CHARACTERIZATION OF NICKLE FREE TITANIUM ALLOY TI-27NB FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

Bone implantation is common since several decades. Titanium alloys are the most commonly used bone implant materials. TI-27Nb (Titanium-27% Niobium) having no toxic effects on human body and also having low modulus. The objective of this paper is the mechanical characterization of TI-27Nb. Tensile, hardness, microscopy and scanning electron microscope tests were conducted on TI-27Nb specimens. The tensile strength and young modulus of TI-27Nb were lower than commonly used Titanium alloy i.e Ti-6Al-4V. The SEM results show mixed brittle-ductile surfaces. It is concluded that TI-27Nb has lower stress shielding/bone restoration because of low modulus than commonly used implant materials.

KEYWORDS: *Ti-27Nb, Nickle Free Titanium, Low modulus, Non-Toxic titanium Alloy, Human Implant.*

INTRODUCTION

Bones are the important parts of the human body because it supports the whole-body structure(Rahman *et al.* 2016). In human bones, degradation and diseases like inflammation of joints and arthritis frequently occur (He & Hagiwara 2006) which leads to immovability and high pain. The replacement of effected bone with implant is for the normal functionalities of the body and can enhance the quality and longevity. Due to the continuous increase in the world population, there has been increasing prominence on materials applications in biomedical areas and now the field of biomaterials has led to multi-million-dollar business(Shi 2006). Conventional metallic biomaterials such as stainless steel, Ti alloys, Pure Ti, Co-Cr materials are in use in medical field for the purpose of implant for many years(Niinomi 2002). These conventional metallic biomaterials can cause potentially serious health problems(Perl & Brody 1980), However the aspect of implant biological bio-compatibility and mechanical bio compatibility to the human body are the most importance factors. Implants failure, corrosion, wear, stress shielding and toxic effect in a human body not only risks the life of patients but also increase the rate of revision surgery and economic over burden. The in-service life of the implants is strongly affected by the human body environment-fatigue loading, including corrosion and wear. Thus, a comprehensive, integrated understanding of materials characterization with respect to their biological and mechanical compatibility is a fundamental consideration in the development of overall biomaterial implant. To meet the demand for longer implant life within the service, implants used should not only avoid the short term rejection and infection, but also provide long term compatibility i.e its high strength, low modulus, long lifetime, high-wear resistance, high resistance to corrosion in the human body environment, no toxicity to human body etc(He & Hagiwara 2005, Niinomi 2002)'

Titanium based alloys are widely used as a bio materi-als implant because of its excellent biocompatibility, low density, and excellent corrosion resistance(Niinomi 2002, Wang, Liu *et al.* 2017).Most widely used titanium alloy as implant is Ti-6Al-4V but it exhibit problems during biomedical applications. Aluminum (Al), Vanadium(V) and Nickle(Ni) having a toxic effects on the respiratory, circulatory and central nervous systems, the diges-tive organs, kidneys, allergic and immunologic effect, renal effect and carcinogenesis(Banks & Kastin 1989, Venkataraman & Sudha 2005).

New compatible biomaterials are also introduced in implants which are nontoxic and low young modulus to avoid stress shielding. Beside the toxicity, difference in young modulus of bone and implant alloy cause stress shielding. Stress shielding refers to the reduction in bone density as a result of removal of typical stress from the bone by an implants (Ridzwan, Shuib *et al.* 2007). So the modulus should be near to bone i.e. 10-30 GPa to avoid stress shielding phenomena(Niinomi 2008).

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Titanium alloy Ti-27 Nb are without toxic elements like Al, V and Ni due to the health concerns. The objective of this paper is the mechanical characterization of Ti-27Nb bone implant material. Tensile, hardness, fractographic and microstructure tests were performed in this study. Next section describes the experimental testing of Ti-27Nb. Section 3 presents the experimental data analysis. Section 4 presents the results and discussions. The conclusion and recommendation of the study are presented in the last section of the paper.

EXPERIMENTAL TESTING

Experiments were carried out for the Tensile testing, microstructure evaluation, fractography and hardness. The following subsections describe the specimen preparation and test procedures for corresponding tests programs.

