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Constitutive modeling and processing map for elevated temperature flow behaviors of a powder metallurgy titanium aluminide alloy

W. Zhang[a,*], Y. Liu[a], H.Z. Li[b], Z. Li[b], H. Wang[a], B. Liu[a]

[a] *State Key Lab of Powder Metallurgy, Central South University, Changsha 410083, Hunan, PR China*
[b] *School of Materials Science and Engineering, Central South University, Changsha 410083, PR China*

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ABSTRACT

The flow behaviors of PM titanium aluminide alloy were studied by isothermal compression simulation test. The apparent activation energy of deformation was calculated to be 313.53 kJ mol^{-1} and a constitutive equation had been established to describe the flow behavior. Processing map was developed at a strain of 0.7. With an increase of strain, two domains can be found: dynamic recrystallization and superplastic deformation, which are further confirmed by microstructural observations. The dynamic recrystallization occurs extensively at 1000 °C and 10^{-3} s^{-1}, with a peak efficiency of 50%, and the superplastic deformation occurs at 1100 °C and 10^{-3} s^{-1}, with a peak efficiency of 60%. At a strain rate higher than 10^{-1} s^{-1}, the alloy exhibits flow instability.

1. Introduction

TiAl-based alloys are considered for applications in high-temperature structures for their low density, high strength-to-weight ratio, high stiffness and high strength at elevated temperatures compared with conventional Ti alloys. As reported by Das et al. (2004), TiAl sheets have wide applications such as exhaust nozzle components, back structures of scramjets for space applications, heat shields for helicopters, and thermal protection systems for reusable launch vehicles. Several methods have been developed for fabricating TiAl sheets, including ingot metallurgy (IM) and powder metallurgy (PM) routes. Semiatin et al. (1997) proposed that the coarse and inhomogeneous original microstructure and low yield are key problems for the IM rolling process. The large amount of thermo-mechanical treatment required for microstructural refinement makes the sheet processing very expensive. Das et al. (2003) concluded that the use of PM plate as a starting material for the rolling process leads to a reduction of the aforementioned problems. PM TiAl alloys usually have a finer microstructure than cast TiAl, and thus, having a low flow stress in hot rolling. By using near-net shaping technology, for example, hot isostatically pressing (HIP), by which large-sized plate materials can be fabricated, and are usefully for making large sheets.

PM processing involves HIP of alloy powders followed by a multi-stepped rolling under near isothermal conditions in the $\alpha + \gamma$ phase field. After rolling, the sheet is decanned and subjected to a thermal treatment for reduction of internal stresses. The resulting sheet has a homogenous microstructure and uniform properties. The understanding of deformation behavior of PM TiAl alloy has a great importance for designing hot rolling process. The precise control of hot deformation parameters is required to develop the optimal microstructure and properties. But only a limited number of studies have been performed on hot workability of PM TiAl alloys: Nieh et al. (1999) studied superplastic deformation behavior of a powder metallurgy TiAl alloy with a metastable microstructure; Wegmann et al. (2002) examined high temperature mechanical properties of hot isostatically pressed and forged gamma titanium aluminide alloy powder; Gerling et al. (2004) analyzed the structural characterization and tensile properties of a high niobium containing gamma TiAl sheet obtained by powder metallurgical processing. Because the flow behavior during hot working is often complex, and the hardening and softening mechanisms are both significantly affected by the temperature and strain rate as demonstrated by Berbenni et al. (2007).

This paper aims to discuss the nature of hot deformation behavior of PM TiAl alloy by hot compression tests. The optimum processing parameters will be given according to processing maps of energy dissipation efficiency.

2. Experimental

TiAl alloy powder with a nominal composition of Ti–47Al–2Cr–0.2Mo (at.%) was produced by plasma rotating electrode process (PREP). Alloy powder of particle size 100–150 μm was filled

* Corresponding author. Tel.: +86 731 8830406; fax: +86 731 8710855.
E-mail address: w.zh.csu@gmail.com (W. Zhang).

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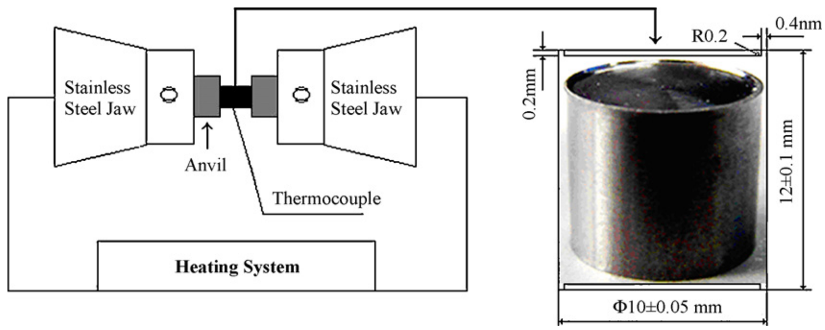

Fig. 1. Schematic presentation of thermal simulation unit and initial specimen.

into steel can and degassed at 400 °C, then HIPed at 1200 °C, 140 MPa for 4 h. Cylindrical compacts with the dimensions of approximately Φ50 mm × 100 mm and high relative density of more than 99.6% were obtained. Pieces with a diameter of 10 mm and a height of 12 mm were cut by electric-discharge. To entrap the lubricant, the ends of the specimens were recessed to a depth of 0.2 mm. The high temperature compression tests were conducted in Gleeble-1500 thermo-simulation machine (Fig. 1) at temperatures of 1000, 1050, 1100, 1150 °C and strain rates of 10^{-3}, 10^{-2}, 10^{-1}, 1 s^{-1}. Specimens were heated by induction coils with a heating rate of 10 °C s^{-1} and soaked for 5 min at testing temperatures before compression.

