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Analysis of shear stress promoting void evolution behavior in an α/β Ti alloy with fully lamellar microstructure

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ABSTRACT

With the help of X-ray synchrotron tomography, in situ tensile tests have been performed on Ti-6Al-4V titanium alloy with full lamellar microstructure. The rendered 3D images have shown that void could nucleate as soon as the material yields, although local stress triaxiality (T = 0.472) seems not to be high and even tends to maintain a constant value in the following damage steps(T = 0.474–0.510). It can be inferred that local stress triaxiality could not be the dominating factor during damage development in this current work. By combining this result with the result of *post mortem* analysis by SEM and EBSD, it can be found that voids preferentially nucleate and propagate along either the α/β

interface, or along shear bands within one grain/colony, or at grains/colonies boundary. This could be interpreted by the role of shear stress during this processing. Based on the location of voids, shear stress can be taken into consideration at α/β interface, shear band within one grain and grains/colonies boundaries, respectively. The origins of shear stress at different scales seems correlated to local microstructure inhomogeneity and subsequent heterogeneous plastic deformation at different scales. Void nucleation and propagation could depend on this local shear stress instead of stress triaxiality.

1. Introduction

Titanium and its alloys play an important role in modern industries i.e. aerospace, biomedical, and chemical processing and synthesis, due to the integrated properties including excellent mechanical properties, unrivalled corrosion resistance and outstanding biocompatibility [1]. Ti-6Al-4V(TA6V), because of its integrated properties and lower cost, is considered as the most common titanium alloy [2,3]. Depending on the thermo-mechanical treatment or heat treatment of such (α + β) titanium alloy, the microstructure morphologies or mechanical properties may vary in a wide range [3]. It is well recognized that the mechanical properties are mainly dependant on microstructural features; furthermore, failure behavior of Ti alloys could be affected by these features significantly [3,4].

Depending on the thermo-mechanical treatment of such (α + β) titanium alloy, different microstructures can be obtained, which can lead to different mechanical properties [5–7]. Two extreme microstructure morphologies are fully lamellar microstructure and equiaxed microstructure. The fully lamellar microstructure could present a lower strength and lower ductility, but better fatigue crack propagation resistance; whereas the equiaxed microstructure can show a better initiation fatigue crack resistance. Any bimodal microstructure is a combination of equiaxed and lamellar microstructures that combine both mechanical properties and can present well-balanced fatigue properties.

From the literature it can be noticed that most of researchers' attention was paid on fully equiaxed [8–13] or bimodal microstructure [14–16] rather than fully lamellar microstructure [17,18]. However, after casting or welding process, the existence of fully lamellar microstructure cannot be avoided. In order to enhance the mechanical properties of components with this structure, it is necessary to focus on the failure mode of TA6V presenting a fully lamellar microstructure. Because TA6V is consisting of HCP α phase and BCC β phase, microstructural inhomogeneity is inevitable. This may induce an

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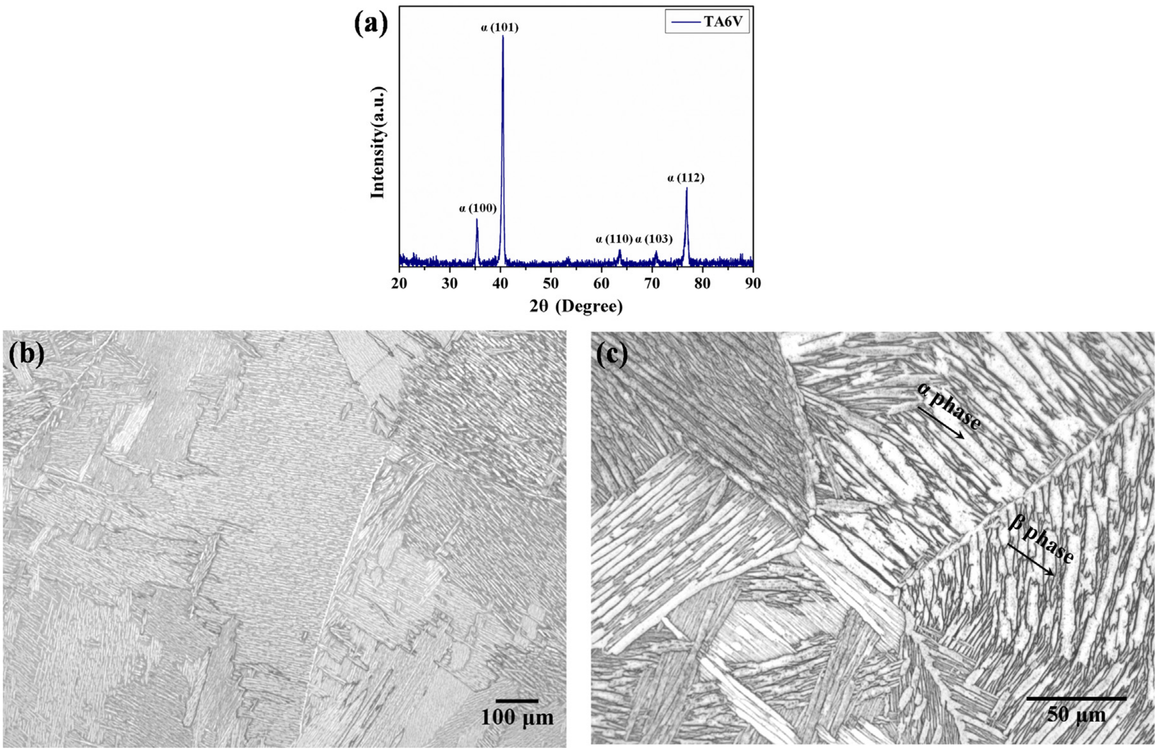

