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Evolution of hot rolling texture in β (B2)-phase of a two-phase (O+B2) titanium–aluminide alloy

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Abstract

The evolution of texture in the β-phase of a two-phase (O+B2) titanium–aluminide Ti–22Al–25Nb (at.%) alloy during thermo-mechanical processing in single β-phase-field has been studied. Variations in microstructure and texture have been observed as a result of variation in the amount of rolling deformation for a given rolling temperature. The evolution of crystallographic texture in the β-phase can be understood by considering the increase in dynamic recrystallisation to which is associated a grain size reduction.

Keywords: Titanium–aluminide; B2-phase; Hot rolling; Texture; Phase transformation

1. Introduction

The discovery of the orthorhombic-phase (O-phase, based on Ti_2AlNb with *Cmcm* symmetry) in high Nb containing Ti_3Al intermetallic alloys by Banerjee et al. [1], followed by a patent by Rowe [2], had spurt the interest in understanding the processing–property relationship of these alloys in 1990s. Banerjee and his co-workers have thoroughly studied various aspects with regard to understanding the thermal and mechanical responses of Ti–aluminides based on the orthorhombic crystal structure [3–5]. It is now well-known that Nb addition, in excess to Ti_3Al based titanium–aluminides, stabilizes the β (B2)-phase in addition to the O-phase. One typical example of such alloys is Ti–22Al–25Nb (at.%) which undergoes phase transformation from the β-phase to the O-phase as well as the ordered transformation of the remaining β-phase portion to its ordered form B2 (based on Ti_2AlNb, with $Pm\bar{3}m$ symmetry).

Suitable processing of this alloy is well-known to produce a variety of microstructures with diverse properties and has been summarised in an extensive review by Banerjee [6]. However, an important aspect of the microstructural study, that is, crystallographic texture, is still missing in the literature. It is to be mentioned here that in order to tailor desired properties in such materials, there is a need to understand the processing–texture–microstructure relationship. An ambitious research program has, therefore, been developed to perform a comprehensive study on various aspects of texture evolution in two-phase (O+B2) alloys. The present paper deals with one such aspect, that is, the texture development in the high temperature β-phase due to processing in the β-phase-field. Such treatments are inevitably carried out during the preliminary stage of processing of such alloys, while transforming the cast structure to a wrought one. The texture developed in the β-phase has a strong influence on the texture of the 'O'-phase which is the final transformation product. In addition, the texture of the remnant β-phase in the microstructure can also influence the properties of the as-processed material.

In the present work, the evolution of texture and microstructure during hot rolling of the (O+B2) alloy Ti–22Al–25Nb in the β-phase-field has been studied. The temperature of rolling and the amount of reduction have been carefully selected so that the material remained in the β-phase-field throughout the deformation process and, at the same time, a qualitative variation in the microstructure can be tailored due to the differences in the amount of deformation. This is done by imparting 50% and 80% rolling reduction at 1100 °C. In order to nucleate a substantial amount of the 'O'-phase from these two deformed materials, the samples were furnace cooled to room temperature. Even so,

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this treatment leads to the retention of substantial amount of β (B2)-phase, which has been characterized in the present investigation. The texture of the 'O'-phase will be the subject for a separate paper.

2. Material and methods

As-received alloy with the nominal composition Ti–22Al–25Nb (at.%) in the form of a cast pancake was cut into rectangular pieces with dimensions 30 mm × 20 mm × 10 mm. These pieces were unidirectionally hot rolled to 50% and 80% reduction in thickness at 1100 °C in multiple passes followed by furnace cooling. The reduction in finish rolling pass was ∼20%. Small pieces were cut along the longitudinal direction and were subjected to microscopic characterization. For scanning electron microscopy (SEM), the samples were subjected to electrolytic polishing after conventional metallographic preparation. The texture was determined by electron backscatter diffraction (EBSD) method using a JEOL 6500-F field emission gun scanning electron microscopy. Several orientation maps were measured to cover the maximum area. The resulting inverse pole figures (IPFs) and orientation distribution functions (ODFs) were obtained from post treatments of these orientation maps using the HKL®Channel 5 software.

3. Results

Although the microstructure has been thoroughly studied with SEM in back-scattered mode, only the results obtained from EBSD will be given in the present study. The EBSD orientation imaging maps with their corresponding IPFs are given in Fig. 1(a–d) for the 50% and 80% hot rolled (HR) samples, respectively.

