Synthesis and Characterization of Ti-6Al-6Mo Prepared by Arc Melting Process

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Abstract. The Ti-6Al-6Mo alloy was arc-melted eight times from pure Ti, Al, and Mo. The Ti-6Al-6Mo were analyzed by using an optical microscope, SEM-EDS, XRD and Vickers Hardness Tester. Corrosion test was performed by using Hank’s solution at 37 °C and pH 7.4. The optical micrograph showed a similar structure of this alloy. The microstructure of Ti6Al6Mo was basketweave with α lath. The map of Ti, Al and Mo showed a similar distribution of this alloy. The XRD analysis showed that the α and β phase occurred. The Vickers hardness value of Ti6Al6Nb was 398.7 HV, higher than pure Ti. The corrosion rate of as cast Ti-6Al-6Mo was 0.0016 mmpy (mm/year). The result showed that this alloy can potentially be used for biomedical application.

Keywords: Ti-6Al-6Mo, arc melted, Biomedical application

1. Introduction
Ti (pure Ti) and its alloys have become attractive biomaterials due to their corrosion resistance, biocompatibility, specific strength, and lower young’s modulus than other metallic biomaterials such as stainless steels and Co-Cr alloys [1]. The α+β Ti-6Al-4V alloy has been used widely because of better mechanical properties than pure titanium [2]. Although α+β Ti-6Al-4V alloy presents lower young’s modulus than stainless steels and Co-Cr alloys, various studies have shown that the release of a small amount of V in the human body can induce cytotoxic effects [3]. Vanadium is known as β isomorphous element. In this study, V element was substituted with Mo which is known as β isomorphous element [4].

Various studies have been done by using Mo as a beta stabilizer in titanium alloy [5-7]. The β grain boundary presented when Mo content above 5 wt.% although the X-ray diffraction does not confirm the occurrence of β phase due to its small volume fraction [6]. Wen Fu Ho has studied the influence of Mo on Ti-5Cr system and reported that Ti-5Cr-9Mo alloy has the highest bending strength/modulus ratio 26.0 which is higher than pure Ti [7]. In the previous study, the influence of Mo content on the Ti-6Al system has been investigated but did not report the phase stability and mechanical properties in as-cast condition. Whereas α/β phase formation process begins in casting process. Cardozo report in developing titanium for implant application, the correlation of each step has an important role, start from determining chemical composition, microstructure characteristics, heat treatment process, and mechanical properties of alloy [6]. Another study reported that microstructure and phase formed in casting process have important role in the next process (thermomechanical
process) [8-10]. The objective of this study is to investigate the phase stability, mechanical properties (hardness value), and electrochemical behavior of as cast Ti-6Al-6Mo alloy.

2. Experimental Method

2.1 Material Preparation
Ti-6Al-6Mo was prepared from commercially available pure Ti (99.9 % pure), aluminum (99.9%pure) and Mo (99% pure). 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.

2.2 Examination
As cast Ti-6Al-6Mo was sectioned by using cutting wheel machine with dimension 1×1×1 cm. The block specimen mounted by using resin and mechanically polished via a metallographic procedure to a final level of 0.3 μm alumina powder and then etched in a solution of water, nitric acid, and hydrofluoric acid (80:15:5 in volume). The microstructure of the etched alloy was analyzed by using Meiji Japan optical microscope. X-ray diffraction (XRD) measurement for phase analysis was conducted by using Rigaku smart lab diffractometer, was performed at room temperature by using Cu Kα radiation and operating at 30 kV/15 mA. Hardness measurements were measured by using Shimazu Vickers hardness tester with a load 500 gf for 30 s. Corrosion test in simulated body fluid were tested to confirm the biocompatibility properties of the Ti6Al6Nb alloy. The corrosion test was tested in Hank’s Solution of pH 7.4 at 37 °C to simulate the body fluid environment and body temperature. A standard three electrodes cell used in this test. Graphite is the counter electrode; saturated calomel electrode is the reference electrode and sample as a work electrode. The total amount of Hank’s Solution taken in the cell is about 500 ml. The potential scanning rate is 1 mV/s.

