Materials Characterization 106 (2015) 218–225

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Effects of strain rates on deformation twinning behavior in α-titanium

Tongbo Wang, Bolong Li *, Mian Li, Yingchao Li, Zhenqiang Wang, Zuoren Nie

College of Material Science and Engineering, Beijing University of Technology, Beijing 100124, China

ARTICLE INFO

Article history:
Received 11 December 2014
Received in revised form 22 April 2015
Accepted 12 May 2015
Available online 22 May 2015

Keywords:
Commercial pure titanium
High strain rate
Deformation twins
EBSD

ABSTRACT

The deformation twins of commercial pure titanium were investigated under the split Hopkinson pressure bar compression with different strain rates. It was demonstrated that the types of twins induced by high-speed compression included $\{11\bar{2}2\}$, $\{11\bar{2}4\}$ contraction twins and $\{10\bar{1}2\}$, $\{11\bar{2}1\}$ extension twins. Furthermore, the quantities of the deformation twins at the high strain rates were more pronounced than those at the low to medium speed deformation. The content of $\{11\bar{2}2\}$ twin increased with the strain rate, while $\{11\bar{2}1\}$ twin's quantity decreased slightly with the increasing strain rate. The semi-quantitative relationship between twin density and strain rates was derived and discussed, which indicated that twin density was nonlinearly proportional to the strain rate.

© 2015 Elsevier Inc. All rights reserved.

1. Introduction

The deformation behavior of hexagonal close-packed (hcp) metallic materials is complicated due to the activation of both different slip systems and twinning systems [1]. In the past several decades, the occurrence of deformation twinning in hcp metallic materials under low speed deformation has been widely reported [2–5]. In terms of the application of hcp metallic materials in high strain rate circumstances [6], much more attention should be paid to its high-speed deformation behavior. As is known [7,8], α-titanium is a typical hcp metallic material, whose ratio of c to a is 1.587. Owing to its low symmetry, α-titanium's deformation is governed by both dislocation slipping and twinning. In fact, the plastic deformation of α-titanium is caused mainly by dislocation slipping. Meanwhile, twinning can transform the grain orientation with a lower Schmid factor to the benefit orientation for dislocation slipping. Therefore, high-speed deformation twinning behavior becomes a significant part of α-titanium's plastic deformation mechanism [9].

For hcp structural α-titanium, the type of dislocation slipping includes <a> and <a + c> type. The main dislocation slip systems consist of $\{1\bar{1}00\}\langle 11\bar{2}0\rangle$, $\{0002\}\langle 11\bar{2}0\rangle$ and $\{10\bar{1}1\}\langle 11\bar{2}3\rangle$, whose critical shear stresses are 30 MPa, 150 MPa and 125 MPa, respectively [10]. On the basis of less independent slip systems and lower stacking fault energy, twins become the main factor for further deformation by adjusting the hard orientation to the soft one. Deformation twins are formed by the mutual shearing of parallel lattice plane, and they belong to an important mechanism for plastic deformation. In the low-speed plastic deformation, the main twins include $\{10\bar{1}2\}$, $\{11\bar{2}1\}$ and $\{11\bar{2}2\}$. Among these, $\{10\bar{1}2\}$ extension twin is one of the most active twins induced by deformation at ambient temperature, and $\{11\bar{2}2\}$ twin belonged to the contraction twins [10,11]. Rosi [12] has suggested that the deformation of $\{1\bar{1}00\}$ slip system and $\{10\bar{1}2\}$, $\{11\bar{2}1\}$, $\{11\bar{2}2\}$ twinning system should be more active in the quasi-static plastic deformation.

Jonas et al. [13] investigated the twinning behavior of commercial pure titanium at the quasi-static compression, suggesting that the critical strain for twinning was sensitive to the strain rate. The $\{11\bar{2}2\}$ twin is the most popular type, and a large number of $\{11\bar{2}2\}$–$\{10\bar{1}2\}$ twins and a few $\{10\bar{1}2\}$–$\{11\bar{2}2\}$ twins were generated during the quasi-static compression. Moreover, the presence of low Schmid factor twins was established as well as the absence of potential high Schmid factor twins, and the high Schmid factor twins needed the dislocation slipping for further deformation. A. Serra and his coworkers [14] reported that $\{11\bar{2}1\}$ and $\{11\bar{2}2\}$ twins had blocked or synergistic effects on the different dislocation slip systems, and pointed out that the dislocation-twin structure induced by deformation greatly contributed to the strength of the material, which was consistent with other results [11,15,16]. Research on dislocation-twin structure became a significant issue, and further study [17] found that the interaction between $\{11\bar{2}1\}$ and (a + c) type dislocation slipping was beneficial to the strain

---

* Corresponding author at: College of Material Science and Engineering, Beijing University of Technology, China.
E-mail address: blli@bjut.edu.cn (B. Li).

http://dx.doi.org/10.1016/j.matchar.2015.05.016
1044-5803/© 2015 Elsevier Inc. All rights reserved.

Table 1
Chemical composition of commercial pure titanium (wt%).

Element	Fe	C	N	H	O	Ti
wt.%	0.30	0.05	0.04	0.015	0.15	Bal.

hardening. α-Fe [18], copper [19,20], and aluminum [21] could generate twins during high-speed deformation, but it was difficult to form twins during the low-speed deformation. In particular, the content of α-titanium's twin can increase under high-speed deformation, which can enhance particular texture [22,23]. However, the effects of strain rates (≥1000/s) on the type and content of the twin need more detailed study and discussion.