At room temperature, the microstructure of the β-phase in the 50% HR sample mainly consists of large deformed grains characterized by significant deformation gradients with a few small equiaxed grains mostly present at the grain boundaries of the large grains (Fig. 1(a)). On the other hand, the microstructure of the β-phase of the 80% HR sample consists of small β grains separated by high angle boundaries (Fig. 1(c)). The texture, as depicted by the IPFs, is characterized by a major ⟨1 1 1⟩||ND fibre, that spreads over ⟨1 1 2⟩||ND and ⟨0 0 1⟩||ND orientations for the 50% HR sample (Fig. 1(b)). Comparatively, it is clear that the texture has been modified in the 80% HR sample (Fig. 1(d)). For a more detailed idea of texture evolution, the corresponding ODFs have been calculated. As most of the important texture components and fibres belonging to the texture of a bcc material can be identified in the $\varphi_2 = 0°$ and 45° sections of the ODF [7,8] (see Fig. 2 for a recall), the ODFs are presented here in the same coordinates (Fig. 3) and the information obtained is summarised in Table 1.

4. Discussion

Both microstructure and texture are modified as the amount of rolling deformation is increased from 50% to 80%. The observed smoothening of texture with generation of smaller grains separated by high angle grain boundaries could be due to dynamic recrystallisation (DRX). Since a short term annealing was done between the successive passes of rolling (to compensate for a possible temperature drop), it could be argued that these small β grains do not result from DRX, but form by secondary recrystallisation during intermediate annealing. However, the microstructural feature supports DRX, as the materials were not subjected to any annealing after the final pass (20%

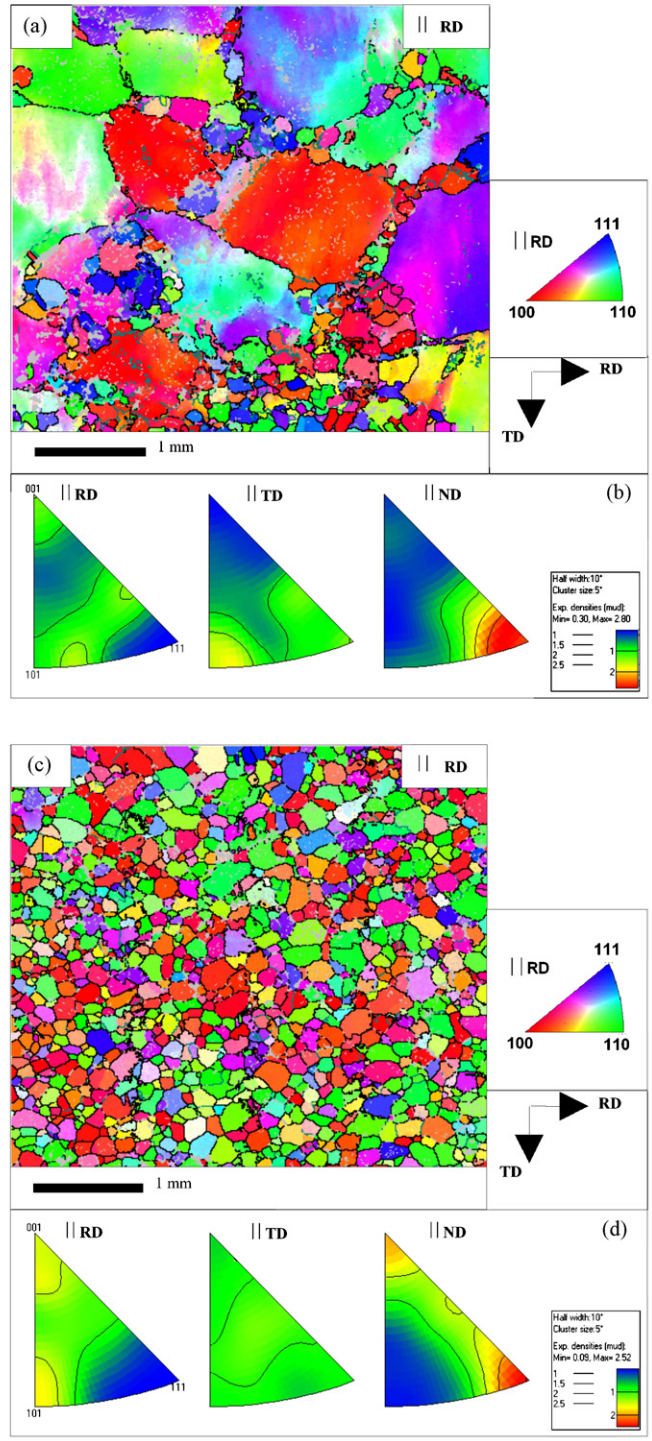

Fig. 1. Orientation maps of β-phase with their inverse pole figures for the 50% HR (a and b) and 80% HR Ti–22Al–25Nb (at.%) alloy (c and d).

