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Microstructure evolution of TA15 titanium alloy during hot power spinning

CHEN Yong, XU Wen-chen, SHAN De-bin, GUO Bin

School of Materials Science and Engineering, Harbin Institute of Technology, Harbin 150001, China

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Abstract: The microstructure evolution of TA15 titanium alloy during hot power spinning was studied. Effects of wall reduction on microstructure evolution of TA15 titanium alloy were researched. Slip deformation is the main deformation mechanism accompanying with twinning to coordinate the deformation. The microstructure gradually transforms into fine fibrous microstructure and the aspect ratio of primary α grain increases with increasing wall reduction. The recrystallization fraction and microhardness increase with increasing reduction.

Key words: microstructure evolution; hot power spinning; TA15 alloy

1 Introduction

Titanium alloys have been gaining extensive applications all through the years in the aerospace industry because of the demand of high performance, light weight and high payload capacity [1]. Due to the excellent combination of high specific strength and toughness along with excellent corrosion resistance, TA15 alloy is adopted extensively in aerospace application [2]. TA15 titanium alloy is a near α titanium alloy, which is similar to BT20 titanium alloy widely used in aircraft industry in Russia. Until now, quite a few researches have been carried out on TA15 alloy. Analogue experiments for isothermal local loading were designed and carried out by FAN et al [3] to study the microstructure evolution of TA15 alloy under different temperatures and complex strain path. ZHU et al [4] analyzed the influence of deformation parameters on microstructure and mechanical properties of TA15 titanium alloy after compressive deformation. SESHACHARYULU and SEMIATIN et al [5−7] found dislocation glide and climb to be the main subtransus deformation mechanism of Ti-6Al-4V alloy with lamellar structure through kinetics analysis. The effects of initial microstructure on the microstructure evolution of a near α titanium alloy during deformation in the two-phase region of α+β were studied at different deformation temperatures by POORGANJI et al [8]. By the isothermal compression conducted on Thermecmaster-Z simulator, the high temperature deformation behavior of Ti-5.6Al-4.8Sn-2.0Zr was studied on the basis of analysis of the stress−strain behavior, kinetics and processing map [9]. Isothermal compression of the TC11 titanium alloy was conducted on Gleebe−1500 hot-simulator and the effect of deformation temperature, strain rate and strain on the flow stress and the apparent activation energy for deformation was in depth analyzed [10].

The spinning process, as an important advanced plastic processing technology, has become a preferred method to manufacture thin-wall rotational workpieces. With regard to spinning process, most studies focus on how to avoid forming defects and improve dimensional precision of as-spun workpieces while the researches relative to precise controlling of microstructure and mechanical property are not fully conducted [11−14]. Since hot spinning process has special advantage to produce thin-wall rotational workpieces of titanium alloy, it is necessary to study the microstructure evolution of titanium alloy during spinning process. The objective of the present work is to study the microstructure evolution and deformation mechanism of TA15 alloy systematically during hot power spinning, which is helpful to optimize spinning process of titanium alloy.

2 Experimental

TA15, a near-α titanium alloy, was used in the current

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Corresponding author: SHAN De-bin; Tel: +86-451-86418732; E-mail: shandb@hit.edu.cn

experiments with the chemical composition (mass fraction, %) of 6.60 Al, 2.31 V, 2.20 Zr, 1.70 Mo, 0.06 Fe and balanced Ti. The TA15 alloy received in hot rolled bar was supplied by Baoji Titanium Industry Co., Ltd., China.

The billets for power spinning with dimensions of 100 mm (inner diameter)×8 mm (thickness)×150 mm (length) were turned from as-rolled TA15 bar. The experiments were carried out at about 800 °C with wall reduction (ε) of 20%, 50% and 80%. The hot power spinning processes were conducted at a RLE800 CNC hot spinning machine. All of the specimens were sectioned parallel to the axial direction. Glass protective lubricant was adopted for the purpose of lubrication and also reducing surface oxidation of the tubular billets. The microstructures before and after deformation were examined by optical microscopy (OM), SEM and TEM.

3 Results and discussion

The initial microstructure of the as-rolled TA15 alloy is given in Fig. 1. The initial TA15 mainly contains primary α phases within small amount of β transformation microstructure. Image-Pro Plus version 6.0, a popular and powerful image analysis program, was used in this work to research the microstructure. The average primary α grain size is approximately 14.2 μm and the aspect ratio is about 1.6. There is no obvious β grain boundary in the β matrix. The spun tube of TA15 alloy is shown in Fig. 2.

