Microstructure and Properties of Ti-8Mo-12Fe and Ti-8Mo-8Cu alloys with Cr$_3$C$_2$ Additives Produced in the Powder Metallurgy Processes

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Abstract

Titanium base composites with a 3% wt of Cr$_3$C$_2$ additives were processed by powder metallurgy using vacuum sintering between 1423~1523K. Different elements of the alpha-beta type Ti alloys were compared. Fe-based alloys accelerate the sintering process. Mo proves to be a good candidate for solution strengthening and Cu effectively increase the material ductility of the Ti matrix. Therefore Cr$_3$C$_2$ and Mo are both very suitable $\beta$ stabilized additives for reinforcing Ti-based composites. The development of the plastic deformation of the ternary alloys has been observed and the morphology of the eutectic alloy Ti-8Mo-8Cu causing refinement and supersaturating of the $\beta$ phase is crucial factor for improving the ductility of the Ti alloys. On the contrary Ti-8Mo-12Fe induced a change of the morphology of the eutectic and increase fraction. The aim of this project is to compare the sintering behavior and evolving phases using SEM images taken from polished specimens and bending testing fractured surfaces.

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1. Introduction

Superior physical phenomena of Ti alloys are its lightweight and strong mechanical properties, particularly its low elastic modulus and low density. This also gives it a better thermal conductive coefficient compared with conventional metals. The chemical properties of Ti alloys include good resistance to corrosion, good antiseptic properties, and high biocompatibility with humans. These properties make Ti alloys a common choice for biomaterial (such as teeth and bone supplements) planted into human bodies [1-3]. Although Ti-6Al-4V is commonly used as an implant material, researchers have pointed out that V ions can release poison, and that Al ions conflict with the human body. This issue has been argued severely. Our study continues on the success of previous research, using Mo to substitute the Al and V ions with the addition of Fe or Cu elements to create a stabilized phase structure. Titanium shares the hcp structure of a phase under room temperature but when sintering at 882°C the phase is transmitted into β phase BCC structure[4, 5]. However, a high-temperature BCC structure can be stabilized at room temperature by addition of alloy elements such as Fe, Mo, Cr, and Nb. The compound ratio must be adjusted properly to achieve these results. Our main goal is to add a β stabilizer to develop a β-Ti alloy that can serve as a stable biomaterial. For example, we will add Fe and Cu to form a ternary alloy (Ti-Mo-Fe or Ti-Mo-Cu) and then compare the mechanical properties and microstructures of the results. It has been shown that CrC2 particles may be used as an alternative applicant to strengthen Ti alloys. CrC2 is used as reinforcement and two practical methods are designed to prepare Ti-Mo-Fe/CrC2 and Ti-Mo-Cu /CrC2 composites in this study. The thermal expansion coefficient of CrC2 was comparable to Ti-Mo-Fe so lower residual stress was expected to be built in the procedure wetting. A β-rich α+β alloy (Ti-8Mo-12Fe) with added CrC2 particles was used in the process and its products show better properties than Ti-6Al-4V: fine microstructure, superior sintering ability, excellent mechanical properties [6-8]. Fe and Mo elements provide the enhancement of sintering and microstructure refinement to the alloys. It has been shown that the combination of these elements in a Ti-Mo-Fe alloy has a good balance between mechanical properties and hot workability (excellent sintering ability due to the immersion of a temporary liquid phase at the start of the sintering process)... On the other hand, it has been recognized to be difficult to apply the blended process to β-titanium-based alloys due to its difficulty in preparing ductile master-alloy powders of lower aluminum content by an easy grinding method. A high degree of freedom in selection of alloy composition and in microstructure design is a major advantage due to the cost benefit of the blended elemental procedure and the ingot metallurgy process could be used[10-12]. However we have succeeded in developing a new high performance β-titanium alloy composite using vacuum sintering process.

Fig. 1. SEM morphology of the Ti alloy powder (A) Ti-8Mo-12Fe (C1) (B) Ti-8Mo-8Cu (C2).
2. Experimental

The composition of powder Ti-8Mo-12Fe (C1) and Ti-8Mo-8Cu (C2) was first carefully mixed in dry-jar after adding 3wt% of Cr3C2. The metallurgy powders Ti, Mo, Cu, and Fe elements (99.99wt%) in figure 1 was composed with a wide distribution in particle size which the additive of Cr3C2 powder was as-received of mean particle size 20 μm that was milled into 5μm for 48hr. Both powder of Ti-8Mo-12Fe(C1) and Ti-8Mo-8Cu(C2) was compressed into green powder pellets and rods at 3 tons for 3 min and sintering in a vacuum furnace with a vacuum better than 10⁻⁵torr. First the compact were sintered at 373K and 773K for 30 min. Second heating the samples at 10°C/min to 1423~1523K for 30 min followed by furnace cooled. The examination of microstructure of sintered bulk samples was cut across their centers, and then ground, polished and etched with a solution of HF:H2O:HNO3. Both fracture surface and polished surface was compared using scanning electron microscopy(SEM), EDS was also carried to determined the precipitation; phase analyses of specimen using X-ray diffraction(XRD) with Cu Kα radiation was attend. After sintering, the pellet density was first measured by Archimedes method. For mechanical property testing, both Ti-8Mo-12Fe (C1) and Ti-8Mo-8Cu (C2) with variety of temperature parameters were applied for bending test.

