Texture Control of TiAl Based Alloys by Uniaxial Compressive Deformation at High Temperature

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This study investigates lamellar microstructure orientation control in the (α+β) two-phase region of TNM alloy under high-temperature compression. Dynamic recrystallization in the (α+β) two-phase region with a small content of β phase leads to a correlation between peak stress and average lamellar colony size. In this region, a fiber texture forms with the $(0001)_{\alpha_2}$ plane tilted about 35° away from the compression plane. In the (α+β) two-phase region with a higher β-phase content, a fiber texture with the $(0001)_{\alpha_2}$ plane oriented about 35° and 90° away from the compression plane was produced by the phase transformation of β phase to α phase based on to the Burgers orientation relationship.

Keywords: *Titanium aluminide-based alloy, high-temperature deformation, lamellar orientation control, dynamic recrystallization*

1. Introduction

TiAl alloys have attracted attention as candidates for high-temperature structural materials. Improving toughness at room temperature is one of the issues for the practical use of TiAl alloys. Mechanical properties are affected by lamellar orientation [1, 2)]. The lamellar orientation controls under uniaxial compression in an α single-phase region and subsequent compression in a (α+γ) two-phase region have been studied in Ti-43Al and Ti-45Al-10V alloys [3-6)]. In this case, the $(0001)_{\alpha_2}$ plane was tilted about 35° away from the compression plane under uniaxial compression in the α single-phase region. Further compression in the (α+γ) two-phase region caused the $(0001)_{\alpha_2}$ plane parallel to the compression plane. It has also been clarified that lamellar orientation control improves creep properties and fracture toughness of polycrystal materials. Recently, the TiAl alloy Ti-43.7Al-4Nb-1Mo-0.1B (mol%), known as TNM alloy, have attracted attention due to their superior hot workability by adding β phase stabilizing element such as Nb and Mo. Much research has been conducted on the microstructure control of the TNM alloy under high-temperature deformation and related heat treatment [7)]. However, a crystal orientation control for lamellar microstructures in the TNM alloy is limitedly studied because of the absence of the α single-phase in the composition. Originally, TNM alloy was supposed to be processed in a state where a large amount of β phase is precipitated. This study performed the lamellar orientation control in the (α+β) two-phase region (small content of β phase) of the TNM alloy by high-temperature uniaxial compression.

2. Experiment

In this study, Ti-43.7Al-4Nb-1Mo-0.1B (mol%) alloy was examined. After centrifugal casting, the ingots were hot isostatic pressed (HIPed) at 1473 K under 200 MPa for 14.4 ks. Cylindrical specimens with a diameter of 8 mm and a height of 12 mm were cut by electric discharge machining. High-temperature uniaxial compression tests were conducted by a screw-driven type testing machine in conjunction with a tungsten meshed furnace. The specimen [1]was heated in a vacuum (~ $1\text{x}10^{-3}$ Pa) at a heating rate of 20 K/min to the testing temperature and held there for 7.2 ks. The compression tests were performed at temperatures between 1543 K to 1623 K and true strain rates ranging from 1.0×10^{-3} s^{-1} to 2.0×10^{-4} s^{-1}. After deformation up to a true strain of -1.0, the specimens were immediately cooled by furnace cooling. After the compression tests, the mid-plane section and cross-section of the specimens were prepared by mechanical and chemical mechanical polishing. The compressed specimens were observed by scanning electron microscope (SEM). The texture was characterized by X-ray diffraction (XRD) using the Schulz reflection method by Cu Kα radiation. From the pole figures obtained, the orientation distribution function (ODF) was calculated. The main component and sharpness of the texture, which corresponds to the position and value of the maximum pole density, were determined from the normalized pole figure and inverse pole figure derived from the ODF. The volume fractions for the regions aligned within 15°of the main component were calculated. The electron backscattered diffraction (EBSD) technique was used to measure the local crystal orientation of the specimens.

3. Results and discussion

3.1 Deformation behavior and microstructure formation in the (α + β) two-phase region

The HIPed TNM alloy consisted of three phases: γ, α_2, and β_0. Fig. 1 shows an example of a true stress - true strain curve under uniaxial compression deformation in the (α + β) two-phase region. The compression was conducted up to a true strain of -1.0 under a true strain rate of 5.0×10^{-4} s^{-1}, at a temperature of 1543 K, 1573 K, and 1623 K. In all compression tests, true stress - true strain curves showed a work softening behavior, the flow stress reaches a maximum in the initial stage of deformation and then

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decreases with further deformation. Hereafter, the maximum flow stress is referred to as the peak stress. After the process, the lamellar colonies and a small amount of fine β_0 phased grains were observed in the specimens. The fraction of the β_0 phase increases and the lamellar colony size decreases with the increase in the deformation temperature. The fractions of β_0 phase at deformation temperatures of 1543 K, 1573 K, and 1623 K were 1, 4, and 9%, respectively.