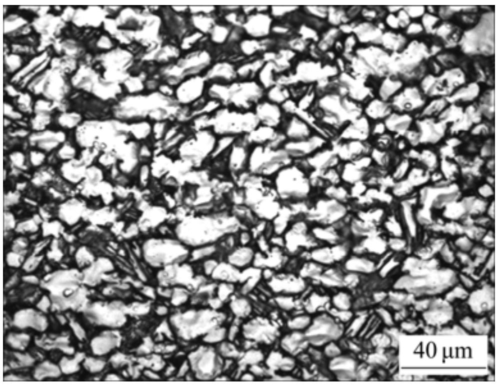

Fig. 1 Microstructure of as-rolled TA15 alloy

Figure 3 shows the microstructure of TA15 alloy deformed at about 800 °C with different wall reduction. It can be seen that prior α phase is plastically formed parallel to the axial direction and tends to elongate during hot deformation. In addition, the microstructure is refined gradually with the increase of wall reduction. The primary α phase transforms into fiber morphology

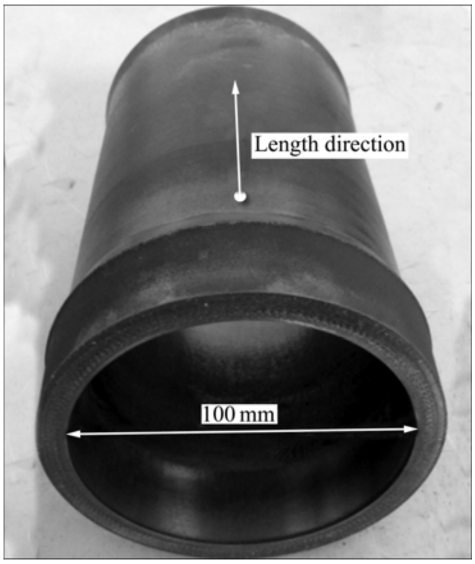

Fig. 2 Spun tube of TA15 alloy

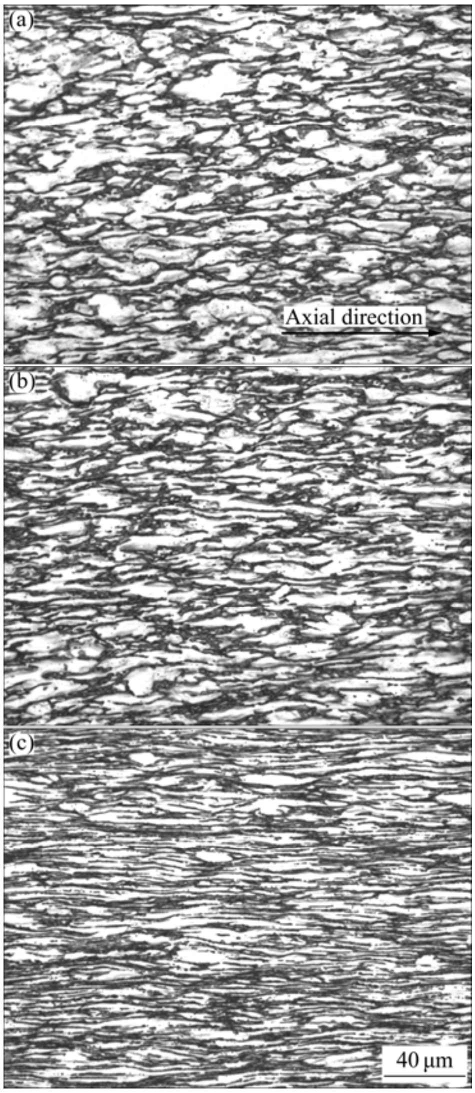

Fig. 3 Microstructures of TA15 alloy spun at 800 °C with wall reduction of 20% (a), 50% (b) and 80% (c)

parallel to axial direction obviously due to the large plastic deformation at the wall reduction of 80%. When the wall reduction increases, the β phase is crashed during the process of deformation to be chain-like β phase, which distributes among α phase along the direction parallel to the axial direction, as shown in Fig. 4. The aspect ratio of primary α phase increases with increasing wall reduction as shown in Fig. 5.

