IMPACT OF MICROSTRUCTURE-INDUCED ANISOTROPY ON THE OVERALL RESPONSE OF ELASTIC-VISCOPLASTIC POLYCRYSTALLINE METALS

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1. Introduction

It is well known [1, 2] that the overall response of the polycrystalline material in the inelastic regime is strongly influenced by the anisotropy of the single crystal related to the presence of easy- and hard-to-initiate mechanisms of plastic deformation. Prediction of the effective properties of such materials by means of mean-field schemes is a challenging task. For the case of elastic-viscoplastic material response one can use either the schemes based on the Laplace-transform technique [4] or the approaches that employ the approximate linearization in a real time space, e.g. [3, 5]. Yet another possibility is offered by computational homogenization. In the present contribution the comparison of predictions offered by mean-field schemes and finite element RVE analyses are presented for TiAl-like crystals of varying viscoplastic anisotropy and strain rate sensitivity subjected to the inelastic deformation processes involving the strain path changes.

2. Methodology and results

Within the mean-field sequential scheme the response of the Maxwell-type elastic-viscoplastic polycrystal is established by solving at each strain increment two subproblems: creep-type one (purely viscoplastic) and instantaneous one (purely elastic). In the simplest version of the sequential self-consistent scheme, when the additional accommodation step is not necessary and the grains are of the spherical shape, two interaction equations corresponding to two mentioned subproblems take the form:

$$(1) \qquad \dot{\boldsymbol{\varepsilon}}_g^v - \dot{\boldsymbol{\varepsilon}}_0^{\mathrm{V}g} = -\bar{\mathbf{M}}_*^v \cdot (\boldsymbol{\sigma}_g - \boldsymbol{\Sigma}), \quad \dot{\boldsymbol{\varepsilon}}_g^e - \dot{\boldsymbol{\varepsilon}}_0^{\mathrm{E}g} = -\bar{\mathbf{M}}_*^e \cdot (\dot{\boldsymbol{\sigma}}_g - \dot{\boldsymbol{\Sigma}})$$

where $\dot{\boldsymbol{\varepsilon}}_g^e + \dot{\boldsymbol{\varepsilon}}_g^v = \dot{\boldsymbol{\varepsilon}}_g$, $\dot{\boldsymbol{\varepsilon}}_0^{\mathrm{V}g} + \dot{\boldsymbol{\varepsilon}}_0^{\mathrm{E}g} = \dot{\mathbf{E}}$ and $\dot{\boldsymbol{\varepsilon}}_g^{v/e}$ and $\boldsymbol{\sigma}_g/\dot{\boldsymbol{\sigma}}_g$ are the viscoplastic/elastic strain rate and stress/stress rate in the grain g, while $\dot{\mathbf{E}}$ and $\bar{\boldsymbol{\Sigma}}$ the overall strain rate and the stress in the polycrystal, correspondingly. The tensors $\bar{\mathbf{M}}_*^{v/e}$ are the inverse Hill tensors for purely viscous and purely elastic problems obtained with use of the corresponding overall stiffness calculated according to the self-consistent procedure. In the case of non-linear viscoplastic polycrystals tangent or secant linearization of the local response is performed in order to use the Eshelby result.

At the level of single grain the standard formulation of rate-dependent crystal plasticity is used. The linear anisotropic Hooke's law is assumed for elasticity. Viscoplastic flow takes place by movement of dislocations on the crystallographic slip systems defined by the lattice geometry. For simplicity the Norton-type power law without hardening is assumed. It relates the slip rate and the resolved shear stress at a single slip system (for details look at [1]). FE calculations are performed using AceFEM software for the volume element of polycrystal of checkerboard distribution of randomly selected N grain orientations (Fig. 1(a)). Each grain is divided into M^3 elements. The macroscopic strain program is imposed using microperiodic boundary conditions.

Mean-field and finite element calculations are performed for a tetragonal γ-TiAl-like aggregate (L1 lattice geometry, 4 ordinary dislocations: $\{111\}\langle1\bar{1}0]$, 8 super-dislocations $\{111\}\langle10\bar{1}]$, with $\tau_c^{sup}/\tau_c^{ord} = \alpha > 1$, where α is an indicator of viscous anisotropy due to only 3 independent easy slip systems). Components of the elasticity tensors are assumed as reported in [1]. The exemplary results for a tension-compression and shear cyclic loading are shown in Fig. 1c,d. FE predictions lie between the results of the sequential method combined with the tangent and affine linearization of viscous response. For the presented example of polycrystal with

strong viscous anisotropy satisfactory agreement has been obtained when the modified tangent linearization with a tuning parameter $\beta = 3$ [6] is used in the purely viscous step.
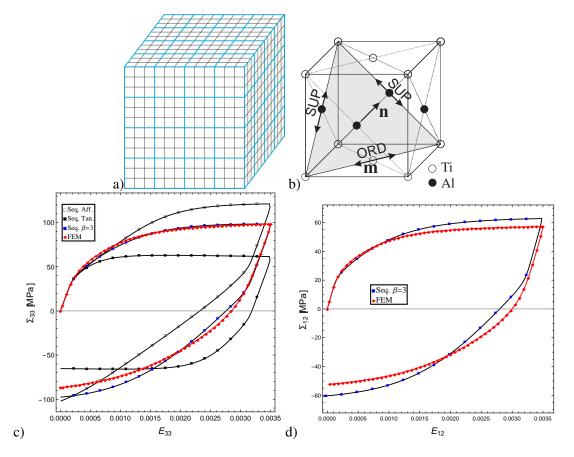

Figure 1: Example of RVE with FE mesh ($N = 64$, $M = 3$) (a); slip systems in γ-TiAl (ORD - ordinary dislocations, SUP - superdislocations) (b); overall response in tension-compression (c) and shear (d) cycle for γ-TiAl aggregate shown in (a) with exponent $n = 8$ in the local power law and an anisotropy factor $\alpha = 5$.

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