SPECIMEN PREPARATION AND TESTING PROCEDURE

Ti-27Nb was obtained from Shaanxi Baoji Pelifly Titanium Industry Co., Ltd china in the form of 300mm x 300mm x 3mm sheet. The tensile test specimens were prepared according to ASTM E8. Figure 1 and figure 2 show the typical tensile test specimens geometry and final prepared sample respectively.

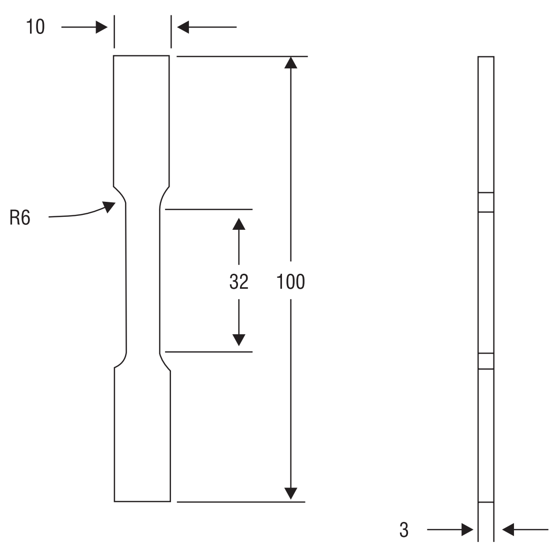

Fig.1 Geometry of Specimen

Fig.2 Final Prepared Specimen

Test Procedure

The tensile tests were carried out as per ASTM E8. Three specimens were tested. Test system INSTRON 600 UTM were used for testing. The specimen was clamped in the jig as shown in the figure 3. The load was applied at the rate of 10 N/minute. During tests, the displacement and load were recorded by the machine computer. The test was stopped when the specimen was finally ruptured.

Fig 3. Instron 600DX Universal Testing Machine

MICROSTRUCTURE STUDY

For the microstructural evaluation of the material the specimens were grinded with silicon carbide paper and polished. Etching was done for the study of micro-structure properties. The specimens were studied using Olympus BX60 optical microscope shown in figure 4. The magnification range for the microstructure evaluation was 100X- 500X.

HARDNESS TEST

The test specimens for hardness tests were prepared from the same Ti-27Nb Sheet. A typical specimen for the hardness test is shown in figure 5. Vicker hardness test was carried out on Mastuzawa Sciki Co. Ltd Japan Model DVK-2 as shown in the figure 6. The tests were carried at room temperature and pressure conditions. For longitudinal direction 28 hardness values were determined at different location. For the transverse direction 6 hardness values were determined.

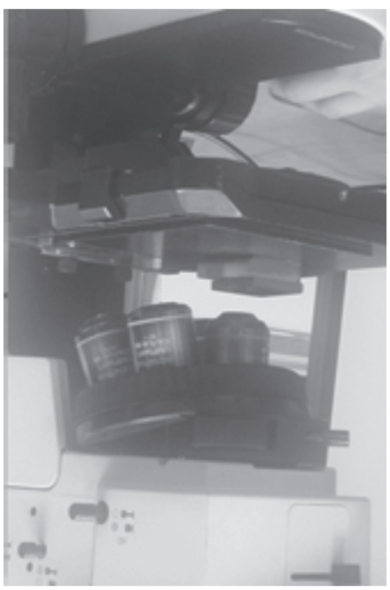

Fig 4. Olympus BX60 optical microscope

FRACTOGRAPHIC Test

Samples for fractographic study, samples were cut from the fractured tensile specimens. The top corner of the fracture surface was examined in the SEM S-3400 as shown in figure 7. The voltage during SEM examination was 5kV. SEM images of the fracture surface were taken in the range 25X-5000X.

