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Microstructure evolution and dynamic recrystallization behavior of a powder metallurgy Ti-22Al-25Nb alloy during hot compression

Jianbo Jia [a,b], Yue Yang [a], Yan Xu [a,b,*], Bo Xu [c], Junting Luo [a,b], Kaifeng Zhang [d]

[a] Education Ministry Key Laboratory of Advanced Forging & Stamping Technology and Science, Yanshan University, Qinhuangdao 066004, China
[b] State Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, China
[c] Institute of Petrochemistry Heilongjiang Academy of Sciences, Harbin 150040,
[d] National Key Laboratory for Precision Hot Processing of Metals, Harbin Institute of Technology, Harbin 150001, China

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A B S T R A C T

The flow behavior of a powder metallurgy (P/M) Ti-22Al-25Nb alloy during hot compression tests has been investigated at a strain rate of 0.01 s^{-1} and a temperature range of 980–1100 °C up to various true strains from 0.1 to 0.9. The effects of deformation temperature and strain on microstructure characterization and nucleation mechanisms of dynamic recrystallization (DRX) were assessed by means of Optical microscope (OM), electron backscatter diffraction (EBSD) and transmission electron microscope (TEM) techniques, respectively. The results indicated that the process of DRX was promoted by increasing deformation temperature and strain. By regression analysis, a power exponent relationship between peak stresses and sizes of stable DRX grains was developed. In addition, it is suggested that the discontinuous dynamic recrystallization (DDRX) and continuous dynamic recrystallization (CDRX) controlled nucleation mechanisms for DRX grains operated simultaneously during the whole hot process, and which played the leading role varied with hot process parameters of temperature and strain. It was further demonstrated that the CDRX featured by progressive subgrain rotation was weakened by elevating deformation temperatures.

1. Introduction

Based on the ordered orthorhombic Ti_2AlNb phase, Ti_2AlNb-based alloys are of considerable attention as potential high-temperature structural materials due to their attractive properties, such as higher strength-to-density ratio, better creep resistance and better workability [1–3]. As a second generation Ti_2AlNb-based alloy, Ti-22Al-25Nb (at.%) alloy possesses good mechanical properties at elevated temperatures [4,5], which is considered to be an excellent potential structural material in engineering application [6,7]. However, limited plastic formability of Ti_2AlNb-based alloys at room temperature has seriously limited its practical application. Therefore, the secondary plastic processing at elevated temperature is necessary to refine the grain size and improve the mechanical properties of materials. During hot deformation, dynamic recrystallization (DRX) can play a critical role in microstructural refinement and strain hardening reduction [8,9], which is beneficial to obtain fine-grained structural components with high mechanical properties [10,11]. Generally, there exist two type nucleation mechanisms of DRX during hot deformation. And a DRX nucleation behavior is ordinarily operated by the two mechanisms, with one as the dominant reason, for a certain strained materials [12,13]. One is the discontinuous dynamic recrystallization (DDRX) promoted by bulging of grain boundaries [14], and the other is the continuous dynamic recrystallization (CDRX) dominated by progressive subgrain rotation [15]. It is generally known that the evolution of dynamic recrystallized microstructure and nucleation mechanisms depend on hot deformation temperature and strain [16,17]. Therefore, it is significant and meaningful to systematically investigate the microstructure characterization and nucleation mechanisms of DRX for the powder metallurgy (P/M) Ti-22Al-25Nb under different hot deformation conditions. Unfortunately, relevant researches were seldom carried out, especially for the P/M Ti-22Al-25Nb alloy.

The present paper aims at studying the evolution of DRX microstructure during hot compression with deformation temperature and strain for the P/M Ti-22Al-25Nb alloy, and clarifying the nucleation mechanisms of DRX. Furthermore, the development of DRX under different hot deformation conditions was also systematically investigated by referring to the grain boundary misorientations.

2. Materials and Experimental

The spherical pre-alloyed powders of Ti-22Al-25Nb (at.%) alloy was adopted in this study, which were produced by argon atomization. The chemical composition (at.%) of the pre-alloyed powders is as follows: Al,

* Corresponding author at: Education Ministry Key Laboratory of Advanced Forging & Stamping Technology and Science, Yanshan University, Qinhuangdao 066004, China.
E-mail address: xuyan_916@163.com (Y. Xu).

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22.37; Nb, 24.70; O, 430 × 10^{-4}; N, 52 × 10^{-4}; H, 9 × 10^{-4}; Bal., Ti. The P/M Ti-22Al-25Nb (at.%) billet was firstly prepared by hot pressing sintering at 1050 °C and 35 MPa pressure for 60 min in high vacuum followed by furnace cooling. Then, hot compression specimens with dimensions of Φ6mm × 9 mm were spark machined from the P/M Ti-22Al-25Nb billet. The direction of the hot pressing is parallel to the axis of cylindrical compression specimens. Hot compression tests were carried out on a Gleeble-1500 thermal simulator at temperatures of 980–1100 °C with 30 °C intervals and strain rate of 0.01 s^{-1} to different true strains range of 0.1–0.9. All the hot compression specimens were heated to the preset deformation temperatures with a rate of 10 °C/s, and then kept isothermally for 3 min to homogenize the temperature. All the compressed specimens were water quenched immediately to room temperature and cut along the longitudinal compression axis for microstructure observation. The cut surface was firstly treated by rough grinded and mechanically polished, and then chemically etched with a Kroll solution (1 ml HF: 3 ml HNO_3:10 ml H_2O) for optical microscope (OM) examination. Samples for transmission electron microscope (TEM) examination were firstly prepared by mechanically grinding to about 80 μm thickness foils, and then thinned by twinjet polishing at −40 °C with a solution of $HClO_4$, N-butanol and methanol. The specimens for electron backscattered diffraction (EBSD) analysis were prepared by standard mechanical polishing and electropolished with a solution of $HClO_4$, N-butanol and methanol.

