Materials Science & Engineering A 684 (2017) 1–13

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

The influence of defect structures on the mechanical properties of Ti-6Al-4V alloys deformed by high-pressure torsion at ambient temperature

Zheng-Yang Hu[a], Xing-Wang Cheng[a,b], Zhao-Hui Zhang[a,b,*], Hu Wang[a], Sheng-Lin Li[a], Galiya F. Korznikova[c], Dmitry V. Gunderov[d,e], Fu-Chi Wang[a,b]

[a] School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, PR China
[b] National Key Laboratory of Science and Technology on Materials under Shock and Impact, Beijing 100081, PR China
[c] Inst for Metals Superplasticity Problems, RAS, Ufa, Russia
[d] The Institute of Molecule and Crystal Physics, USC RAS, Ufa, Russia
[e] Nabereznye Chelny Institute of the Kazan Federal University, Nabereznye Chelny, Russia

ARTICLE INFO

Keywords:
High-pressure torsion
Mechanical behaviors
Defect-structures
Grain refinement

ABSTRACT

The high-pressure torsion method was employed to deform Ti-6Al-4V (TC4) alloy. The ambient temperature and high pressure were used to restrain the grain growth. Clear images showing the microstructure evolution of the deformed TC4 alloys were obtained using SEM, TEM and HRTEM. It was found that the HPT-deformed TC4 alloys contain a high density of dislocations and many defect structures. These dislocations were found to be generated on one or both sides of the elongated grains, and the dislocation lines were able to move across the elongated grains (mostly at ~60°) to form an uncondensed dislocation wall. Although deformation twins did not appear in the alloys deformed at intermediate strains ($\gamma \leq 23.1$), quantities of (10−12) < 10-1-1 > tensile twins containing prismatic stacking faults were observed in the specimens deformed at a much larger plastic strain ($\gamma \geq 157$). The hardness-strain behaviors of the TC4 alloys were similar to those of pure Ti, which have a maximum hardness followed by a strain softening at large strains. In addition, the formation of the omega phase was suppressed due to the dissolution of substitutional Al and V. The alloy that received the highest levels of strain ($\gamma \sim 357$) was found to have a nanoscale structure (~49.41 nm) with non-equilibrium GBs, as well as an increased microhardness (~424 HV) and yield strength ($\sigma_S \sim 960$ MPa). The effects of these defect-structures on the mechanical behaviors of a TC4 alloy are mainly determined by their structures' sizes according to Hall–Petch relationship. However, the effect of this mechanism reduces at large strains due to the existing high-dense dislocations and non-equilibrium grain boundaries.

1. Introduction

Ti and its alloys are very popular as competitive metal matrix materials and have received considerable attention for potential aerospace and biomedical applications due to their low density, relatively high strength and good biocompatibility [1,2]. However, compared with steel, the mechanical properties of Ti alloys still need to be improved to fulfill the increasing demand for engineering materials in the aviation and automotive industries [3]. Severe plastic deformation (SPD) techniques, such as high-pressure torsion (HPT), equal channel-angular pressing (ECAP) and accumulative roll bonding (ARB), have usually been applied to achieve ultrafine-grained (UFG, 100–1000 nm) and nano-grained (NG, ≤100 nm) metals with improved mechanical properties due to their inherent simplicity and good applicability. Among these methods, HPT has been acknowledged as the most effective grain refinement method because it can provide a large plastic strain. Importantly, this method involves significantly higher hydrostatic pressure, which can inhibit crack formations in the specimen during the deformation process; this feature would imply that there is almost no limitation on the applicable strain. Consequently, this technique allows SPDs of intermediate-strength and high-strength materials such as steels and titanium [4,5]. Furthermore, HPT is also fairly simple, making the method quite reliable and cost-effective compared to other SPD processes [6,7]. Considerable research has been carried out on pure Ti deformed using the HPT method. The experimental results reveal that a significant improvement in the mechanical properties of the deformed metals can be obtained [8,9]. However, limited data are available on the microstructures and mechanical properties of the Ti-6Al-4V (TC4) alloy processed by HPT. Fu [10] and Wang [11] have investigated the influence of phase

* Corresponding author at: School of Materials Science and Engineering, Beijing Institute of Technology, Beijing 100081, PR China.
E-mail address: zhang@bit.edu.cn (Z.-H. Zhang).

http://dx.doi.org/10.1016/j.msea.2016.12.033
Received 24 June 2016; Received in revised form 7 December 2016; Accepted 8 December 2016
Available online 09 December 2016
0921-5093/