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Hot deformation behavior and microstructure evolution of titanium alloy Ti-Al-Zr-Sn-Mo-Si-Y

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Abstract: Samples of Ti-Al-Zr-Sn-Mo-Si-Y alloy were compressed on the Gleeble-1500 heat stimulation machine. The compression test was carried out in the temperature range from 800 ℃ to 1 100 ℃ and strain rate range from 0.001 s^{-1} to 10 s^{-1}. Stress-strain behavior and variation of microstructure of the alloy during hot compression were investigated. The experimental results show that the alloy is sensitive to temperature and strain rate, and the flow softening behavior is more obvious with the decrease of deformation temperature. At higher strain rate, discontinuous yielding is observed in β phase region. When deformed in $\alpha+\beta$ phase region, with the increment of deformation temperature, the lamellar α structures globularization is more quick and more uniform. When deformed in β phase region, coarse β grains can be got because of high deformation temperature.

Key words: Ti-Al-Zr-Sn-Mo-Si-Y alloy; high temperature titanium alloy; hot deformation; microstructure

1 Introduction

The titanium alloys have been used for aerospace applications because of anattractive combination of properties such as low density, high specific strength and good corrosion resistance. The Ti-Al-Zr-Sn-Mo-Si-Y alloy is a kind of near-alpha titanium alloy, in particular, the addition of a little mass rare-earth element yttrium(Y) resulted in improving the properties of the alloy such as tensile strength, elevated temperature creep resistance and endurance strength[1−2]. Titanium alloy is more difficult to process in comparison with other engineering materials such as aluminum and steels. The need to hot work these materials at relatively low temperatures in order to control microstructure and final properties often requires the utilization of isothermal or near-isothermal deformation processing. Many factors can affect the deformation behavior of materials during hot working: deformation temperature, deformation rate and deformation degree and so on. So the characterization of deformation behavior is essential for the optimization of the hot deformation processes of titanium alloys. The microstructures of the alloy play a very important role in the mechanical properties of alloys, such as strength, ductility, creep resistance and fracture toughness[3−4]. At the same time, the microstructure, e.g. the phase size and the 'lamellar' dimensions of the phase α is affected by the hot working parameters, such as processing temperature, strain and strain rate. Experiments showed that dynamic or metadynamic recrystallization could occur in titanium alloys during isothermal forging and hot compression. Many typical high temperature Ti alloys such as IMI685, IMI834, Ti1100 have been studied by heat stimulation machine[5−6]. The aim of studying hot deformation of alloy and its microstructures evolution in a given range of temperature and strain rate is to obtain good hot working parameters, which can achieve a perfect combination of the hot work with microstructures and properties.

In this work, the hot deformation behavior of near-alpha alloy Ti-Al-Zr-Sn-Mo-Si-Y was investigated by heat processed and cast samples under the hot working conditions of varying temperature and strain rate conducted on isothermal compression heat stimulation machine.

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The objective of the present paper is to investigate the variation of its microstructure under different hot working conditions by optical microscopy(OM), and to determine the influence of the hot working parameters on the microstructural evolution of the Ti-Al-Zr-Sn-Mo-Si-Y alloy.

2 Experimental

The near-alpha titanium alloy with the following main composition was used in this study: Al, Zr, Sn, Mo, Si, Y and balance Ti. The β transus temperature of this alloy is approximately 1 010 ℃. The compression specimens were heat-processed specimens received in the form of hot rolled bars of 12 mm in diameter. The specimens were machined into cylindrical shape with 8 mm in diameter and 12 mm in length using linear cutting machine. The hot compression test was carried on Gleeble 1500 simulator. In order to reduce the friction at the die-specimen interface, a graphite foil was inserted between the die and the specimens. A thermocouple was welded at the mid-span of the specimens to provide an accurate temperature control and measurement during testing. The test was conducted at five strain rates (0.001, 0.01, 0.1, 1 and 10 s^{-1}) to a deformation of approximately 70% and at seven temperatures (800, 850, 900, 950, 1 000, 1 050 and 1 100 ℃). Specimens were automatically water quenched immediately upon the completion of compression test without moving the specimen from the machine. Starting structure of the alloy is shown in Fig.1. As can be seen from this figure, the microstructure consists of lamellar α colonies in coarse prior β grains of 100−200 μm, a grain boundary α layer of 2−3 μm thickness, and a continuous prior β grains boundary of 1−2 μm thickness.