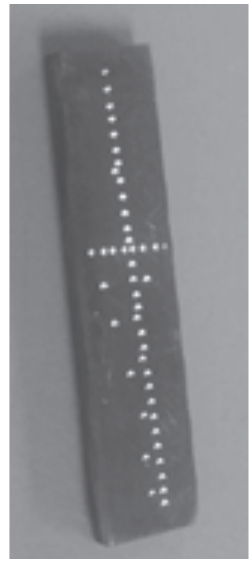

Fig 5. Hardness Test Specimen

Fig 6. Mastuzawa Sciki Co Ltd Japan DVK-2

EXPERIMENTAL DATA ANALYSIS

The stress σ and strain ε was calculated using equation: 1 and 2 respectively (Pytel 1989)

$$\sigma = \frac{F}{A} \quad (1)$$

$$\varepsilon = \frac{\delta}{l} \quad (2)$$

where

F is the load applied

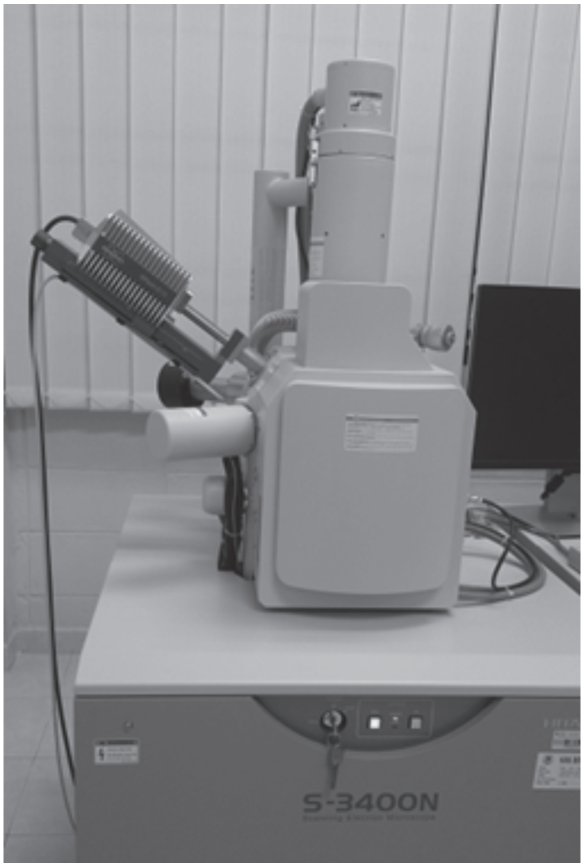

Fig 7. Hitachi SEM S-3400

A is the cross-sectional area of the tensile specimen

δ is the deformation of the specimen

l is initial length of the specimen.

From stress-strain data, young modulus '*E*" was calculated using equation: 3

$$E = \frac{\sigma_{max}}{\varepsilon_{max}} \quad (3)$$

Where $\boldsymbol{\sigma}_{max}$ and $\boldsymbol{\varepsilon}_{max}$ are the maximum stress and maximum strain at failure.

RESULTS AND DISCUSSION

Tensile Test

The stress-strain diagram of the Ti-27Nb is shown in figure 8. The yield strength of the material is 740 MPa. The ultimate tensile strength of the material is 860 MPa. The material exhibits reasonable amount of plasticity up-to failure. The material is less ductile as compared to its counterpart materials e.g. Ti-6Al-4V, however the strength is approximately 12% less than Ti-6Al-4V. This is beneficial for implant due to its lower dimensional change. The true stress is same to engineering stress up-to yield point however its value slightly deviates from the engineering stress after yielding point. The necking phenomenon is absent and the material suddenly breaks at the ultimate strength as shown in the figure. The elastic modulus of the material is 86 GPa. The elasticity is lower than its commonly used bio implant materials e.g. Ti6AL4V (110 GPa). Due to its lower elasticity, the stress shielding/bone restoration will be lower in this material.

