Journal of Materials Science & Technology xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Materials Science & Technology

journal homepage: www.jmst.org

Fatigue crack tip plastic zone of α + β titanium alloy with Widmanstatten microstructure

Yingjie Ma[a,b], Sabry S. Youssef[a,b], Xin Feng[a], Hao Wang[a,b], Sensen Huang[a,c], Jianke Qiu[a], Jiafeng Lei[a,b,*], Rui Yang[a,b,*]

[a] Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China
[b] University of Science and Technology of China (USTC), Hefei 230026, China
[c] Northeastern University, Shenyang 110089, China

ARTICLE INFO

Article history:
Received 17 August 2017
Received in revised form 11 February 2018
Accepted 9 March 2018
Available online xxx

Keywords:
Titanium alloy
Widmanstatten microstructure
CTPZ
Slip
Deformation twinning

ABSTRACT

The recent studies had focused on the fatigue crack propagation behaviors of α + β titanium alloys with Widmanstatten microstructure. The fascinated interest of this type of microstructure is due to the superior fatigue crack propagation resistance and fracture toughness as compared to other microstructures, which was believed to be related to the fatigue crack tip plastic zone (CTPZ). In this study, the plastic deformation in fatigue CTPZ of Ti-6Al-4V titanium alloy with Widmanstatten microstructure was characterized by scanning electron microscope (SEM) and electron backscatter diffraction (EBSD). The results showed that large-scale slipping and deformation twinning were generated in fatigue CTPZ due to the crystallographic feature of the Widmanstatten microstructure. The activation of twinning was related to the rank of Schmid factor (SF) and the diversity of twin variants developing behaviors reflected the influence of SF rank. The sizes of CTPZ under different stress intensity factors (K) were examined by the white-light coherence method, and the results revealed that the range of the plastic zone is enlarged with the increasing K (or crack length), while the plastic strain decreased rapidly with the increasing distance from the crack surface. The large-scale slipping and deformation twinning in Widmannstatten microstructure remarkably expanded the range of fatigue CTPZ, which would lead to the obvious larger size of the observed CTPZ than that of the theoretically calculated size.

© 2018 Published by Elsevier Ltd on behalf of The editorial office of Journal of Materials Science & Technology.

1. Introduction

Titanium and titanium alloys are extensively used as structural materials for aerospace, biomedical and marine applications due to their high specific strength (strength/density), favorable performance at elevated temperature and corrosion resistance [1,2]. Ti-6Al-4V is an α + β titanium alloy and one of the most widely used structural materials for aerospace applications [3–6], moreover, this alloy is estimated to be about 60% of employed titanium alloys production [7,8].

Fracture toughness (K_{IC}) and fatigue crack growth resistance have been extensively scrutinized due to their importance for aerospace applications [9]. The previous investigations concerning the effect of microstructure on fatigue crack growth of Ti-6Al-4V alloy proved that β heat-treatment leads to Widmanstatten microstructure, which could provide higher resistance to fatigue crack growth comparing with α + β heat-treatment [10,11]. For α + β titanium alloys with Widmanstatten microstructure, the propagation of fatigue crack is sensitive to the mean size of α colony that composed of the almost parallel α lamellas [12–14]. Fatigue crack growth rates (FCGR) of titanium alloys with Widmanstatten microstructure, where crack bifurcation arises at the boundaries of α colonies, can be considerably decreased [15–17]. Many studies declared that FCGR and K_{IC} are highly influenced by the microstructure due to the impact of Crack Tip Plastic Zone (CTPZ) [18–21]. For Widmanstatten microstructure, the high level of crack closure effect induced by the large size of CTPZ and the curving crack propagation route, will decrease FCGR and promote K_{IC} [22]. Fatigue CTPZ features are studied for the Ti-6Al-4V alloy with equiaxed and lamellar microstructures including the appearance of twin and the dissipated energy in CTPZ [23]. However, a systematic study concerning fatigue CTPZ of titanium alloy with Widmanstatten microstructure still needs to be executed, such as the comprehensive influence of slip and twin on fatigue CTPZ, et.al.

For Ti-6Al-4V alloy, the plastic deformation behavior is mainly affected by the hexagonally close-packed (h.c.p) α phase due to the

---

* Corresponding authors.
E-mail addresses: jflei@imr.ac.cn (J. Lei), ryang@imr.ac.cn (R. Yang).

https://doi.org/10.1016/j.jmst.2018.03.012
1005-0302/© 2018 Published by Elsevier Ltd on behalf of The editorial office of Journal of Materials Science & Technology.

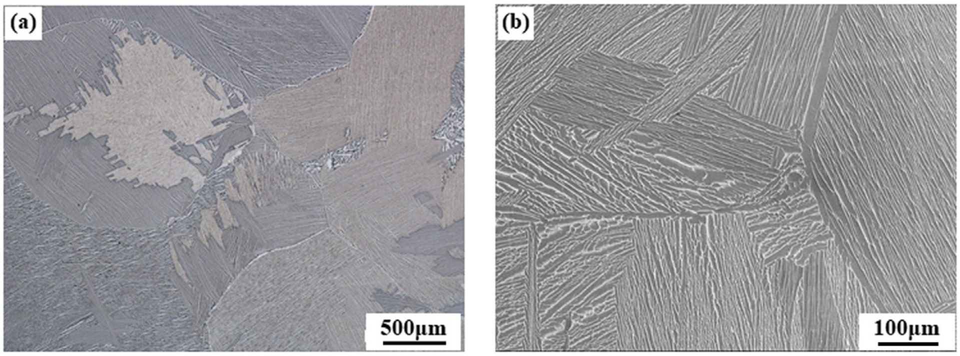

Fig. 1. Optical (a) and SEM (b) morphology of Ti-6Al-4V alloy with Widmanstatten microstructure obtained by furnace cooling from β phase region.

