Accepted Manuscript

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PII: S0749-6419(13)00195-2
DOI: http://dx.doi.org/10.1016/j.ijplas.2013.10.004
Reference: INTPLA 1717

To appear in: *International Journal of Plasticity*

Received Date: 22 June 2013
Revised Date: 1 October 2013

Please cite this article as: Smith, B.D., Shih, D., McDowell, D.L., Cyclic Plasticity Experiments and Polycrystal Plasticity Modeling of Three Distinct Ti Alloy Microstructures, *International Journal of Plasticity* (2013), doi: http://dx.doi.org/10.1016/j.ijplas.2013.10.004

Cyclic Plasticity Experiments and Polycrystal Plasticity Modeling of Three Distinct Ti Alloy Microstructures

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Abstract

Cyclic deformation experiments have been performed on three α–β titanium alloy microstructures to facilitate calibration of two distinct simplified polycrystal plasticity model frameworks. These microstructures include Ti-6Al-4V β-annealed, Ti-18 in a solution-treated, age-hardened (STA) condition (Fanning, 2011), and Ti-18 with a beta-annealed, slow-cooled, age-hardened (BASCA) treatment. Experimental results suggest that superior uniaxial yield strength, ultimate strength and tensile ductility are achieved through the STA processing for the Ti-18 material. This processing route produces a fine bi-modal microstructure. In contrast, corresponding measured properties of the Widmanstätten morphology generated via the BASCA heat treatment were lower. The constitutive frameworks for the two different simplified polycrystal plasticity models and associated flow rules have been outlined and the model parameters have been estimated for cyclic loading such that the simulated stress-strain response is consistent with experimental results for each of the titanium microstructures investigated. In view of envisioned application to fatigue, focus is placed on cyclic behavior after the initial loading cycle(s). Certain estimated parameters differ for each model among microstructures, mainly related to elasticity, threshold for slip system yielding, and work hardening; this suggests limits on a simplified model framework and the need for in situ studies of dislocation-interface reactions and the relative role of β-phase fraction.

1. Introduction

Titanium alloys are utilized in many advanced engineering applications owing to its high strength-to-weight ratio, corrosion resistance, and high temperature strength. Although utilization of Ti alloys in industry is often inhibited by high cost, it remains highly attractive for biomedical implants, sporting goods, and several aerospace applications where the demand for exceptional properties out-weigh the additional cost (Boyer, 1996). The mechanical properties of α-β Ti alloys are strongly influenced by microstructure and crystallographic texture formed as a result of thermo-mechanical processing (Bache and Evans, 2001; Lütjering, 1998). Depending on the processing route, the microstructure morphology can be tailored to variations of the following forms: an equiaxed structure composed of equivalent sized primary α-phase (HCP) grains, a duplex structure comprised of a mixture of α-phase and colony phase (secondary α with BCC β-phase) grains, or a fully lamellar, a.k.a. Widmanstätten, structure composed of prior β-phase grains containing α-phase laths (Welsch et al., 1994). These different microstructures exhibit compromise relationships between beneficial and detrimental effects on the performance of the alloy (Lütjering, 1999). The broad span of achievable properties for α + β titanium alloys has naturally drawn researchers to investigate the correlation between its microstructure morphology and mechanical behavior (Filip et al., 2003; Lin et al., 1984). These experimental works have attempted to isolate