Rare Metal Materials and Engineering
Volume 51, Issue 12, December 2022
Available online at www.rmme.ac.cn

Science Press

Cite this article as: Tan Haibing, Zhao Zibo, Yang Jiuxu, et al. Connection Between Local Microstructure Heterogeneity and Local Texture in Deformed Near-α Titanium Alloy[J]. Rare Metal Materials and Engineering, 2022, 51(12): 4385-4388.

ARTICLE

Connection Between Local Microstructure Heterogeneity and Local Texture in Deformed Near-α Titanium Alloy

Tan Haibing[1,2], Zhao Zibo[2], Yang Jiuxu[2], Liu Yuanhong[2], Wang Qingjiang[2], Liu Jianrong[2], Zhu Shaoxiang[2]

[1] School of Materials Science and Engineering, University of Science and Technology of China, Shenyang 110016, China; [2] Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China

Abstract: A heterogeneous microstructure was found in a compressed near-α titanium alloy with a bimodal microstructure. The effect of the local texture on microstructural morphology was analyzed by electron backscattering diffraction techniques. Advanced orientation data processing was performed to study the micro-texture of primary α (α_p) and β. The results show that there is a close relationship between local microstructure heterogeneity and local texture. The deviation angle θ can be used to quantitatively evaluate the orientation relationship (OR) between α_p and the surrounding β grains from Burgers OR. The fractions of the α_p/β boundary with small θ are always higher in the regions where coarse β grains exist than in the regions where the β grain is completely recrystallized. The orientation relationship between α_p and β affects the recrystallization of prior β during deformation; it also exerts effects on the morphology of the transformed α phase by variant selection.

Key words: titanium; EBSD; local texture; recrystallization; microstructure

The uniformity of the grain size and local texture in metals and alloys has attracted much attention from both fundamental and technological viewpoint. Deformation often generates a range of microstructural heterogeneities in titanium alloys[1], and predicting and controlling micro-structural evolution during thermomechanical processing are two of the most important tasks in engineering due to the extensive use of titanium alloys in aerial industries[2-6].

For $\alpha+\beta$ and near-α titanium alloys, heterogeneity in the local orientation distribution is often observed in bimodal microstructures[7]. Our recent work has shown that the connection between crystallographic orientation and geometrical direction of the lamellae α is inherent in titanium alloy[8]. Sharma et al[9] examined the morphology of α plates formed during $\beta\rightarrow\alpha$ transformation in Ti-4.5Fe-6.8Mo-1.5Al. They found that the total degree of α plate nucleation increases with increasing grain boundary misorientation of β/β. Shi et al[10] recently studied the variant selection of grain boundaries α in Ti-5553. They also suggested that the morphology of the grain boundary α is affected by the β/β boundary's nature. The study of the relationship between β texture intensity and microstructural morphology in a β-annealed near-α titanium alloy showed that the microstructural morphology of transformed α colony is influenced by the intensity of the β (110) texture[11]. Additionally, our another work found that both the dissolution of the equiaxed α_p and growth of the prior β grains are influenced by the deviation angle, θ, that quantitatively evaluates the deviation of the orientation relationship (OR) between α_p and the surrounding β grains from Burgers OR during $\alpha+\beta$ annealing[12].

To date, the effect of the local texture on the microstructural morphology have been studied. Those results imply that the local texture has a significant influence on the local morphology during heat treatment and cooling processing. However, few studies have focused on the deformed material and connections between the heterogeneity of the local microstructure and the micro-texture. In the present study, we investigated connection between the heterogeneity of the local microstructure and texture in deformed Ti65 titanium alloy in

Received date: May 24, 2022
Foundation item: National Science and Technology Major Project (J2019-VI-0005-0119); Youth Innovation Promotion Association CAS (2020193)
Corresponding author: Zhao Zibo, Ph. D., Associate Professor, Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, P. R. China, Tel: 0086-24-23971959, E-mail: zbzhao@imr.ac.cn

Copyright © 2022, Northwest Institute for Nonferrous Metal Research. Published by Science Press. All rights reserved.

an $\alpha+\beta$ phase field. This connection may be related to the root of heterogeneous microstructures and homogeneous properties in annealed titanium alloy due to microstructural heredity.

