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Improvement of room temperature ductility for Mo and Fe modified Ti_2AlNb alloy

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ABSTRACT

The effect of hot bar rolling and a subsequent annealing in the ($B2+\alpha_2$) two-phase region on the mechanical properties was investigated for the Ti–25Al–14Nb–2Mo–1Fe (mol%) orthorhombic phase base alloy. After this thermomechanical treatment in the ($B2+\alpha_2$) two-phase region, a 'Van Gogh's Sky (VGS)' structure, with wavy and curled bands of spherical α_2 precipitates, was obtained. Electron probe micro-analysis (EPMA) examinations indicated that the VGS bands correspond to the Nb and Mo lean regions. The width and spacing of VGS bands varied with thermomechanical treatment conditions (forging temperature before hot bar rolling as well as annealing temperature after the rolling). The samples with the VGS structure exhibited the higher tensile elongation-to-failure at room temperature. The creep resistance at 923 K decreased with the existence of the VGS structure. These mechanical properties were affected by the width and spacing of the VGS bands.

1. Introduction

Ti–Al–Nb alloy based on Ti_2AlNb intermetallic with the ordered orthorhombic phase (O phase) [1,2] offers a higher strength-to-weight ratio, better creep resistance, and better workability than conventional titanium aluminides such as TiAl-based and Ti_3Al-based alloys [3–7]. For these qualities, Ti_2AlNb-based alloys have attracted much attention as potential materials for advanced aerospace applications such as aircraft engine parts [6,7].

One prototypical alloy is a Ti–22Al–27Nb (mol%), which consists mainly of a (O + B2 (CsCl)) two-phase microstructure [3–5]. Ti–22Al–27Nb alloy shows well-balanced mechanical properties. For example, Rowe reported that the Ti–22Al–27Nb alloy solution treated at 1273 K followed by aging at 1033 K exhibits a high tensile strength (TS) of around 1080 MPa and tensile elongation of about 5% at room temperature, and TS of above 650 MPa and elongation of above 16% when tested at 1033 K [4].

One major drawback of Ti–22Al–27Nb alloy is its extremely high Nb content, which corresponds to around 45 mass% exceeding the Ti content. Nb as additional element has some problems such as high cost and high density. Efforts have been made to reduce the Nb content of Ti–22Al–27Nb alloy by substituting Nb with other alloying elements, such as W and Mo [8,9]. The present authors have found that multiple additions of Mo and Fe are effective to reduce Nb content and also to improve tensile and creep strength at elevated temperatures up to 923 K [10]. This Mo and Fe modified alloy, however, exhibits poor room temperature tensile elongation of less than 1%.

Reduction of the grain size of the prior B2 phase aids improvement of the room temperature elongation-to-failure of Ti_2AlNb alloys. We have succeeded in controlling and refining the prior B2 grain size of Ti–22Al–27Nb alloy processed by powder metallurgy using the pinning effect of α_2 ($D0_{19}$) particles homogeneously dispersed in the B2 matrix during hot bar rolling and subsequent annealing in the ($B2+\alpha_2$) two-phase region [11]. This fine-grained material with the average prior B2 grain size of 8 μm exhibited a room temperature tensile elongation of more than 15%.

In the present study, we have applied this thermomechanical treatment to the Mo and Fe modified alloy produced by levitation melting, and obtained a unique microstructure as shown in Fig. 1. Instead of a homogeneous distribution of the α_2 phase particles in the above-mentioned powder metallurgy Ti–22Al–27Nb alloy, the distribution was heterogeneous forming wavy and curly bands when viewed from the rolling direction in these samples. Similar microstructures have been observed by other researchers [12–15], especially in Nb-containing B2 phase-based alloys. They referred to this microstructure as 'Van Gogh's Sky (VGS)' structure because it resembles Van Gogh's sky paintings. It was also reported that Ti–Nb–Al and Ti–Zr–Nb–Al alloys with the VGS structure exhibited larger tensile elongation-to-failures at room temperature [13]. So it is expected that the room temperature tensile elongation-to-failure of Mo and Fe modified Ti_2AlNb alloys can be improved when processed into this VGS structure. Meanwhile, because Ti_2AlNb alloys are expected to be high-temperature materials, the high-

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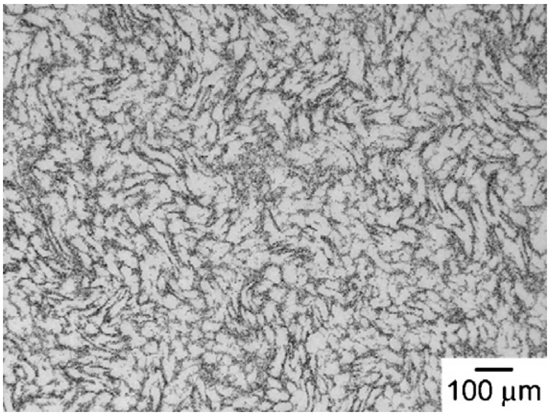

Fig. 1. Typical OM image of Ti–25Al–14Nb–2Mo–1Fe with Van Gogh's Sky microstructure. (Homogenized, hot forged, hot rolled and annealed at 1273 K followed by furnace cooling at 0.03 K/s.)

