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Dynamic globularization kinetics of a powder metallurgy Ti–22Al–25Nb alloy with initial lamellar microstructure during hot compression

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ABSTRACT

The flow behavior of a powder metallurgy (P/M) Ti–22Al–25Nb alloy was evaluated during hot compression at temperature range of 950–1070 °C and strain rate range of 0.001–1 s^{-1}. The dynamic globularization kinetics at elevated temperature was quantitatively characterized and investigated. The results showed that the dynamic globularization kinetics and kinetics rate were sensitive to deformation conditions. The variation of globularization fraction with strain approximately followed an Avrami type equation. It can be found that the process of dynamic globularization was promoted by decreasing strain rate and increasing deformation temperature. Moreover, the critical strain (ε_c) for the onset of dynamic globularization and the completed strain (ε_f) for the full dynamic globularization were predicted to be 0.094–0.198 and 1.082–2.113, respectively. The kinetics rate of dynamic globularization firstly increased severely to a peak value at a strain corresponded to 12.7–26.7% globularization fraction, and then decreased sharply with increasing strain. It was revealed that the peak value of kinetics rate increased with increasing temperature and decreasing strain rate. Furthermore, the microstructure examination was conducted by applying optical microscope (OM), scanning electron microscope (SEM) and electron backscattered diffraction (EBSD) techniques. The results exhibited a good agreement with the predicted dynamic globularization kinetics model.

1. Introduction

Ever since the discovery of the ordered orthorhombic Ti_2AlNb (O) phase in a Ti–25Al–12.5Nb (at.%) alloy by Banerjee et al. [1], Ti_2AlNb-based alloys have been of great interest as potential high-temperature structural materials used in advanced aerospace applications because of their attractive properties, such as high strength-to-weight ratio and good workability [2–4]. The phase structure of Ti_2AlNb-based alloy is different from the conventional Ti alloy. It includes ordered orthorhombic O phase, ordered hexagonal intermetallic α_2 phase, and ordered B2 phase [5–8]. Ti–22Al–25Nb (at.%) alloy is an important member in Ti_2AlNb-based alloys [9,10], which has excellent potential to be applied in engineering practice due to its good mechanical properties both at room and elevated temperatures[11,12].

The mechanical properties of Ti_2AlNb-based alloy are strongly influenced by its microstructure [13]. And this alloy exhibits two different types of microstructures for the precipitates [14]. The first type consists solely of lamellar precipitates of the O phase distributed in B2 grains. And the second type consists of a combination of equiaxed and lamellar precipitates dispersed in B2 matrix. The existence of the equiaxed particles significantly plays an important role for improving the ductility of this alloy [4]. The lamellar O phase associated with Ti_2AlNb-based alloy has been found to break up or globularize during deformation at elevated temperature [15]. Globularization process plays a key role to the acquirement of desired microstructure for final forming. Because of its great technological importance, the globularization process has received considerable attentions. Several studies have been carried out on dynamic globularization kinetics of two-phase titanium alloys [16–19]. Shell and Semiatin [16] studied the effect of initial microstructure on dynamic globularization of Ti–6Al–4V alloy with colony α structure. The strains required for initiation and completion of dynamic globularization were obtained. Semiatin et al. [17] investigated the dynamic globularization kinetics of Ti–6Al–2Sn–4Zr–2Mo–0.1Si alloy during uniaxial compression. And the detailed relationships between thermal-mechanical processing parameters and resulting microstructures for this alloy were established. The dynamic globularization of Ti-17 alloy with initial

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lamellar microstructure had been quantitatively characterized and investigated using isothermal hot compression tests by Wang et al. [18]. They demonstrated that the dynamic globularization kinetics and kinetics rate were sensitive to deformation conditions. Ma et al. [19] investigated the dynamic globularization kinetics of BT25 alloy during deformation at temperature range of 940–1000 °C and strain rate range of 0.01–10 s^{-1}, and found that the globularization process was restricted by the migration rate of intraphase boundary. However, most of the previous researches have focused on the kinetics of dynamic globularization for two-phase titanium alloys, but that on Ti–22Al–25Nb alloy are few reported, especially for powder metallurgy (P/M) Ti–22Al–25Nb alloy.

In the present work, the aim is to investigate the hot deformation behavior and dynamic globularization kinetics of a P/M Ti–22Al–25Nb alloy with initial lamellar microstructure by applying the isothermal compression tests at different deformation temperatures and strain rates. The kinetics model of dynamic globularization for the hot deformed P/M Ti–22Al–25Nb alloy was established to predict the strains for initiation and completion of dynamic globularization. In addition, the optimum processing parameters were determined within experimental conditions corresponding to the significant globularization.

2. Materials and experimental

P/M Ti–22Al–25Nb alloy billets used in this investigation were prepared by vacuum hot pressed sintering (VHPS) from pre-alloyed powders at 1050 °C under a pressure of 35 MPa for 1 h followed by furnace cooling. The pre-alloyed powders with a nominal composition of Ti–22Al–25Nb (at.%) obtained by argon gas atomization were provided by Research Institute of Aerospace Special Material and Technology, China Aerospace Science and Industry Corporation. Table 1 shows the chemical composition (at.%) of pre-alloyed powders. It can be found that the pre-alloyed powders are in good agreement with the nominal composition.