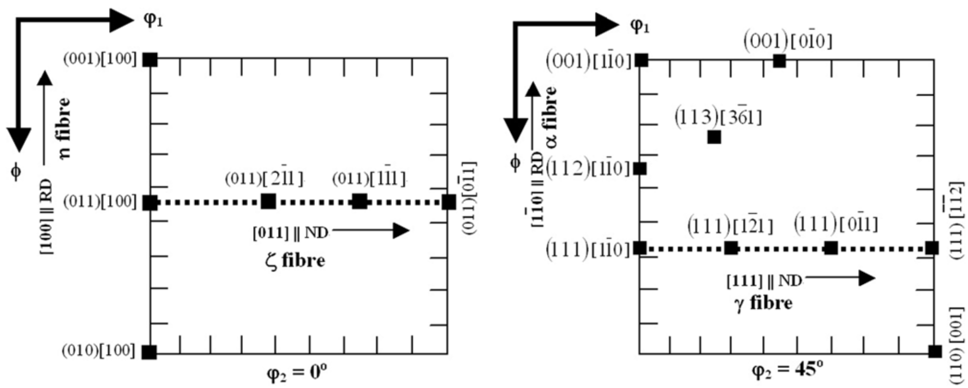

Fig. 2. Ideal rolling orientations for rolled bcc metals in the $\varphi_2 = 0°$ and 45° sections.

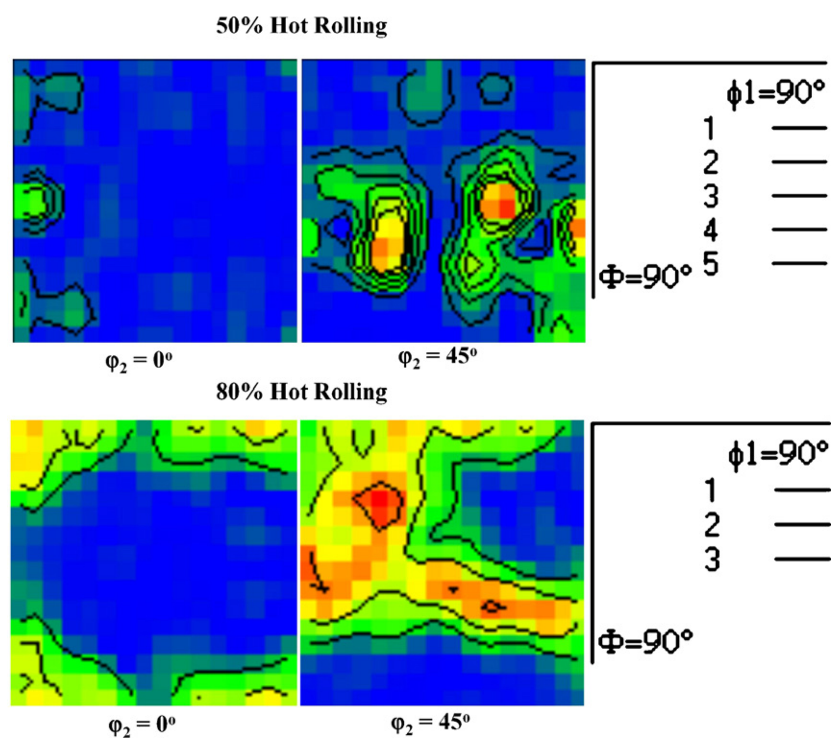

Fig. 3. ODF sections $\varphi_2 = 0°$ and 45° from the β-phase for the 50% and 80% HR materials.

rolling reduction) and still end up with equiaxed β grains. The microstructure of 50% HR sample at many locations consists of coarse β grains surrounded by fine β grains. The investigations on Ni_3Al [9] has revealed a similar necklace structure during DRX. Local orientation measurements revealed that with progressing DRX the orientation coherency of DRX grains with the matrix grains diminishes rapidly. This has the effect of reducing the strength of the texture by redistributing orientations in

