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Effect of hot working and post-deformation heat treatment on microstructure and tensile properties of Ti-6Al-4V alloy

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Abstract: The effects of hot compression, hot rolling and post-rolling annealing on microstructure and tensile properties of Ti-6Al-4V were analyzed. Hot compression tests were conducted in the temperature range of 800−1 075 °C and at strain rates of 0.001−1 s^{-1}, and the relations between the characteristic points of flow curve and processing variables were developed. Two passes of hot rolling test with total reduction of 75% were performed in the temperature range of 820−1 070 °C and at constant strain rate of 2 s^{-1}. After hot rolling, some specimens were subjected to heat treatment at 870 °C and 920 °C for 2 h followed by air cooling. Hot rolling in beta phase field resulted in coarse beta grains transforming to martensite by cooling. Otherwise, rolling in the alpha/beta phase filed gave rise to a partially globularized alpha microstructure. The post-rolling heat treatment completed the partial globularization of alpha phase in two-phase region and otherwise broke down the martensitic structure of beta-rolled samples. Tensile tests showed that the strength characteristics as well as elongation decrease significantly with increasing the rolling temperature from the two-phase to the single-phase region. Increasing heat treatment temperature contributed to lower strength for the specimens rolled in two-phase region and higher strength characteristics for the beta-rolled specimens.

Key words: recrystallization; hot rolling; hot compression; heat treatment; globularization

1 Introduction

Hot deformation parameters and post-deformation heat treatments are often selected in a way to control the microstructure and properties of many industrial alloys. The desired strength characteristics and corrosion resistance in titanium alloys are achieved by the precise control of processing route and therefore microstructure. Ti-6Al-4V is a very well known alloy for its desirable mechanical properties and corrosion resistance. The application of this alloy is particularly attractive to aerospace and biomaterial industries [1]. The mechanical and microstructural characteristics of Ti-6Al-4V depend actually on the variables of hot deformation and/or heat treatment. The previous researchers have tried to investigate the microstructural and mechanical behavior of this alloy during hot working. SESHACHARYULU et al [2] studied the hot deformation behavior and damage mechanisms in an extra low interstitial grade Ti-6Al-4V. A number of studies got involved in the effect of texture or morphology of α-phase on the hot deformation characteristics of the alloy [3−6]. Other investigators proposed the occurrence of dynamic globularization of α-phase during hot deformation or static globularization during post-deformation heat treatment [7−11]. However, fewer contributions analyzed the hot deformation behavior of the alloy in the β-phase region and proposed the occurrence of dynamic recrystallizations (DRX) [12]. Some other researchers attempted to probe the mechanical characteristic and microstructural evolutions of this alloy during industrial processes. The deformation stability, plastic anisotropy and cavity formation during hot forging were analyzed in detail [13−14]. Although investigations on hot working behavior of this alloy are numerous, but very few attempts have been made to correlate hot rolling conditions to the mechanical properties [15−16]. Moreover, only limited data on the effect of actual processing conditions on tensile properties are available. Hence, in this investigation thermomechanical processing parameters−microstructure−tensile property relations for Ti-6Al-4V are studied using hot compression, hot rolling and post-deformation heat treatment.

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2 Experimental

The studied Ti-6Al-4V alloy with the composition of 6.66% Al, 5.13% V, 0.21% Fe, 0.03% Mo, 0.02% Mn, 0.02% Si and the balance of Ti was received as hot rolled strips with 12 mm in thickness. The beta transus temperature was approximated 970 °C by thermal dilatation method. The as-received material was primarily subjected to beta annealing treatment at 1 050 °C for 35 min followed by air cooling. The microstructure developed by beta annealing treatment consisted of a lamellar α within the prior β grains along with grain boundary α (Fig. 1). The prior β grain size in the annealed material was measured to be about 350 μm. Cylindrical compression samples of 15 mm in height and 10 mm in diameter were prepared with the axis along the rolling direction of the as-received plate. An INSTRON 8502 testing machine equipped with a fully digital and computerized control furnace was employed to perform hot compression tests under constant strain rates, ranging from 10^{-3} s^{-1} to 1 s^{-1} at an interval of an order of magnitude and at temperatures of 800, 850, 900, 950, 1 000, 1 025, 1 050 and 1 075 °C. Rolling samples with size of 40 mm×60 mm were cut from the as-received plate and subjected to hot rolling at temperatures of 820, 870 and 920 °C in two-phase alpha/beta region and at temperatures of 970, 1 020 and 1 070 °C in single-phase beta region. All rolling samples were reheated prior to testing to simulate actual industrial hot rolling process. The rolling strain rate was 2 s^{-1} and a total reduction of 75% was performed in two-passes. All samples were air cooled after rolling to simulate actual production practice. Some hot rolled specimens were subjected to post-rolling heat treatment at temperatures of 870 °C and 920 °C for 2 h followed by air cooling. All specimens were then prepared according to the standard procedures and subjected to microstructural observations by optical microscopy and tensile testing.