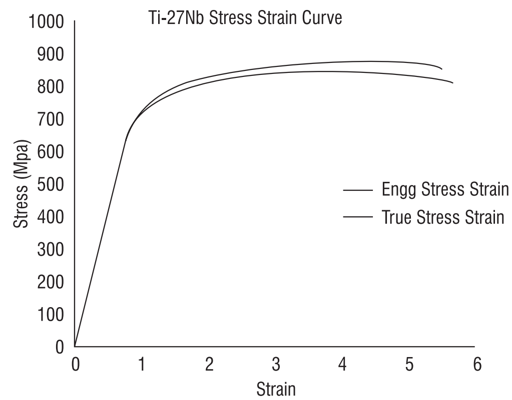

Fig 8. Stress Strain Curve

Microstructure Evaluation

The properties such as fatigue resistance, hardness, tensile strength and resultant fracture behaviour are mostly influence by the morphology of microstructure and volume fraction of phases in Ti-based alloys. Figure 9.a, and b shows the micrographs of as-cast Ti-27Nb alloys at two different magnification by optical microscope which clearly indicate the near equiaxed grains of alpha and transformed beta (i.e **α**+β) phase. The dual phase i.e α+β offer a combination of ductility and strength(-Froes 2000, Poondla, Srivatsan *et al.* 2009) and also the advantage in term of fatigue resistance(Lütjering 1998). In such microstructures, the bi-modal (i.e α+β) structure composed of primary near equiaxed shaped alpha-grains (light phase) with a mean size of 9μm and colonies of very disperse lamellar matrix of transformed beta (β) phase (dark portion). The fine acicular shape can be observed in both micrographs like a basket-weave which demonstrate the Widmannstetter structure. The volume fraction of the beta-phase in following Ti-27Nb alloy is 0.61 measured by Fiji-Image j software, which is very large compared to Ti-6Al-4V (i.e 0.12). This change in volume fraction, morphology and distribution of the two phases is attributed to the addition of Niobium which is strong beta-phase stabilizer (Oliveira, Chaves *et al.* 1998).

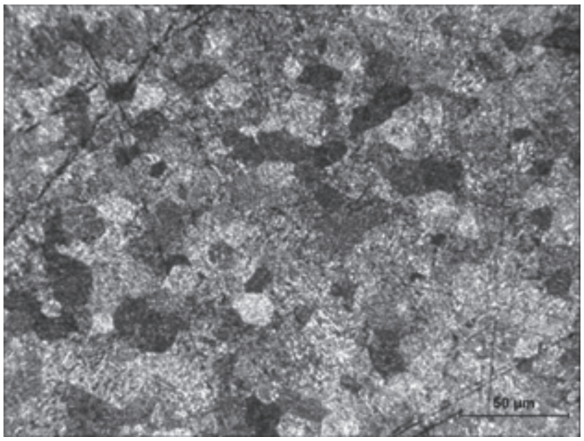

Fig. 9a

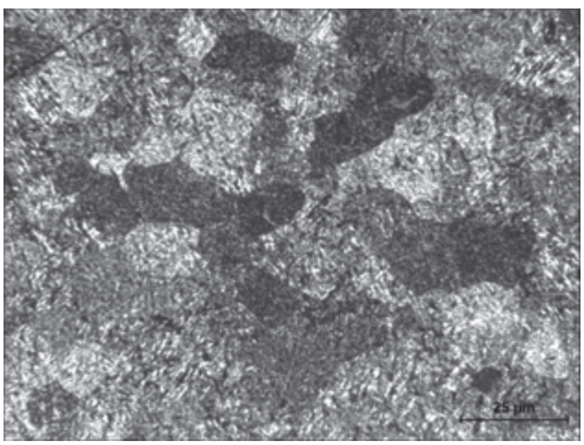

Fig. 9b

Figure 9a,& 9b showsTi-27Nb microstructure in a basket-weave arrangement, where the α phase is the white grains, while the β phase is the dark grains at magnification of 100x and 200x.

FRACTOGRAPHY

The fracture surfaces of tensile tested specimens shown in figure 10 were examined by Hitachi S-3400N Scanning Electron Microscope (SEM) for both macroscopic and microscopic study. In figure 11a ,b the macrograph showing a fracture surface of mixed behaviour of brittle and ductile phases with no extensive plastic deformation. In central interior portion of the specimen, irregular and fibrous appearance which is indicative of ductile phase while some portion especially near edges of the specimen clearly showing no gross plastic deformation which is indicative of cleavage facet brittle fracture. While on microstructure level, the figure 11.b showing dimples characteristics that's indicate a intergranular fracture and faceted textures surface thats indicate the transgranular fracture which is the demonstration of a typical mixed ductile and brittle fracture respectively.

