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Numerical study of the effect of prior deformation history on texture evolution during equal channel angular pressing

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ABSTRACT

It is experimentally well known that mechanical properties of the material depend on crystallographic texture distribution which varies depending on deformation history. When the material deforms at several stages, it is not easy to follow up the effect of prior deformation on the final texture of the material. In the present study, the effect of deformation history on texture evolution during equal channel angular pressing (ECAP) of FCC polycrystalline metal like AA1050 is investigated by the finite element method and polycrystal plasticity model based on full constraints Taylor model. The texture evolution during the multi-pass ECAP is simulated with the initial textures determined by three virtual specimens prepared by the fully annealed, extruded, and flat-rolled materials. By comparing the pole figures and orientation distribution functions, the effect of prior deformation histories on the texture evolution is numerically studied according to the routes A and C up to four passes across the thickness of the specimen. For the extruded specimen, it is not enough to wipe out the trace of the initial textures originated from the extrusion even after four passes. For the rolled specimen, strong development of the rotated simple shear texture readily occurred with the rotation about the transverse direction of the ECAP die. This study indicates that it is necessary to control the initial texture properly for achieving a desired mechanical property.

1. Introduction

During forming processes, crystals in metals are rotated in the preferred orientations resulting in a strong crystallographic texture and highly anisotropic deformation behavior of the polycrystalline material. In the bulk forming processes, it is experimentally well known that mechanical properties of the material depend on crystallographic texture distribution which varies depending on deformation history [1–3]. Especially, equal channel angular pressing (ECAP) [4], the most representative and widely applied severe plastic deformation (SPD) bulk forming process, induces severe texture evolution and anisotropy [5,6]. ECAP process involves repeating insertion of the sample into a die that has two channels with equal cross section intersecting at an angle Φ with a corner angle Ψ as shown in Fig. 1a. Since the sample undergoes no change in the cross section even in the multi-pass process, it is possible to fabricate the sample repeatedly without changing its geometry, consequently resulting in significant grain refinement. According to the strain path change, there are three processing routes, which are generally represented by routes A, Bc, and C [5,6]. Route A refers to pressing the sample repetitively without any rotation, route Bc refers to a rotation of 90° in a counter-clockwise (CCW) direction, and route C refers to a rotation of 180° about the billet-axis prior to each reinsertion, respectively.

Since the ECAP has received much attention owing to the attractiveness of making ultrafine-grained metals [5], a wide spectrum of researches have been reported in the literature in regard to the effect of processing parameters such as die angle, friction, pass number, and route on the material flow and texture evolution during the ECAP [7–12]. For the numerical approach, there were several attempts to model and predict the texture evolution for understanding the relation between the underlying mechanism and mechanical properties. Analytical studies [4,13] for investigating the plastic deformation zone (PDZ) in the ECAP have been conducted by either strain or stress analysis under the idealized assumptions such as simple shear deformation, perfectly plastic material, and frictionless conditions. In order to take into account the realistic processing conditions, finite element (FE) analyses of

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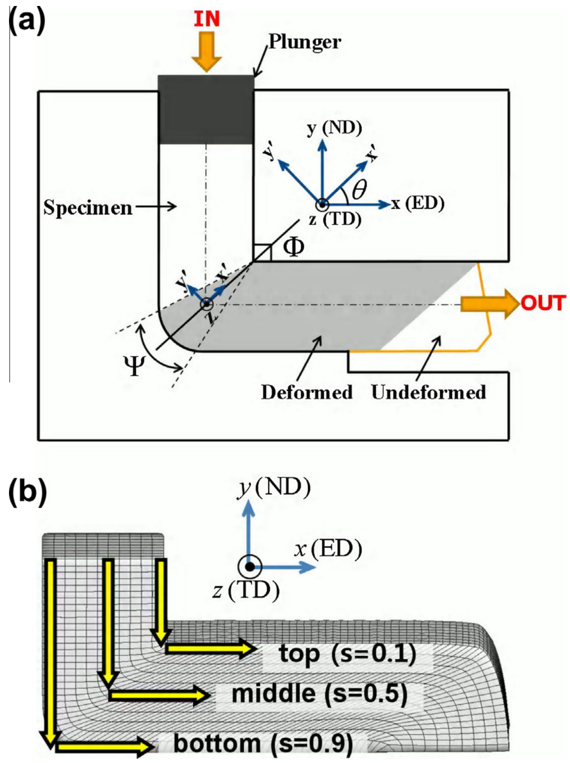

Fig. 1. Illustration of (a) the ECAP process and (b) the FE mesh represented with three deformation streamlines.

the ECAP process were carried out and the effects of various processing parameters on the material flow were investigated [7,8].