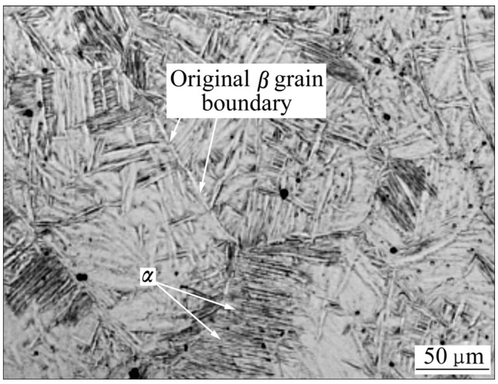

Fig.1 Starting microstructure used in investigation

3 Results and discussion

3.1 Stress—strain curves of alloy

The typical true stress—strain curves of the alloy obtained at 900 ℃ and 1 050 ℃ in the strain rate range of 0.001−10 s^{-1} are presented in Fig.2 respectively. In the α+β temperature range (Fig.2(a)), the true stress-strain curve showed a sharp increase in stress at the beginning stage of the test, eventually in a peak stress. After the peak stress, the true stress-strain curves dropped continuously and the continuous flow softening was observed. Flow softening behavior is considered to be a characteristic of titanium alloys with lamellar starting microstructure[7]. In the β range, flat stress—strain curves were observed in the strain rate range of 0.001−1 s^{-1} (Fig.2(b)), which is indicative of steady state flow stress. However, at the highest strain rate of 10 s^{-1} and deformation temperature above or near β transus temperature, the discontinuous yielding phenomenon has been observed, e.g. flow stress has a rapid drop and then increases with increasing strain, and the behavior has been repeated for many times until the flow stress reaches steady state (Fig.2(b)). This type of behavior has been reported for many titanium alloys, for example, Ti-15V-3Al-3Cr-3Sn and Ti-6.8Mo-4.5Fe-1.5Al[8−9]. The discontinuous yielding phenomenon cannot be well explained by the conventional static theory, which

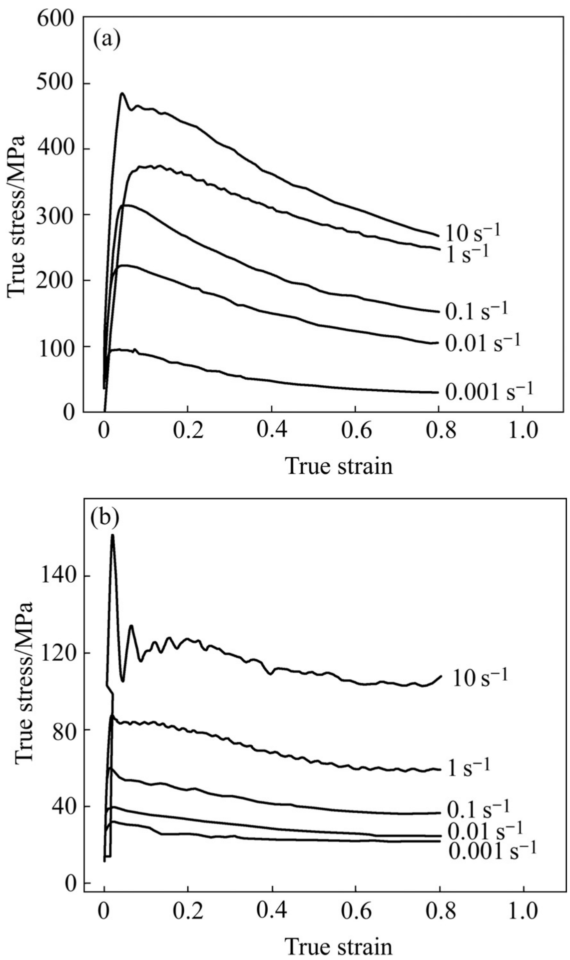

Fig.2 True stress—strain curves of alloy at different strain rates in (α+β) range (900 ℃) (a) and β range (1 050 ℃) (b)

involves dislocation locking and unlocking. It has been generally accepted that this phenomenon was associated with the sudden generation of new mobile dislocation from grain boundary sources[10−13].

