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The influence of thermomechanical processing on microstructural evolution of Ti600 titanium alloy

Yuanfei Han[a], Weidong Zeng[a,*], Yunlian Qi[b], Yongqing Zhao[b]

[a] State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an 710072, China
[b] Northwest Institute for Nonferrous Metal Research, Xi'an 710016, China

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ABSTRACT

The influences of thermomechanical processing on microstructural evolution of Ti600 alloy were studied in the temperature range of 800–1100 °C, and at the strain rate of 0.001–10 s^{-1}. During the isothermal compression experiment, the flow stress–strain curves are examined in the β single-phase and in the α + β two-phase regions. The results show that the thermomechanical processing parameters have significant influences on the microstructure of Ti600 alloy, especially on the grain size, morphologies of α phase. Moreover, the microstructural evolution was analyzed by optical microstructure (OM) and transmission electron microscopy (TEM). It was found that typical of dynamic recovery and dynamic recrystallization phenomenon occurring in the thermomechanical processing. These results will optimize the microstructural control for hot working of Ti600 alloy and deepen the understanding of the flow softening mechanism of near-α titanium alloy.

1. Introduction

Titanium alloys are important aerospace materials for structural and engine applications because of their high strength to weight ratio and ability to withstand elevated temperatures up to 600 °C [1]. In recent years, it is attractive to develop high temperature titanium alloys for use in aircraft engine as compressor discs and blades under a long-term load in temperature range of 550–600 °C, such as IMI834 [2], Ti-1100 alloy [3] and BT36 alloy [4]. These alloys have been used successfully in different aircraft engines. As is well known, the useful deformation process "window" is much more restricted when the deformation of high temperature is performed for these titanium alloys. Profound knowledge of the influence of processing parameters on hot working behavior is important for the manufacturing of titanium alloy. A large number of studies on deformation mechanism of high temperature titanium alloys are available in the literature [2,3,5]. Wanjara et al. [2] studied the influence of thermomechanical processing on microstructural evolution in near-α alloy IMI834 and found that the flow stress behavior exhibited strain hardening and minor flow softening, while in the two-phase alpha–beta region considerable flow softening occurred. Chandravanshi et al. [3] investigated the effect of 0.2 wt.% of boron on the mechanical properties of Ti-1100 alloy at 600 °C in the thermomechanically processed (α–β rolled) condition, and pointed that boron (B) addition in Ti-1100 significantly increased the yield strength and ultimate tensile strength without any drop in elongation-to-failure. Jia et al. [5] studied the high temperature deformation behavior of near-α Ti60 alloy and concluded that the flow stress behavior revealed greater flow softening in the two-phase field compared with that of single-phase field. In general, most of the above studies are mainly focus on the influence of thermomechanical processing on microstructural evolution of high temperature titanium alloys. It is well known that the microstructure of titanium alloy is very sensitive to the hot processing parameters, and the thermomechanical processing not only influences the flow behavior of materials, but also determines the microstructural features of materials [6,7]. Therefore, it is necessary to study the effects of thermomechanical processing on microstructure evolution for titanium alloys based on understanding of deformation mechanism in order to realize the microstructure control, to optimize processing parameters.

In recent years, near-α titanium alloy, Ti600 alloy was developed by Northwest Institute for Nonferrous Metal Research of China. It contains small amounts of yttrium (Y), which has been gaining considerable interest due to their attractive mechanical properties that includes high-temperature creep properties, good tensile strength and superior high temperature properties at the servicing temperature of at least 600 °C [8]. For manufacturing of specific component shapes like compressor disks and blades, it is recognized that the thermomechanical processing conditions are required to be optimized for controlling the microstructure–mechanical property characteristics [9]. Therefore, profound understandings of the

* Corresponding author. Tel.: +86 29 88494298.
E-mail address: zengwd@nwpu.edu.cn (W. Zeng).

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relationship between the microstructure and thermomechanical processing parameters are important for the manufacturing of Ti600 titanium alloys.

In the present study, the near-α Ti600 titanium alloy was compressed using various thermomechanical processing parameters. The influence of various thermomechanical parameters on the microstructure evolution characteristics of Ti600 alloy was investigated comprehensively. The deformation mechanisms of Ti600 alloy were discussed based on the microstructural observations.

2. Materials and experimental procedures

2.1. Materials

The experimental material used in this research is a Ti600 titanium alloy with a nominal composition (wt.%) of Ti–6Al–2.8Sn–4Zr–0.5Mo–0.4Si–0.1Y. Its β-transus temperature was measured to be approximately 1010 °C by metallographic observations. The as-received Ti600 alloy bar had been subjected to a large number passes of forging in the β phase field. Finally, the initial microstructure consisted of thin lamellar α phase in length of 30–40 μm and width of 2 μm, also approximately 10% block α phase within a fine transformed matrix, as shown in Fig. 1.

