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Evolution of texture during equal channel angular extrusion of commercially pure aluminum: Experiments and simulations

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ABSTRACT

The evolution of crystallographic texture has been comprehensively studied for commercially pure Al as a function of amount of ECAE deformation for the three major routes of ECAE processing. It has been observed that processing through different routes leads to different type of texture, in both qualitative as well as quantitative sense. The results have been analyzed on the basis of existing concepts on ECAE deformation and simulations have been carried out using the simple shear model of ECAE implemented into the Viscoplastic Self Consistent model of polycrystal plasticity. The simulations revealed that non-octahedral slip is needed to reproduce the experimental texture development.

1. Introduction

Texture evolution during equal channel angular extrusion (ECAE) has received attention because the process involves imparting very high plastic strains in order to refine the microstructure; however, such a deformation is also likely to develop strong deformation texture. The ECAE process involves pressing of a well-lubricated billet into one of the two die-channels having the same cross-section placed at an angle (Fig. 1). It is now well established that during extrusion, the material is deformed successively nearly by simple shear in a narrow zone at the crossing plane of the channels (the shear plane). In this way, the complete billet (except small end regions) is deformed in the same uniform manner. As the overall billet geometry remains nearly constant during ECAE processing, multiple passes through the die are possible without any reduction in cross-sectional area.

ECAE is a discontinuous process, involving re-insertion of the sample in the die. The ECAE processing route can involve any number of passes through the die, by either clockwise (CW) or counter clockwise (CCW) rotations, usually about the sample's longitudinal (or bar) axis, between subsequent ECAE passes: A, no bar axis rotation; C, 180° rotation after every pass; Ba, clockwise 90° rotation after even numbered passes and counter clockwise 90° after odd numbered passes; and B_c, 90° rotation after every pass. All possible ECAE routes lead to changes in strain path, including the original route A that involves no intermediate rotation about the sample bar axis between passes.

The evolution of the deformed state, microstructure as well as texture, during deformation by ECAE, and the mechanisms that lead to grain refinement to the sub-micron scale, have been studied by several research groups in the recent past including the group of present authors [1–31]. A comprehensive review of texture development in ECAE is given by Beyerlin and Tóth [32]. However, the texture development in aluminum using ECAE does not lead to unique agreement in terms of effect of strain and strain path. There are many reasons for this. One of them is that the starting conditions of the material prior to ECAE are generally not uniquely reported in these investigations. It is well known that the starting texture has a very significant role on texture evolved after deformation. Moreover, most of the studies documented so far largely rely on pole figure measurements, in which different crystal orientations can overlap. More precise information on texture can be obtained with the help of three-dimensional texture analysis using orientation distribution function (ODF), which can be derived from pole figures.

The present study is realized using the ODF method for texture analysis of materials processed through the routes A, B_c and C of ECAE with identical starting material. The number of passes has been limited to five for each of the routes. The first pass is common for each route, so differences can be obtained starting from the second pass. Thus, considering the first pass deformed material

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Table 1
Chemical composition of the starting material.

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V	Pb
Wt%	99.60	0.12	0.27	<0.005	<0.005	<0.005	<0.005	0.01	0.01	<0.005	<0.005

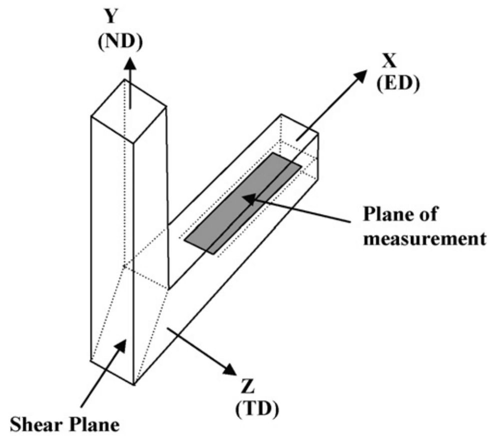

Fig. 1. Texture measurement plane (*XZ*) with reference to ECAE geometry.

as the initial (already deformed) state, four additional passes will bring the material into the initial sample configuration after having undergone through the routes B_c and C. This is why we carried out five passes for each route.