In the present paper, the effects of the strain rate (ranging from 1500/s to 3500/s) on deformation twinning behavior of α-titanium were investigated. It aimed to elaborate on the relationship between the twinning behavior and the strain rate. Besides, the paper makes an effort to provide an initial theory for the high-speed deformation mechanism of hcp materials.

2. Experimental procedure

The as-annealed commercial pure titanium (grade 1) was selected as a model material, whose chemical composition is shown in Table 1. Its microstructure consisted of equiaxed grains with an average size of 50 μm, and no twins could be seen. The cylindrical specimens with the dimensions of Φ4 × 4 mm were cut from the as-annealed commercial pure titanium through electrical discharging cutting. In addition, the error of dimension was controlled in the range of 0.02 mm, and the roughness of specimens' surface was 1.6.

2.1. High-speed compression

The device employed to realize the high-speed deformation was the split Hopkinson pressure bar (SHPB), which was made up by two high-strength steel bars with the diameter of 14.5 mm. The striker bar has a length of 200 mm. The input and output bars' signals could be obtained by the strain gauges. The strain, the strain rate, and the stress could be calculated by the signals. The different strain rates were attained by adjusting the gas pressure to the striker bar, and the relationships between them were 0.07 atm—1500/s, 0.11 atm—2500/s, and 0.165 atm—3500/s. The cylindrical specimen and the pressure bars must be coaxial. Moreover, the contacting surface between the sample and the bar was coated with Vaseline to minimize the transverse friction. During high-speed compression, the strain was limited to 10% by the blocking ring, which was a steel tube with a thickness of 3.6 mm.

2.2. Microstructural analysis

2.2.1. EBSD

As-impacted specimens were coarsely grinded and electro-polished for Electron Backscatter Diffraction (EBSD) testing, and the electro-polishing liquid was a solution of 60% perchloric acid (6 ml) and glacial acetic acid (94 ml). The electro-polishing was performed at 35–40 V, 120 s, and ambient temperature. These samples were examined in a Quanta FEG 650 scanning electron microscope, and the backscatter signal data were obtained by Nordlys collection probe. HKL Channel 5 software was used to process the data, in order to analyze the misorientation, IPF map, the type and content of the twin, and the Schmid factor of the different grains.

2.2.2. TEM

Microstructure observation of commercial pure titanium impacted at the strain of 0.11 was performed on JEM-2010F transmission electron microscopy (TEM). Samples were mechanically polished to a thin sheet. A disk with a diameter of 3 mm was twin-jet electro-polished of in a 60% $HClO_4$ 50 ml-$CH_3(CH_2)_3OH$ 350 ml-CH_3OH 600 ml solution at 248 K and 20 V. Sub-structures were obtained at 200 keV by the standard TEM techniques, and selected area diffraction patterns were analyzed at the twinning boundaries.

3. Results and discussion

3.1. Initial microstructure and dynamic strain rate

The IPF map can illustrate the microstructure and orientation distribution of the grain. Fig. 1 shows the IPF map and the misorientation distribution of as-annealed commercial pure titanium. As shown in Fig. 1(a), the annealed microstructure reveals the equiaxed grains with an average size of 50 μm, indicating a recrystallized microstructure. It should be emphasized that there are few twins inside the grains. Fig. 1(b) presents the misorientation distribution, where the data with misorientation of less than 2° are excluded. Obviously, the distribution profile of the large-angle and small-angle grain boundaries in annealed titanium was consistent with the theoretical curve and without the distinct peaks. Similar to the IPF map, the misorientation distribution clearly indicated that no preferred orientation was induced by twinning in as-annealed α-titanium.

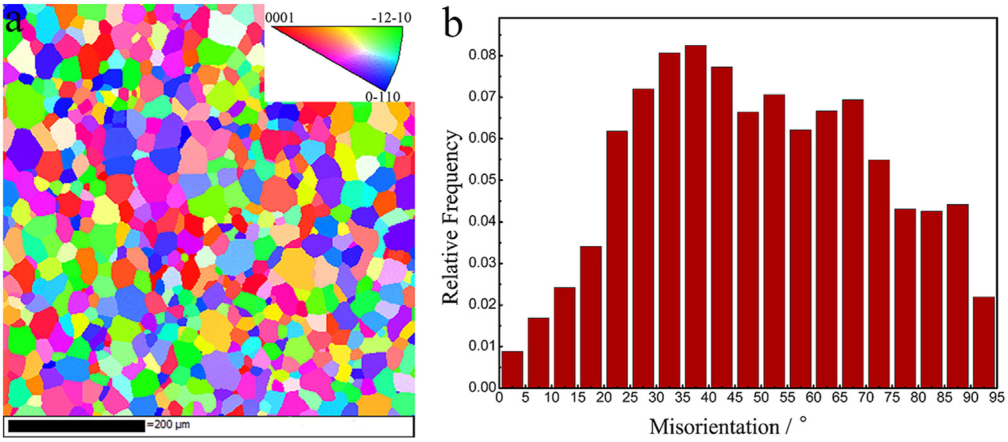

Fig. 1. IPF map and misorientation distribution of as-annealed commercial pure titanium.

Download English Version:

https://daneshyari.com/en/article/7970299

Download Persian Version:

https://daneshyari.com/article/7970299

Daneshyari.com