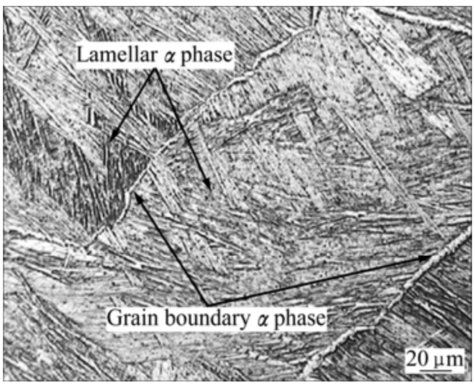

Fig. 1 Microstructure of as-received sample after β annealing treatment at 1 050 °C for 35 min followed by air cooling

3 Results and discussion

Hot compression tests in this research were performed to identify the general flow characteristics of the studied alloy in hot working conditions. Indeed, hot compression is widely used as a simulation technique for actual industrial hot working processes in order to develop practical relationships between critical strains for microstructural changes and processing variables. The typical flow stress curves obtained in $\alpha+\beta$ region at 900 °C, and in single-phase β region at 1 000 °C, are shown in Fig. 2. As seen, the flow stress level actually increases with the strain rate increasing and decreases with temperature increasing. Figure 3 shows the dependence of the characteristic strain and stress on Zener-Hollomon parameter which incorporates the effects of strain rate and temperature as follows:

$$Z = \dot{\varepsilon}\exp(\frac{Q}{RT}) \tag{1}$$

where Q denotes the apparent activation energy, and R and T are the gas constant and absolute temperature, respectively. The values of Q for single-phase β and $\alpha+\beta$

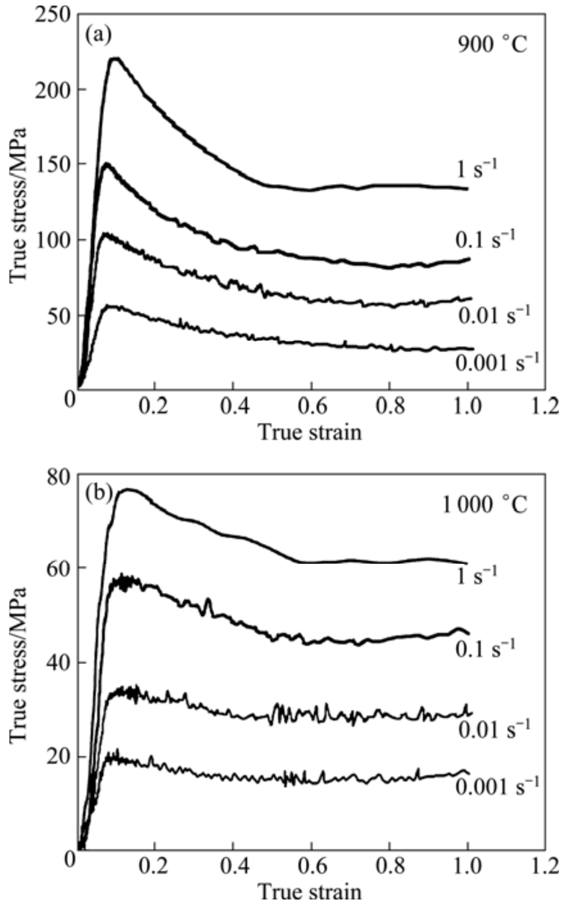

Fig. 2 Typical flow stress curves obtained in two-phase $\alpha+\beta$ region at 900 °C (a) and in single-phase β region at 1 000 °C (b)