Cylindrical specimens with 6 mm in diameter and 9 mm in height were cut from the hot pressed billets using electro-discharge machining (EDM). The axial of cylindrical compression specimens is parallel to the hot pressing direction. The isothermal compression tests were conducted on a Gleeble-1500 thermal simulator in a temperature range of 950–1070 °C and a strain rate range of 0.001–1 s^{-1}. Specimens were resistance heated to the test temperatures at a heating speed of 10 °C/s, held isothermally for 3 min, and then uniaxially compressed to a height reduction range of 20–70% at a given strain rate. After hot compression deformation, all specimens were water-quenched immediately to preserve the hot-deformed microstructure. The deformed specimens were cut along the longitudinal compression axis for microstructure examination by applying optical microscope (OM), scanning electron microscope (SEM) and electron backscattered diffraction (EBSD) techniques. Specimens for OM and SEM microstructure observation were carried out by using standard procedures, and then chemically etched with a Kroll solution (1 ml HF:3 ml HNO_3:10 ml H_2O). EBSD specimens were prepared by standard mechanical polishing and twinjet polishing at −40 °C with a solution of $HClO_4$, N-butanol and methanol. Due to the inhomogeneous deformation and non-uniform strain distribution in the compressed specimens, finite element method (FEM) analysis was adopted to provide a relatively good estimate of local strains for microstructure analysis. Globularization behavior of α_2/O lamellae was then quantified using moderate magnification SEM by a quantitative metallographic image analysis system (Image-pro plus) considering α_2/O phases with the aspect ratio (length/width) lower than 2.5 as a globular.

3. Results and discussion

3.1. Initial microstructure and phases

The initial microstructure and XRD patterns of hot pressed billets are exhibited in Fig. 1. The backscattered electron (BSE) image (Fig. 1(a)) shows that the billets consist of the (O + B2) two-phase lamellar microstructure, with a large number of lamellar O phases participated in the prior B2 grains. Some α_2 phase also exists mainly along the prior B2 grain boundaries (Fig. 1(b)). The average size of B2 grains is approximately 218 μm.

Table 1
The chemical composition (at.%) of pre-alloyed powders.

Ti	Al	Nb	O	N	H
Bal.	22.37	24.70	430×10^{-4}	52×10^{-4}	9×10^{-4}

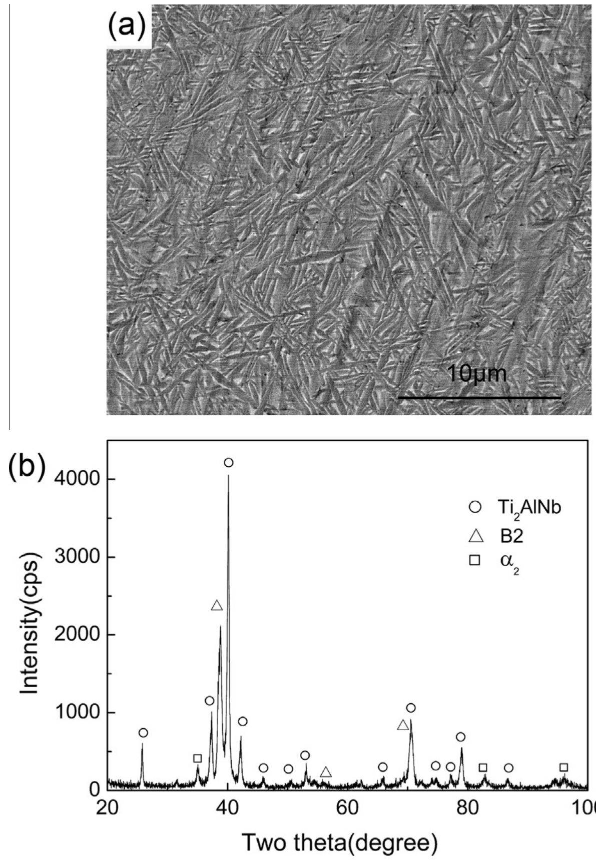

Fig. 1. BSE image and XRD patterns of hot pressed billets: (a) initial microstructure and (b) XRD patterns.

3.2. Flow behavior

The true stress-true strain curves of the P/M Ti–22Al–25Nb alloy obtained under various compression deformation conditions can be classified into two types, discontinuous yielding and dynamic recrystallization (DRX), which are shown in Fig. 2. Typical feature of discontinuous yielding type flow curve is characterized

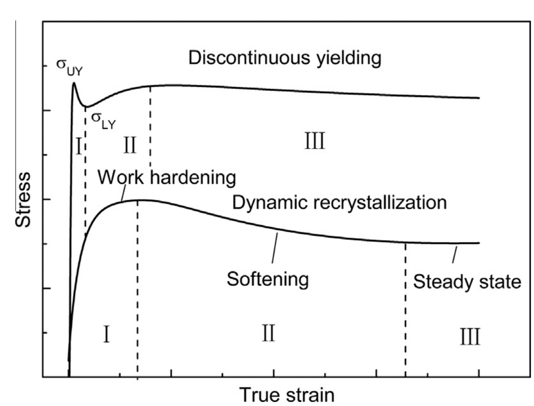

Fig. 2. Typical flow curves obtained under various compression deformation conditions.