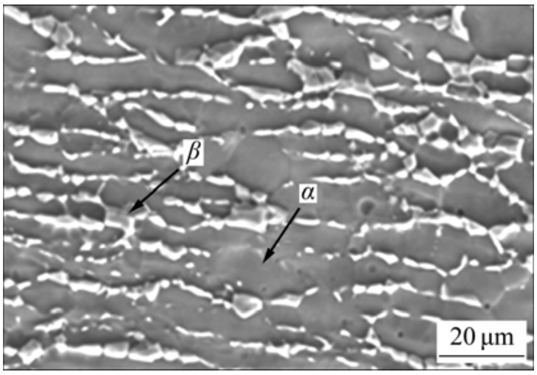

Fig. 4 SEM image of TA15 spun at 800 °C with wall reduction of 80%

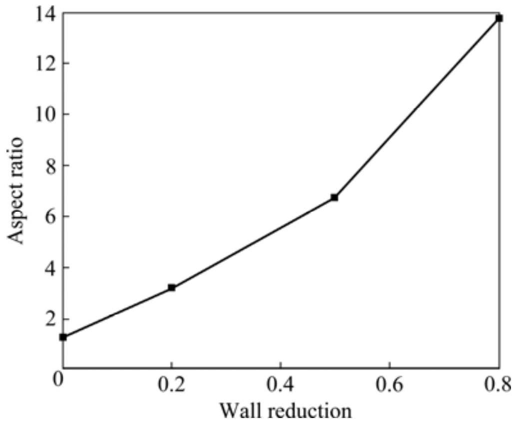

Fig. 5 Aspect ratio of primary α phase vs wall reduction

Figure 6 presents the TEM images of the TA15 alloy deformed at 800 °C with wall reduction of 20%. Large amount of slip bands are observed in Fig. 6. There are more dislocations and slip bands in α phase than in β phase.

Figure 7 presents the TEM images of the TA15 alloy deformed at 800 °C with wall reduction of 50%.

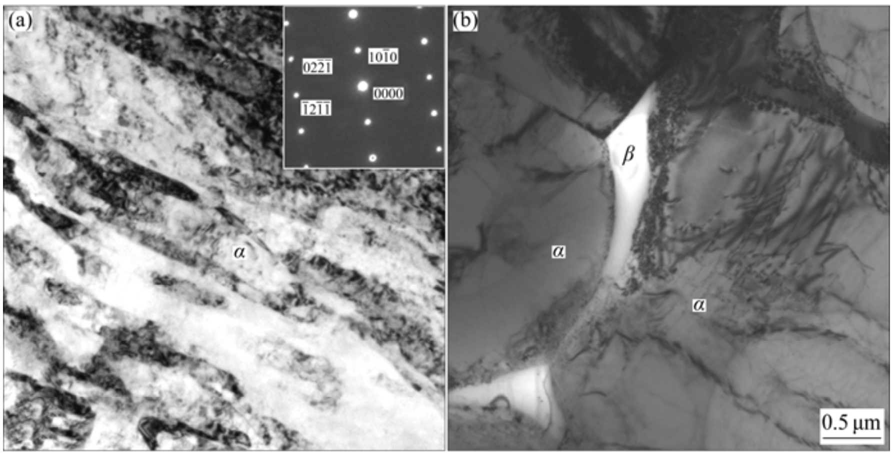

Fig. 6 TEM images of TA15 alloy spun at 800 °C with wall reduction of 20%

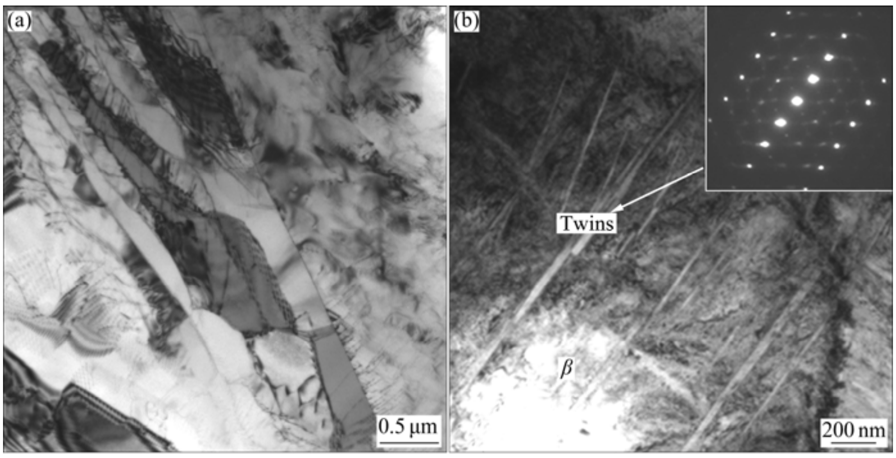

Fig. 7 TEM images of TA15 alloy spun at 800 °C with wall reduction of 50%

Subgrains and fine recrystallization grains are observed in the slip band of α phase as shown in Fig. 7(a), which indicates that dynamic recrystallization occurs under wall reduction of 50%. More amount of subgrains are examined in α phase than in β phase. At the same time, deformation twins are observed at the wall reduction of 50% as shown in Fig. 7(b). Twinning is an effective deformation mechanism of β phase besides dislocation slip due to its low plasticity.