3. Results and Discussion

3.1. Initial Microstructure and Phases

The initial microstructure and the phases characterized by XRD of the P/M Ti-22Al-25Nb alloy are exhibited in Fig. 1(a) and Fig. 1(b), respectively. The SEM image (Fig. 1(a)) demonstrates that the initial microstructure is mainly comprised of B2 and lamellar O (Ti_2AlNb) phases. Meanwhile, a small amount of α_2 phases also exist (Fig. 1(b)), which mainly distribute along B2 grain boundaries (Fig. 1(a)).

3.2. True Stress-true Strain Curves

The true stress-true strain curves of the P/M Ti-22Al-25Nb alloy obtained at a strain rate of 0.01 s^{-1} with various compression temperatures are presented in Fig. 2. It can be obviously revealed from this figure that the flow stress increases significantly with the decreasing temperatures. In addition, each of the flow stress curve exhibits a

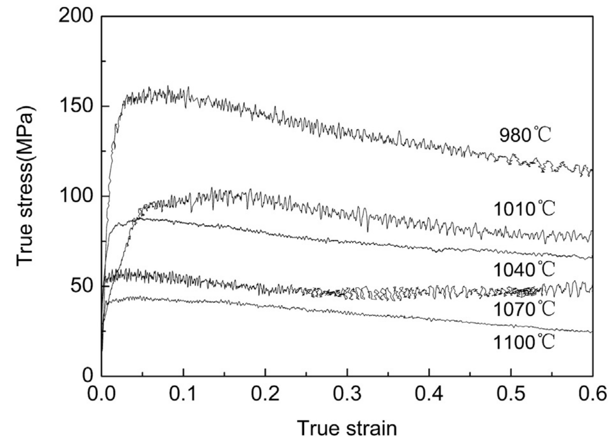

Fig. 2. True stress- strain curves for the P/M Ti-22Al-25Nb alloy at various temperatures with a strain rate of 0.01 s^{-1}.

prominent work hardening to a single stress peak followed by a flow softening stage and then sometimes reaches a steady-state flow at higher strain. It is generally accepted the fact that the flow softening behavior during hot deformation may be caused by DRX, lamellar globularization or adiabatic heating [18–20]. In order to further clarify the softening behavior, the microstructure of hot compressed specimens were investigated and shown in Fig. 3. It can be indicated that the deformed specimens exhibit fine DRX structure at temperatures range of 1010–1070 °C (Fig. 3(b–d)). In addition to the metallography, the occurrence of DRX can also be indicated by the inflection point in plots of work hardening rate (θ) versus stress (σ) [21–23]. The θ-σ curves analysis have been conducted to predict the onset of DRX for the P/M Ti-22Al-25Nb alloy under different deformation conditions in the authors' previous work [24]. And the DRX parameters such as the critical strain (ε_c), the maximum softening rate (ε^*) and the critical stress (σ_c) under different deformation conditions were deduced. The values of ε_c at 1010 °C/0.01 s^{-1}, 1040 °C/0.01 s^{-1} and 1070 °C/0.01 s^{-1} are determined to be 0.074, 0.026 and 0.022, respectively. Therefore, DRX process has already initiated when the specimens deformed at a true strain of 0.7 larger than the value of their critical strain, which is consistent with the metallographic results in Fig. 3(b)–(d). Meanwhile, as can be seen from Fig. 3(a), the microstructure deformed at 980/0.01 s^{-1} is featured by lamellar dynamic globularization. Lamellar globularization can offer a steady flow by simultaneously softening

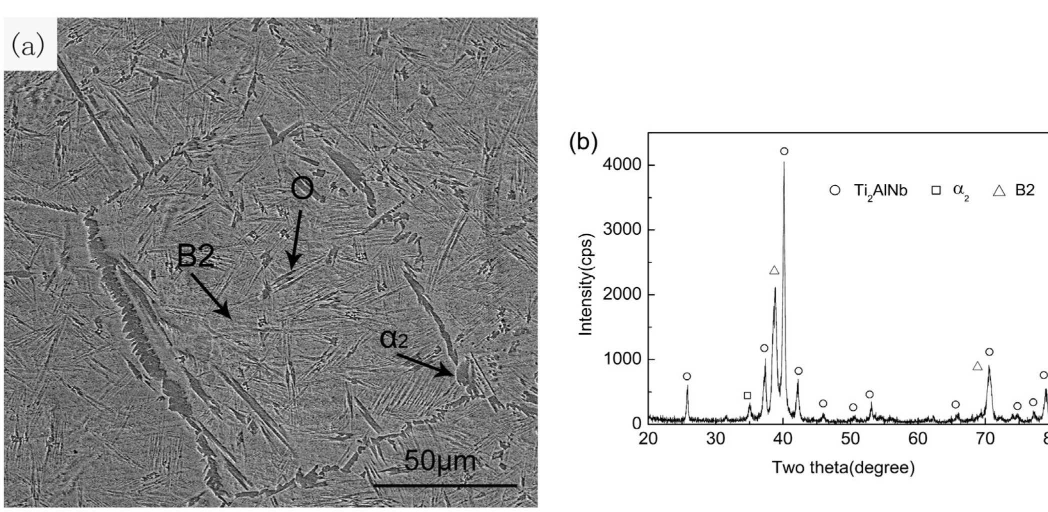

Fig. 1. SEM image and XRD patterns of the P/M Ti-22Al-25Nb alloy: (a) initial microstructure and (b) XRD patterns.