Table 1
Summary of observation from the ODFs of the β hot rolled samples

50% Hot rolling	80% Hot rolling
Instead of a complete γ fibre, three of its components: (1 1 1)[1 $\bar{1}$ 0], (111)[1 $\bar{2}$ 1], (1 1 1)[$\bar{1}$ $\bar{1}$ 2]	Isotropic γ fibre of moderate intensity
Instead of a complete η fibre, three components:(0 0 1)[1 0 0], (0 1 1)[1 0 0], (0 1 0)[1 0 0]	Suppression of (0 1 1)[1 0 0] with slight increase in intensities of (0 0 1)[1 0 0] and (0 1 0)[1 0 0]
Presence of a weak (1 1 0)[0 0 1] component	(1 1 0)[0 0 1] component is totally eliminated
No significant recrystallisation texture components	A weak {0 0 1}⟨7 4 0⟩ and a sharper (1 1 3)[3 $\bar{6}$ 1] recrystallisation texture components

the Euler space. A similar phenomenon can be observed in our samples.

The most common cold rolling textures of bcc metals/alloys are α fibre ((0 0 1)[1 1 0] to (1 1 1)[1 $\bar{1}$ $\bar{0}$]) and γ fibre ((1 1 1)[1 $\bar{1}$ 0] to (1 1 1)[1 1 2]). The broken-up γ fibre in the 50% HR sample containing three strong texture components (1 1 1)[1 $\bar{1}$ 0], (1 1 1)[1 $\bar{2}$ 1] and (1 1 1)[$\bar{1}$ $\bar{1}$ 2] becomes an isotropic γ fibre with lesser intensity in the 80% HR sample. One could argue that only a part of the 50% HR sample was dynamically recrystallised with the rest of the microstructure consisting of recovered matrix that, thereby, retained the deformation texture components. It is to be mentioned also that no α fibre could be traced in both samples.

In the 50% HR sample, even the η fibre ($\varphi_2 = 0°$) is discontinuous, only three of its components (0 0 1)[1 0 0], (0 1 1)[1 0 0] and (0 1 0)[1 0 0] appear. The 80% HR sample shows complete elimination of (0 1 1)[1 0 0] component. Similarly, another texture component from the same orientation family, (1 1 0)[0 0 1] ($\varphi_2 = 45°$) is present in 50% HR sample but disappears after 80% hot rolling. Earlier, Suwas and Ray [8] carried out similar kind of hot rolling experiments in single β domain of ($\alpha_2 + \beta$) alloy Ti–24Al–11Nb (at.%). Many orientations found by them were also observed in the present alloy, for example ⟨1 1 2⟩||ND and ⟨0 0 1⟩||ND fibres. However, one of their observations was that {0 1 1}⟨1 0 0⟩ orientations increased with the increase in deformation level. This is in fact contrary to the present case where DRX takes place. Apart from elimination of certain texture components, the 80% HR sample shows two new orientations which were not inherited from 50% hot rolling, namely, {0 0 1}⟨7 4 0⟩ which is close to {0 0 1}⟨3 2 0⟩ and (1 1 3)[3 $\bar{6}$ 1] (see Figs. 2 and 3). These components are reported in the recrystallisation texture of bcc materials, for example, {0 0 1}⟨7 4 0⟩ in IF steel [10] and (1 1 3)[3 $\bar{6}$ 1] in Mo [11]. Park et al. [10], using the strain energy minimization model [12], explained the formation of these orientations in the recrystallisation texture. They proposed that the evolution of the {0 0 1}⟨7 4 0⟩ orientations in IF steel takes place by consumption of the {0 0 1}⟨1 1 0⟩ component during annealing. On the other hand, the (1 1 3)[3 $\bar{6}$ 1] component in recrystallisation texture of Mo was proposed to be due to conversion of the (112)[$\bar{1}$ 1 0] texture component by 20° rotation around [1 0 1] axis. This explanation holds too for the present experimental study of our alloys where the (1 1 2)[$\bar{1}$ 1 0] and the (1 1 3)[3 $\bar{6}$ 1] texture components are depicted.

5. Conclusions

Examination of crystallographic textures and microstructure developed in the β-phase of the Ti–22Al–25Nb (at.%) alloy as a result of hot rolling (50% and 80%) at 1100 °C (single β domain) leads to following conclusions:

(i) Supported by microstructure and texture results, it is understood that hot rolling to a deformation level equivalent to 50% reduction leads to a heavily recovered plus partially recrystallised microstructure. Thereby, the material retains a partial deformation fibre texture.

(ii) Comparatively, 80% HR deformation results in a dynamically recrystallised microstructure characterised by a finer grain size. The DRX process leads to the build-up of the (1 1 2)[$\bar{1}$ 1 0] and (1 1 3)[3 $\bar{6}$ 1] texture components.

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