The flow stress–strain curves were obtained from the load-displacement data. In order to determine the microstructure evolution during the deformation, the specimens were water quenched from the test temperature immediately. The deformed samples for microstructural analysis were sectioned and prepared by the standard metallographic procedure. Microstructure observations were carried out by means of optical microscopy and transmission electron microscopy.

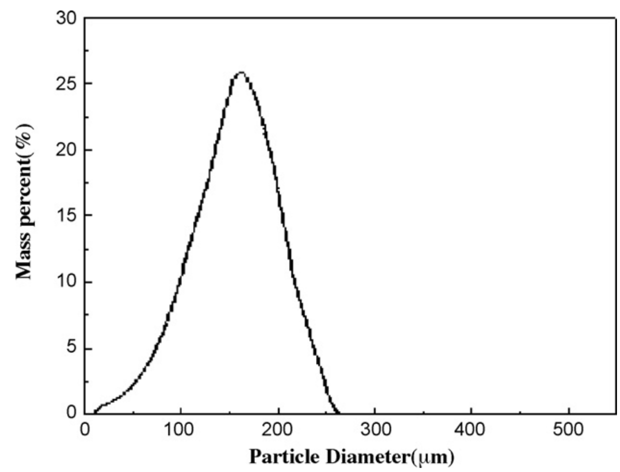

Fig. 2. Particle size distribution of TiAl alloy powder.

3. Results

3.1. Characteristics of TiAl alloy powder

The particle size of TiAl alloy powders ranges mostly from 50 to 250 μm, and the average particle size is 164 μm (Fig. 2).

The particles are of spherical shape, and have good flowability, as shown in Fig. 3(a). X-ray diffraction (XRD) analyses reveal that the powder contains γ phase (TiAl), α phase (Ti_3Al) and a small amount of β (B_2) phases. The presence of β phase in TiAl alloys with additions of β stabilizers, such as Cr and Mo, has been reported previously by Masahashi and Mizuhara (1995). The oxygen and nitrogen contents were 660 ppm and 28 ppm, respectively.

3.2. Hot deformability and flow behaviors

The deformation results of the HIPed TiAl alloy powder by isothermal compression are presented in Fig. 4. The largest strain without failure under different conditions can be found. The crack is sensitive to the strain rate. Surface cracking begins to appear

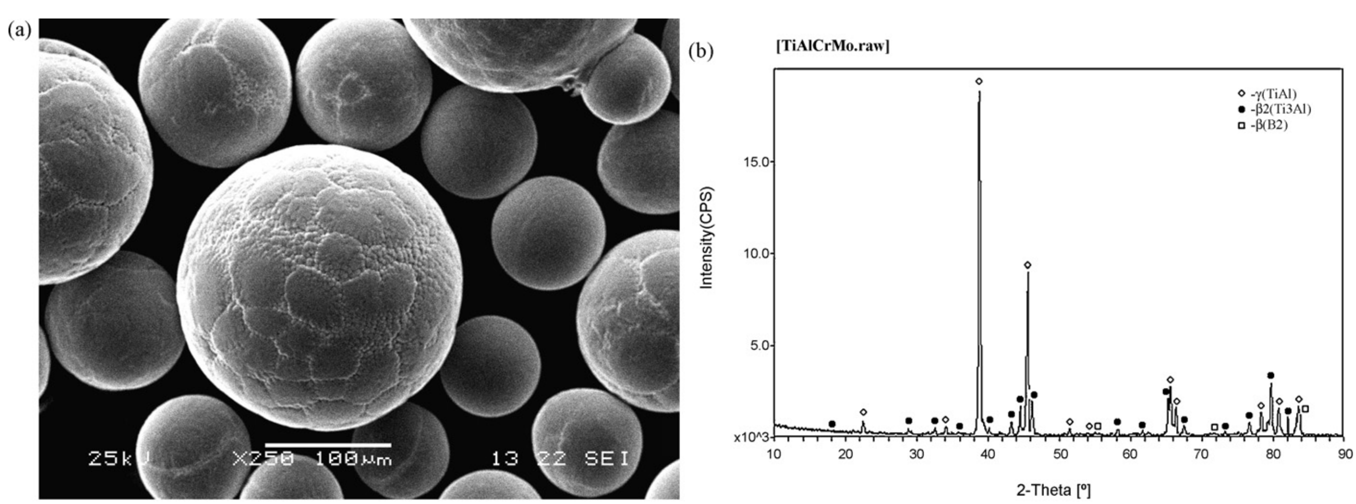

Fig. 3. Morphology (a) and XRD patterns (b) of the alloy powder.