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Original Research Article

A study of mechanical properties of titanium alloy Ti-6al-4v used as dental implant material

Hosam Alegaly Alaraby[1], Magdi Mohamad A. lswalhia[2], Tajammul Ahmed[2]*

[1]Department of Conservative and Endodontics, [2]Department of Prosthodontics, Al-Jabal Al-Gharbi University, Gharyan, Libya

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***Correspondence:**
Dr. Tajammul Ahmed,
E-mail: tajjuprostho@gmail.com

ABSTRACT

Background: Titanium and its alloys are being extensively researched and are applied relatively in different fields of dentistry since 1970s. Its inherent advantages like high strength, ductility, low modulus of elasticity, ease of formation of oxidized surface layer, ability to retain mechanical integrity after autoclave and relatively low toxicity has led to extensive application of titanium and its alloys in implant dentistry.
Methods: The Titanium alloy Ti-6Al-4V dental implant material used for the present study was procured from Mishra Dhatu Nigam (Midhani, Hyderabad). The mechanically polished samples were etched using Kroll's reagent (5% hydrofluoric acid+10% nitric acid+85% water). The etched specimens were examined under optical microscope.
Results: The primary α phase being the low temperature phase, is stable and shows single phase microstructure. The size and volume fraction of the primary α and transformed β phases depend on the solution treatment temperatures and the subsequent rate of cooling.
Conclusions: The success of the treatment modality relies on the knowledge of the properties required to employ them at the right situation.

Keywords: Titanium, Alloy, Dental implant, Material

INTRODUCTION

Titanium alloys of interest to dentistry exist in three structural forms: alpha (α), beta (β) and alpha-beta. The alpha (α) alloys have a hexagonal closely packed (HCP) crystallographic structure, while the beta alloys (β) have a body-centred cubic (bcc) form. These different phases originate when pure titanium is mixed with elements, such as aluminium and vanadium, in certain concentrations and then cooled from the molten state. Aluminium is an alpha-phase stabilizer and increases the strength of the alloy, while it decreases its density. On the other hand, vanadium is a beta-phase stabilizer. Allotropic transformation of pure titanium (Ti) from the α to β phase occurs at 882° C.[1] With the addition of aluminium or vanadium to titanium, the α-to-β transformation temperature changes over a range of temperatures. Depending on the composition and heat treatment, both the alpha and beta forms may coexist.[2,3]

Ti-6Al-4V, the alloy of present study is a 'α + β' type of titanium alloy. This alloy was introduced in 1954 and is often known as the 'Work Horse' alloy of Titanium.

The alpha-beta combination alloy is the most commonly used for the fabrication of dental implants. This alloy consists of 6% aluminium and 4% vanadium (Ti-6Al-4V). Heat treatment of these alloys generating fine precipitation improves their strength, resulting in favourable mechanical and physical properties that make them excellent implant materials. They have a relatively low density, are strong and highly resistant to fatigue and corrosion. Although they are stiffer than bone, their modulus of elasticity is closer to bone than any other implant material, with the exception of pure titanium.[3] This lower modulus of elasticity is desirable, as it results in a more favourable stress distribution at the bone-implant interface.[4]

METHODS

The titanium alloy Ti-6Al-4V dental implant material used for the present study was procured from Mishra Dhatu Nigam (Midhani, Hyderabad). The present study was conducted with the co-operation of Department of Metallurgical Engineering, Institute of technology, BHU and the microstructure and mechanical properties of Titanium alloy Ti-6Al-4V were evaluated.

Study period: March 2016-September 2016

A. Microstructure

Cylindrical specimens of 7 mm height and 10 mm diameter were prepared from the as received rods of 11 mm diameter of the titanium alloy Ti-6Al-4V. These specimens were cold mounted in self-curing acrylic resin. Standard metallographic technique was used for preparation of transverse surfaces for metallographic examination. This involves careful mechanical polishing using successively finer grades of emery paper from 1/0 to 4/0. The final polishing was carried out on sylvet cloth, mounted on a polishing wheel, using aqueous suspension of alumina powder of 0.017 mm size.

The mechanically polished samples were etched using Kroll's reagent (5% hydrofluoric acid+10% nitric acid+85% water).

The etched specimens were examined under optical microscope.

B. Mechanical testing

The Titanium alloy which was used to fabricate the dental implant was tested for its hardness, tensile and compressive strength.

1. *Hardness testing*: For hardness testing, cylindrical specimens of 10mm height and 11mm diameter were machined and mechanically polished from the as received rod. Hardness was measured using the Vickers hardness tested at an applied load of 20kg. Six readings were taken for each specimen and the average of these values was taken as the hardness of the sample.
2. *Tensile testing*: Standard cylindrical tensile specimens with gauge length 16.0 mm and gauge diameter 4.5 mm were prepared from the rod of 11mm diameter. Tensile testing was carried out using Instron universal testing machine, at a constant cross head speed of 0.05 mm/min. The specimen was fixed between the upper and lower pull rods, using standard split type Hounsfield Tensometer grips. The samples were pulled in tension till fracture and the load extension plot was automatically recorded on the chart. The test was carried out at room temperature in the laboratory air.
3. *Compressive testing:* Cylindrical specimens of 7.5 mm gauge length 5 mm gauge diameter were machined from the as received rod. These cylindrical specimens were loaded under compression, between the upper and lower rods of the Universal testing Machine. The samples were compressed to a maximum load of 13 tons or till fracture whichever was earlier. The load vs. compression plot was recorded.