Fig. 2 shows the relationship between the average size of the lamellar colony and the peak stress from the true stress-true strain curve. It could not be seen the one-to-one correspondence between the lamellar colony size and the peak stress. It seems that the lamellar colony size decreases with decreasing peak stress. However, when focusing on each processing temperature, there will be a one-to-one correspondence between the average size of the lamellar colony and the peak stress. The lamellar colony size increases with decreasing peak stress. Thus, from the work softening behavior of true strain - true stress curves and one-to-one correspondence between the average lamellar colony size and the peak stress, it is considered that the dynamic recrystallization occurred in the α phase during deformation even in the (α + β) two-phase region of TNM alloy. In addition, when the amount of the β phase is in a high ratio, the size of the lamellar colony will not increase with the decrease in peak stress. This behavior is different from the general feature of dynamic recrystallization. This behavior is due to the fact that the β phase precipitates surrounding the α phased grains, and the precipitated β phase suppressed the grain growth of the adjacent α phase.

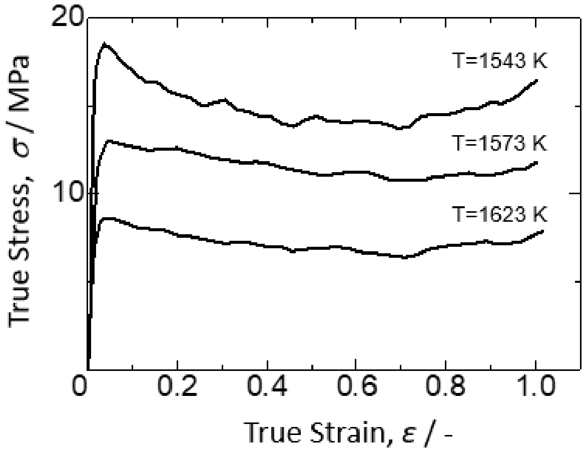

Fig. 1 True stress-true strain curves of TNM alloy obtained by uniaxial compression tests at various temperatures under a true strain rate of 5.0×10^{-4} s^{-1}up to a true strain of -1.0.

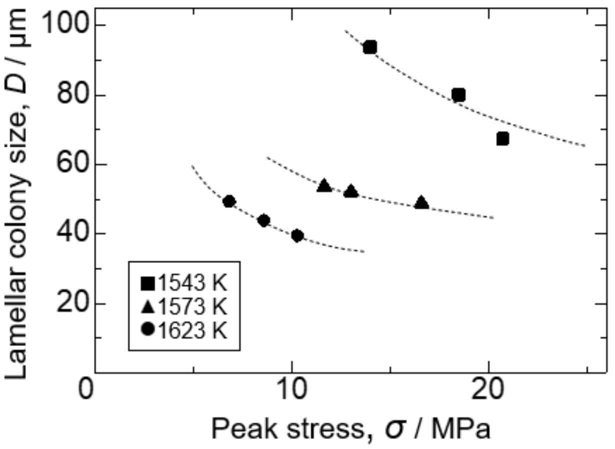

Fig. 2 Relationship between the average size of lamellar colony and peak stress.

3.2 Texture formation by uniaxial compressive deformation in the (α + β) two-phase region

Fig. 3 shows $(0001)_{\alpha_2}$ pole figures showing the distribution of pole densities of the compression plane. The average density is used as a unit. The compression was conducted up to a true strain of −1.0 under a true strain rate of 5.0×10^{-4} s^{-1}, in different temperatures. In the case of the specimens deformed at 1543 K and 1573 K, a fiber texture was obtained with the $(0001)_{\alpha_2}$ plane tilted about 35° away from the compression plane. However, in the case of the specimen deformed at 1623 K, a fiber texture where the $(0001)_{\alpha_2}$ plane is tilted about 35° and 90° from the compression plane was formed (Fig. 3(c)).

It is reported that a fiber texture where the $(0001)_{\alpha_2}$ plane is tilted about 35° from the compression plane will form in the of TiAl alloy in the α single-phase region. Further cooling will form lamellar microstructure by precipitating the γ phase from the α phase by the Blackburn orientation relationship [8)]. In this case, the lamellar plane will be tilted about 35° from the compression plane [4, 6)]. Thus, it is considered that the fiber texture was formed in the α phase in the same way under the uniaxial compressive deformation in the (α + β) two-phase region of TNM alloys at 1543 K and 1573 K where the β phase content is low.