Fig. 1. X-ray diffraction spectrum(a), microstructure morphology at low magnification (b) and high magnification (c) for the Ti-6Al-4V sample before deformation (α phase in bright, and β phase in dark).

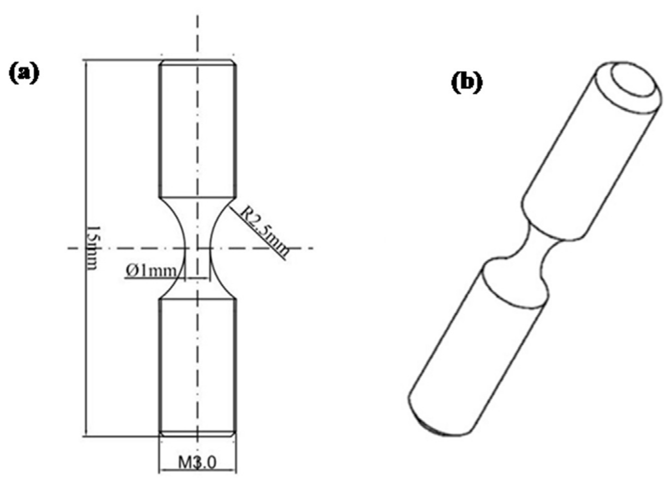

Fig. 2. Schematic illustration of tensile sample, (a) geometry of the sample, (b) 3D view [33].

inhomogeneous stress/strain distribution, which could play a key role in the ductile damage evolution [19].

In order to describe this microstructure inhomogeneity and consequently, heterogeneous stress/strain distribution at micro-scale, microstructure-based micromechanical modeling approach can be adopted [13,20–24]. Consequently, numerous models were proposed and validated to elucidate micromechanical behavior with microstructure features for dual phase metals, especially for dual phase steels [20–24].

As indicated by Q.Xue et al. [25], microstructure inhomogeneity, internal boundary and favorable orientation of grains or colonies could affect the distribution of strains which could determine the site for shear band formation, on which void nucleation occurs. Because of local constraints induced by microstructure distribution heterogeneities, heterogeneous void growth can be found for Ti-6Al-4V alloy during damage development [13]. Unfortunately, up till now, for TA6V dual phase titanium alloys, the micro-mechanism of heterogeneous stress/strain distribution and its acting on damage evolution is not completely known.

This work aims at deepening our understanding in the origins of plastic deformation inhomogeneities and its role in the failure processing of TA6V alloy. Based on the authors' previous work [26], ductile damage, a process driven by plastic deformation, is the main failure mode for such alloy. It is commonly proved that the procedure can be divided into three steps [16], void nucleation, void growth and void coalescence. With the help of 3D tomography technology, it is possible to investigate the action of such heterogeneities in the development of ductile failure [13,26–29].

Hence, in the present work, in situ tensile tests are carried out based on synchrotron X-ray micro-tomography for Ti-6Al-4V alloy with a fully lamellar microstructure in order to track and analyze void evolution. Then, post mortem procedure are performed by scanning electron microscopy(SEM) and electron backscatter diffraction (EBSD) in order to analyze the micro-mechanism of plastic deforming heterogeneities in terms of microstructure inhomogeneities. Then, shear behavior, correlated with such plastic deforming heterogeneities, is analyzed at the micro-scale and grain-scale. This leads to the formation of micro-shear band, shear band initiation or neighbor grains /colonies rotation, respectively. The influence of these shear induced mechanisms on void nucleation and propagation are also analyzed and interpreted in this work.