Introduction of Millefeuille-like α/β Layered Structure into Ti-Mo Alloy through Thermomechanical Treatment

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Recently, new type of high strength and good ductility magnesium alloys with long-period stacking ordered (LPSO) phase were developed. Their superior mechanical property is related to the kink deformation of LPSO phase, which has layered structure (millefeuille structure). In this study, as a trial to realize kink deformation in titanium alloys, we successfully introduced millefeuille-like layered hcp (α) / bcc (β) two phase structure through slight cold rolling followed by aging heat treatment into β type Ti-12 mass% Mo alloys. After slight cold rolling at rolling reduction of 5 %, {3 3 2}<1 1 3> β type deformed twins, typical twins in metastable β titanium alloys, were formed with layered features. Following aging treatment at 973 K, film-like α phases were precipitated and grew on the twin boundaries and made an alternately stacked millefeuille-like α/β layered structure.

Keywords: *Titanium molybdenum alloys, slight cold rolling, aging heat treatment, millefeuille-like layered structure, {3 3 2}<1 1 3> β twinning*

1. Introduction

In early 2000's, new type of Mg alloys with unique fine lamellar structure were developed [1, 2]. They had a long-period stacking ordered (LPSO) structure along with long-period chemical ordered structure and exhibited superior balance of high strength and good ductility after extrusion. Further studies revealed that one of the reasons for the high strength of these alloys attributed to deformed kink structure of bent LPSO lamellar [3, 4]. This type of kink deformation has not only been reported in Mg alloys but also in other metals [5, 6] and even in titanium alloys [7, 8]. However, it is still unclear whether strengthening by kink deformation is applicable to titanium alloys. To realize the kink deformation in titanium alloys, hcp (α) / bcc (β) layered structure similar to LPSO lamellar (so called millefeuille structure) seems to be favorable due to their plastic anisotropy.

In this study, as a trial to realize kink deformation in titanium alloys, we successfully introduced millefeuille-like layered α/β two phase structure in β type Ti-Mo alloys through thermomechanical treatment [9].

2. Experimental Procedure

Cold crucible levitation melted ingot (70 mm in diameter and 1.2 kg in weight) of Ti-12 mass% Mo alloy was hot forged and hot rolled into a plate with 5-mm-thickness at 1073 K. After removing the surface oxidation layer, the plate was cold rolled into a plate with 1-mm-thickness. Small coupons with 50-mm-length and 5-mm-width were taken from the cold rolled plate and solution treated at 1173 K (in β single phase region) for 18 ks to obtain large β grains. Slight cold rolling with the reduction rate of 5% was performed on the coupons with the direction orthogonal to the hot rolling and initial cold rolling direction. Slight cold rolled coupons were finally aged at 973 K (in α/β two phase region) for up to 180 ks for precipitation of α phase, followed by water quenching. Microstructural observations were performed using optical microscopy (OM), scanning electron microscopy (SEM), electron backscattered diffraction (EBSD).

3. Results and Discussion

Figure 1 shows the OM image of a slightly cold rolled Ti-12Mo sample taken from the transverse plane (TD plain). Plate-like layered features can be observed.

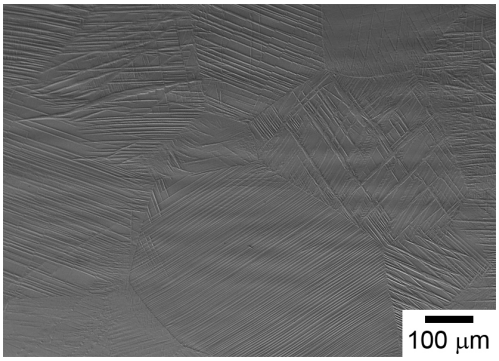

Fig. 1 OM image of slightly cold rolled Ti-12Mo sample taken from TD plane [9].

Figure 2 exhibits the results of EBSD analysis of slightly cold rolled Ti-12Mo sample (also done on TD plain). From the inverse pole figure (IPF) map (Fig. 2(a)), the sample still has β single phase after slight cold rolling, but these β phases have two different directions in one grain. In Fig. 2(b), red lines indicate the boundaries with a misorientation angle of 50.5° along the < 1 1 0> direction. This is corresponding to the {3 3 2}<1 1 3> β twin boundaries, which is typical twinning system in metastable β titanium alloys such as Ti-12Mo alloys [10]. After slight cold rolling, these {3 3 2}<1 1 3> β twins were introduced into coarse β matrix with layered features.