3. Results and Discussion
Figure 1 show pancake ingot obtained after eight times remelting process. The pancake weight was 100 g approximately with 100 mm diameter. The as cast appearance was shine which indicated there was no oxide layer on the as-cast surface. Figure 2 EDS energy spectrum analysis of as-cast Ti-6Al-6Mo. The energy of Ti, Al, and Mo was observed. The desired chemical compositions were Al 6 wt.%, Mo 6 wt.%, and Ti 88 wt.%. The actual chemical compositions were Al 4.69 wt.%, Mo 5.60 wt.% and Ti 89.71 wt.%

Figure 1. Pancake As-Cast Ti-6Al-6Mo
| Element | Wt.% |
|---------|------|
| Al      | 4.69 |
| Ti      | 89.71|
| Mo      | 5.60 |

**Figure 2.** Chemical composition of Ti-6Al-6Mo by using EDS

**Figure 3.** Microstructures of Ti–6Al-6Mo alloy. (a) SEM image and (b) OM image. Etched Kroll Reagent

Figure 3 shows microstructure of as-cast Ti-6Al-6Mo. The microstructure of as-cast Ti-6Al-6Mo was basketweave structure with α lath and β grain was observed. The α lath width was approximately less than 1 µm. Thus, the microstructural results are identical to Fengying result [11]. Fengying process Ti-6Al-Mo by using Laser Solid Formed (LSF) and confirmed the expected effect of replacing vanadium by molybdenum. Figure 4 shows diffraction pattern of Ti-6Al-6Mo. The α and β phases were observed. The metallographic result is shown in Figure 3.
Figure 5 shows hardness value of as-cast Ti-6Al-6Mo and as-cast another titanium alloy for the biomedical purpose. As-cast Ti-6Al 6Mo has hardness value of 398.7 HV, which is higher than pure Ti (186 HV), Ti-15Mo-5Nb (246HV), and Ti-15Mo-10NB (257HV), but lower than Ti-5Sn-5Cr (503 HV). Ti-6Al-6Mo has a higher hardness than pure titanium due to increasing of β volume fraction. The β volume fraction was influenced by the addition of Mo as a β stabilizer in titanium α + β system.

In this case (Ti-6Al-6Nb alloy) has the higher hardness than pure titanium due to solid solution strengthening or crystal structure effect/phase (α, β, ω) [6,11]. Another study by A. Kumar in Ti-6Al-4V alloy showed that the increasing of β volume fraction could increase hardness value in α + β system [12].
Figure 6 shows tafel diagram corrosion test of as cast Ti-6Al-6Mo in simulated body fluid Hank’s Solution. The corrosion rate of as-cast Ti-6Al-6Mo was 0.0016 mm/py (mm/year). Compared to another implant materials such as stainless steel 316L (0.004 mm/y), Co alloy (0.00127 mm/y), and Ti-6Al-4V (0.00018 mm/y) Ti-6Al-6Mo shows better corrosion resistant than Stainless Steel 316L and Co alloy, but lower than the common Ti6Al4V [13].

Figure 6. Tafel Diagrams of Ti-6Al-6Mo alloy in Hank’s Solution

4. Conclusion
The characteristics of microstructure, mechanical properties, and biocompatibility of as-cast Ti-6Al-6Mo have been observed in this study. The as-cast Ti-6Al-6Mo has similar microstructure as the conventional implant of Ti-6Al-6V. The microstructure was lamellar, α and β phases were observed in the microstructure and diffraction pattern result. The hardness of Ti-6Al-6Mo was higher than pure Ti and lower than β type alloy Ti-5Sn-5Cr. The corrosion rate of as cast Ti-6Al-6Mo was 0.0016 mm/py.

5. References
[1] Niinomi M et al 2012 Acta Biomaterialia 8 3888-3903
[2] Lautenschlager E P et al 1993 International Dental Journal 43 245-253
[3] Kuroda D et al 1998 Materials Science and Engineering: A 243 244-249
[4] Lutjering G et al 2007 Titanium
[5] Senopati G et al 2016 AIP Conference Proceedings
[6] Cardozo F F et al 2014 Journal of The Mechanical Behavior of Biomedical Materials 32 31-38
[7] Ho W F et al 2011 Biomaterials 20 2115-2122
[8] Kent D et al 2013 Journal of the Mechanical Behavior of Biomedical Materials 28 15-25
[9] Hsu L C et al 2014 Material Science and Engineering A 606 157-164
[10] Xu L J et al 2013 Trans. Nonferrous Met. Soc. China 23 692-698
[11] Fengying z et al 2013 Rare Metal Materials and Engineering 42 1332-1336
[12] Kumar A et al 2012 Advanced material research 585 381-386
[13] Gurappa I 2002 Materials Characterization 49 73-79
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