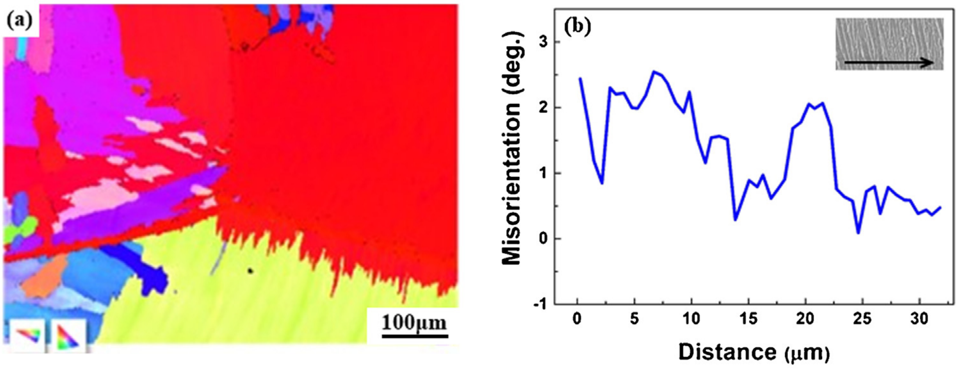

Fig. 2. The EBSD morphology of Ti-6Al-4V alloy with Widmanstatten microstructure (a), and (b) the small misorientation between neighboring α lamellas in a single α colony.

Table 1
Chemical composition of Ti-6Al-4V alloy employed in this study.

Materials	Chemical composition (wt.%)				
	Al	V	O	Fe	Ti
Ti-6Al-4V	6.05	4.10	0.06	0.05	Bal.

low volume fraction of the body-centered cubic (b.c.c) β phase [5]. The plastic deformation of Ti-6Al-4V alloy occurs by slipping or/and twinning [24–26]. In Widmanstatten microstructure, the large-size of α colony, in which α lamellas exhibits the same crystal orientation, prompts a slight amount of slip inside the unit volume as compared with what happens in the equiaxed microstructure. Consequently, the deformation twinning is desired to accommodate the required plastic deformation. However, several studies [27–31] about deformation twinning of titanium alloys rarely focused on the Widmanstatten microstructure.

In the present work, we characterized the fatigue CTPZ of Ti-6Al-4V alloy with Widmanstatten microstructure, including large-scale slip and deformation twinning close to crack surface. Furthermore, the large-scale twins were investigated by discussing the influence of microstructure and Schmid factor (SF). Twin variants were illustrated, and the activation of the twin variant with very low-rank SF was reported. Finally, the influence of deforming modes on the size of CTPZ was discussed by comparing the measured and calculated sizes of CTPZ with different length of fatigue crack.

2. Material and experimental procedures

The material used in this study is Ti-6Al-4V alloy with a chemical composition detailed in Table 1. The β transus temperature of the employed alloy is $970 \pm 5\,^{\circ}\mathrm{C}$. The Widmanstatten microstructure of Ti-6Al-4V alloy with coarse prior β grains and α colonies was obtained after heat-treatment at 1000 °C for 60 min followed by furnace cooling. The Optical and SEM morphologies of Ti-6Al-4V alloy with Widmanstatten microstructure are shown in Fig. 1. The average size of prior β grains is about 550 μm and the width of α platelets is close to 2 μm. The EBSD morphology of the obtained microstructure of Ti-6Al-4V alloy is depicted in Fig. 2. The α lamellas in a single α colony approximately exhibit the uniform crystal orientation (Fig. 2a), while the neighboring α lamellas usually show a small misorientation as shown in Fig. 2b.

Single-edge specimen (Fig. 3) with an initial crack of 2 mm in length was prepared for the observation of CTPZ during fatigue crack propagation (FCP). The FCP experiments were carried out on the MTS 810 test system with a sinusoidal waveform of 20 Hz and $R = 0.1$, where R indicates the ratio of minimum to maximum stress. Scanning electron microscope (SEM) was used for the characterization of plastic behavior in the CTPZ, and electron backscattered diffraction (EBSD) analysis was carried out to investigate the mechanism of deformation twinning. The SF based on slipping or twinning and the 3D crystal viewer of twins and parent were confirmed by EBSD. The two-dimensional and three-dimensional morphologies of plastic deformation area near the fatigue crack were observed and measured by the white-light coherence method. Then the measured size of CTPZ was compared with the theoretically calculated size.

3. Result and discussion

3.1. Slipping in CTPZ

Fig. 4 shows a large-scale straight slipping line in the fatigue CTPZ. The Burgers relationship of $(110)_{\beta}//(0002)_{\alpha}$ and

Please cite this article in press as: Y. Ma, et al., J. Mater. Sci. Technol. (2018), https://doi.org/10.1016/j.jmst.2018.03.012

Download English Version:

https://daneshyari.com/en/article/7951841

Download Persian Version:

https://daneshyari.com/article/7951841

Daneshyari.com