to the diffusion of oxygen into the surface at high temperatures. This layer masked the differences of wear behavior of the specimens.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.
I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Manar Nady Abd EL-Ghany Mansour Date:
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Dedication

To my Family and my Husband who supported me along the way.

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List of Nomenclature

B	**Beta phase**
A	Alpha phase
α_2	Intermetallic compound Ti_3Al
Γ	Intermetallic compound TiAl
Ω	Brittle omega phase
Bcc	Body centered cubic
Hcp	Hexagonal close packed
T_β	β- Transus temperarure
CP Ti	Commercial pure titanium
DSC	Differential scanning calorimetry
OM	Optical microscope
SEM	Scanning electron microscope
EDX	Energy dispersive X-ray spectroscope analysis
HV	Vickers hardness
Wt. loss	Weight loss

Abstract

In the current work, several heat treatments were carried out below and above the beta transus temperature of the Ti-6Al-4V alloy. The resultant microstructures and their effects on hardness, wear resistance and hot tensile properties of the Ti-6Al-4V alloy were examined. The results showed that solution treatment of Ti-6Al-4V samples followed by water quenching from β and α/β fields raised the alloy hardness from 380 to 575 and 656 HV respectively while no remarkable changes were observed after aging. Hot tensile strength of the as-forged sample increased from 671 to 756 MPa after water quenching from the β-phase field, while the air cooling decreased the tensile strength 644 MPa. The fracture mode of the tensile samples was more ductile in case of the solution treated samples compared to the as forged samples. A subsurface layer was formed due to the diffusion of oxygen into the surface at high temperatures. This layer masked the differences of wear behavior of the specimens.

Keywords: titanium alloys; heat treatment; wear resistance; hot tensile.

Chapter 1: Introduction

Titanium alloys are widely used in many fields of applications because of their high strength, low density and excellent corrosion resistance [1].Commercial pure titanium is used in aerospace applications due to its high corrosion resistance but its low strength is hindering its usage in many applications. Therefore, there is a high demand to develop titanium alloys more and more [2]. Titanium alloys are used basically in rockets, engine parts, fuel tanks, gas bottles and in the structures of air frame too. This is due to their high fatigue resistance, easy formability and many of them can serve in the high temperature applications. Titanium alloys can be used also in the biomedical fields in the surgical implants and heart valves; Ti-6Al-4V alloy is considered the first titanium alloy that developed to serve in this field [3]. Moreover, titanium alloys are used in the automotive industries, e.g. the Japanese company, Toyota, produced recently titanium engine valves.

The high cost of titanium alloys compared with the other engineering materials and alloys is a disadvantage that hinders the usage of titanium alloys in a wider range of applications compared with the steel for example [3].

Ti-6Al-4V alloy is α/β titanium alloy and is considered the most widely used titanium alloy as it covers 50% of the total usage around the world. This alloy can be used as a biomaterial and in the high temperature applications up to 427°C. Due to its usage in the high temperature fields, it is necessary to evaluate its tensile properties at high temperature and study its wear behavior.

The mechanical properties of titanium alloys are highly influenced by heat treatment which controls the morphology, volume fraction and size of the secondary α phase [4]. It has been reported that the morphology of α phase affects the mechanical properties of α/β titanium alloys. Many research works have been devoted to investigate the secondary α-phase evolution due to heat treatment of (α/β) titanium alloys [4-7]. However, there are many points that have not been yet clarified. This is because the heat treatment temperature in these alloys and its position relative to the α/β transition temperature are very critical hence these parameters control the volume fraction of different phases. It has been reported that it is necessary to solution treat the α/β alloy at a temperature in the α-β field, close to the beta transus temperature (i.e., 25 to 85°C below the beta transus) to obtain high strength with adequate ductility [8]. If high fracture toughness is required, beta annealing or beta solution treating maybe desirable, but considerable loss of the ductility will occur [9, 10]. It has been also reported that the changes in microstructure, due to solution treatment close to the transformation temperature, can significantly alter the wear resistance of the Ti-6Al-4V alloy [11, 12]. This is due to the increase in hardness after solution treatment, which is beneficial in improving the wear resistance of the alloy by retaining the transformed beta at room temperature. The hot tensile deformation behavior of the Ti-6Al-4V alloy was also studied [13-15]. This type of deformation has great significance for the use of titanium alloys in the high temperature applications. The tensile properties of Ti-6Al-4V were observed to vary with the shape of α-phase which is dependent on the quenching temperature after hot deformation. However, the data of the effect of heat treatment on the hot tensile properties of Ti-6Al-4V is still very limited. In the current work, several heat treatments were carried out below and above the transition temperature. The resultant microstructures and their effects on hardness, wear resistance and hot tensile properties of the Ti-6Al-4V alloy were investigated.