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Influences of pre-torsion deformation on microstructure and mechanical properties of pure titanium subjected to subsequent tension deformation

Jie LIU [a], Fuguo LI [b,*], Han CHEN [b]

[a] *School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China*
[b] *State Key Laboratory of Solidification Processing, School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China*

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Abstract A series of experimental studies was carried out to investigate the influences of pre-torsion on microstructure evolution, mechanical properties, and fracture appearance of pure titanium subjected to subsequent tension deformation. An introduction of pre-torsion strain can improve the materials' mechanical properties through micro hardness evaluation. That is, the micro hardness of tensile samples with pre-torsion deformation is much higher than that of samples processed by single torsion or tension. It can be seen from the microstructure that pre-torsion deformation can be used to refine grains better and control grains' morphology by combining subsequent tension. The results indicate that the grains are refined most evidently for tensile samples with 2 turn pre-torsion deformation. Moreover, fracture analysis indicates that tensile samples with pre-torsion strain can present good comprehensive performance. In conclusion, pre-torsion deformation plays an important role in improving comprehensive performance and controlling microstructure evolution on pure titanium subjected to later tension deformation.

1. Introduction

Pure titanium and its alloys are widely used in the aviation industry due to their excellent properties such as low density and high specific intensity.[1–3] Besides, for its good biocompatibility, excellent corrosion resistance, and low modulus of elasticity, the use of pure titanium and its alloys for automotive and biological applications is increasing.[4,5]

* Corresponding author. Fax: +86 29 88492642.
E-mail addresses: ljjie@mail.nwpu.edu.cn (J. LIU), fuguolx@nwpu.edu.cn (F. LI), chenhan590@mail.nwpu.edu.cn (H. CHEN).
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Pure titanium is usually shaped by bulk forming where the material is actually subjected to large plastic deformation. It is well known that large plastic deformation can be used to prepare billets with desired shapes and excellent comprehensive properties.[6,7] A torsion test is an ideal means to provide large strain dominated by shear deformation.[8] In addition, a torsion test can achieve large uniform deformation without rupture or strain localization, and thus it can accumulate a higher plastic strain than tension and compression deformation.[9,10] Therefore, torsion deformation has been paid extensive attention to in recent years. The microstructures, mechanical properties, and deformation behaviors of materials during torsion have been studied by many scholars.[10–18] However, the accumulated plastic strain is limited in single torsion deformation, and thus the torsion deformation is often combined with other deformation modes to obtain a higher strain accumulation with the purpose of improving the comprehensive performance of materials, for instance, high pressure torsion (HPT)[19,20] and twist extrusion (TE).[21,22] Unfortunately, the applications of these severe plastic deformation processes are limited because of their higher costs, complicated manufacturing processes, and products with small sizes.[6]

Recently, a kind of simple and practical deformation process called combined tension and torsion has been proposed and studied by many scholars.[23–25] It has been shown that an introduction of pre-tension has important effects on microstructures and mechanical properties of materials subjected to later torsion deformation. It is because different loading patterns lead to different dislocation movements.[25] Thus it is reasonable to speculate that microstructures and mechanical properties have different trends of variation for tensile samples via pre-torsion deformation.[26] However, scarce special studies on microstructure evolution and mechanical properties of materials in tension deformation with pre-torsion strain have been conducted. Therefore, there is a detailed investigation of the impacts of pre-torsion on the microstructure evolution, mechanical properties, and fracture morphology of pure titanium subjected to subsequent tension deformation at room temperature in this paper. The detailed investigation may provide a new idea for improving materials' comprehensive performances by combining different deformation modes, which can provide theoretical and experimental supports to the preparation of materials with excellent high-tough-matching using traditional metal materials.

2. Experiments and methods

Pure titanium Ti-GR2 (ASTM) rods were annealed at 823 K for 1 h in argon atmosphere and then cooled in air for removing residual stress. The rods after annealing were subjected to torsion and tension deformation, and the detailed dimensions about the samples are shown in Fig. 1(a). Torsion and tension tests were carried out at room temperature using an XC-10 wire torsion testing machine and an Instron 3382 tension testing machine, respectively. The torsion speed and tension strain rate are 30 r/min and 10^{-3} s^{-1}, respectively. The first group of rods was subjected to tension deformation and torsion deformation separately, and the maximum tensile strain and torsion turns were 0.212 (marked as Torsion-0-Tension) and 3.1 turns (marked as Torsion-3.1). A schematic diagram of the experimental procedure is shown in Fig. 2(a). The second group of rods was subjected to single torsion deformation, and samples after twisting 1, 2, and 3 turns were marked as Torsion-1, Torsion-2, and Torsion-3. A schematic diagram of the experimental process is shown in Fig. 2(b). The third group of rods was firstly subjected to torsion deformation for 1, 2, and 3 turns, and then the twisting samples were subjected to tension deformation until an occurrence of failure. The elongations were 19.6%, 13.5%, and 9.84%, respectively, and the three deformed samples were marked as Torsion-1-Tension, Torsion-2-Tension, and Torsion-3-Tension. A schematic diagram of the technological process is shown in Fig. 2(c).

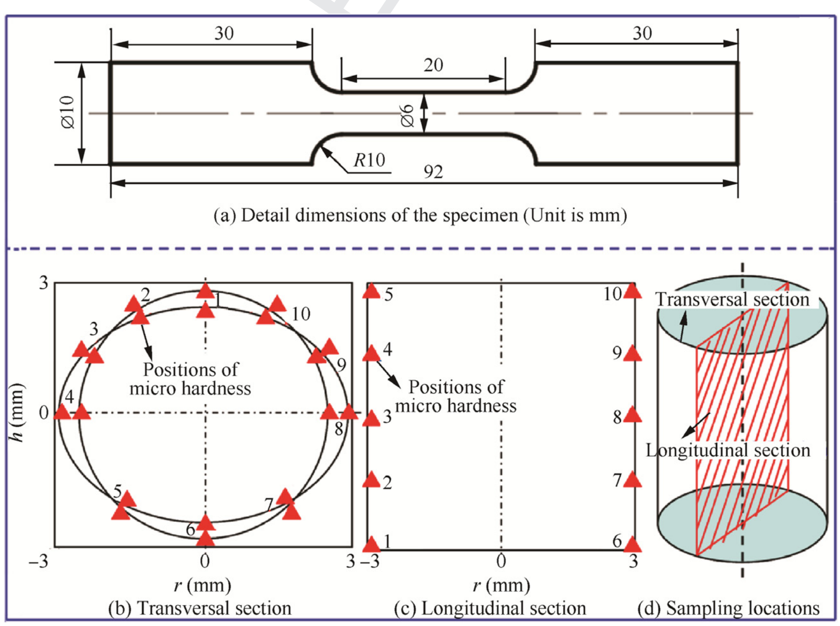

Fig. 1 Detailed dimensions of specimens and positions for micro hardness measurements on transversal and longitudinal sections as well as sampling locations for microstructure.

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