3.2 Influence of deformation on microstructures

The macro-photo after hot compression is shown in Fig.3(a). The specimen cross-section is divided into three regions. Rregion Ⅰ(RⅠ), which is a difficult deformation zone, in which the microstructures are a litle different from the starting microstructures. In this region, the deformation is relatively small, the microstructure is quite coarse, strip α becomes shorter, as shown in Fig.3(b). The deformation in region Ⅱ(RⅡ) is quite large, as shown in Fig.3(c), the grains in the center of the specimens are very fine, which are lengthened and flattened along the stress direction. As shown in Fig.3(d), region Ⅲ is in the rim of the specimens, all around the center of region Ⅱ, and without any hinder as the other two regions. As one of the relatively free deformation regions, the deformation in region Ⅲ(R Ⅲ) is moderate, just between region Ⅰ and region Ⅱ.

3.3 Influence of temperature on microstructures

Fig.4 shows the microstructure of the alloy deformed at various temperatures with the strain rate of 0.1 s^{-1}. Lamellar α with small aspect ratio can be found in the alloy deformed at relatively lower temperature, e.g. 850 ℃. Meanwhile, lamellar α twisted and had the tendency to spherordize when deformed below β transus temperature, as shown in Fig.4(a). Lamellar α becomes shorter and broader with even smaller aspect ratio, and obviously tend to spherordize when deformed at 900 ℃, the spherordization rate is 10% or so, as shown in Fig.4(b). The spherordization rate increases to about 50% (volume fraction) for the alloy deformed at 950 ℃. The microstructure after spherordization process is comparatively homogeneous, as shown in Fig.4(c). Needle α precipitated from coarsened and lengthened β grains along deformation direction, as shown in Fig.4(d). Diffusion coefficient of the atoms is great, β grains can be easily coarsened above β transus temperature. Influence of deformation temperature on hot compression microstructure is quite different for the alloy deformed above or below β transus temperature. The breaking and spherordization degrees of lamellar structure increase with the deformation temperature for the alloy deformed below β transus temperature, the rise of the deformation temperature is favorable to the spherordization of α phase and the homogenization of the whole microstructure. Temperature has significant effect on the morphology of the alloy deformed above β transus

