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Designed bimodal size lamellar O microstructures in Ti_2AlNb based alloy: Microstructural evolution, tensile and creep properties

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ABSTRACT

Microstructure evolution, tensile and creep properties of designing bimodal size lamellar O phases by thermo-mechanical processing including conventional forging, isothermal forging process and heat treatment for Ti–22Al–25Nb (at%) orthorhombic alloy were investigated. The microstructures were obtained by different solution- and age-treatment temperatures, and analyzed by the BSE technique. The creep behavior of the alloy was studied at 650 °C/150 MPa for 100 h in air. The tensile strength of the alloy at room temperature and 650 °C was also investigated. The experimental results showed that the microstructure of the isothermally forged alloys at 1080 °C contained the non-uniform distribution of lamellar O phases and B2 matrix. The advantage of the bimodal lamellar size distributed alloy can be concluded that firstly, the coarse lamellar O formed during solution process makes the alloy owns good elongation and secondly, the fine lamellar O precipitate during the aging process strengthens the alloy. The volume fraction and mean thickness of the lamellar O could be well controlled by the heat treatment. The yield strength was sensitive to the thickness of lamellar O, increase in the aging temperature leads to a decrease in strength and an increase in ductility. The relationship between creep resistance of alloys and microstructural features, such as the volume fraction of each phases, the morphology of lamellar O phases was also discussed.

1. Introduction

Recently, a new class of titanium intermetallic alloys, based on the orthorhombic Ti_2AlNb phase, has been receiving attention as potential materials for aircraft engine applications due to their high strength-to-weight ratio, greater fracture toughness, and better workability than conventional intermetallic alloys such as TiAl-based and Ti_3Al-based alloys [1–4]. A typical orthorhombic alloy is Ti–22Al–25Nb (at%), in which a high-temperature B2 phase was incorporated in the alloy's constitution to further improve ductility and fracture toughness. The alloys, which primarily consists of an O+B2 two-phase microstructure, is said to have the optimum combination of strength, creep, and fracture toughness properties [5–7].

The microstructure of Ti_2AlNb based alloys can be varied in a wide range depending on processing methods and subsequent heat treatments [8]. Similar to conventional titanium alloys, equiaxed, and duplex, near lamellar and fully lamellar microstructures can be obtained by appropriate thermo-mechanical processing (TMP) and heat treatment [9]. A duplex microstructure of Ti_2AlNb based alloys shows good ductility and strength at both low and high temperatures, but poor fracture toughness and creep resistance. In contrast, a fully lamellar microstructure provides good creep resistance and fracture toughness, but shows low ductility at room temperature [10]. Especially, the high creep resistance makes these alloys very interesting for high temperature structural parts. For practical application of Ti_2AlNb alloys, their ductility, toughness, and strength have to be optimized by means of appropriate microstructural design. The microstructural design requires detailed knowledge of the relationship between microstructure and mechanical properties. As a compromise, so-called designed bimodal size lamellar O microstructures were proposed which offers a good balance between the mechanical properties of both the duplex and the fully lamellar microstructure [11].

In the present work, the relationship between TMP and the mechanical property for Ti–22Al–25Nb alloys was studied. The parameters of TMP including isothermal forging, solution- and age-treatment temperature for obtaining better mechanical properties were identified, and the microstructural characteristics for different O phases were revealed. This information will be beneficial to practical production of high performance Ti–22Al–25Nb alloys.

2. Materials and experiments

The Ti–22Al–25Nb bar was provided by Central Iron and Steel Research Institute (CISRI) with a dimension of $\Phi 240 \times 360$ mm. The chemical analysis is shown in Table 1, it can be seen that the

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bar composition was in agreement with nominal composition, and the gas impurity contents were lower (e.g., oxygen ≤ 500 ppm, hydrogen ≤ 300 ppm and nitrogen ≤ 800 ppm). The microstructure of the Ti–22Al–25Nb bar can be seen in Fig. 1(a). The microstructure contained B2 matrix, equiaxed α_2/O particles, and lamellar O. The equiaxed α_2/O particles consisted of α_2 particle and rim-O (Fig. 1(b)) which was formed by the peritectoid reaction of α_2 phase and B2 matrix. The pinning effect of the equiaxed particles is beneficial for restraining the B2 grain growth. The B2 grain size of the Ti–22Al–25Nb bar after eight deformation times is measured to be 38 μm in averaged. The lamellar O (Fig. 1(b)) was precipitated during cooling process after forging.

In order to obtain fully lamellar O phases and enhance the mechanical properties of alloys, the isothermal forging processing in 1080 °C (B2 phase region) is adopted. The heat-treatment experimental specimens of 14 mm × 14 mm × 12 mm were machined along the compression axis on the low-speed wire electrical discharge machine (WEDM). In order to investigate microstructural evolution of alloys, the specimens were solution-treated between 920 °C and 1000 °C at intervals of 20 °C for 1 h followed by water quenching (WQ), and aged between 760 °C and 840 °C at intervals of 20 °C for 12 h followed by air cooling (AC). The alloys after isothermal forging were solution-treated at 940 °C for 1 h followed by water quenching (WQ) and then age-treated at 760 °C, 800 °C and 840 °C for 12 h by air cooling (AC) to study the creep and tensile properties.

