

MICROMECHANICAL MODELLING OF METALLIC MATERIALS OF HIGH SPECIFIC STRENGTH ACCOUNTING FOR SLIP-TWIN INTERACTIONS

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1. Introduction

The aim of the study is development and a preliminary validation of micromechanical model of large plastic deformations of polycrystalline materials characterized by high specific strength and low ductility (eg. Mg alloys or intermetallics). Due to lattice symmetry the number of slip systems in these materials is limited. Disadvantageous effect of this fact on ductility may be partially balanced by the initiation of other mechanism of plastic deformation - twinning. In modelling of twinning, as compared to modelling of crystallographic slip, one should account for its polarized character (uni-directionality) and appearance of new twin related orientation within the grain [1]. Nowadays growing interest in hcp metals such as magnesium or titanium alloys and intermetallics resulted in development of models of crystal plasticity accounting for twinning, e.g. [2–4]. In the paper the single grain model proposed by Gambin (cf. [5]) reformulated to incorporate twinning is used. In order to account for appearance of twin related orientations a new reorientation scheme, called Probabilistic Twin Volume Consistent (PTVC) scheme, is developed. Experiments indicate couplings between evolution of activity of slip and twin mechanisms. The hardening rule describing slip-twin interactions is proposed. Model predictions will be analyzed for hcp materials and intermetallics.

2. Model description

Twinning, similarly to slip, is realized by simple shear, however, in this case only some volume fraction of a matrix grain is sheared on the specified twin plane in the specified twin direction with the specified amount of shear γ^T . As a result the twinned sub-grain is formed. Contrary to slip mechanism twin is unidirectional. The twinned part has different, but specified lattice orientation with respect to the matrix grain, though the lattice orientation in the matrix grain is also unaltered, cf. [1]. In order to account for twinning in the proposed model we follow the standard procedure, eg. [2; 4]. Twinning is described as uni-directional slip mode. The rate of pseudo-slip $\dot{\gamma}^r$ is connected to the rate of volume fraction \dot{f}^r of twinned part created by the twin system r according to the formula $\dot{\gamma}^r = \gamma^T \dot{f}^r$. Modelling of twinning in the context of texture evolution requires taking into account the appearance of new twin-related orientation. A new method, the PTVC scheme, which originates in Van Houtte reorientation condition is developed. It takes into account the history of the deformation process and maintains the volume fraction of reoriented grains at a level that is consistent with shear activity of twins contributing to the deformation. On the other hand, contrary to Predominant Twin Reorientation scheme, cf. [3], the PTVC scheme does not require the analysis of the whole polycrystalline aggregate and the identification of any additional constants or parameters [6].

Crystal plasticity with single yield surface modified in order to incorporate twinning is used, cf. [5],[7]. The evolution of slip and twin activity is captured by the hardening rule. Following the reasoning presented in [3] the hardening rule is proposed in the form (M, N - number of slip and twin systems, respectively)

$$(1) \quad \dot{\tau}_c^r = H_{(ss)}^r \sum_{q=1}^M h_{rq}^{(ss)} \dot{\gamma}^q + H_{(st)}^r \sum_{q=2M+1}^{2M+N} h_{rq}^{(st)} \dot{\gamma}^q, \quad \dot{\tau}_c^{r+M} = \dot{\tau}_c^r, \quad r \leq M$$

$$(2) \quad \dot{\tau}_c^r = H_{(ts)}^r \sum_{q=1}^M h_{rq}^{(ts)} \dot{\gamma}^q + H_{(tt)}^r \sum_{q=2M+1}^{2M+N} h_{rq}^{(tt)} \dot{\gamma}^q, \quad r > 2M$$

and $\dot{\gamma}^q = \dot{\gamma}^q + \dot{\gamma}^{q+M}$. Hardening sub-matrices $h_{rq}^{(\alpha\beta)}$ account for the mutual interactions of the deformation mechanisms of the slip-slip, slip-twin, twin-slip and twin-twin types. These matrices have the form which distinguishes between the hardening due to slip or twinning on coplanar and non-coplanar systems. The functions $H_{(\alpha\beta)}^r$ describe the hardening of r -th slip system or r -th twin system due to activity of other slip or other twin systems. For hardening of the slip system r due to activity of slip systems the Voce-type law with saturation is prescribed in the form used in [4]. This law accounts for the athermal statistical storage of moving dislocations and dynamic recovery. For the hardening of slip system r due to twin activity the following rule is used

$$(3) \quad H_{(st)}^r = h_0^{st} \setminus \tau^r \left(f^T \setminus (f_{sat}^{st} - f^T) \right)$$

that accounts for geometrical effects of twin boundaries in reducing main free path distance and h_0^{st} and $f_{sat}^{st} \leq 1$ are the material parameters. The hardening of twin system due to slip activity is neglected or governed by the simplified linear law while the hardening of twin system due to activity of twinning is assumed similarly as in (3). The corresponding parameter $f_{sat}^{tt} < 1$ enables one to describe the saturation of the volume fraction of twins below one. In the model twinning and slip in reoriented grains is more difficult than before reorientation or even impossible. Moreover, slip in reoriented grains is severely restricted to the planes that are coplanar with the matrix-twin boundary.

3. Results

The presented model will be applied to study the material response and texture evolution for hcp materials and γ -TiAl intermetallics of equiaxed and lamellar microstructure. The performance of the developed reorientation scheme will be compared to the existing approaches and available experimental results. It should be noted that both, PTVC scheme and description of slip-twin interactions with use of the hardening rule (1-2), may be applied for different averaging schemes for polycrystal as well as other models of crystal plasticity, for example the rate-dependent model.

4. References

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