Micromechanical modelling of elasto-viscoplastic behavior of near beta-Ti alloys: Effect of elastic anisotropy on elastic-viscoplastic transition, incompatibility stresses and slip activity

S. Lhadi, S. Berbenni, N. Gey, T. Richeton, L. Germain

Laboratoire d'Etude des Microstructures et de Mécanique des Matériaux, LEM3, UMR CNRS 7239, Labex DAMAS, Université de Lorraine, 7 rue Félix Savart 57070 Metz, France

Safaa.lhadi-khalouche@univ-lorraine.fr

Abstract

The last few years, near beta-titanium alloys benefit from a growing interest and are now competing with quasi-alpha or alpha-beta titanium alloys for airframe forging applications like landing gears and rotor systems. High strength are achieved thanks to the building up of complex microstructures. They are mainly composed of bimodal alpha constituents embedded in a retained beta matrix (with often up to 40% beta phase) [1].

The beta phase is reported to exhibit a highly anisotropic elastic behavior. The published elastic constants are however surprisingly spread with anisotropy coefficients ranging from 1 to 8 [2–5]. Moreover, the influence of the beta-phase elastic anisotropy on the mechanical response of near beta-titanium alloys with complex alpha/beta microstructure is not well understood.

Thus the present work applies an advanced micromechanical model to capture elastic/plastic incompatibilities arising in tensile or fatigue tested near beta-titanium alloys. The mechanical properties are estimated based on a recent elasto-viscoplastic self-consistent model (EVPSC) with "affine" linearization of the viscoplastic flow rule. Its allows a good description of the overall response of heterogeneous materials even when the viscoplastic flow rule is highly nonlinear [6,7].

First we consider a fully beta phase microstructure to account for the influence of the elastic anisotropy, the texture, the morphology of the beta grains on the incompatibility stresses during elastic and viscoplastic responses [8,9].

Then the same micro-mechanical approach is applied to Ti-1023 with alpha-nodular microstructure. Our numerical results show how the elastic anisotropy of both beta and alpha phases affects simultaneously the macroscopic elastic-viscoplastic transition, the microscopic fields, the slip activity for different alpha/beta phase morphologies, volume fractions and crystallographic textures.

Keywords: near beta-titanium alloys, polycrystals, homogenization, elasto-viscoplasticity, elastic anisotropy, incompatibility stresses, slip activity.

References:

[1] M. R. Chini, L. Germain, N. Gey, S. Andrieu, and T. Duval, “Advanced Microtexture Analysis of A Ti 10-2-3 Product for Better Understanding of Local Variations in Mechanical Behavior,” in *Proceedings of the 13th World Conference on Titanium*, John Wiley & Sons, Inc., 2016, pp. 1943–1948.

[2] E. S. Fisher and D. Dever, “Relation of the c′ elastic modulus to stability of b.c.c. transition metals,” *Acta Metall.*, vol. 18, no. 2, pp. 265–269, 1970.

[3] S. Fréour, E. Lacoste, M. François, and R. Guillén, “Determining Ti-17 β-phase single-crystal elasticity constants through X-ray diffraction and inverse scale transition model,” in *Materials Science Forum*, 2011, vol. 681, pp. 97–102.

[4] J.-Y. Kim and S. I. Rokhlin, “Determination of elastic constants of generally anisotropic inclined lamellar structure using line-focus acoustic microscopy,” *J. Acoust. Soc. Am.*, vol. 126, no. 6, pp. 2998–3007, 2009.

[5] S. L. Raghunathan, A. M. Stapleton, R. J. Dashwood, M. Jackson, and D. Dye, “Micromechanics of Ti–10V–2Fe–3Al: In situ synchrotron characterisation and modelling,” *Acta Mater.*, vol. 55, no. 20, pp. 6861–6872, 2007.

[6] S. Berbenni and L. Capolungo, “A Mori–Tanaka homogenization scheme for non-linear elasto-viscoplastic heterogeneous materials based on translated fields: An affine extension,” *Comptes Rendus Mécanique*, vol. 343, no. 2, pp. 95–106, 2015.

[7] C. Mareau and S. Berbenni, “An affine formulation for the self-consistent modeling of elasto-viscoplastic heterogeneous materials based on the translated field method,” *Int. J. Plast.*, vol. 64, pp. 134–150, 2015.

[8] S. Lhadi, S. Berbenni, N. Gey, T. Richeton, and L. Germain, “Micromechanical modeling of the effect of elastic and plastic anisotropies on the mechanical behavior of beta-Ti alloys,” *International Journal of Plasticity*, 2018.

[9] S. Lhadi, M.-R. Chini, T. Richeton, N. Gey, L. Germain, and S. Berbenni, “Micromechanical Modeling of the Elasto-Viscoplastic Behavior and Incompatibility Stresses of β-Ti Alloys,” *Materials*, vol. 11, no. 7, 2018.