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Interaction among deformation, recrystallization and phase transformation of TA2 pure titanium during hot compression

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Abstract: TA2 pure titanium was chosen to research the interaction among deformation, recrystallization and phase transformation during hot compression. The samples were hot compressed by thermal simulation method with different processing parameters. Variant selection induced by stress during cooling after compression was found. The prismatical texture component which featured that the [0001] direction perpendicular to the compressing direction produced preferentially under the compressing stress. As a result, the transformed α phase possesses strong prismatical texture which is different with the basal texture of compressed α phase. The minimum elastic strain energy is demonstrated to be the main reason that causes the variant selection. Dynamic recrystallization behavior and microstructure evolution during hot compression were also studied.

Key words: pure titanium; hot compression; phase transformation; texture; variant selection

1 Introduction

Hot deformation has much influence on the $\beta\rightarrow\alpha$ transformation and texture evolution which is found in many studies [1−3]. LIU et al [4] observed that compressing deformation can promote the $\beta\rightarrow\alpha$ transformation in TC4 titanium alloy when the alloy was compressed at 960 °C (5 °C under $\beta\rightarrow\alpha+\beta$ transus temperature). They also found that fine α phase grains could be obtained when the β grains were refined after compression. The deformation mechanism of hexagonal titanium alloys changes when they are deformed at different temperatures or with different processes. As a result, the textures in those alloys are always different. The texture aroused by cold rolling in pure titanium is a basal texture which deviates 15°−20° from the normal direction (ND) and the deviating angle decreases with the increasing strain [5]. Twinning usually occurs when the pure titanium is deformed at a low temperature [6,7]. Although the feature of texture in hot compressed titanium alloy has been studied early [8], its mechanism remains indistinct due to the complicated interaction between deformation and phase transformation.

Commercially pure titanium is usually deformed at the temperature around phase transus temperature [9]. The deforming mechanisms of the two phases in pure titanium would be much different. As a result, both the microstructure evolution and mechanical properties would be different between the two phases. Dynamic recrystallization is a significant way that could refine grains and enhance strength of titanium alloys. SU et al [10] compressed pure titanium at different temperatures with different strain rates to obtain the flow stress of commercially pure titanium under different compressing parameters. They found that dynamic recrystallization was a significant way to soften the pure titanium at high temperature.

The formation of texture in pure titanium is usually complicatedly influenced by both deformation and phase transformation. It is important to study the texture evolution during hot deformation in pure titanium. Inheritance during deformation and phase transformation has been reported [11−13]. LONARDELLI et al [11] compared the texture evolution between pure titanium and TC4 titanium alloy by means of cold rolling and heat treatment. They found that variant selection occurred more obviously in pure titanium and the strong texture is produced after cooling. GEY and HUMBERT [14] studied variant selection after cold rolling and annealing in a titanium alloy. Obvious variant selection was found during $\alpha\rightarrow\beta\rightarrow\alpha$ transformation after cold deformation and heat treatment which proved that deformation could induce preferred orientation. HUMBERT et al [15]

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considered that the strain energy hinders the precipitation of α phase and it is different at different grain boundaries. The reason for variant selection can be explained in terms of the theory of minimum elastic strain energy. Whereas, it is only applicative to the nucleation adjacent to grain boundary in this method, it remains indistinct why variant selections occur inside the grains after hot deformation.

Although hot deformation of commercially pure titanium has been studied, the feature of flow stress and dynamic recrystallization behavior during hot compression have not been researched fully. In addition, the influence of external stress on variant selection remains unclear during hot deformation. In this work, therefore, commercially pure titanium is compressed at high temperatures with different strain rates to investigate the influence of hot compression on phase transformation and variant selection.

2 Experimental

The forged TA2 commercially pure titanium was chosen to investigate the feature of phase transformation and variant selection in this work. Differential thermal analysis by 5 °C/min during heating and cooling was taken to obtain the $\beta\rightarrow\alpha$ phase transformation temperature. The result shows that an extremum occurred at the temperature of 897 °C, which indicates that the phase transformation temperature is 897 °C.

Cylindrical samples of 6 mm in diameter and 12 mm in height were manufactured from the original forged TA2 alloy. All the samples were heated to 920 °C and held for 20 min on a G1500−Gleeble simulating machine to get an entire β phase. Then, three samples were compressed at 920, 900 and 880 °C by 60% reduction with a strain rate of 0.01 s^{-1}. Another two samples were compressed at 920 °C with 1 and 5 s^{-1} to explore the influence on microstructure and texture of the material with different strain rates. To reveal the characterization of deformed α phase, another sample was held for 10 min at 880 °C and then compressed by 60% reduction with a strain rate of 0.01 s^{-1}. The samples were all water-quenched to room temperature after hot compression. Samples, cut perpendicularly to the compression plane, were electrolytically polished for electron backscatter diffraction (EBSD) test. EBSD system (Channel 5), mounted on an Ultra55 scanning electron microscope, was applied to revealing the orientation feature and texture evolution under compression.

3 Results

3.1 Stress−strain curves of different samples

True stress−strain curves are shown in Fig. 1. The stress is low when the samples are compressed at the β region which is shown with the dark curves. The true strength is enhanced with the increase of strain rate as the recovery of dislocations produced by compression would not be accomplished immediately. The blue curve of the sample held at 880 °C for 10 min shows a much higher strength than the samples compressed under β phase state. The α phase has a hexagonal structure which has less slip systems than BCC-β phase, so the deformation of α phase is more difficult than β phase.

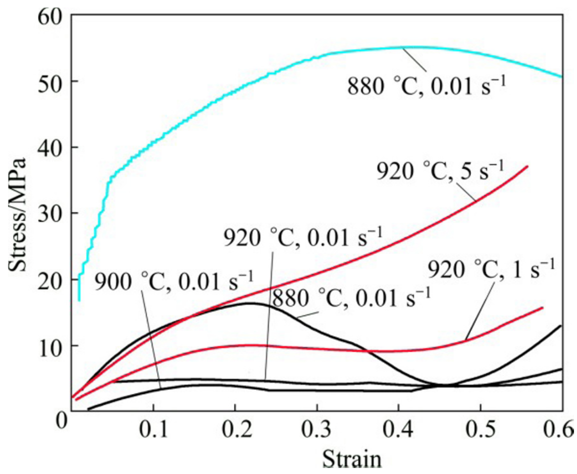

Fig. 1 True stress−strain curves of different samples

The sample compressed at 880 °C shows different properties with ones compressed at temperatures above transformation temperature. Stress decreases obviously after the strain reaching 0.2 due to two possible reasons. Either phase transformation or dynamic recrystallization may cause the decline of stress during hot deformation. As the microstructure of the ultimate α phase is mostly made up of deformed grains, it can be assumed that phase transformation is the main factor that leads to the decrease of stress.

The flow stress of the sample with only α phase increases quickly with the increase of strain at the beginning of compression. Then, the curve becomes flatter accompanying with the increase of strain, and the stress even decreases after the strain reaching 0.4. At the beginning of the compression, dislocation slipping is the main way for deformation. As the limitation of the number of slip systems in hexagonal titanium, dislocation slips more easily than in BCC titanium. Consequently, α phase presented an obviously higher strength than β phase. Dynamic recrystallization occurs obviously during compression under the drive of the increasing storage energy during deformation. And with the proportion of dynamic recrystallization increasing, the sample gets softened and the stress begins to fall down with the increasing strain.