1 Experiment

The as-received material used in this study was Ti65 billet with a composition of Ti-5.8Al-4.2Sn-3.4Zr-0.5Mo-0.8W-1.0Ta-0.3Nb-0.4Si-0.05C (wt%). The β-transus temperature was ~1040 °C. The specimen with 25 mm in diameter and 36 mm in length was manufactured along the axial direction of the billet. After maintaining at 995 °C for 15 min, the specimen was compressed to height reduction of 70% with a deformation velocity of 15 mm/min in an ANS-CMT5205 testing machine. Upon completion of the deformation, the specimen was air-cooled directly. The purpose of the deformation was to make the prior β grain recrystallize incompletely. All microstructure determination focused on the central region of the compressed specimen. For optical microscope observation, the sample was mechanically polished and etched in Kroll's reagent (1% HF, 2.5% HNO_3, and 96.5% H_2O). For EBSD microstructure observation, the sample was polished by electro-polishing in a solution of 5% perchloric acid, 35% butanol, and 60% methanol at about −35 °C with an applied potential of 30 V.

To understand the origin of differences in the local orientation distribution, advanced EBSD data post-processing was applied to reconstruct the prior β grains. First, the secondary α (α_s) laths were selected from the EBSD orientation maps by differentiating α_p grains and α_s according to morphological differences in the optical microscope image. Next, the prior β-orientation maps were calculated from the orientation of measured α_s according to the Burgers orientation relationship (OR) as stated in Ref.[12-14].

2 Results and Discussion

After compression, the microstructure is bimodal as shown in Fig. 1a (CD: compression direction; R_1 and R_2: two radial directions, i. e. RD) and more microstructural information can be seen in our previous work[15]. A high-magnification image shows that the microstructure is heterogeneous, and the prior β grain size differs from one region to another. In Zone I as shown in Fig.1b, fine prior β grains with a size of ~20 μm are easily identified via a continuous film of grain boundary α. However, in Zone II (Fig. 1c), coarse β grains which are inferred from the large α colony crossing several primary α grains are observed. Furthermore, the prior β boundaries are difficult to distinguish because boundary α is inconsecutive. It can be deduced that the heterogeneity of the microstructure is probably due to incomplete recrystallization associated with microstructural heredity from the as-received billet.

The local texture was determined at several locations around the center of the sample. In the present work, we did not observe any obvious macrozones, although the macrozones have often been observed in as-received near-α titanium alloys. This phenomenon can be attributed to a larger deformation along the previous elongation direction of the billet partly, which can efficiently break up the macrozones as stated by Gey et al[1]. Fig. 2 shows representative EBSD analysis for two local regions with typical microstructures described in Fig.1b and 1c. In the region that is recrystallized (Fig. 2a), a relatively homogeneous orientation distribution is observed. The main α texture is a $<11\bar{2}0>$//CD fiber texture, while the {0001} pole is concentrated around some RDs. In contrast, as illustrated in Fig. 2b, a relatively high texture intensity of six unequally strong texture components is observed in a {0001} pole figure in the region with a coarse α colony. It should be noted that this textural feature generally indicates a strong prior β texture and variant selection occurring during the $\beta\rightarrow\alpha$ phase transformation.

The crystallographic orientation of transformed α laths is strongly influenced by the β texture. Fig.3 displays the β grain orientation which is reconstructed from the α phase orientation map shown in Fig. 2. Meanwhile, the deviation angle[12,16], θ, of the orientation relationship between the α_p grain and the neighboring β grain from the Burgers OR is calculated. The reconstructed β grain maps suggest a close link between α local texture and local orientation of parent β grains in deformed near-α titanium alloys. In the region where the microstructure has fine recrystallized prior β grains (Fig. 3a), these prior β grains always provide different neighboring grain orientations. However, a strong local β texture is observed in Fig.3b, and the neighboring grains have relatively similar orientation. The θ analyses show that 15.4% of the α_p/β phase boundary has less than 15° misorientation from the Burgers OR within the less-textured zones (Fig.3a). However, in the zone with a coarse microstructure shown in Fig.3b, the Burgers OR is kept in 35.6% of the cases.

