Mechanical properties, microstructure, and biocompatibility of Ti-6Al-6Nb

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Abstract. The alpha-beta Ti-6Al-4V alloy has been used as biocompatible materials due to its excellent mechanical properties, corrosion resistance, and lower specific strength than other metallic biomaterials such as stainless steel and Co-Cr alloy. However, the concern to the toxic element of vanadium led to the development of a new alpha-beta Ti6-Al-6Nb alloy. This paper presented microstructural, mechanical properties and biocompatibility of as cast Ti-6Al-6Nb alloy. The materials were characterized by scanning electron microscopy, optical microscopy, microhardness test, and X-ray diffraction. In addition corrosion test was performed by using Hank’s solution at 37 °C and pH 7.4. The result showed that Ti-6Al-6Nb alloy could potentially used for biomedical application due to its good mechanical properties and corrosion rate.

1. Introduction

WHO Data in 2012 shows that increasing world population followed by increasing number of traffic accidents especially among young people in developing countries such as Indonesia [1]. This contributes to increasing number of implant materials demand. Besides, surgery process for bone exchange with implant materials and post operation also increase tremendously. Nowadays, researchers have been developing new implants for long term use (long term implantation/life time) of which the post-operation measure for implant change is not needed [2].

Titanium based implant material covers 60 % of the total implant in the world utility due to cheaper price and better mechanical properties than other implant materials such as Co-Cr-Mo. In the previous study, Ti-6Al-6Nb alloy was prepared by using arc melting furnace followed by thermomechanical treatment to study the influence of Nb content on β phase formation, whereas β phase formation process begin in casting process [3]. However, characteristics of as cast Ti-6Al-6Nb have not been investigated well. Cardozo reported in developing titanium for implant application each step has an important role, start from determining chemical composition, microstructural characteristics, heat treatment process, and mechanical properties of alloy [4]. Another study reported that microstructure and phase formed in casting process has important role for next process (thermomechanical processing) [5, 6]. In this paper as cast Ti-6Al-6Nb was characterized to study the microstructure of as cast Ti-6Al-6Nb and the correlation to its mechanical properties and biocompatibility.
2. Materials and Method

2.1. Material Preparation
Ti-6Al-6Nb was prepared from commercially available Ti (99.9 % purity), aluminum (99.9% purity) and niobium (99.5% purity). All materials were processed by arc melting with non consumable tungsten electrode on a water-cooled copper hearth. The alloy was prepared in ultra high purity argon atmosphere and the ingot was melted eight times to improve chemical homogeneity. The obtained ingot was approximately 100 g. The casting was processed at Chiba laboratory Institute of Materials Research Tohoku University.

2.2. Examination
As cast Ti-6Al-6Nb was sectioned by using cutting wheel machine with the dimension of 1x1x1 cm³. The block specimen was mounted by using resin and mechanically polished via a metallographic procedure to a final level of 0.3 µm alumina powder and was then etched in solution of water, nitric acid, and hydrofluoric acid (80:15:5 in volume). The microstructure of the etched alloy was examined using Meiji Japan optical microscope. X-ray diffraction (XRD) measurement for phase analysis was conducted using Rigaku smartlab diffractometer, at room temperature using Cu Kα radiation and operating at 30kV/15mA. Hardness measurement was measured using Shimazu vickers hardness tester with a load 500 gf for 30 s. Corrosion test in simulated body fluid was tested to confirm the biocompatibility properties of Ti-6Al-6Nb alloy. The corrosion test was carried out in Hank’s Solution of pH 7.4 at 37 °C to simulate the body fluid environment and body temperature. A standard three electrode cell were used in this test. Graphite was the counter electrode, saturated calomel electrode was the reference electrode and sample as work electrode. The total amount of Hank’s Solution taken in the cell was about 500 ml. The potential scanning rate was 1 mV/s.

3. Result and Discussion
Figure 1 shows the microstructure of as cast Ti-6Al-6Nb alloy. The microstructures of as cast Ti-6Al-6Nb was lamellar with transformed beta and acicular alpha (light platelets). It was a result of nucleation and growth on crystallographic planes of the prior beta matrix [7]. This structure is similar as Ti-6Al-6V structure [8, 9].
Figure 1. Microstructure of Ti–6Al–6Nb alloy.

Figure 2. XRD Pattern of Ti-6Al-6Nb.

Figure 2 shows diffraction pattern of Ti-6Al-6Nb. The α and β phase were observed. It confirmed the metallographic result showed in figure 1. Figure 3 shows hardness value of as cast Ti-6Al-6Nb and another titanium alloy for biomedical purpose. As cast Ti-6Al-6Nb has hardness value 278 HV, higher than pure Ti (186 HV), Ti-15Mo-5Nb (246HV), and Ti-15Mo-10NB (257HV), but lower than Ti-5Sn5Cr (503 HV). The mechanical strength of materials could influenced by solid solution hardening, high dislocation density, boundary hardening and precipitation hardening. In this case (Ti-6Al-6Nb alloy) has the higher hardness than pure titanium due to solid solution strengthening or crystal...
structure effect/phase ($\alpha$, $\beta$, $\omega$) [6,11]. Another study by A. Kumar in Ti-6Al-4V alloy showed that the increasing of $\beta$ volume fraction could increase hardness value in $\alpha + \beta$ system [12].

![Figure 3. Hardness Properties of as-cast Ti-6Al-6Nb and some as-cast titanium alloy for biomedical application.](image)

Determination the interaction of metal implant with body fluid environment is essential to understand implant stability in the human body. Figure 4 shows tafel diagram corrosion test of as cast Ti-6Al-6Nb in a simulated body fluid Hank’s Solution. No hysteresis loop was observed that indicated the as cast Ti-6Al-6Nb alloy had excellent pitting corrosion resistant. The corrosion rate of as cast Ti-6Al-6Nb was 0.0016 mm/py (mm/year), compared to another implant materials such as stainless steel 316L (0.004 mm/y), Co alloy (0.0014 mm/y), and Ti6Al4V (0.00018 mm/y) Ti-6Al-6Nb show better corrosion resistant than stainless steel 316L, similar to Co alloy, but lower than conventional Ti6Al4V [13].

![Figure 4. Tafel Diagrams Ti-6Al-6Nb alloy in Hank’s Solution.](image)
4. Conclusion
The microstructure, mechanical properties, and biocompatibility of as cast Ti-6Al-6Nb has been investigated in this study. The as cast Ti-6Al-6Nb has similar microstructure with conventional implant Ti-6Al-6V. The microstructure was lamellar, with $\alpha$ and $\beta$ phase observed in the microstructure and in diffraction pattern result. The hardness of Ti-6Al-6Nb was higher than pure Ti and lower than $\beta$ type alloy Ti-5Sn-5Cr. The corrosion rate of as cast Ti-6Al-6Nb was 0.0016 mmpy. The result showed that this alloy could potentially be used for biomedical application.

Acknowledgment
This work is financially supported by 2016 thematic program of Indonesian Institute of Sciences

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