In order to predict the texture evolution and anisotropic flow response of polycrystalline metals, crystal plasticity (CP) theories were utilized under the consideration that the dominant mechanism of plastic deformation of single phase cubic metals is crystallographic slip on the specific slip systems [1,2]. The earlier numerical investigations of the texture evolution in the ECAP were conducted by full constraints (FC) Taylor model and visco-plastic self-consistent (VPSC) model under the assumption of simple shear deformation. Li et al. [14] tried to investigate the texture evolution during the ECAP of FCC and BCC materials by means of the CP analysis and simple shear model [4] for the deformation analysis of the PDZ in terms of the texture developed in simple shear. They showed that the main ideal orientations were similar to the rotated shear texture developed in the ECAP, similar to the works by Tóth et al. [15–17]. In reality, however, the deformation in the PDZ during the ECAP includes tensile and compressive strains which are apart from the ideal simple shear [18,19]. Li et al. [20] reported that when the deformation was provided by the FE analyses of the ECAP, better texture predictions were made in terms of rotations from the ideal simple shear texture and texture heterogeneity. They have claimed that the VPSC model with a grain co-rotation (GCR) scheme performs better than the Taylor model. Furthermore, it has been shown that a better prediction of the texture evolution can be achieved by the crystal plasticity finite element method (CPFEM) in which the CP model is incorporated into the FE framework to define the constitutive relation at the integration point of the FE element.

However, Baik et al. [21] have shown that the simulated texture obtained from the FE analysis based on the Taylor model was in good agreement with the experimentally measured one. Li et al. [22] also demonstrated capability of the CPFE approach for prediction of texture evolution after the simple shear deformation. Wu et al. [23] tried to simulate grain fragmentation and texture evolution during the ECAP by the CPFE analysis under the assumption of the simple shear deformation. Kalidindi et al. [24] proposed an approach that approximately incorporated the boundary conditions involved with the ECAP into the CPFE model by dividing the deformation field into upper, middle, and lower deformation paths and assuming them as idealized micro-ECAP dies for prediction of the texture evolution after the one-pass ECAP. In order to investigate the deformation mechanism, Lu et al. [25] and Deng et al. [26] conducted the CPFE analysis for Fukuda et al.'s experiment [27,28] for the ECAP of an aluminum single crystal and an copper single crystal. They found that the texture evolution and heterogeneity were dependent on the die geometry resulting in the three matrix bands along the thickness direction in terms of the rigid body rotation. Recently, Jung et al. [29] demonstrated that the characteristics of the texture-induced anisotropy of the ECAPed specimen can be successfully predicted by the FE analysis based on the Taylor model. They simulated the full-field texture evolution during the multi-pass ECAP of routes A and C, and predicted the macroscale anisotropic deformation behavior of the ECAPed specimen by the CPFE analysis after mapping the texture information.

To date, it is known that CPFEM is the best means for an accurate prediction of texture evolution during plastic deformation [22,25] and VPSC models with the GCR scheme perform better than the Taylor model [20]. As pointed out earlier, it was reported that the Taylor model does not perform poorly in every case. According to the literatures [29–31], the Taylor model can predict the location of the texture components relatively well only if the deformation field is provided by the FE analysis for routes A and C with the exception of even-numbered passes. So, the Taylor model can be efficiently used in the qualitative texture analyses in case of a great deal of parametric studies because of high computational requirements of the CPFEM and VPSC model with the GCR scheme for parametric studies of the multi-pass ECAP. In this consideration, Taylor model would be helpful to firstly look into the effect of the parameter which was rarely taken into account before conducting the rigorous investigation by the CPFEM and VPSC model with the GCR scheme.

Although many works on texture simulations and experiments of the ECAP have been conducted, the influence of prior deformation history on the texture evolution during the ECAP was rarely investigated so far [6]. In reality, the initial sample in the ECAP could have a texture inherited from the prior manufacturing process and it could affect the texture evolution during the ECAP. Especially, for the case of cubic polycrystalline sample, the effect of initial texture due to the prior manufacturing process was usually ignored although there were some reports on a rule of thumb that the texture evolution might be affected when the initial texture was more intense than 1/10th of that developed by the subsequent deformation [32,33]. To demonstrate the influence of initial textures, Li et al. [34] simulated the texture evolution using the VPSC model without the GCR scheme and provided with information on the texture evolution in each pass. This work, however, was based on the assumption of idealized simple shearing, sharp corner angle, and no work hardening of the material.

In the present study, the effect of prior deformation history on texture evolution during the ECAP of FCC polycrystalline metal like AA1050 is investigated by the FC Taylor model and FEM. The rigid visco-plastic FE analyses were carried out to determine the history of velocity gradient and macroscopic flow characteristics during the process. The calculated history was provided to the CP model to reflect realistic process conditions of material work hardening, die corner angle, and friction at the contact with the die. In order to identify the effect of prior deformation on the texture evolution during the ECAP, CP analyses for three virtual specimens prepared by the fully annealed, extruded, and flat-rolled materials, respec-