Retaining the α_p/β Burgers OR in titanium alloys is not

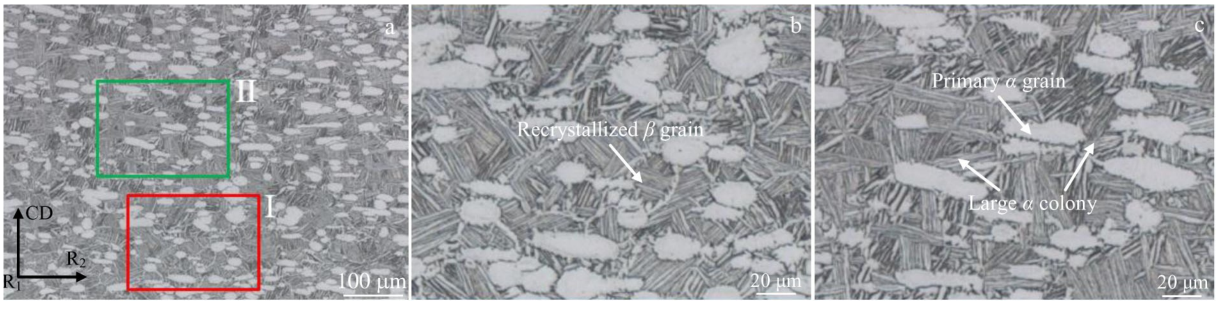

Fig.1 OM microstructures of the Ti65 alloy after deformation (a) and enlarged Zone I (b) and Zone II (c) marked in Fig.1a

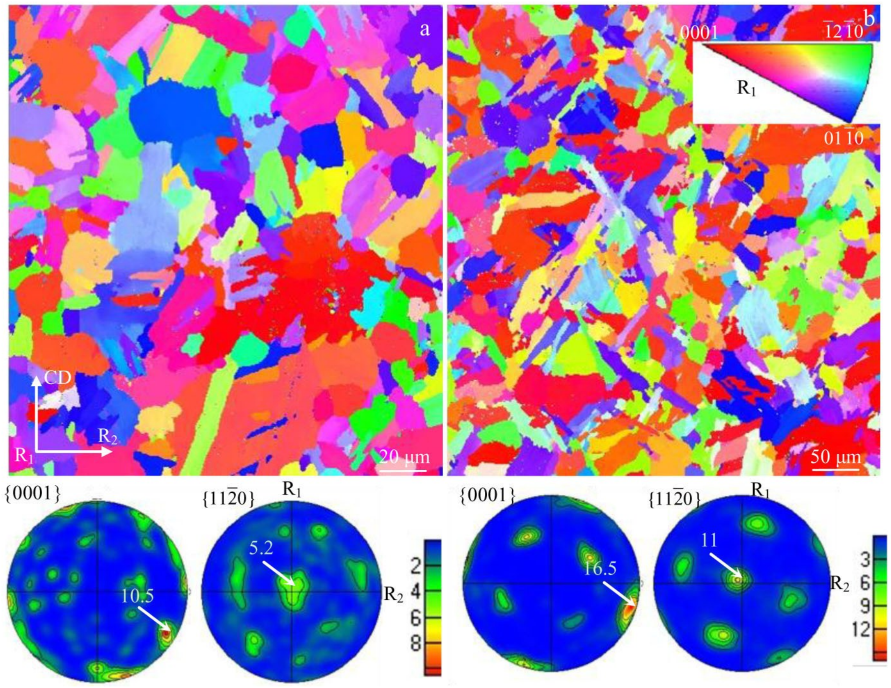

Fig.2 Representative EBSD maps and corresponding pole figures of the zones: (a) recrystallized microstructure and (b) coarse β grains

