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The origin of strain reversal texture in equal channel angular pressing

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Abstract

Numerical simulations of texture development in polycrystalline oxygen-free high conductivity (OFHC) copper have been studied using the Taylor, viscoplastic self-consistent (VPSC) and a recent Taylor type polycrystal grain refinement (GR) model for the forward and reverse strain conditions. The predictions were compared with each other and with experimental results. OFHC copper was deformed by equal channel angular pressing (ECAP) for up to two passes in Route C. In this Route the deformation mode is shear and is reversed every second pass, however, shear texture is still observed experimentally. For this reason this case is suitable to test the predictive capacity of polycrystal models. The simulation results demonstrate that the magnitude of the shear strain increment plays an important role in predicting texture evolution during strain reversal. If the strain increment is large the three models predict a strain reversal shear texture in acceptable agreement with the experimental results. However, when the strain increments are sufficiently small (as they should be to obtain high precision), both the Taylor and VPSC models return the texture to its initial state; only the GR model can produce a strain reversal texture in accord with the experimental results.

Keywords: Equal channel angular pressing; Oxygen free high conductivity copper; Polycrystal modeling; Grain refinement; Reversed strain

1. Introduction

Large plastic strains involve changes in the orientation distribution of crystals (i.e. the crystallographic texture) that compose a polycrystal. These changes can be followed by experimental analysis, such as X-ray and neutron diffraction. They can also be modeled using simulation tools. Prediction of the evolution of texture is a key issue in material forming because it has a significant influence on the thermo-mechanical and physical properties of the material as it determines the macroscopic anisotropy. Several models have been developed for this purpose in the last 70 years. The most known and simplest is the Taylor model [1], which is based on the assumption that plastic deformation is uniform for all crystals that constitute a polycrystal. The Taylor model was improved by relaxing certain strain components in the relaxed constraints model [2], which is still a Taylor type model. A more sophisticated model is the self-consistent approach [3,4] in which the effect of evolving grain shape is taken directly into account using the so-called interaction equation that describes the interaction of a crystal with a polycrystal. Finite element models can also be used efficiently to simulate texture evolution [5–7]. Recently, a new "grain refinement" (GR) model has been presented in which the fragmentation of grains is modeled in a quantitative way within the framework of the Taylor hypothesis [8]. This model has been shown to be fairly predictive simultaneously for texture, grain size, misorientation distribution and hardening [8–10].

During simulation any model that predicts the evolution of crystallographic texture needs a numerical application. Moreover, as usual in plasticity, large strains can only be reached in small increments. Therefore, application of the model is numeric dependent, and has to be dealt with accordingly for any application to approach acceptable

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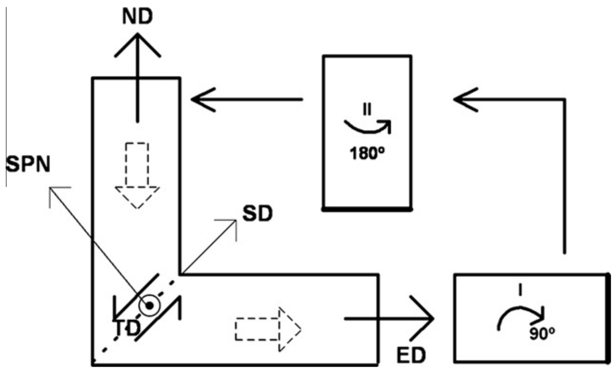

Fig. 1. A schematic representation of the reference systems and sample rotations after the first pass in Route C ECAP.

precision. Too large increments evidently produce incorrect results while too small increments are time consuming. Optimal values are needed which are not easy to define.