RESULTS

A. Microstructure

The microstructure of the alloy Ti-6Al-4V in the as received condition is shown by the optical micrographs in the Figure 1 and 2.

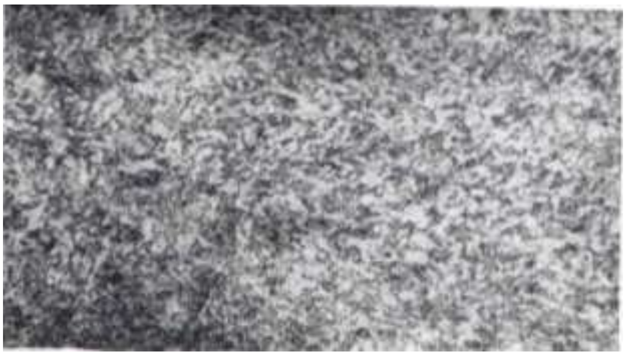

Figure 1: Optical micrograph showing the microstructure of the alloy Ti-6Al-4V (200 X) in as received condition.

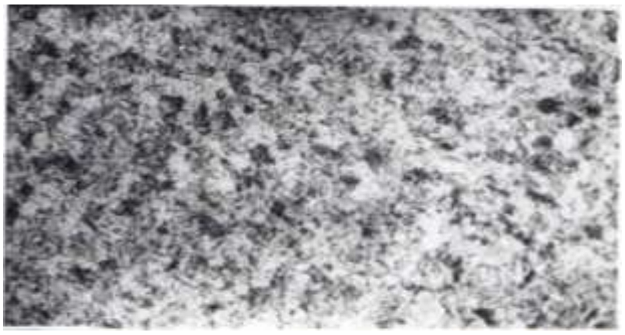

Figure 2: Optical micrograph showing the microstructure of the alloy Ti-6Al-4V (500 X) in as received condition.

It is obvious from these micrographs that there is dual phase microstructure in the as received condition of the alloy. The dual phase microstructure consists of primary α phase; the light phase, and the transformed β phase; the dark phase. There is considerable difference in the size, shape and distribution of the two phases.

The microstructure of the transformed β phase may be seen more clearly at higher magnification (Figure 2).

The primary α phase being the low temperature phase, is stable and shows single phase microstructure. The size and volume fraction of the primary α and transformed β phases depend on the solution treatment temperatures and the subsequent rate of cooling. Since the microstructure of the alloy Ti-6Al-4V in the present investigation shows a dual phase structure and hence it is obvious that it has been processed and heat treated in the two phase field of α and β.

The microstructure affects the mechanical properties. In general, finer the microstructure constituents, stronger the material. Therefore it is essential to establish proper heat treatment to be given to Ti-6Al-4V alloy to have optimum combination of strength and ductility.

B. Mechanical properties

1. *Hardness*: The hardness of the titanium alloy Ti-6Al-4V is in the range of 179-185 VHN with a mean value of 182.16 VHN
2. *Tensile properties*: The results of tensile testing of the Titanium alloy Ti-6Al-4V are given in Table 1.
3. *Compressive properties*: The results of compression test of the titanium alloy Ti-6Al-4V are given in Table 2. The calculations have been recorded in Table 1 and 2.

Table 1: Tensile properties of titanium alloy Ti-6Al-4V.

S. no.	Tensile properties	
1	Yield strength	982 MPa
2	Ultimate tensile strength	1115 Mpa
3	Percentage elongation	16%

Table 2: Compression properties of titanium alloy Ti-6Al-4V.

S. no.	Compression properties	
1	Compressive yield strength	1074 MPa
2	Ultimate compressive strength	1661.6 MPa

DISCUSSION

The mechanical properties of titanium alloy Ti-6Al-4V are good. It is obvious from these data that titanium alloy Ti-6Al-4V has got adequate mechanical properties like yield strength and tensile strength. These properties are required for better absorption and transfer of occlusal forces which range from 150 N in incisor to about 750 N in molar region. However, these forces may vary according to the age and sex of the patient.

The modulus of elasticity of the titanium alloy is slightly greater, being about 5-6 times that of compact bone.[5,6] The greater elastic modulus is not a major drawback and this property places emphasis on the importance of design for proper distribution and transfer of mechanical stresses.

Materials that are subjected to repetitive loads are at greater risk of fatigue fracture. Mechanical stress may be great enough in magnitude to fracture a material at one cycle. If the material receives less stress it may still fracture but after more cycles. The endurance limit of fatigue strength is the level of highest stress a material may be repetitively cycled without fracture. The endurance limit of a material is often less than one half of its ultimate tensile strength.[7,8] Hence fatigue and ultimate tensile strength values are related but fatigue is a more critical factor especially for patients with parafunction since they impose higher stress magnitude and greater cycles of load. The fatigue strength of titanium alloy is 4 times that of pure titanium. Hence long term fracture of implant bodies and components may be dramatically reduced with the use of titanium alloy.[9,10]

CONCLUSION

Titanium alloy Ti-6Al-4V has shown to exhibit the most attractive combination of mechanical and physical properties, corrosion resistance and greater biocompatibility of all the metallic biomaterials. Thus titanium alloy Ti-6Al-4V remains the gold standard for fabrication of oral implants.

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Conflict of interest: None declared
Ethical approval: The study was approved by the institutional ethics committee at Al-Jabal Al-Gharbi University, Gharyan, Libya

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