Accepted Manuscript

Mechanical response of stainless steel subjected to biaxial load path changes: Cruciform experiments and multi-scale modeling

Manas V. Upadhyay, Anirban Patra, Wei Wen, Tobias Panzner, Steven Van Petegem, Carlos N. Tomé, Ricardo A. Lebensohn, Helena Van Swygenhoven

PII: S0749-6419(17)30604-6

DOI: 10.1016/j.ijplas.2018.05.003

Reference: INTPLA 2346

To appear in: *International Journal of Plasticity*

Received Date: 2 November 2017

Revised Date: 4 May 2018

Accepted Date: 5 May 2018

Please cite this article as: Upadhyay, M.V., Patra, A., Wen, W., Panzner, T., Van Petegem, S., Tomé, C.N., Lebensohn, R.A., Van Swygenhoven, H., Mechanical response of stainless steel subjected to biaxial load path changes: Cruciform experiments and multi-scale modeling, *International Journal of Plasticity* (2018), doi: 10.1016/j.ijplas.2018.05.003.

Mechanical response of stainless steel subjected to biaxial load path changes: cruciform experiments and multi-scale modeling

Manas V. Upadhyay[a], Anirban Patra[b,1], Wei Wen[b], Tobias Panzner[c], Steven Van Petegem[a], Carlos N. Tomé[b], Ricardo A. Lebensohn[b], Helena Van Swygenhoven[a,d*]

[a] Photons for Engineering and Manufacturing Group, Laboratory for Synchrotron Radiation Condensed Matter, Synchrotron Radiation and Nanotechnology Division, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[b] MST-8, Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[c] Neutrons for Imaging and Activation Group, Laboratory for Neutron Scattering, Neutrons and Muons Division, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland
[d] Neutrons and X-rays for Mechanics of Materials, IMX, Ecole Polytechnique Federale de Lausanne, CH-1012 Lausanne, Switzerland
* corresponding author: helena.vanswygenhoven@psi.ch

Abstract:

We propose a multi-scale modeling approach that can simulate the microstructural and mechanical behavior of metal or alloy parts with complex geometries subjected to multi-axial load path changes. The model is used to understand the biaxial load path change behavior of 316L stainless steel cruciform samples. At the macroscale, a finite element approach is used to simulate the cruciform geometry and numerically predict the gauge stresses, which are difficult to obtain analytically. At each material point in the finite element mesh, the anisotropic viscoplastic self-consistent model is used to simulate the role of texture evolution on the mechanical response. At the single crystal level, a dislocation density based hardening law that appropriately captures the role of multi-axial load path changes on slip activity is used. The combined approach is experimentally validated using cruciform samples subjected to uniaxial load and unload followed by different biaxial reloads in the angular range $[27°, 90°]$. Polycrystalline yield surfaces before and after load path changes are generated using the full-field elasto-viscoplastic fast Fourier transform model to study the influence of the deformation history and reloading direction on the mechanical response, including the Bauschinger effect, of these cruciform samples. Results reveal that the Bauschinger effect is strongly dependent on the first loading direction and strain, intergranular and macroscopic residual stresses after first load, and the reloading angle. The microstructural origins of the mechanical response are discussed.

Keywords: Bauschinger effect; C mechanical testing; C finite elements; B crystal plasticity; A microstructures

1. Introduction

1.1 Background and motivation

Engineering metals and alloys are often subjected to multi-axial load path changes during their fabrication to form them into the desired shape or under service conditions. The subsequent mechanical response of these materials significantly depends on their deformation history including the loading direction and amount of plastic strain. For instance, a load reversal after a uniaxial tension, compression or shear can result in lowering the yield stress i.e. the Bauschinger effect, an extended elastic-plastic transition regime and a different hardening regime. The origin of such macroscopic behavior has to be found at the microstructural level. At the meso-scale or intergranular level, crystallographic texture evolution and anisotropy play a major role, at the microscale or intra-granular level heterogeneous dislocation activity combined with latent hardening effects have to be taken into account (Beyerlein and Tomé, 2007; Christodoulou et al., 1986; Rauch et al., 2007; Takahashi and Shiono, 1991).

Significant experimental and simulation efforts have been dedicated to understand the mechanical behavior after a 180° load path change during uniaxial tension, compression or shear of various material systems at different

---

[1] Current address: Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, Powai – 400076, India