Sintering Properties of Ti-6Al-4V-xMo Powder Prepared by Addition of Mo to Ti-6Al-4V Scraps and Subsequent Pulverization

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In this study, the sintering properties of Ti-6Al-4V-xMo powder prepared by an addition of Mo to Ti-6Al-4V scraps and subsequent pulverization were investigated. As the content of Mo added to Ti-6Al-4V scraps as a β stabilizer increased, the weight ratio of the α and β stabilizers in the Ti-6Al-4V-xMo changed and the original weight ratio of 6:4 varied to 5.71:8.57 when 5 wt% xMo was added. In order to compare the difference in properties of Ti-6Al-4V-xMo ingots with sintered bodies of the Ti-6Al-4V-xMo powder, we prepared sintered bodies from Ti-6Al-4V-xMo powder with an O content of about 5000 ppm and 325 mesh size. As a result, it was found that the sintered bodies of Ti-6Al-4V-xMo powder showed different properties of density and micro hardness compared to the Ti-6Al-4V-xMo ingots. These differences can be explained by the larger specific surface area of the sintered bodies, which formed a porous oxide layer on the surface due to the increase of Mo in the β zone of the Ti-6Al-4V alloys.

Keywords: Ti-6Al-4V, Mo, recycling, sintering, powder processing

1. INTRODUCTION

Generally, Ti and Ti alloys are commercially used in the electronics and aerospace industries [1-3]. Ti-6Al-4V alloy, among many Ti alloys, accounts for 70% of the overall use of alloys. Ti-6Al-4V is a representative α+β alloy in Ti alloys and is used in various industrial fields because of its excellent machinability and weldability [4]. Despite the outstanding properties of pure Ti and Ti alloys, many studies have been conducted to recycle Ti and Ti alloy scraps due to the high price of Ti production. Most researchers have reported the remelting of pure Ti and Ti-6Al-4V alloys to prepare reliable ingots, and powder preparation by using the Hydrogenation-DeHydrogenation (HDH) method [5-7]. Alternatively, other researchers have prepared functional Ti alloys by the addition of various elements to Ti and Ti-6Al-4V alloys [8,9].

As an additional element, Mo is currently used to develop new functional alloys; Mo is a β-stabilizer that is not harmful to the human body [10,11]. Representative Ti-11.5Mo-6Zr-2Fe and Ti-15Mo alloys have been developed as β-Ti alloys and these studies investigated the effects of Mo addition as a β-stabilizer [12,13]. However, on the subject of recycling Ti-6Al-4V scraps, no fundamental research has been presented concerning the sintering properties of Ti-6Al-4V-xMo powder prepared by the addition of Mo as a β stabilizer to Ti-6Al-4V scraps and the difference in properties of sintered bodies of the Ti-6Al-4V-xMo powder with Ti-6Al-4V-xMo ingots. Therefore, in this study, Ti-6Al-4V-xMo powder is prepared by the addition of Mo to Ti-6Al-4V scraps and subsequent pulverization. The effects of Mo addition on the sintering properties of Ti-6Al-4V-xMo powder and the difference in the properties of sintered bodies with Ti-6Al-4V-xMo ingots were investigated.

2. EXPERIMENTAL PROCEDURE

Ti-6Al-4V alloy scraps were obtained by cutting rod scraps used for implants. A 35 g button type of ingot was prepared by adding granular Mo (Sigma Aldrich, 99.9%, USA) to Ti-6Al-4V alloy scraps in weight ratios ranging from 1.0% to 5.0%. Melting was repeated four times to obtain uniform ingots. Afterwards, in order to obtain Ti-6Al-4V-xMo powder, Ti-6Al-4V-xMo ingots were treated for 2 h under hydrogen atmosphere of 5 × 10⁻⁶ – 7 × 10⁻⁵ Pa at 600 °C. The Ti-6Al-4V-xMo powder obtained after pulverizing the hydrogenated Ti-6Al-4V-xMo ingots into a particle size was then treated for 2 h at 700 °C under a vacuum of 6.7 × 10⁻⁵ Pa for dehydrogenation. The Ti-6Al-4V-xMo powder with a particle size of 325 mesh was compacted at 2,000 kgf/cm² pressure using a vertical press with a 20 mm diameter and 10
mm height. A series of compacted Ti-6Al-4V-xMo powders were separately vacuum sintered at 1100 °C and 1400 °C under a dynamic vacuum of $6.7 \times 10^{-3}$ Pa, for 2 h at each temperature.

