MODELLING MICROSTRUCTURE EVOLUTION IN SPD PROCESSES IN THE FRAMEWORK OF CRYSTAL PLASTICITY THEORY

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Summary Grain refinement and texture evolution has been analysed using two modelling approaches, namely the three-scale crystal plasticity model and the crystal plasticity finite element method. The first approach combines the Taylor iso-strain model and the visco-plastic self-consistent (VPSC) model. The second approach consists in embedding crystal plasticity constitutive equations at each integration point of the finite element mesh.

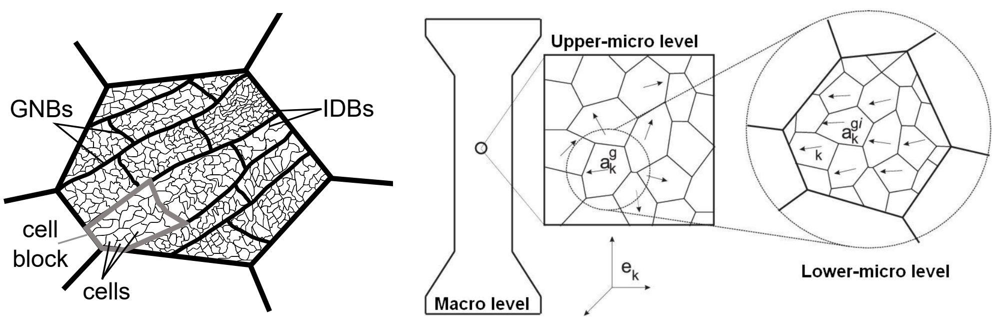
STATE OF THE ART

Modelling of texture evolution and grain refinement is currently a subject of intensive research. The evolution of crystallographic texture can be captured using mean-field models such as Taylor or VPSC [1] models. However, such approaches are unable to predict grain refinement. Therefore these classical formulations are enhanced by some addittional features. Although the developed proposals are usually physically motivated, they still do not reproduce this phenomenon sufficiently well and/or are very computationally expensive. Some potential for modelling both phenomena lies in the use of the crystal plasticity finite element method (CPFEM). Modelling twinning, which seems very important in grain refinement of many metals and alloys, is also at the stage of development. Two models presented below are developed in order to propose efficient and reliable tools for modelling the microstructure evolution of metals and alloys in severe plastic deformation (SPD) processes.

MODELLING APPROACH

The Three Scale Crystal Plasticity model

In the mean-field Three Scale Crystal Plasticity (3SCP) model [2], there are three levels, namely the macroscale level, the upper micorscale level and the lower microscale level. The lowest level corresponds to a part of a grain (a cell block) with initially slightly different orientation than the nominal parent grain orientation. The parent grain is an aggregate of such cell blocks and the interactions between blocks are managed through the VPSC model. The macroscale level represents the representative volume element RVE, which is the material point of the deformed sample. The current deformation gradient is applied to the RVE and the material response is analysed assuming relevant crystal plasticity framework at the lowest level.



a b

Figure 1: a) The basis for the idea of the 3SCP model - the schematic drawing of the dislocation induced cell substructure of a grain observed in fcc materials for small to medium accumulated plastic strain. b) Its representation by a three-scale model, cf. [2].

The Crystal Plasticity Finite Element Method

The CPFEM is now well established tool to model the material behaviour at various scales and in application to diverse processes, cf. e.g. the monograph by Roters et al. [3]. In the presented research twinning has been incorporated in the existing CPFEM procedures on the basis of the Probabilistic Twin Volume Consistent (PTVC) scheme [4]. The developed numerical model is applied to analysis of the SPD processes. By modelling a given polycrystal grain by a number of finite elements it is straightforward to account for in-grain strain inhomogeneities and the resulting grain refinement.

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RESULTS

Results of simulations using the two abovementioned modelling approaches will be compared with each other. Their validity in view of the available experimental data will be discussed. Figure 2 shows some preliminary results obtained using the two models.

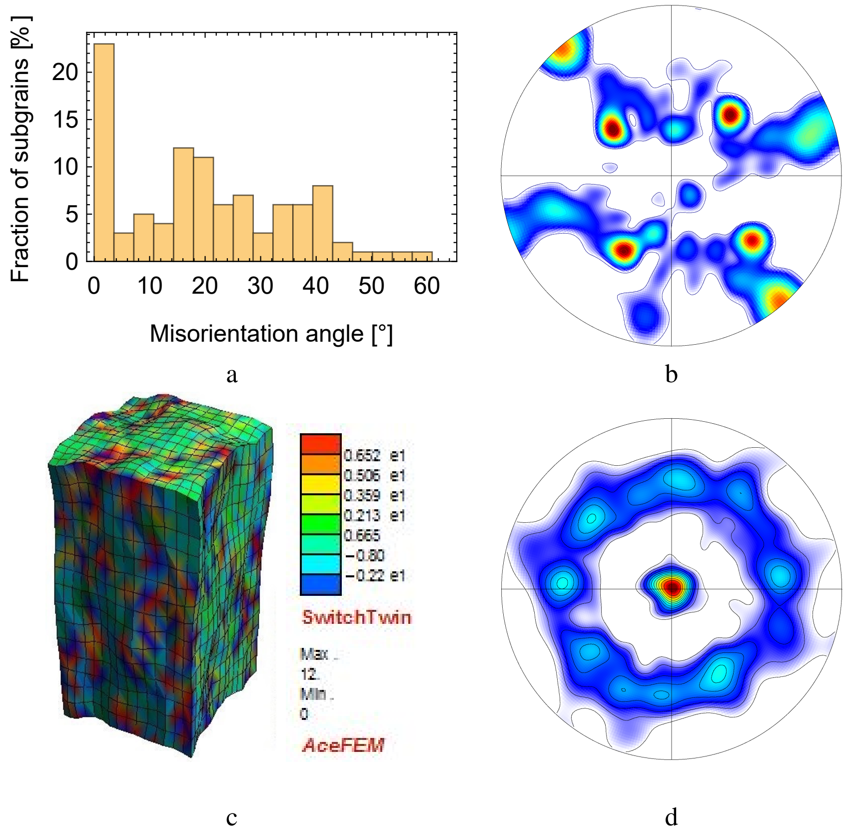

Figure 2: Preliminary results obtained with the use of both modelling approaches. a) Misorientation angle distribution and b) (111) pole figure in the fcc metal subjected to simple shear in 3SCP simulation of ECAP process for polycrystalline aggregate composed of 100x100 orientations with random initial texture. c) Deformed mesh with twinned domains and d) $\{111\}$ pole figure obtained from the CPFEM simulation of the Hadfield steel subjected to uniaxial tension with periodic boundary conditions for a polycrystalline aggregate composed of 125 grains with random initial texture. The PTVC reorientation procedure was applied in c and d. Pole figures graphics by JTEX - Software for Texture Analysis, J.J. Fundenberger, B, Beausir. Universite de Lorraine - Metz 2015.

ACKNOWLEDGEMENT

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