3. Results and Discussion

The XRD patterns of differently prepared Ti-Mo-Fe (Cu) alloy are presented in Fig.2. In the case of Ti-Mo-Cu(C2) alloy, the relative intensity of the β-Ti reflection is smaller than Ti-Mo-Fe(C1) alloy specimen indicating the α peaks of (C2) compact were still in position but those of C1 shifted rightward and a corresponding β phase Ti appeared. This means that the addition of Mo and Fe enhanced the stabilized of β phase in titanium powder compacts. However the determined of intermetallic compounds such as TiC and other precipitate was not success in detecting by XRD analysis in the specimen sintering because the additives of Cr3C2 below 3 wt%. Although some of an unidentified phase, according to JCPDS cards are rare intermetallic compound but to determine which of these minor precipitating compounds are limited by the quantitative analysis. On the other hand, the diffraction patterns of C2 by adding 8wt% Cu have revealed peak strongly correspond to α-Ti. Microstructure mostly consists of an ordered cubic Ti-Mo-Cu which is a solid solution of Cu in a binary Ti2Cu compound and a disordered hcp α-Ti solid solution. In contrast, XRD pattern was dominated by peaks from α-Ti or β-Ti over the diffraction angle which low intensity corresponding peak was compared by EDS.

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<th>Table 1 Characteristics of Ti alloy.</th>
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<td>Density (g/cm³)</td>
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In our project revealed that both Ti alloys that was compare has added the some element Mo and Cr\textsubscript{3}C\textsubscript{2}. Therefore the main coursing of microstructure difference is between Fe and Cu in figure 3(B) and figure 4(B). We first would like to discuss about the addition of Mo. According to phase structure when Mo at a certain range, Mo self-diffusion is slower than Ti which would sustain the grain boundary migration and beneficial the β-grain size refinement in Ti alloys. Previous research shows that Fe addition accelerated the Ti alloy densification [13]. Figure 3(B) show polished cross-section SEM of differently sintering temperature with TiC and β-Ti phases. The Ti-Fe phase diagram indicate the eutectic point at 600°C at 15% Fe addition which we supposed that 12% Fe would have a low sintering temperature of β eutectic. Copper is an excellent β-stabilizing element which its eutectic point located at a copper concentration of 7wt%. Medical scientist has reported that the Ti-Cu alloyed have an adequate biocompatibility and corrosion resistance for dental materials [14]. The microstructure figure 4(B) shows the typical structure of α-Widmannstätten.

When adding 12 wt% Fe, the fracture surface of Ti alloy have a brittle structure, surface reveals the shape of beach fracture, grain structure shape are evidently and low hardness, respectively, figure 3(A). On the contrast, when adding 8wt% Cu of β eutectoid compound surface structure show small dimple of microstructure distribute everywhere. The raise percentage of Cu manages along with grain size shape which the grain size grows while the percentage Cu increases in figure 4(A). Therefore the structure has an excellent ductile material when attending uniform sliding deformation and has a high strength and low elastic modulus. The difference between the additions of 3wt% Cr\textsubscript{3}C\textsubscript{2} of Titanium alloys can be compared by mechanical property in Table 1. Besides the original properties like anti-oxidation or anti-corrosion resistant of titanium alloy, Cr\textsubscript{3}C\textsubscript{2} can also lead to the solid-solution strengthening. Due to the divergence of the lattice constant between Ti alloy and Cr\textsubscript{3}C\textsubscript{2} particles, it causes incoherent strain on the boundary and has been also promoted precipitation hardening effect when dislocation move to the mismatch boundary hinders. The result of the mechanical properties of the alloy influence which concludes phase grain size number as a result of lattice mismatch of residual strain. Cr\textsubscript{3}C\textsubscript{2} were decomposition into Ti matrix and precipitated TiC particles which is determined by EDS in figure 3(C) and figure 4(C). By modifying TiC will restrain the growth of grain, therefore compacted the substrate, raised the density and strengthen the structure. When decreasing particles of TiC; total volume fraction increase the particle spread which evolve the densification. Titanium alloy become harder, wear-resisting ability become more
suitable. The performance of the titanium alloy have been followed by sintering which influence the amount of precipitating compounds to be widely distributed.

4. Conclusions

Adding Cr$_3$C$_2$ and Mo are both found to be a very suitable $\beta$ stabilized additives for reinforcing Ti base composites. The morphology of the eutectic alloy Ti-8Mo-8Cu causing refinement and supersaturating of the $\beta$ phase is crucial factor for improving the ductility of the Ti alloys. On the contrary Ti-8Mo-12Fe induced a change of the morphology of the eutectic and increase fraction. Shortly, granted by the carbide compound is present or not, the titanium alloy can increase the high temperature stability and improve the creep properties causing the formation of similar characteristics of super alloys. Although some have been added to $\beta$ stable element in Ti alloys to retain $\beta$-phase at room temperature, by giving high stress $\beta$-stability alloy, it will be unstable to cross the activity energy barrier and resulting transformation phase. The Cr$_3$C$_2$ particles can reduce the energy of $\beta$-phase which phase transition is not easy to happen again.

Fig. 3. SEM micrographs of Ti-8Mo-12Fe(C1-1200). (A) fracture surface (B) polish surface (C) energy spectra from EDS.

Fig. 4. SEM micrographs of Ti-8Mo-8Cu(C2-1200). (A) fracture surface (B) polish surface (C) energy spectra from EDS.
and more stable exist at room temperature. Ti-8Mo-8Cu in this experiment has reached 824.7 MPa, respectfully.

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References