2. Material and methods

Commercially pure aluminum used for the present study was received in the form of rolled and annealed plate with 10 mm thickness. The chemical composition of the starting material is given in Table 1. Fig. 2 shows the microstructure of the starting material. It consists of quite flattened grains with an equivalent grain size of ~200 μm. Specimens with dimensions of 100 mm × 10 mm × 10 mm (rectangular cross-section) were machined from the rolled plates. The ECAE experiments were carried out at a cross head speed of $1\ \mathrm{mm\,s^{-1}}$ at room temperature using a Zwick 200 kN screw driven press and a die set with rectangular intersection of the extrusion channels (90°) without any rounding of the corner region. The samples were subjected to routes A, B_c and C.

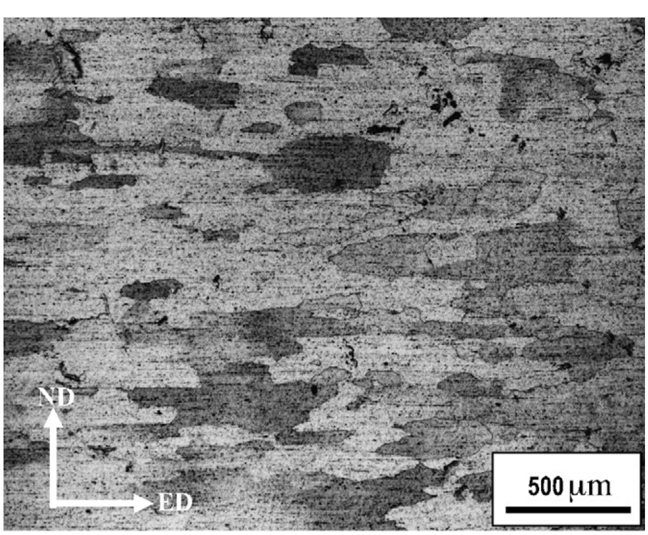

Fig. 2. Optical micrograph recorded on the *XY* plane of the material before ECAE.

2.1. Measurement and representation of texture

Texture measurements were carried out by X-ray diffraction using a Siemens D-5000 Texture Goniometer (Cu K_α radiation, λ = 1.5406 Å). For each sample (area 25 mm × 10 mm), the texture was examined through pole figures as well by calculating orientation distribution functions (ODF), which describe the crystallite orientation densities in a three-dimensional orientation space defined by the Euler angles ϕ_1, φ, ϕ_2. For this purpose, from each texture (1 1 1), (2 0 0) and (2 2 0) pole figures were recorded on the mid-horizontal plane (*XZ*) of the sample (Fig. 1), in the ND plane, using Schultz-reflection mode. This choice of the measuring plane was selected in order to avoid the texture gradient inherently present in an ECAE deformed sample [28–30]. Namely, in a rectangular channel, the texture gradient can be relevant in the ND direction. Thus, in a plane perpendicular to it the texture corresponds to the well defined middle position and the possibly existing variation along the ND axis does not affect the measured texture. The ODFs were calculated using the softwares developed at LETAM, University of Metz, and by Van Houtte [33], without imposing any restriction on symmetry, that is, assuming triclinic sample symmetry using the series expansion method of Bunge [34] with $l_{max} = 22$.

2.2. Microstructural investigation

The microstructural examination has been carried out using a JEOL 2000 Field Emission Gun Scanning Electron Microscope (FEG-SEM) with EBSD attachment. The results were analysed using the software “Channel 5” developed by HKL technology.

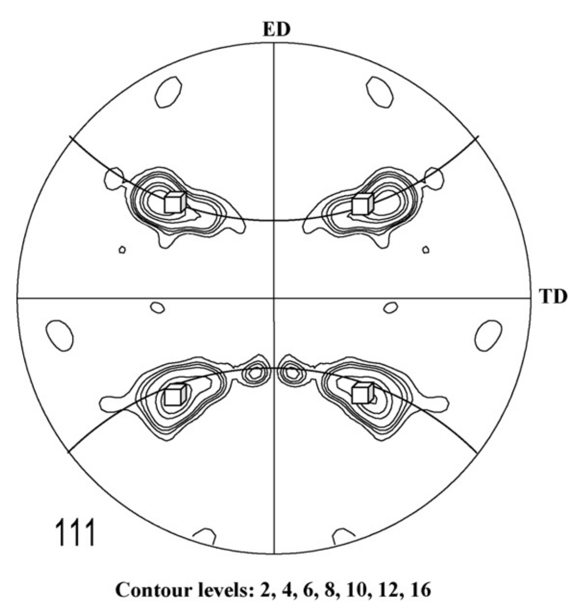

Fig. 3. (1 1 1) pole figure for the starting material. Cube symbol indicates the cube position.