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# The influence of deformation texture on nucleation and growth of cube grains during primary recrystallization of AA1050 alloy

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The influences of microstructure and texture on the early stages of recrystallization of a commercial AA1050 alloy have been characterized with particular attention to cube grain formation. Samples were deformed along two deformation modes to form different as-deformed texture components and then lightly annealed: one group was plane strain compressed (PSC) in a channel-die, whereas the second group was deformed by equal channel angular extrusion (ECAE). The textures were measured by X-ray diffraction and SEM/EBSD. After both deformation modes a very weak residual cube texture component was observed in the samples. Cube-oriented grains were not formed during annealing of the ECAE samples whose main as-deformed texture components were close to {124}<651>. During recrystallization these transformed to two components of ~{100}<011> and ~{221}<114>-type essentially by <110> rotations. Cube grains were extensively formed only during annealing of PSC samples. They were situated preferentially inside or in between the S-oriented deformed areas with local misorientations about <111> axes.



## 1. Introduction

The origin of strong cube recrystallization textures during annealing of face centred cubic (fcc) metals has been a matter of debate for decades, e.g. Refs. [1–11]. It is widely accepted that cube {100}<001>-oriented grains evolve from cube bands which are present in the deformed microstructure, often as thin cube zones between high orientation gradients created by diverging rotations of unstable orientations [3], i.e. fragmented leftovers of the original cube grains [4]. Two different explanations for the high rate of cube grain formation have been put forward. A *first "nucleation" approach*, originally presented by Ridha and Hutchinson [4] proposes that deformed cube-oriented bands recover faster due to the easy annihilation of two sets of screw dislocations with perpendicular Burger's vectors (specific to PSC of fcc cube grains). The *second "microgrowth" approach* was proposed by Duggan et al. [5] and Samajdar and Doherty [6]. It is based on the strong growth rate dependence of ~40°<111> relations [7] between cube recrystallized nuclei and the four S{123}<634> orientation 6 + variants of the deformed state (as developed in rolled sheet). Their applications to hot and cold rolled aluminium alloys have been numerous, e.g. Refs. [8–11]. Note that these studies also imply that orientations of the deformed state are retained in recrystallized nucleus/grain orientations, i.e. (near) cube$^{def}$ are transformed into (near) cube$^{rex}$, as predicted by the oriented nucleation model.

These two cube grain nucleation models may be concurrent or in competition, or even superseded by some other mechanism. It would therefore be useful to investigate cube nucleation under conditions where the initial microstructures, textures and microtextures are quite different in the same alloy system. The present analysis focuses on cube nucleation in commercial purity Al (AA1050 alloy) deformed to two significantly different textures: (i) cold rolling texture by plane strain compression (PSC) in a channel-die and (ii) shear texture by equal channel angular extrusion (ECAE). We decided to use the material taken from the medium stage of the technological process (after the reversible mill) with well-marked copper, brass and S texture components. This texture, as expected, is not essentially changed during further PSC up to 40% (logarithmic strain of 0.5) and the applied deformation is too low to develop plastic flow instabilities, e.g. in the form of shear bands. This strongly simplifies the analysis.

It is clear that in the case of ECAE samples it is impossible to

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apply exactly the same amount of deformation as in the case of the PSC sample. After 1–2 passes of ECAE processing (logarithmic strains of ~1–2) the textures are dispersed without clearly marked texture components. A simple texture with two strong components is obtained after 5–6 passes of ECAE processing, independently whether the initial texture is random or not-random. It is clear that the different amount of strain after both deformation modes, leads to difference in the state of the microstructure, in particular, the ratio of the high (HAB) to low (LAB) angle boundaries is quite different. However, it is assumed here that the ratio of HAB/LAB is not so critical for cube grain nucleation. We believe that the main factor which influences cube grain nucleation is the specific texture of the as-deformed state. This assumption is well-confirmed by analyses on cold-rolled material where essentially there is no special difference between the annealing behaviour of the sample deformed up to moderate and very high strains; in both cases cube grains are formed intensively.

The formation of cube grains after light annealing was analysed by means of a scanning electron microscopy equipped with an electron backscattered diffraction (SEM/EBSD) facility as well as by X-ray diffraction. The use of aluminium practically excludes mechanical and recrystallization twinning, as occurs in lower stacking fault energy (SFE) metals, e.g. Ref. [12], to facilitate orientation analysis during the initial recrystallization stages.