Crystallographic orientation development is important in severe plastic deformation, in which equal channel angular pressing (ECAP) is a promising technique to produce ultrafine grained materials [11]. Previous simulation works have shown [12] that texture can be well predicted when assuming ideal simple shear deformation in each pass for Routes A and B. These routes involve 0° or ±90° rotations around the sample longitudinal axis after every pass, respectively. However, for Route C (180° rotations around the sample longitudinal axis after every pass, Fig. 1) most efforts at modeling have failed [12]. Route C ECAP is especially promising for technical applications as this is the only Route in ECAP which can be done without exiting the sample after each pass (by pushing the sample back and forth between the two channels of the die). Route C is also a specific strain path during which strain reversal takes place between subsequent passes so that the straining direction is reversed. Accordingly, the grain shape is expected to recover to the initial state every second pass, in contrast to Route A in which the grain shape becomes very elongated. However, the crystallographic texture is not recovered; there is an ECAP shear texture after every even number of passes in Route C.

Given the challenging difficulties of simulating the textures in Route C ECAP, the present work aims at examining the numerical aspect of polycrystal modeling for the example of strain reversal in this route. Only three successful simulations can be quoted for Route C textures [13–15]. In Mahesh et al. [13] and Li et al. [14] the modeling was based on possible deviations from the assumption of simple shear. Furthermore, the fact that the original grains fragment into subgrains which then become new grains at large strains also needs to be examined. Enikeev et al. [15] introduced a disclination-based model using the differences in deformation of individual grains with respect to the whole sample inherent in VPSC modeling. They obtained reasonably good textures in Route C but the model does not account for the main reason for grain subdivision: the gradients in strain and lattice orientation near the grain boundaries. Such gradients are considered in the GR model, especially for the lattice curvature which will be employed in the present work. Experimental analyses clearly show the existence of large misorientations even within newly formed grains (see Fig. 7 of Li et al. [14]).

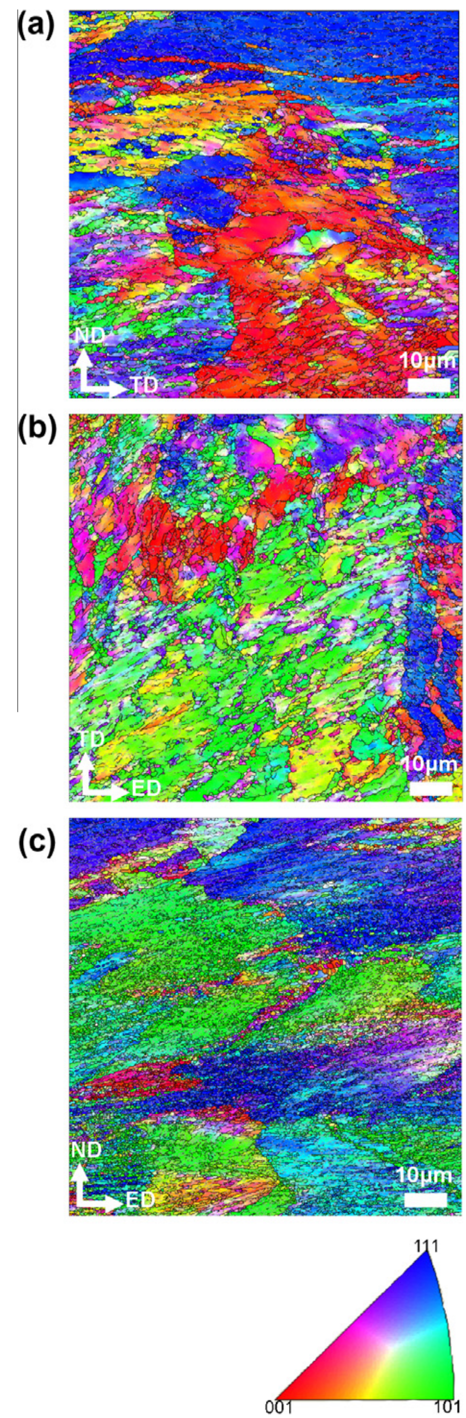

Fig. 2. Orientation maps after two Route C ECAP passes in pure copper: (a) ED plane; (b) ND plane; (c) TD plane. Boundaries with at least 5° misorientation are marked with black lines. The color code of the orientations is also shown, with the direction of projection perpendicular to the measured plane.