A Study on Microstructures and Hardening Behaviors of Ti-12.1Mo-1Fe Alloy

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Abstract

Ti-Mo-Fe alloy was developed as low cost beta Ti alloys for automotive springs, and designed based on Molybdenum equivalency and Bo-Md molecular orbital method. Low priced Mo-Fe master alloys were introduced as alloying elements for the cost and elastic modulus reduction. A laboratory scale ingot was melted by ISM (Induction Skull Melting). Then, microstructure characterization and hardening behavior of a new designed Ti-12.1Mo-1Fe alloy during solution and aging treatment were investigated in the present study by microscopy, X-ray diffraction and hardness test. The results showed that ω phase played a more important role than α phase in hardening. The hardening due to ω phase can lead to high hardness about 470 Hv. However, the coarse α phase resulted in hardness below 300 Hv. On the other hand, the alloy exhibited fast aging response due to high diffusion rate of Fe element in the Ti matrix.

1 Introduction

Titanium alloys are extensively applied in automobiles and vehicles due to excellent strength to density ratio, formability, low elastic modulus and good balance of mechanical properties [1-3]. Considering the low cost and light weighting of automobiles and vehicles which primarily made from conventional iron steel materials, aluminum, magnesium and titanium alloys are gradually involved in application of automobiles [4]. However, titanium alloy exhibits the best high strength to density ratio among the materials above but with the highest price at the same time. Consequently, in the present study a new beta titanium alloy was developed with good properties based on that lower cost of elements were used to replace some expensive elements for the formulation cost reduction. And microstructure characterization of the new designed alloy was primarily investigated for understanding on microstructure-property relations.

2 Experimental Procedure

The experimental alloy with a nominal composition, Ti-12.1Mo-1Fe, was fabricated by Induction Skull Melting (ISM, Consac). Molybdenum equivalent ([Mo]eq) of this alloy is about 15.1.

Samples from the alloy were solution treated in a pre-heated air furnace at 810°C and then held for 1 h followed by water quench. All the samples were solution treated in an air box furnace. In view of the chemical activity of titanium at high temperatures, all the samples are coated with Acheson's Deltaglaze 151 to form the protective coating, then to minimize the formation of α case during the heat treatment. Following the solution treatment, the samples were subjected to aging at temperatures ranging from 350°C to 600°C for different time in a pre-heated air furnace and followed by water quench

Specimens for optical microscopy (OM) were mechanically polished with the standard metallographic procedure and etched in the Kroll's reagent (5% HF + 15% HNO3 + 80% H2O) to reveal grain boundaries. Microstructure characterization was performed on an Axiovert 200 MAT (OM).

Phase identification was characterized by a PANalytical XPert Pro MPD Diffractometer (XRD) using a Cu-Kα radiation operated at 40 kV and 30 mA in the angular (2θ) range of 20-90°.

Micro hardness measurement was performed on a MITUTOYO Vickers micro-hardness testing machine with a load of 1 kg force applied for 10 seconds. A minimum of five indentations for each sample are taken and averaged to minimize the scatter (the measured error is within 5%).

3 Results and Discussion

3.1 Determination of the beta transus temperature

Beta transus temperature is basis for selecting forging and rolling temperatures, and also subsequent solution temperatures. So the beta transus temperature of Ti-12.1Mo-1Fe alloy has been measured with a metallography method, firstly.

According to Equation 1 [5], the beta transus temperature was predicted about 770.4°C. Based on that, 770°C and 780°C were selected to carry out solution treatment. The relative microstructures are shown in Fig. 1. With temperature increased, both of inter-granular and intra-granular primary α phases are getting less. Primary α phases are disappeared and transformed into equiaxed β phase completely when solution treated at 780°C. Accordingly, the transus temperature could be considered as 780°C.

$$T_\beta=872+23.4[Al]+32.1[Si]-7.7[Mo]-12.4[V]-14.3[Cr]-8.4[Fe]-4.3[Zr] \quad (1)$$

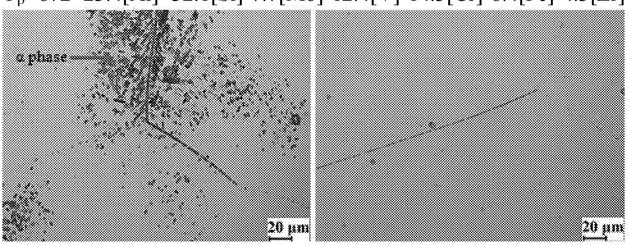

Fig. 1 Microstructures of Ti-12.1Mo-1Fe alloy after solution treatment: (a) 770°C/1h/WQ (b) 780°C/1h/WQ

3.2 Microstructure Characterization and X-ray diffraction analysis

As mentioned above, all the samples were primarily solution treated above the transus temperature. And the microstructure of the alloy after aging at 810°C is shown in Fig. 2. As seen from that, the microstructure mainly consists of equiaxed beta grains with size of 25 μm.