2.2. Hot compression

The cylindrical compression specimens had 8.0 mm in diameter and 12.0 mm in height, and concentric grooves of 0.2 mm in depth were machined at both end faces of the cylinders to retain the lubricant for reducing the friction in isothermal compression of Ti600 alloy. Isothermal compression experimental were conducted on a computer controlled Gleeble-1500 thermal simulator over a deformation temperature range of 800–1100 °C with an interval of 50 °C at the strain rates of 0.001, 0.01, 0.1, 1, and 10 s^{-1}. The height reduction of the specimen was 70%. A thermocouple was welded at the mid height of the specimen for controlling of temperature and measurement of the adiabatic temperature rise in the specimen during deformation. The specimens were heated to corresponding compression temperature at a heating rate of 10 °C/s and homogenized for 5 min before deformation. After hot compression, the specimens were quenched immediately in water, to preserve the hot-deformed structures. The true strain–stress curves were recorded automatically in the isothermal compression process.

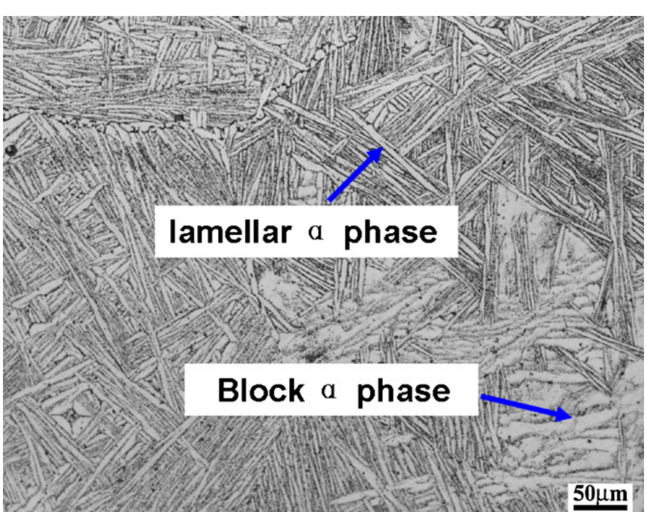

Fig. 1. Initial microstructure of Ti600 alloy.

2.3. Microstructure tests

To observe the microstructural evolution, the deformed specimens were sectioned parallel to the compression axis from one side of the deformation specimens and the cut surface of the smaller part was prepared for metallographic examination using standard procedures. The polished samples were etched with a solution of 6% HNO_3 + 2% HF in water for a few seconds, and the microstructure observations were carried out using Olympus/PMG3 optical microscopy. TEM samples were performed on thin foils (0.3 mm) prepared by electropolishing in a solution (12.5 ml $HClO_4$ + 83.3 ml C_4H_9OH + 167 ml CH_3OH). Its observations were carried out on a HITACHI H-800 microscope operated at 125 kV.

3. Experimental results and analysis

3.1. Flow stress behavior

Fig. 2 shows the typical stress–strain curves of the Ti600 alloy deformed in the temperature range of 800–1100 °C and the strain rate of 0.001–10 s^{-1}. Similar to other titanium alloys, the Ti600 alloy is significantly sensitive to the deformation temperature and strain rate. As illustrated in Fig. 2(a) and (b), the flow stress decreased with the increasing of deformation temperature and the decreasing of strain rate. Flow softening phenomenon could be observed at all temperatures and strain rates used in this study. In Fig. 2(a), the curve shows a quick flow softening at the temperature below 950 °C, whereas at higher temperature, the flow stress attains a steady state with the increase of strain. Because the alloy was deformed in β phase region, it is suggested that the temperature

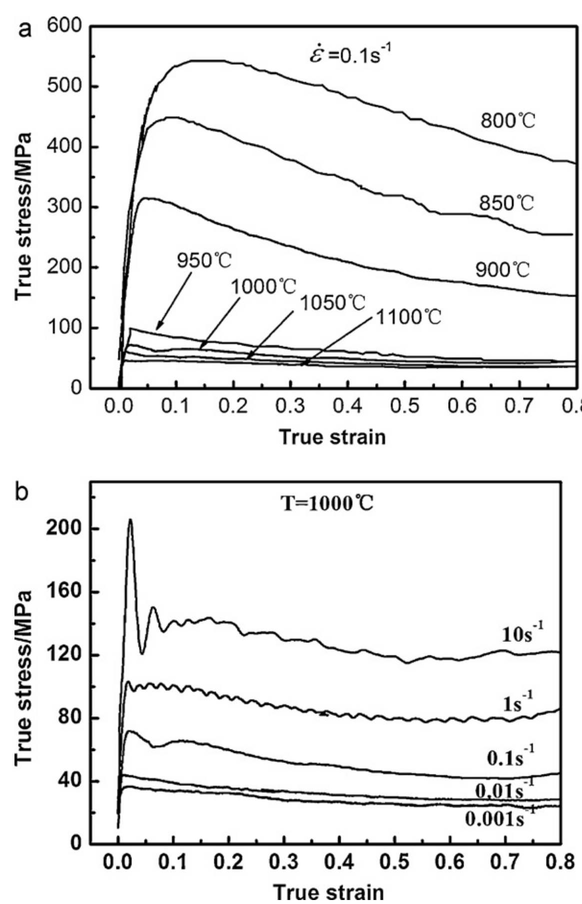

Fig. 2. Flow stress–strain curves in the isothermal compression of Ti600 titanium alloy: (a) 0.1 s^{-1} and (b) 900 °C.