SIMULATIONS OF THE EQUAL CHANNEL ANGULAR PRESSING PROCESS USING CRYSTAL PLASTICITY FINITE ELEMENT METHOD WITH SOLUTION MAPPING

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1. Introduction

Simulations of equal channel angular pressing (ECAP) process using the crystal plasticity finite element method (CPFEM) are described in this paper. The ECAP process is a well known severe plastic deformation (SPD) process, in which the material deforms by shearing. To obtain considerable grain refinement, multiple passes through an angular channel need to be conducted. One approach that enables the understanding of mechanisms leading to texture evolution and grain refinement is to use CPFEM simulations. Modelling multiple passes using the finite element method formulated in the Lagrangian approach is however challenging due to strong element distortions. The possible solution is the application of remeshing and solution mapping. However, solution mapping of micro-mechanical variables that is consistent with the macroscopic response is not a trivial task. The crystallographic orientations and tensorial variables cannot be interpolated directly, because it would lead to spurious rotations. Instead, one can pass the orientations and tensorial variables from point to another point or one can make use of spherical linear interpolation algorithm (SLERP) [**?**] to deal with interpolating the variables. While the first approach will necessarily lead to less accurate results, in the second one there are additional difficulties. One arises from the fact that the SLERP algorithm deals only with interpolating between two points, and in general 3D case interpolation between four points is needed. The other question is how to properly interpolate points close to sharp orientation changes.

2. Modelling framework

In the CPFEM implementation used, the total Lagrangian setting together with the Euler backward integration scheme has been applied. The deformation gradient is multiplicatively decomposed into elastic and plastic parts. The plastic velocity gradient is the sum of shears on slip systems. Simulations reported in this paper have been conducted using the rate-independent formulation with a single yield surface [**?**, **?**]. The yield surface F is defined as follows [**?**, **?**]:

$$F = \left(\sum_r \left(\frac{\tau^r}{\tau_c^r} \right)^{2n} \right)^{1/(2n)} - 1\,, \tag{1}$$

where τ^r is the resolved shear stress and τ_c^r is its critical value. Shear rates $\dot{\gamma}^r$ depend on the stress state by the associated flow rule, namely

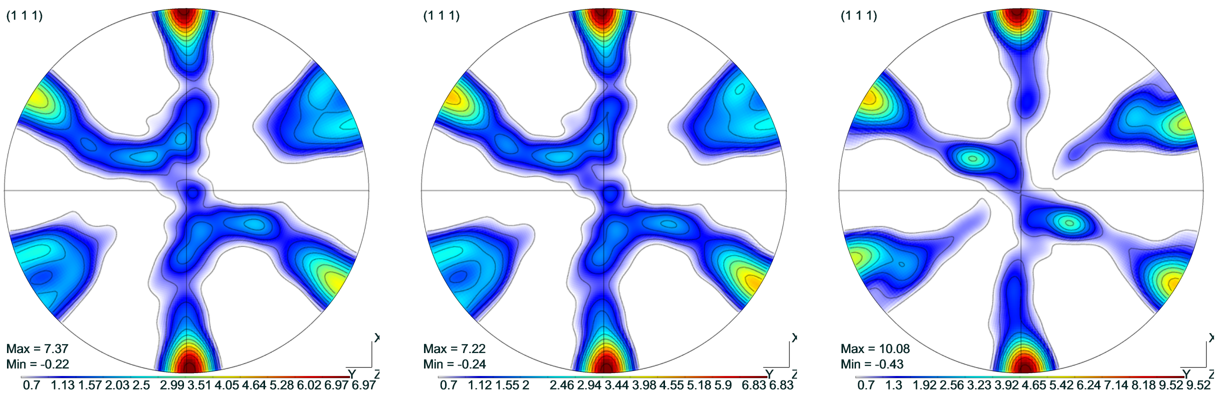
$$\hat{\mathbf{L}}^p = \dot{\lambda} \frac{\partial F}{\partial \mathbf{M}_e} \rightarrow \dot{\gamma}^r = \dot{\lambda} \frac{1}{\tau_c^r} \left(\frac{\tau^r}{\tau_c^r} \right)^{2n-1}\,, \tag{2}$$

where $\dot{\lambda}$ is the plastic multiplier obtained from the Karush-Kuhn-Tucker conditions and $\mathbf{M}_e$ is the Mandel stress tensor obtained from hyper-elastic law from the anisotropic St. Venant-Kirchhoff hyperelastic law, cf. [**?**].

For a typical rate-independent formulation there is a problem of unique selection of active slip systems. Using a single yield surface (1) enables to avoid this problem, therefore the standard procedures of finite strain elasto-plasticity in the fully Lagrangian displacement-based formulation can be implemented [**?**]. Implementation of the element code including crystal plasticity has been done with the use of a code generator AceGen, which joins the symbolic algebra capabilities of Wolfram Mathematica software with automatic differentiation and advanced optimization of expressions [?]. The finite element simulation itself has been performed using the AceFEM package. The proposed scheme for remeshing and solution mapping shares some key concepts with solution mapping applied for simulation of the accumulated roll bonding process [?].

3. Results

The simulations of two passes of the ECAP process have been carried out. The simulated textures were compared with available experimental data [?]. Satisfactory agreement has been obtained.



a) b) c)

Figure 1: Simulated {111} pole figures of copper subjected to ECAP process. a) After one pass, b) after one pass and remeshing, c) after two passes. JTEX software [?] was used to draw the pole figures.

4. Acknowledgement

The KMM-VIN Research Fellowship grant is gratefully acknowledged.