To investigate the microstructural evolution, the samples isothermal forged, solution- and age-treated were characterized using the BSE (back scattered electron) mode in SEM (scanning electron microscope). The specimens for SEM were prepared by standard metallographic techniques. The phase structural analysis was performed by X-ray diffraction (XRD). Diffraction utilized Cu Kα radiation in the angular range of $2\theta = 20–90°$ at a recording rate of 2 °/min. The finer microstructure details of the alloys before and after creep deformation were carried out in a JEM-200CX transmission electron microscopy (TEM). The TEM samples were prepared by the following steps. Firstly, the samples were cut from the alloys after heat treatment state and creep deformation. Then, they were thinned down to 30–50 μm by polishing with SiC paper. Finally, they were punched to 3 mm disc samples. The electrochemical polishing is the final stage of thinning in a solution of 6% perchloric acid, 34% n-butanol and 60% carbinol at −30 °C with an applied current of 70 mA and a voltage of 30 V.

Fig. 2(a) shows the cylindrical tensile specimens. Fig. 2(b) shows the cylindrical creep specimens. The creep specimens with a gauge diameter of 5 mm and length of 70 mm were machined after heat treatment. Creep testing was conducted in air using RD testing machine. The testing temperature was 650 °C. The applied stress was 150 MPa. The creep time was 100 h. The temperature fluctuations were less than ±2 °C. The tensile samples were 12 mm in diameter and 70 mm in gauge length. The tensile tests were carried out in air at room temperature using an Instron 1185 mechanical testing machine. The high temperature tension experiments were performed at 650 °C using a MTS mechanical testing machine.

Table 1
Chemical composition of the Ti–22Al–25Nb alloy (at%) (the true chemical composition of the alloy was measured with a chemical analysis method, which was Ti–10.8Al–43.0Nb–0.050O–0.007C–0.005N–0.004H in weight percent (wt%)).

Ti	Al	Nb	O	N	H
Bal	22.3	25.7	0.00043	0.000052	0.000009

3. Results and discussion

3.1. Investigation of bimodal lamellar size distribution

The microstructure of the isothermally forged alloys at 1080 °C is shown in Fig. 3. It can be seen from the XRD analysis results (Fig. 3(a)), the alloys contained O phase and B2 matrix. In BSD image, the black equiaxed particles are α_2 phases, the gray regions are O phases, and light regions are B2 phases. Lamellar O phases and B2 matrix could be seen in Fig. 3(b). A very small amount of lamellar α_2 phases are also presented in Fig. 3(b). The diffraction peak of the α_2 phase is very weak, so it is very difficult to detect the α_2 phases in Fig. 3(a). The α_2 and lamellar O-phases were formed during the gradual air

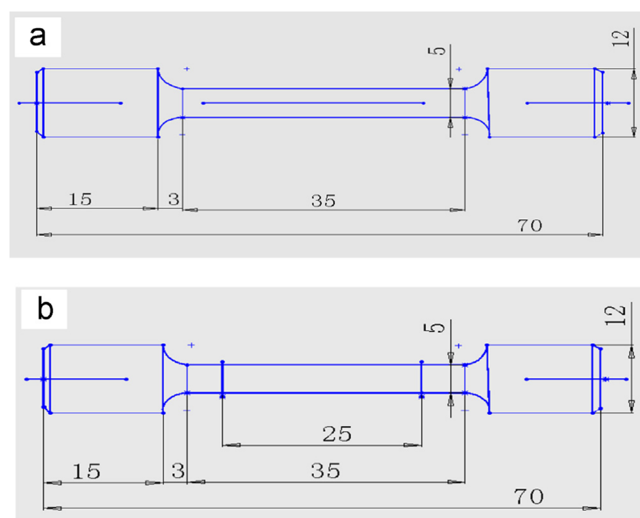

Fig. 2. Geometry and dimensions of tensile (a) and creep (b) testing specimens

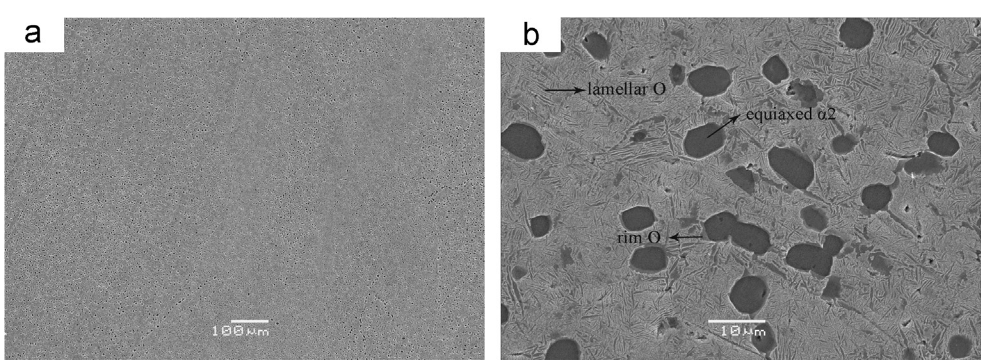

Fig. 1. Microstructure of the as-forged alloy (a) macro-microstructure; (b) microstructure at higher magnification (the black equiaxed particles are α_2 phases, the gray regions are *O* phases, and light regions are B2 phases).