MODELLING OF MICROSTRUCTURE EVOLUTION IN METALS AND ALLOYS OF HIGH SPECIFIC STRENGTH

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1. Introduction

Metals and alloys of high specific strength and stiffness (e.g. intermetallics, Mg and Ti alloys) gain increasing interest in the automotive or aerospace industry and for biomedical applications (Ti alloys). It has its source in the advantageous relation between the element weight and its mechanical parameters combined with enhanced durability. Moreover, this interest is driven by a demand for reducing the energy (or fuel) consumption and heightening the requirements concerning the reprocessing of the worn out elements. Limitations of usage are basically caused by restricted ductility and formability. The solution to the problem is sought in two ways: by alloying or by tailoring the material microstructure by applying e.g. severe plastic deformation (SPD) process. The controlled modification of microstructure (i.e. inducing specific texture or grain refinement) requires a vast number of experiments that can be significantly reduced when the modelling framework is available. Micromechanics seems to provide a natural tool enabling understanding and description of a relation between the material microstructure and its evolution and the applied plastic deformation process. The aim of this contribution is to present, recently developed, relevant micromechanical approaches.

2. Multiscale crystal plasticity models

In order to predict texture evolution and grain refinement on a complex deformation path two-scale and three-scale models of polycrystal have been developed (Fig. 1(a)). In the two-scale version of the model [1, 2], enabling the prediction of texture evolution, the polycrystalline aggregate is subdivided into grains. In the enhanced three-scale variant [3], with the experimental reference to the development of the dislocation induced cell substructure, these grains (called at this stage metagrains) are themselves subdivided into subgrains. The calculated misorientation evolution of subgrains with respect to the reference orientation of a metagrain is an indicator of grain refinement. The notion 'subgrain', although conceptually related to the term used in quantitative metallography for domains separated by low angle boundaries, here, denotes a single component of discrete orientation at the lower-micro level.

The single grain (or the subgrain in the three-scale model) is described by means of a crystal plasticity framework. Depending on the material under consideration, relevant slip and twin systems are enabled as plastic deformation modes. Twinning is described as a pseudo-slip mode and classical viscoplastic formulation with the power law is used to relate the slip or pseudo-slip rate with the resolved shear stress. In order to account for a volume effect of twin related orientations in the texture image the probabilistic twin volume consistent (PTVC) scheme proposed in [1] is used. Additionally, the mutual slip-twin interactions are described employing there proposed hardening laws governing the evolution of critical shear stresses needed for the activation of available deformation modes.

For the transition from micro to polycrystal level in the two-scale framework the viscoplastic self-consistent scheme (VPSC) developed by Lebensohn and Tome in different variants have been considered. The variants differ by linearization procedures of the non-linear viscoplastic power law needed in order to use the Eshelby solution to the inclusion problem. In the proposed three-scale model the iso-strain Taylor and the VPSC schemes have been applied to both inter-level transitions.

3. Results

In figure 1 (b) and (c) the examples of possible predictions obtained using the developed modelling framework are shown.

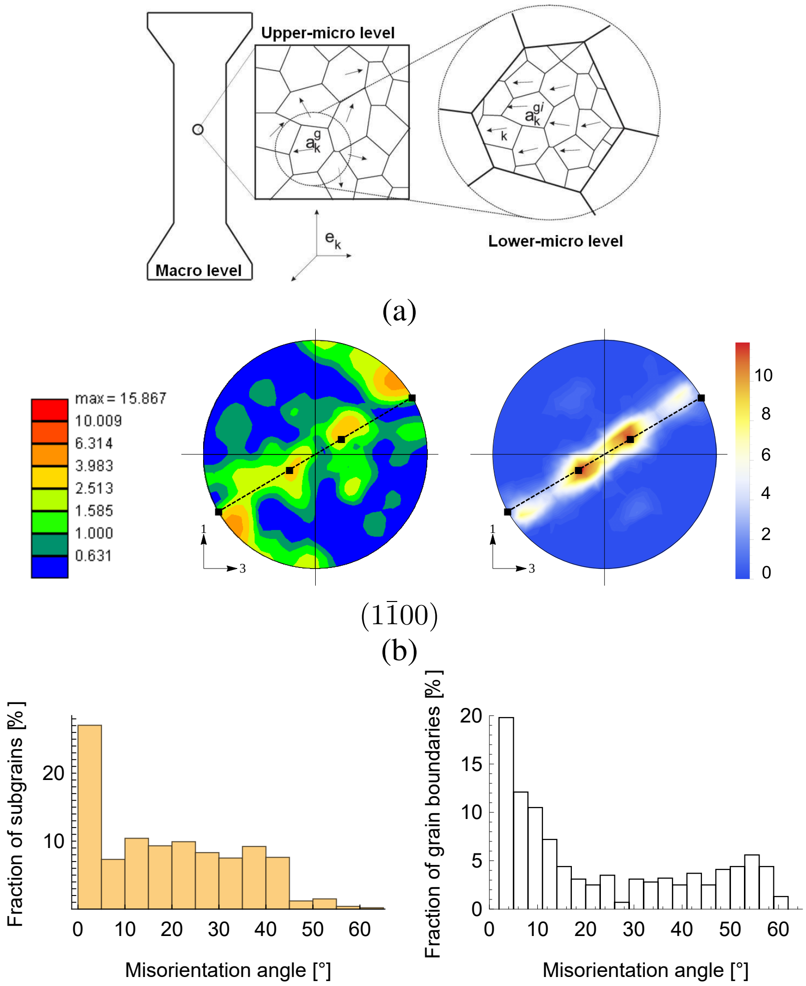

Figure 1. (a) The three-scale polycrystal model [3]; Predicted and experimental (b) texture in CP Ti (for details see [2]); (c) misorientation distribution in pure Al (for details see [3]), both subjected to four passes of equal channel angular extrusion.

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4. References

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