## 2. Experimental

### 2.1. Material and sample processing

The initial material was a commercial purity AA1050 alloy in the form of hot-rolled sheet 22 mm thick prepared at the Huta Konin SA. As detailed below it had a typical hot rolling texture. The deformation was carried out along two deformation modes. Room temperature PSC to a logarithmic strain of 0.51 (reduction of 40%) was carried out in a channel-die at an initial strain rate of 0.02 $s^{-1}$ using an Instron machine. (At this stage of deformation macroscopic plastic flow instabilities are not observed in the deformed microstructure). The multi-stage tests were performed at ambient temperature on samples cut from the hot rolled sheet to dimensions of 10 × 10 × 10 $mm^3$. In order to limit the friction between the sample, the punch and the walls of the channel-die, each sample was wrapped in 0.2 mm thick Teflon™ tape. ECAE was performed using a 10 × 10 $mm^2$ die with an angle of 90° and outer corner radius of 5 mm. The samples of 70 mm length were processed up to 6 passes through route A (no sample rotation between consecutive passes). The billet and tooling were well-lubricated with $MnS_2$-containing grease. The deformed samples were sectioned perpendicular to ED, i.e. along the ND/TD section (in the middle of the sample) and analysed in central areas of the section. The deformed samples were annealed for 1 h at temperatures ranged between 100 °C and 450 °C to obtain different stages of recrystallization.

### 2.2. Sample characterization

The microstructures of the initial material, after deformation and then annealing were mostly analysed in the ND/ED (PSC samples) and ND/TD (ECAE samples) sections. The electron backscattered diffraction (EBSD) measurements were made using TSL-EDX orientation imaging microscopy on an FEI QUANTA 3D FEG-SEM. The maps were created with step sizes ranging between 100 nm and 700 nm. The numbers of correctly indexed points was always above 97%. In each case, the orientation maps covered an area of at least 100 μm × 100 $μm^2$. The orientation maps are presented using the inverse pole figure (IPF) colour code combined with the distribution of grain boundaries. Bold black lines denote boundaries having high-angle misorientation (HAB), i.e. >15°, whereas solid grey lines show low-angle boundaries (LAB), i.e. 2°–15°. In the {111} pole figures corresponding to the SEM orientation maps, the indices {*hkl*}<*uvw*> represent the texture component which has the {*hkl*} plane parallel to the ED/TD plane and the <*uvw*> direction parallel to ED (extension and extrusion directions).

At the sample scale, the textures were measured by scanning the whole ND/TD (ECAP) or ED/TD (PSC) sample sections (usually 100 $mm^2$) using a Philips X Pert PW-1830 X-ray diffractometer. In the case of ECAE samples the {111} pole figures were transformed to the ED/TD 'rolling' coordinate system. In all cases, three incomplete pole figures, i.e. {111}, {110} and {100} were measured using the reflection method. The results are presented in the form of complete {111} pole figures using LaboTex 3.0 software. For selected cases the texture is presented in the form of the orientation distribution function (ODF).

Microhardness measurements were performed to evaluate softening during annealing, and hence estimate the recrystallized fractions after 1 h at temperatures from 100 to 400 °C. The tests were carried out on finely polished surfaces of the ND/TD (ECAP) or ND/ED (PSC) sections and values averaged over 10 independent indentation measurements. The recrystallized fraction was estimated using the relation: $X_{rex} = (HV_{def} - HV)/(HV_{def} - HV_{rex})$, where: $HV_{def}$ and $HV_{rex}$ are microhardness values of the sample in the deformed and fully recrystallized state, respectively.

## 3. Results

### 3.1. Microstructure and texture of the initial material

The initial material shows a basically hot rolled microstructure with some minor recrystallization. In both sections perpendicular to rolling (|| compression) plane, i.e. ND/RD (Fig. 1a) and ND/TD the high angle boundaries are situated along RD(ED) and TD. ND, RD(ED) and TD denote the normal, rolling (extension) and transverse directions, respectively. The average distance between HAB in the ND and TD are ~7 μm and 16 μm, respectively, whereas along the RD is significantly larger, and often exceeds 50 μm.

At this initial stage, the material possesses a typical copper-type

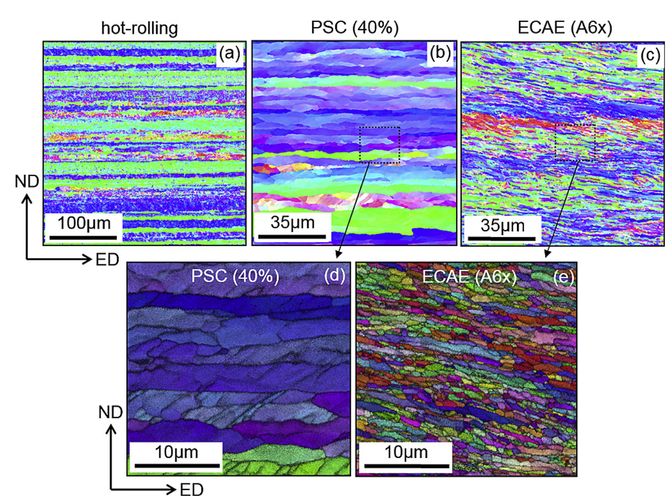


**Fig. 1.** Microstructures of initial material (a), after 40% deformation in channel-die (b, d) and after six passes along route A of ECAE process (c, e), observed in ND/ED sections. Details from (b) and (c) are presented in (d) and (e), respectively. SEM/EBSD local orientation measurements with step size of 2 μm (a), 100 nm (b, c) and 70 nm (d, e). Orientation maps presented using IPF colour code.