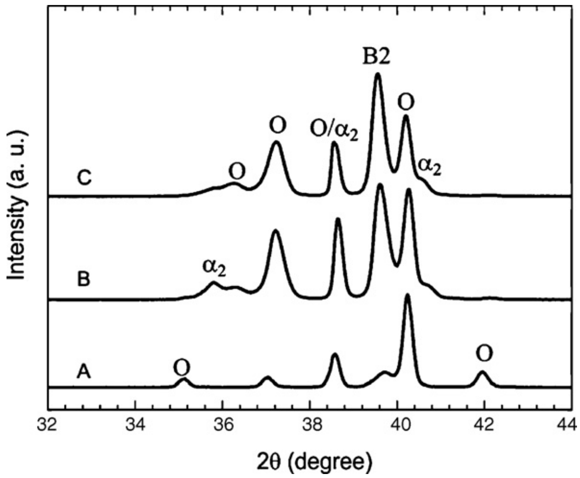

Fig. 3. X-ray diffraction profiles of Ti–25Al–14Nb–2Mo–1Fe with different processing conditions.

temperature mechanical properties such as creep resistance are also important. In the present study, we investigated the effect of the VGS structure on the room temperature tensile properties and the high-temperature creep properties of the Mo and Fe modified Ti_2AlNb alloy.

2. Experimental

The Ti–25Al–14Nb–2Mo–1Fe (mol%) alloy was prepared by the cold crucible levitation melting. Each ingot with around 70 mm diameter and around 60 mm length had a weight of around 1.2 kg. The ingots were hot forged and then hot rolled into 11.8 mm square bars followed by annealing for 3.6 ks. We have prepared samples with three different thermomechanical treatments. The thermomechanical treatments are schematically shown in Fig. 2. For the sample A, the ingot was hot forged, hot bar rolled and annealed at 1373 K in the B2 single phase region. For the samples B and C, the forged bar was hot bar rolled and annealed in the $(B2 + \alpha_2)$ two-phase region. The difference between samples B and C was the forging temperature before the hot bar rolling. For sample B, all steps of the thermomechanical treatment were performed at 1273 K in the $(B2 + \alpha_2)$ two-phase region. For sample C, the forging was performed at 1523 K in the B2 single phase region, followed by bar rolling at 1273 K. The annealing temperature for sample C was 1293 K, which is 20 K higher than that for sample B but both are in the $(B2 + \alpha_2)$ two-phase region. In all the treatments, the hot bar rolling was performed for 16 passes, and the samples were reheated after every pass. For evaluating the microstructure and mechanical properties, the annealed materials were all furnace-cooled (cooling rate: 0.03 K/s) to room temperature and then aged at 1073 K in the (O + B2) two-phase region for 360 ks followed by air-cooling to stabilize the microstructure.

The phase identification was made by an X-ray diffraction (XRD) analysis using a Cu-Kα radiation operated at 40 kV–300 mA. X-ray profiles were taken on the planes normal to the rolling direction (RD plane, as shown in Fig. 2). Microstructural observations were performed on an optical microscope (OM) and a scanning electron

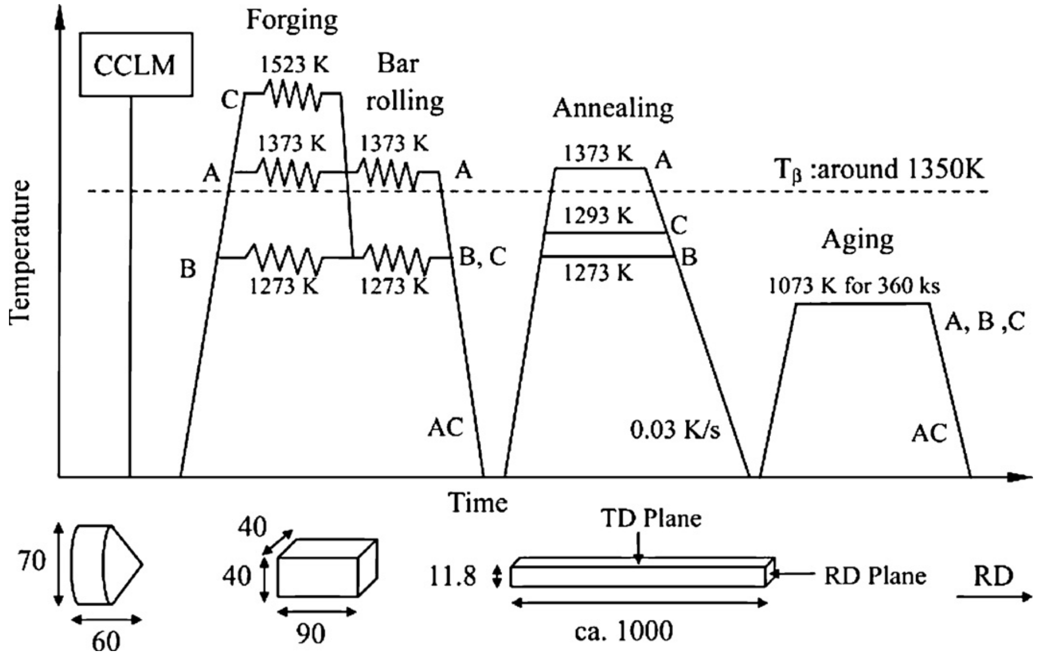

Fig. 2. A schematic drawing of the thermomechanical treatment for Ti–25Al–14Nb–2Mo–1Fe. CCLM, AC, TD and RD refer to cold crucible levitation melting, air-cooling, transverse direction and rolling direction, respectively.