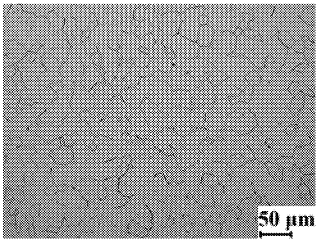

Fig. 2 Microstructure of the alloy after solution treated at 810°C for 1 hour and water quench.

Figure 3 shows microstructures of the solution treated alloy after aged at 350°C, 400°C, 450°C, 500°C, 550°C and 600°C for 1 hour. It can be seen that, no α phase was found in Fig. 3-a to 3-d when the alloy aged at from 400°C to 500°C within 1 hour. The same results can be proven in Fig. 4, indicating the XRD profiles of the relative conditions. No α phase but isothermal ω phase was found from 350°C to 500°C. However, ω phase disappeared with increasing aging temperature and α phase formed. As seen in Fig. 3-e and 3-f, lath-shaped α phase with 1 variant formed parallel along the prior beta grain boundaries, and lamellar α phase also formed in beta grains with 2 variants with a relatively larger size of about 20 μm.

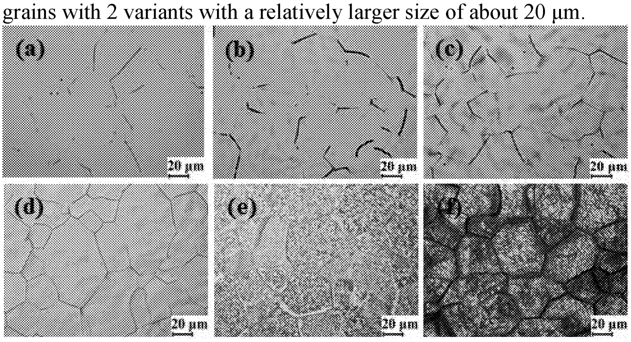

Fig. 3 Microstructures of the alloy after aging for 1 hour and water quench
(a) 350°C, (b) 400°C, (c) 450°C, (d) 500°C, (e) 550°C, (f) 600°C

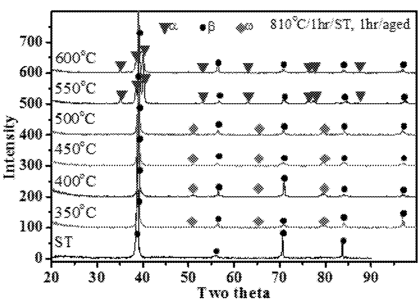

Fig. 4 XRD profiles of the alloy aged at from 350°C to 600°C

3.3 Age hardening behavior

Figure 5 shows the hardening behavior of the alloy aged at from 350°C to 600°C for 1 hour. As mentioned above, ω phase formed at from 350°C to 500°C and disappeared at above 500°C. Consequently, the hardness goes through a peak value and then decrease because of the microstructure experiences an increase of ω phase, and transformation to α phase and coarsening of α phases, as seen in Fig. 3 and 4. The ω phase contributed hardness is above 400 Hv and the maximum hardness was found to near 500 Hv when the alloy aged at 450°C. That is because ω phase can lead to a drastic increase in yield strength. However, the α phase formed at above 500°C results in lower hardness below 290 Hv. Therefore, the ω phase plays a more important role than α phase in hardening.

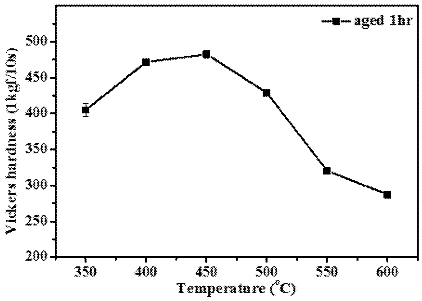

Fig. 5 hardness change of the alloy after aging at 400°C, 500°C and 600°C for 1 hour and water quenched

4 Conclusions

A newly developed Ti-12.1Mo-1Fe alloy has been investigated in the present study. The microstructure characterization and hardening behavior have been studied. The main results are summarized as follows:

1. The beta transus temperature of new Ti-12.1Mo-1Fe alloy was measured to be 780°C.
2. Isothermal ω phase was found in Ti-12.1Mo-1Fe alloy when aged at 400°C and 500°C, but not found at 600°C.
3. The ω phase plays a more important role than α phase in hardening. The hardening due to ω phase can lead to a high hardness about 470 Hv, but the α phase coarsening results in a hardness below 300 Hv.

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