More dynamic recrystallization grains are observed at wall reduction of 80% as shown in Fig. 8. Some recrystallization grains grow to bigger size than that at wall reduction of 50%, although the recrystallization is still not complete. The recrystallization fraction increases with increasing wall reduction at the experiment temperature. Dynamic recrystallization is an effective mechanism to get fine grains through hot deformation. After recrystallization, the dynamic recrystallization α phase exhibits equiaxed grains with mean size of about 7.6 μm.

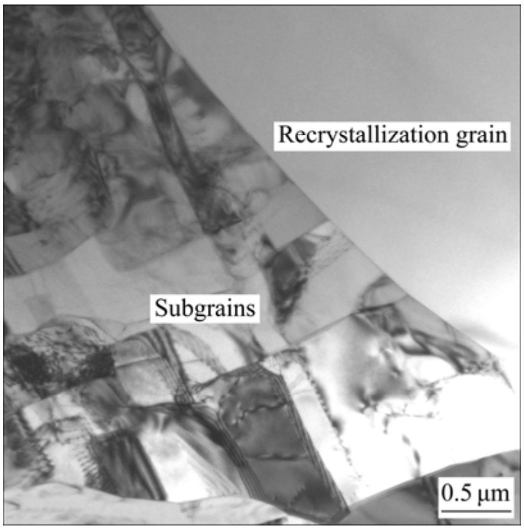

Fig. 8 TEM image of TA15 alloy formed at 800 °C with wall reduction of 80%

Figure 9 shows the microhardness of TA15 alloy deformed at 800 °C with different wall reduction. It can be seen that the microhardness increases with increasing wall reduction. With increasing wall reduction, the microstructure gradually transforms into fine fibrous microstructure. The work hardening is the major deformation mechanism during the hot power spinning deformation, although dynamic recrystallization observed in the spun deformation will soften the microstructure. So, when the wall reduction increases to 80%, the microhardness gets to about HV 560 which is 40% higher than the original microhardness.

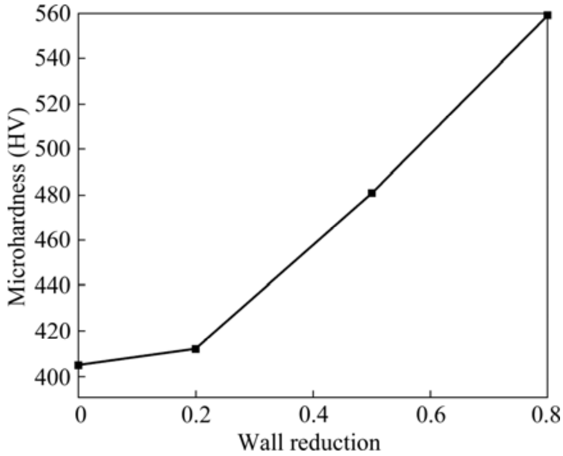

Fig. 9 Microhardness of TA15 spun tube deformed at 800 °C with different wall reduction

4 Conclusions

1) The aspect ratio of primary α phase increases with increasing wall reduction during the spinning process. The fine fiber microstructure comes into being parallel to the axial direction with increasing wall reduction.

2) During the power spinning process of TA15, slip deformation is the main deformation mechanism accompanying with twinning to coordinate the deformation. The recrystallization of primary α phase is the major softening mechanism during hot spinning of TA15. The recrystallization fraction increases with increasing wall reduction at the experiment temperature. The microhardness increases with increasing wall reduction due to the work hardening effect.

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TA15 钛合金强热旋微观组织演变

陈 勇，徐文臣，单德彬，郭 斌

哈尔滨工业大学 材料科学与工程学院，哈尔滨 150001

摘 要：研究 TA15 钛合金热强旋过程中的微观组织演变，探讨壁厚减薄率对 TA15 钛合金微观组织演变的影响。变形过程中，滑移变形是主要的变形机制，孪晶起到协调变形的作用。微观结构逐渐转变为细小的纤维组织，并且初生 α 晶粒的长径比随着壁厚的减薄而增加，再结晶分数和显微硬度也随着减薄率的增加而增加。

关键词：微观组织演变；热强旋；TA15 合金

(Edited by YUAN Sai-qian)