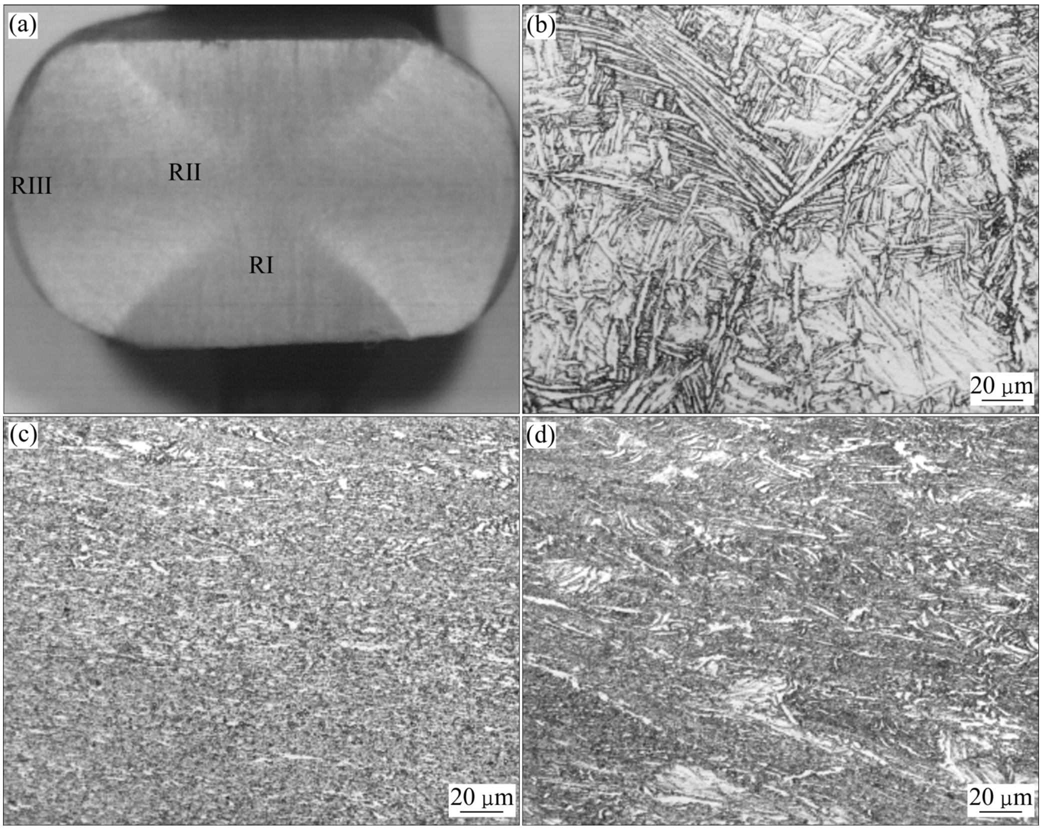

Fig.3 Microstructures in different fields after hot compression: (a) Macro-photo of hot compression; (b) Region Ⅰ; (c) Region Ⅱ; (d) Region Ⅲ

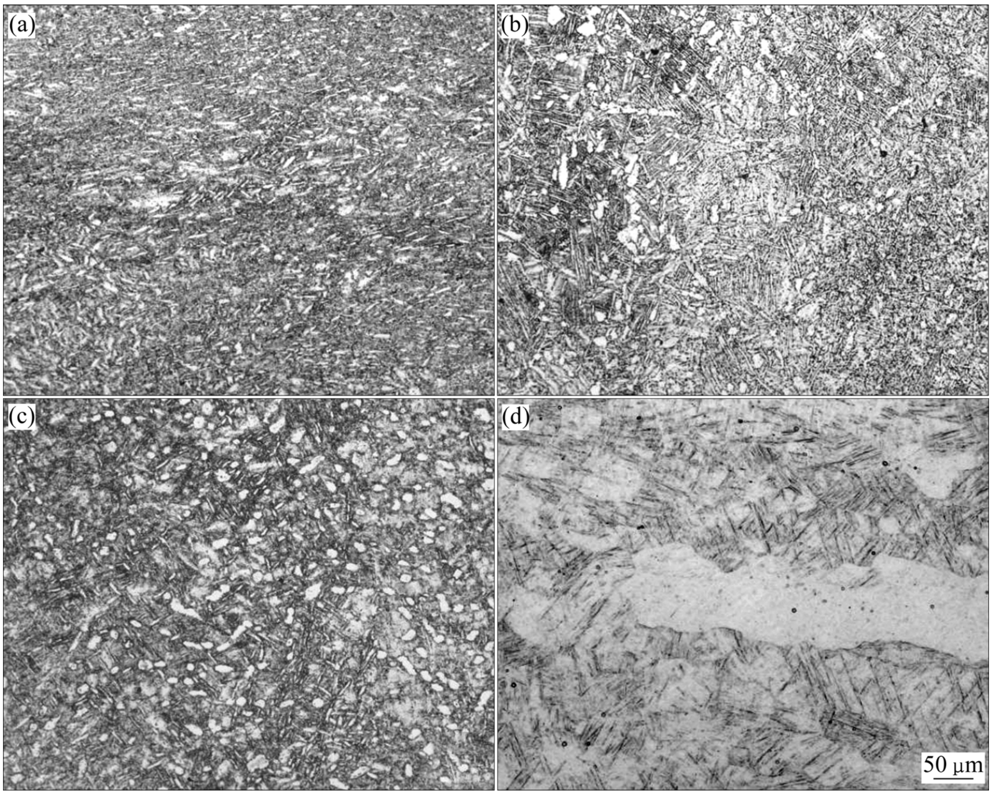

Fig.4 Microstructures after deformed at various temperatures with strain rate of 0.1 s^{-1}: (a) 850 ℃; (b) 900 ℃; (c) 950 ℃; (d) 1 050 ℃

temperature, which represents as coarsened β grains.

4 Conclusions

1) Ti-Al-Zr-Sn-Mo-Si-Y alloy is sensitive to the temperature and strain rate, and the flow softening behavior is more obvious with the decrease of deformation temperature. At higher strain rate, typically 10 s^{-1}, discontinuous yielding followed by flow oscillations was observed in β phase region. The phenomenon can be explained by dynamic theory.

2) When deformed in $\alpha+\beta$ phase region, lamellar structures globularization is the main deformation dynamic. With the increment of deformation temperature, the lamellar α structures globularization is more quick and more uniform.

3) When deformed in β phase region, coarse β grains can be got because of high deformation temperature.

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