EFFECTS OF BISMUTH ADDITION ON BENDING PROPERTIES OF CAST Ti-35Nb BASED ALLOY SYSTEM

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Introduction

Due to their low density, excellent biocompatibility, corrosion resistance and mechanical properties, titanium and titanium alloys have been widely used for many biomedical applications today. For example, pure titanium is being used for hip cup shell, dental crown and bridge, endosseous dental implant and plate for oral maxillofacial surgery, while Ti-6Al-4V alloy is used for hip prosthesis, artificial knee joint and trauma/fixation devices such as nails, plates, screws and wires.

Although Ti-6Al-4V ELI is widely used as an orthopaedic implant material due to its excellent corrosion resistance and mechanical properties, studies have shown that the release of aluminum and particularly vanadium ions from the alloy might cause such long term health problems as peripheral neuropathy, osteomalacia and alzheimer diseases. Recently, much research effort has been devoted to the study of more biocompatible, lower modulus, better processability β or near-β Ti alloys, such as Ti-13Nb-13Zr, Ti-11.5Mo-6Zr-2Fe and Ti-15Mo.

According to the earlier results of the present research group, addition of a small amount of bismuth could significantly increase the castability of Ti-Mo-based and other Ti alloys. Reported in this study is the effect of bismuth addition on bending properties of an in-house developed Ti-35Nb-based alloy system under as-cast condition.

Experimental

The materials used for this study, Ti-35wt%Nb, Ti-35wt%Nb-1wt%Bi and Ti-35wt%Nb-3wt%Bi alloys, were prepared using a commercial arc-melting vacuum-pressure type casting system (Castmatic, Iwatani Corp., Japan). Prior to melting/casting, the melting chamber was evacuated and purged with argon. An argon pressure of 1.5 kgf cm^{-2} was maintained during melting. Appropriate amounts of metals were melted in a U-shaped copper hearth with a tungsten electrode. The ingots were re-melted several times to improve chemical homogeneity of the alloy.

Prior to casting, the alloy ingots were re-melted again in an open-based copper hearth in argon under a pressure of 1.5 kgf/cm^2. The difference in pressure between the two chambers allowed the molten alloys to instantly drop into a graphite mold at room temperature.

X-ray diffraction (XRD) for phase analysis was conducted using a Rigaku diffractometer (Rigaku D-max IIIV, Rigaku Co., Tokyo, Japan) operated at 30 kV and 20 mA with a scanning speed of 2^o/min. A Ni-filtered CuKα radiation was used for the study. A silicon standard was used for the calibration of diffraction angles. The various phases were identified by matching each characteristic peak in the diffraction patterns with JCPDS files.

The microhardness of polished alloys was measured using a Matsuzawa MXT70 microhardness tester with a load of 200 g for 15 sec. Average microhardness values were obtained from at least 15 tests under each condition.

Three-point bending tests were performed using a desktop mechanical tester (Shimadzu AGS-500D, Kyoto, Japan). The bending strengths were determined using the equation, $\sigma=3PL/2bh^2$], where σ is the bending strength (MPa), P is the load (kg), L is the span length (mm), b is the specimen width (mm), and h is the specimen thickness (mm). The dimensions of the specimens were: L = 30 mm, b = 5.0 mm and h = 1.0 mm. The modulus of elasticity in bending is calculated from the load increment and the corresponding deflection increment between the two points on the straight line as far apart as possible using the equation: $E=L^3\Delta P /4bh^3\Delta\delta$, where E is the modulus of elasticity in bending (Pa), ΔP is the load increment as measured from preload (N), and Δδ is the deflection increment at midspan as measured from preload. The average bending strength and modulus of elasticity in bending were taken from 5 tests under each condition.

Results and Discussion

The XRD patterns (Fig. 1) indicate that the as-cast binary Ti-35Nb alloy exhibited a monolithic β phase with a bcc crystal structure, consistent with an earlier study [1]. The addition of either 1 or 3 wt% Bi did not change the phase of the alloys.

The microhardness values of Ti-35Nb and Ti-35Nb-1Bi were similar (~ 200 HV), as shown in Fig. 2. However, when 3 wt% Bi was added, the microhardness significantly increased to ~ 220 HV, indicating a solution-hardening effect.

Unlike microhardness, addition of only 1 wt% Bi had a significant effect on bending strength of the alloy. As shown in Fig. 3, the average bending strength of Ti-35Nb-1Bi (930 MPa) was higher than that of Ti-35Nb (830 MPa). As 3 wt% Bi was added, the average bending strength of the alloy further increased to 1000 MPa.

It is interesting to note that, although the bending strength of the alloy increased with increasing Bi content, the bending modulus of the alloy decreased with increasing Bi content. As demonstrated in Fig. 4, the average bending modulus of Ti-35Nb-1Bi (65 GPa) was significantly lower than that of Ti-35Nb (70 GPa). As 3 wt% Bi was added, the bending modulus of the alloy further decreased to as low as 57 GPa. Although the reason for this Bi-induced decrease in elastic modulus is not fully understood at this moment, it has been known that using implant materials with lower modulus (close to that of human bone) could reduce the stress shielding effect (REF).