As shown in Fig. 3, the texture changed when the specimen was deformed at 1623 K. This change in texture is considered due to the increase of the β phase content with the increase in temperature at the (α + β) two-phase region. The fraction of α and β phases is different in different processing temperatures. A part of the β phase in the (α + β) two-phase region transforms to α phase by decreasing the temperature from 1623 K. It is reported that the fraction of α phase and β phase at 1623 K are 30 % and 70 %, respectively [7)]. On the other hand, the area fraction of lamellar colonies and β_0 phases derived by rapid cooling from 1623 K in this study was 91% and 9%, respectively. This indicates that 61% of the β phase transforms to the α phase during cooling. When the β phase has a preferential orientation during deformation at 1623 K, the transformed α phase during cooling will have its texture which is related to the preferential orientation formed in the β phase.

Therefore, the texture of the uniaxially compressed β phase and the orientation relationship between the β phase and α phase during phase transformation was investigated.

It is known that the β phase in TiAl alloy has a BCC structure. Generally, it has been reported that the specimen which is uniaxially compressed at high temperatures shows {001} + {111} double fiber texture or {001} fiber texture 9). In the case of the β-Ti alloys, the volume fraction of {001} component increases, and the volume fraction of {111} component decreases with the increase in deformation temperature and strain and decrease in strain rate. Finally, the {001} + {111} double fiber texture changes to the {001} fiber texture 10-12). In this study, the specimen was deformed in the range of 1543 K to 1623 K, which will be a higher deformation temperature condition than the condition that was reported. Thus, it seems that the {001} fiber texture was formed in this study.

It is known that the orientation relationship in a titanium alloy between the α (hcp) phase and β (bcc) phase is called Burgers orientation relationship, and is given as,

$$\frac{(110)_\beta}{(0001)_\alpha}, \frac{[111]_\beta}{[11\bar{2}0]_\alpha}{}^{13)}. \#(1)$$

In this case, only the plane is focused since the fiber texture is formed. It is considered that it will be possible to understand the inheritance of orientation by comparing the {110} pole figure and $(0001)_{\alpha_2}$ pole figure. When the {001} fiber texture has formed in the β phase, the {011} plane will be tilted at about 45° and 90° away from the compression plane. This distribution of {011} plane mostly corresponds to the position of the $(0001)_{\alpha_2}$ plane in the $(0001)_{\alpha_2}$ pole figure shown in Fig. 3(c). Therefore, it is concluded that $(0001)_{\alpha_2}$ pole figure in Fig. 3(c) was formed by inheriting the orientation distribution of the uniaxially deformed β phase based on the Burgers orientation relationship between β phase and α phase.

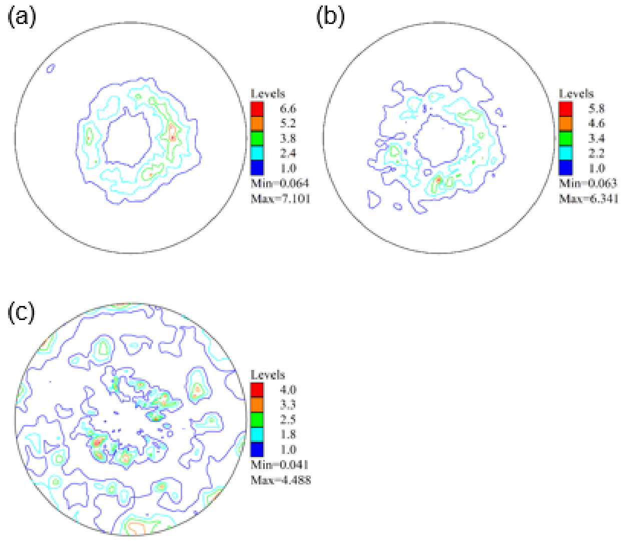

Fig. 3 $(0001)_{\alpha_2}$ pole figures showing the distribution of pole densities of the compression plane. The average density is used as a unit. The compression was conducted in different temperature up to a true strain of −1.0 under a true strain rate of 5.0×10^{-4} s^{-1}. (a) 1543 K, (b) 1573 K, and (c) 1623 K.

4. Conclusion

The possibility of microstructure and lamellar orientation control in different deformation conditions was investigated in the (α+β) two-phase region of TNM alloy by high-temperature uniaxial compression. The main conclusions are summarized as follows.

(1) Based on the true stress - true strain curve indicating the work softening and the one-to-one correspondence between the peak stress and the average lamellar colony size, it is considered that the dynamic recrystallization occurred in the α phased grains during deformation in the (α+β) two-phase region.

(2) During the deformation in the (α + β) two-phase region with a small content of β phase, a fiber texture formed with the $(0001)_{\alpha_2}$ plane tilted about 35° away from the compression plane is α phase. The produced lamellar plane will also decline about 35° away from the compression plane.

(3) During the deformation in the (α + β) two-phase region with a high content of β phase, a fiber texture where the $(0001)_{\alpha_2}$ plane is tilting about 35° and 90° away from the compression plane is formed in α phase. This texture formation is due to the Burgers orientation relationship caused by the transformation from β phase to α phase during cooling. The lamellar plane will decline about 35° and 90° away from the compression plane.

Acknowledgments

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