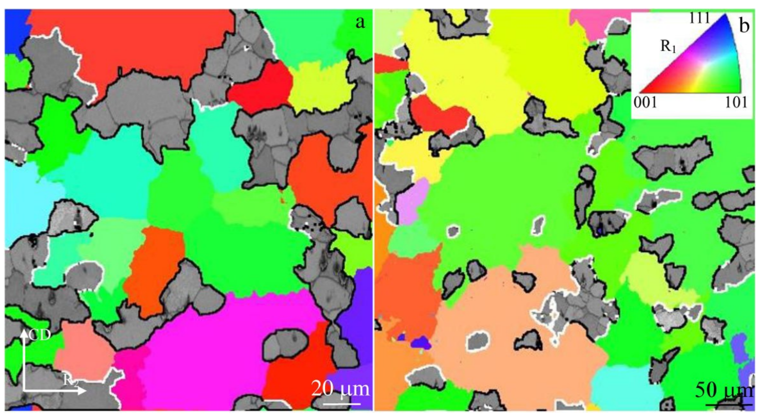

Fig.3 EBSD maps of reconstructed β for the zone with recrystallized microstructure (a) and coarse β grains (b) (low (≤15°) and high (>15°) deviation angle, θ, from Burgers OR between α_p, is represented by BC (band contrast) map, and the surrounding β phase are depicted as white and black lines)

expected; unfortunately, the neighboring α_p/β often keeps the Burgers OR, and macrozones have often been observed in billets and disks of near-α titanium alloys[1,7,17-19]. Indeed, the α_p/β phase boundary is an important microstructural parameter in titanium alloys with bimodal microstructure. During deformation in $\alpha+\beta$ phase field, the effect of β recrystallization leading to more random orientation has been extensively studied as a function of process parameters[20], and it is clear that this process is strongly local orientation dependent. Some research state that the α_p grains contribute to increase in the dislocation generation rate and development of surrounding deformation zones in the β matrix[3]. Meanwhile, there is orientation dependence in the orientation gradients[21]. Therefore, the β recrystallization process is also dependent on the neighboring α_p/β orientation to some extent. Previous work has shown that an easy slip transmission across the α/β interface can be attributed to the Burgers OR between the α and the β phase[22-24]. Thus, at local zones in which the Burgers OR of neighboring α_p/β have been destroyed, β grains recrystallize more easily, and heterogeneous microstructures with relative random local texture are more likely to produce after deformation. Inversely, it can be deduced that the local strains around α_p/β boundaries may be low in the zones where most of the α_p/β boundaries obey the Burgers OR within a small angle and recrystallize less efficiently. Thus, the OR between the α_p/β not only affects the growth of the prior β grains during the annealing process[12] but also affects the recrystallization of the prior β during deformation.

According to the above analysis, heterogeneity in the local texture may be one of the reasons for heterogeneity in microstructures during the deformation process. Furthermore, during the cooling process, α variant selection has been observed during the $\beta\rightarrow\alpha$ transformation in titanium alloys. The degree of nucleation of grain boundary α appears to increase gradually with increase in the β/β boundary energy, which is related to the misorientation of neighboring β grains. Naturally, the variant selection of α_s laths is also influenced by the orientation relationship of neighboring α_p/β and β/β. Thus, a homogenous microstructure with a distinct grain boundary α phase is found in the zone where β grain is completely recrystallized as shown in Fig. 1b. Inversely, in cases where the α_p/β phases are in Burgers OR[7] or neighboring β grains have a common <110> β pole[24], variant selection during the $\beta\rightarrow\alpha$ phase transformation will occur and result in the local texture as well as large α colonies in the microstructure as shown in Fig.1c.

3 Conclusions

1) There is a close link between the local micro-structural morphology and local texture distribution in Ti65 alloy with bimodal microstructure.

2) The low misorientation angles, $\theta<15°$, are more likely to be found in the regions with coarse β grains than in the regions where β grains are completely recrystallized.

3) Various microstructure evolution mechanisms, such as β recrystallization and variant selection, are affected by the crystallographic orientation of α and β phase.