The densities of the Ti-6Al-4V-xMo alloy ingots and sintered bodies were calculated using the Archimede’s principle. The O contents of the Ti-6Al-4V-xMo alloy ingot, powder, and sintered bodies were determined by inert gas fusion infrared absorption using an O/N analyzer (TCH-600, LECO Corporation, USA). The shape and grain size of the Ti-6Al-4V-xMo powders were examined by scanning electron microscopy (SEM, JEOL, JSM-6380LA). X-ray diffraction (XRD, RIGAKU, RTP 300 RC) was conducted to analyze the phase of each specimen. Micro-Vickers hardness tests of the Ti-6Al-4V-xMo ingots and sintered bodies were performed on the samples with a 250 g load using the Akashi (MVK-E, Mitutoyo Corporation, Japan) hardness tester.

3. RESULTS AND DISCUSSION

Pure Ti and Ti alloys must be melted in a vacuum or inert gas conditions because they have a strong affinity with gases such as O and N [4]. Therefore, O and N contents of prepared Ti-6Al-4V-xMo ingots with variable contents of Mo addition were analyzed. In the case of O, the Ti-6Al-4V ingot contained 1725 ppm, and the O content of the Ti-6Al-4V-xMo ingots showed no distinct difference considering the error range of O analysis. The N content of each specimen was approximately 75 ppm, and also showed no difference within the error range of N concentration. The error ranges of the oxygen concentration in the ingot and the powder were ±20 ppm and ±40 ppm, respectively. And the respective error ranges of the nitrogen in the ingot and the powder were ±7 ppm and ±14 ppm. Figure 1(a) shows a variation in the weight ratios of the α and β stabilizers in the Ti-6Al-4V-xMo ingots with increasing the Mo content. Except for the initial weight ratio of 90% Ti, the 6% Al and 4% V elements occupied α stabilizer of 6% and β stabilizer of 4%. With increasing Mo content, the ratio of the α stabilizer reduced from 6% to 5.71% and the ratio of the β stabilizers for V and Mo increased from 4% to 8.57%. More stable β Ti-6Al-4V-xMo alloy could be obtained when 3% or more Mo was added to the Ti-6Al-4V scraps. Furthermore, the density of the Ti-6Al-4V-xMo ingots, as shown in Fig. 1(b), gradually increased from 4.38 g/cm$^3$ to 4.54 g/cm$^3$. It was considered that the density of the Ti-6Al-4V-xMo ingots linearly increased due to the substitution of lattices in Ti-6Al-4V to Mo with higher density.

The Ti-6Al-4V-xMo ingots were used as a raw material to prepare powder by HDH method. Figure 2 shows SEM images of the Ti-6Al-4V-xMo powder obtained by the HDH method as a function of the Mo content. The Ti-6Al-4V-xMo powder prepared by the HDH method shows typical irregular shapes and the particle size of the powder ranged from 10 to 150 μm.

No shape and size changes have been detected by the Mo addition. This result was similar to the previous results of Ti and Ti-Mo powders [14]. XRD analyses were performed to observe the change in the phase of the Ti-6Al-4V-xMo powders as a function of the Mo addition and the results are shown in Fig. 3. Overall, the XRD results show typical phases of α+β peaks in the Ti-6Al-4V alloy, while the intensity of the height of the β-Ti peak at 39.8° gradually increased with increasing Mo content. This indicates that the β phase distinctly grew with the addition of Mo as a β stabilizer in the Ti-6Al-4V alloy.

The O contents of the Ti-6Al-4V-xMo powders with a particle size of 325 mesh selected for vacuum sintering were analyzed. The Ti-6Al-4V powder showed 5120 ppm, which contrasted with the 1725 ppm of the Ti-6Al-4V ingot, and it seems that the specific surface area of powder to be affected.