Figure 3 shows the SEM backscattered electron (BSE) image of a Ti-12Mo sample slight cold rolled and aged at 973 K for 180 ks, taken from TD plane. Alternatively stacked α phase layer (dark contrast) and β phase layer (bright contrast) can be seen in Fig. 3. Millefeuille-like layered α/β two phase structure was successfully introduced into Ti-12Mo alloy.

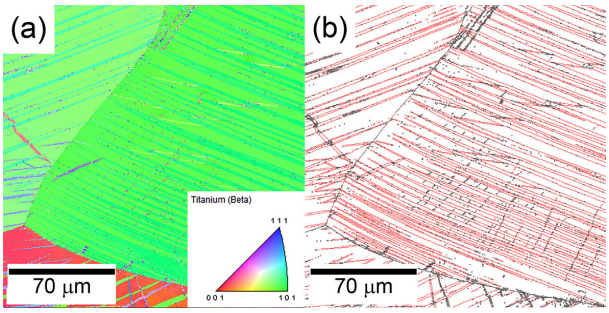

Fig. 2 EBSD analysis results on TD plane of slight cold rolled Ti-12Mo sample; (a) IPF map of β phase for the TD direction, and (b) boundaries with a misorientation angle of 50.5° along the <1 1 0> direction shown as red lines [9].

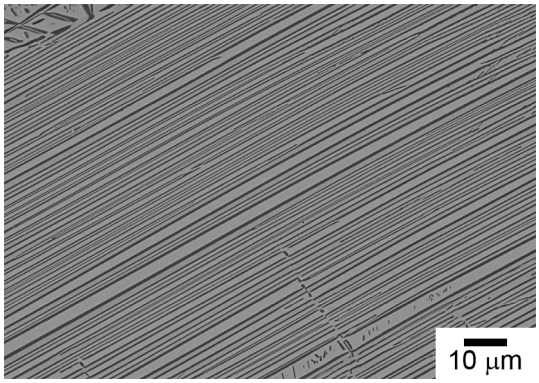

Fig. 3 SEM BEI image of Ti-12Mo sample after aging at 973 K for 180 ks taken from TD plane [9].

Comparison with the microstructure before and after aging, layered α phases seem to precipitate on the {3 3 2}<1 1 3> β twin boundaries. α phase precipitation on the twin boundaries has already been reported by Furuhara [11] and Ohyama [12]. So, we checked the very early stage of α phase precipitation in the Ti-12Mo sample after slight cold rolling. Figure 4 shows the SEM BEI image of a Ti-12Mo sample slight cold rolled and aged at 973 K for 60 seconds, taken from TD plane. Film like thin α phases were precipitated on the twin boundaries along with inside β matrix. These thin α phases had the Burgers orientation relationship [13] ((0 0 0 2) α // (1 1 0) β) with both side of matrix β phase (parent portion and twinned portion), which corresponds to the confirmation by Furuhara [11]. As the aging time became longer, these thin α phase layers became thicker and the α precipitates inside β matrix became smaller, and finally millefeuille-like layered α/β two phase structure was obtained, as shown in Fig. 3.

4. Summary

Millefeuille-like layered α/β two phase structure was successfully introduced in β type Ti-12Mo alloy plates through slight cold rolling and following aging heat treatment. α phase layer was precipitated on the deformed {3 3 2}<1 1 3> β twin boundaries introduced by slight cold rolling during following aging treatment and formed layered α/β structure.

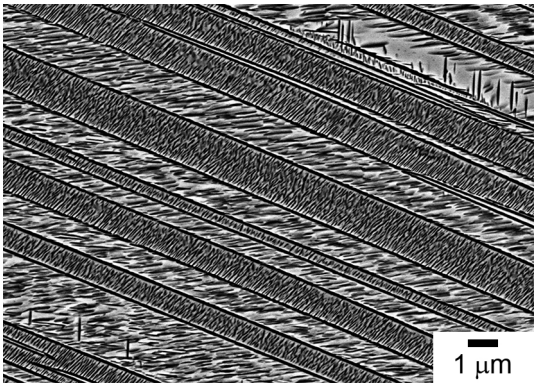

Fig. 4 SEM BEI image of Ti-12Mo sample after aging at 973 K for 60 s taken from TD plane [9].

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