References

1 Gey N, Bocher P, Uta E *et al*. *Acta Materialia*[J], 2012, 60(6-7): 2647
2 Zherebtsov S, Murzinova M, Salishchev G *et al*. *Acta Materialia*[J], 2011, 59(10): 4138
3 Vo P, Jahazi M, Yue S. *Metallurgical and Materials Transactions A*[J], 2008, 39: 2965
4 Warwick J L W, Jones N G, Bantounas I *et al*. *Acta Materialia*[J], 2013, 61(5): 1603
5 Banerjee D, Williams J C. *Acta Materialia*[J], 2013, 61(3): 844
6 Chen H. *Rare Metal Materials and Engineering*[J], 2011, 40(6): 946
7 Germain L, Gey N, Humbert M *et al*. *Acta Materialia*[J], 2005, 53(13): 3535
8 Zhao Z B, Wang Q J, Wang H *et al*. *Journal of Applied Crystallography*[J], 2018, 51(4): 1125
9 Sharma H, Bohemen S M C van, Petrov R H *et al*. *Acta Materialia*[J], 2010, 58(7): 2399
10 Shi R, Dixit V, Viswanathan G B *et al*. *Acta Materialia*[J], 2016, 102: 197
11 Zhao Z B, Wang Q J, Hu Q M *et al*. *Acta Materialia*[J], 2017, 126: 372
12 Zhao Z B, Wang Q J, Liu J R *et al*. *Acta Materialia*[J], 2017, 131: 305
13 Leo Prakash D G, Honniball P, Rugg D *et al*. *Acta Materialia*[J], 2013, 61(9): 3200
14 Glavicic M G, Kobryn P A, Bieler T R *et al*. *Materials Science and Engineering A*[J], 2003, 346(1): 50
15 Zhao Z B, Wang Q J, Liu J R *et al*. *Metallurgical and Materials Transactions A*[J], 2018, 49: 4937
16 Shi R, Dixit V, Fraser H L *et al*. *Acta Materialia*[J], 2014, 75: 156
17 Glavicic M G, Bartha B B, Jha S K *et al*. *Materials Science and Engineering A*[J], 2009, 513-514: 325
18 Germain L, Gey N, Humbert M *et al*. *Acta Materialia*[J], 2008, 56(16): 4298
19 Birosca S, Buffiere J Y, Karadge M *et al*. *Acta Materialia*[J], 2011, 59(4): 1510
20 Banerjee D, Pilchak A L, Williams J C. *Materials Science Forum*[J], 2012, 710: 66
21 Raabe D, Zhao Z, Park S J *et al*. *Acta Materialia*[J], 2002, 50(2): 421
22 Suri S, Viswanathan G B, Neeraj T *et al*. *Acta Materialia*[J], 1999, 47(3): 1019
23 Bridier F, Villechaise P, Mendez J. *Acta Materialia*[J], 2005, 53(3): 555
24 Bhattacharyya D, Viswanathan G B, Denkenberger R *et al*. *Acta Materialia*[J], 2003, 51(16): 4679

变形近α钛合金局部组织不均匀性与局部织构的关联性

谭海兵[1,2]，赵子博[2]，杨久旭[2]，刘远宏[2]，王清江[2]，刘建荣[2]，朱绍祥[2]

(1. 中国科学技术大学 材料科学与工程学院，辽宁 沈阳 110016)

(2. 中国科学院 金属研究所，辽宁 沈阳 110016)

摘　要：一种具有双态组织的近α钛合金经压缩变形后微观组织呈现出不均匀性。利用电子背散射衍射技术分析了局部织构对组织形貌的影响，通过取向数据处理研究了初生α相（α_p）和β相微织构。结果表明，局部组织不均匀性和局部织构之间具有紧密联系。引入角θ定量分析α_p相与相邻β相偏离Burgers取向关系程度，发现在具有粗大β晶粒的区域内具有较小θ角的α_p/β界面体积分数高于完全再结晶的β晶粒区域。α_p相和β相之间的取向关系不仅影响原始β晶粒变形过程中再结晶，还通过影响变体选择对转变α相形貌产生影响。

关键词：钛合金；电子背散射衍射；局部织构；再结晶；微观组织

作者简介：谭海兵，男，1986年生，博士，高级工程师，中国科学院金属研究所，辽宁 沈阳 110016，电话：024-23971959，E-mail：hibine.tan@163.com