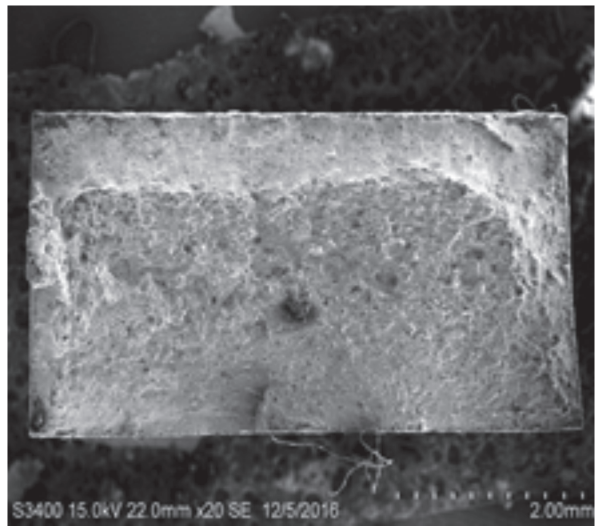

Fig.10. Fracture surfaces of tensile tested specimens of Ti-27Nb by using SEM

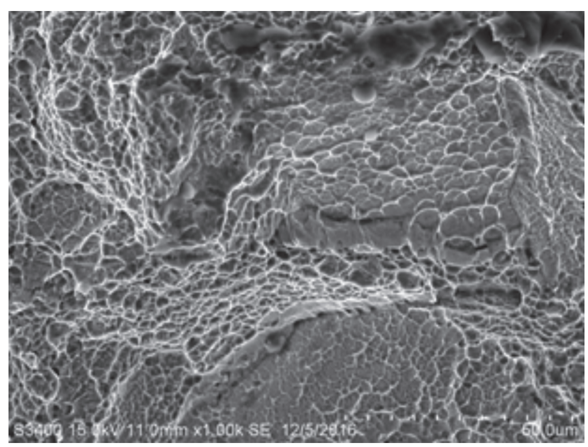

Fig. 11a Macrograph

HARDNESS

Hardness test was carried out along the lognitudnal and transverse direction. 27 data points were taken along the longitudinal direction and 8 data points were taken

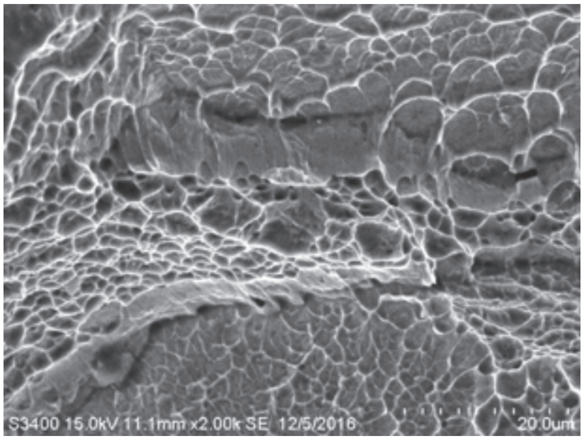

Fig. 11b Micrograph

along the transverse direction. After analyzing the data, average come out to be 273 Hv for Ti-27 Nb. It is also observed that no significant change in the hardness value was observed along the edges of the specimen.

CONCLUSIONS

Ti-27Nb was mechanically characterized in this work. The material is non-toxic as compared to other bio-implant materials. Its strength and modulus is 860 MPa and 86 GPa which is lower than commonly used Ti-6Al-4V, implying lower stress shielding effect. The optical microstructure reveals nearly equiaxed grains of alpha and transformed beta (i.e $\alpha+\beta$) phase. The volume fraction of the beta-phase Ti-27Nb alloy is 0.61 comparatively very large than Ti-6Al-4V (i.e 0.12). The SEM results show mixed brittle-ductile surfaces. Large plastic deformation was not observed. The brittle fracture reveals cleavage facet nature. The stress- strain diagram support dominant ductile fracture implying local plastic zones. The hardness of Ti-27Nb was observed to be uniform through material cross-section. It is recommended that further investigation is carried out in human's body fluid and finite element analysis of implant should be done as per actual loading of humans.

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