The combination of increase in strength and decrease in modulus of the Bi-containing alloys was directly reflected in their larger elastic recovery angles than that of the binary Ti-35Nb alloy. As indicated in Fig. 5, the average elastic recovery angle of Ti-35Nb-1Bi (17 ^{o}) was significantly larger than that of Ti-35Nb (11^{o}). As 3 wt% Bi was added, the average elastic recovery angle of the alloy further increased to 23 ^{o}. The titanium alloy with a larger elastic recovery angle may potentially have a higher strain-controlled fatigue resistance, which remains to be proved.

References

1. .C.M. Lee, C.P. Ju, J.H. Chern Lin, Oral Rehab., 29:314-322, 2002.

Acknowledgement

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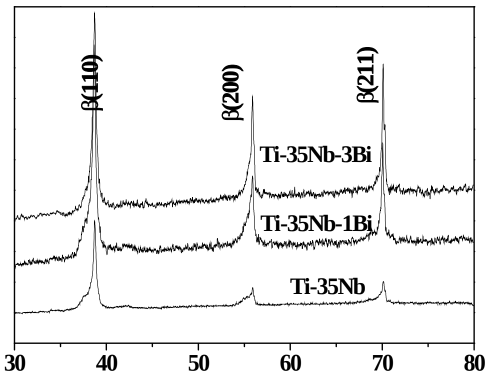

Fig. 1. XRD patterns of Ti-35Nb, Ti-35Nb-1Bi and Ti-35Nb-3Bi alloys

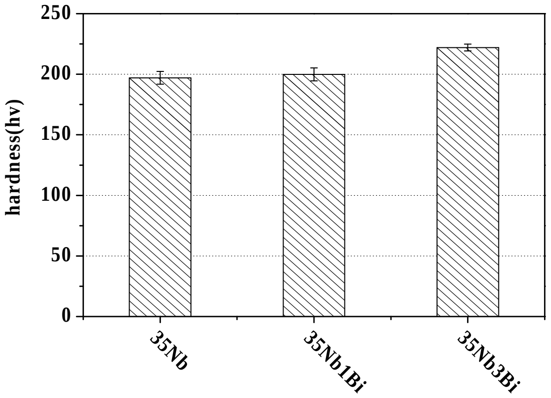

Fig. 2. Microhardness values of Ti-35Nb, Ti-35Nb-1Bi and Ti-35Nb-3Bi alloys

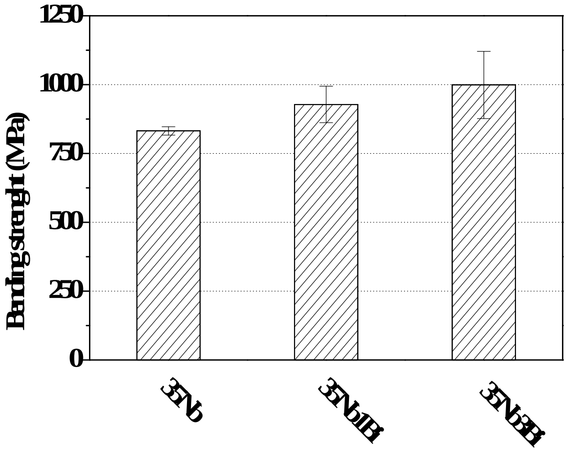

Fig. 3. Bending strength values of Ti-35Nb, Ti-35Nb-1Bi and Ti-35Nb-3Bi alloys

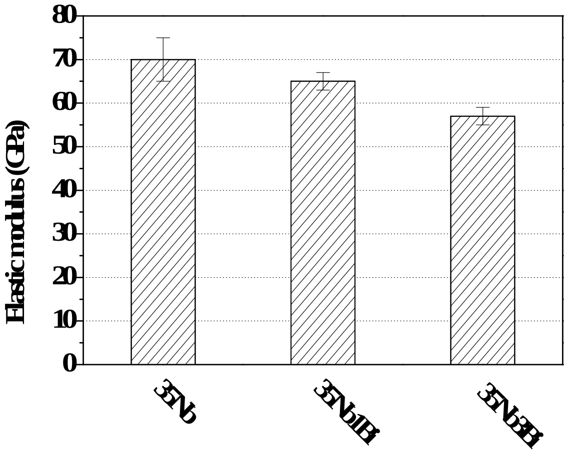

Fig. 4. Bending modulus values of Ti-35Nb, Ti-35Nb-1Bi and Ti-35Nb-3Bi alloys

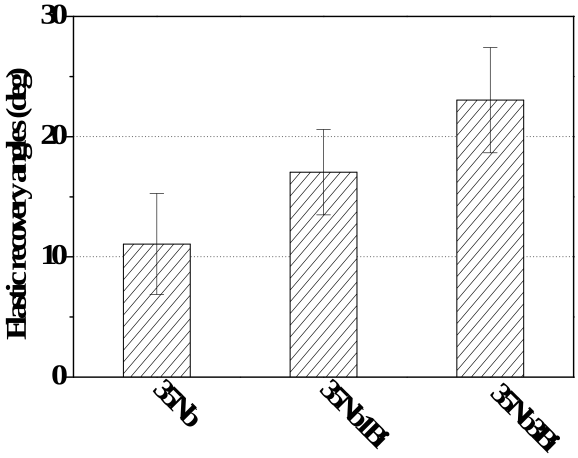

Fig. 5. Elastic recovery angles of Ti-35Nb, Ti-35Nb-1Bi and Ti-35Nb-3Bi alloys