CUBE TEXTURE EVOLUTION DURING HOT PLANE STRAIN COMPRESSION OF Al-Mg ALLOYS

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ABSTRACT

Four polycrystalline Al-Mg alloys of intermediate compositions between binary and industrial alloys (AA1070 + 0, 1, 3 and 5 wt.%Mg) have been deformed in plane strain compression using a hot channel-die device. To systematically investigate the cube texture evolution, a wide range of deformation conditions has been covered : temperatures between 20 and 500°C, strain rates between 10^{-3} s^{-1} and 1 s^{-1}, strains of 0.5 and 1. Macroscopic textures have been characterised by X-ray diffraction measurements. A complementary study of the local behaviour of cube grains embedded in a polycrystal has been carried out at a microscopic scale using the Electron Back Scattering Diffraction (EBSD) technique and the individual reorientations of near-cube oriented grains and their surrounding neighbours have been followed during hot plane strain compression. It is shown that the boundary conditions imposed by the neighbouring grains have a pronounced effect on the plastic deformation and lattice rotations of the cube grains.

Keywords : *Al-Mg alloys, hot plane strain compression, cube texture evolution, lattice reorientations.*

1. INTRODUCTION

The microstructures and final properties of non heat-treatable alloys (grain size, texture and anisotropy) depend to a great extent on the thermomechanical conditions of the hot deformation process (rolling or extrusion). In particular, for Al-Mg alloys, understanding cube texture evolution during hot compression is of major technological concern because it controls the subsequent recrystallization behaviour and the final anisotropy of the sheet products.

Previous studies of cube orientation behaviour during hot deformation have been limited to either single crystals of pure aluminium (or binary alloys) or a statistical analysis of the macroscopic texture changes in industrial alloys. For example, the plane strain compression of cube oriented single crystals has been studied by Akef [1] for pure aluminium and by Theyssier [2] and Theyssier et al [3] in the case of a binary Al-1% Mg alloy. The cube texture component in some industrial alloys has also been investigated by Hühne et al [4] for AA5109 and by Daaland and Nes [5] and Vatne et al [6] for commercial Al-Mn-Mg alloys.

By studying polycrystalline Al-Mg alloys of intermediate compositions between binary and industrial alloys, the present work is an attempt to bridge the gap between these two approaches. To shed more light on the evolution of cube grains during hot plane strain compression, the texture behaviour of these alloys has been characterised over a wide range of deformation temperatures and strain rates, both at the macroscopic and microscopic scales.

2. EXPERIMENTAL PROCEDURE

The alloys studied in the present work were cast as 10 kg ingots at the Pechiney CRV research centre using AA1070 as the base alloy to which 0, 1, 3 and 5 wt.% Mg has been added. Their compositions in weight % are given in table 1.

	Mg	Fe	Si	Mn	Cu	Cr	Ni	Zn	Ti
Al-0%Mg	0.05	0.40	0.25	<0.03	<0.005	0.0020	0.003	<0.01	0.004
Al-1%Mg	1.18	0.17	0.12	<0.03	<0.005	0.0019	0.002	<0.01	0.004
Al-3%Mg	3.25	0.21	0.14	<0.03	<0.005	0.0020	0.003	<0.01	0.004
Al-5%Mg	5.01	0.27	0.16	<0.03	<0.005	0.0017	0.003	<0.01	0.004

Table 1 : Alloy compositions.

The ingots were hot rolled and annealed to develop a microstructure of equi-axed grains of size 100 μm. Texture measurements by X-ray diffraction reveal fairly weak textures with a cube volume fraction suitable for the local analysis (see below). Further details are to be found in [7]. The rectangular section compression samples were machined to dimensions 11 mm (height) x 7 mm (width) x 14 mm (length) and mechanically polished (down to a 20 μm granulometry) before testing.

The plane strain compression (PSC) tests were carried out in a high temperature channel-die apparatus, described by Maurice [8] and Maurice and Driver [9], comprising a set of compression dies, a heating system and a hydraulic actuator placed inside a 100 kN Schenck servo-hydraulic tension/compression testing machine; the computer controlled actuator movement of the latter enables true constant strain rate tests. The lateral walls of the die are first pressed against each other by means of the hydraulic piston to make a channel which limits the lateral deformation to near-zero values (always less than 0.02). Friction between the sample and the tool surfaces was reduced by using Teflon films wrapped around the sample. Using a small gas-operated piston, the sample is then pushed out from the die and quenched within 3 seconds after the end of the plastic deformation.

A large number of samples from the four alloys Al-0, 1, 3 and 5% Mg considered here were deformed in the temperature range 20-500°C, at strain rates between 10^{-3} and 1 s^{-1} and up to logarithmic strains of 0.5 or 1 (0.58 or 1.15 Von Mises).

The homogeneity of the deformation and the quench efficiency were checked by metallographic examination of the grain structures through a good number of selected samples. After large deformations at 400°C or above Al-Mg alloys can recrystallize very rapidly. Optical metallography shows that the 5% Mg alloy is almost always partially recystallized during the 3 second quench time. The 1 and 3% Mg alloys occasionally exhibit some signs of partial recrystallization along the sample surface. Apart from these recrystallization effects, the deformed grain structure appears fairly homogeneous through the sample.

Macroscopic textures of the deformed samples have been characterised by X-ray diffraction measurements performed in a copper-tube Scintag goniometer at Los Alamos National Laboratory. The data analysis and orientation distribution function (ODF) calculation were done with the popLA software (Preferred Orientation Package of Los Alamos, see [10]).

In addition, a local study of the cube grain reorientations has been carried out using the Electron Back Scattering Diffraction (EBSD) technique in a Jeol 6400 scanning electron microscope (SEM) at the Ecole des Mines de Saint-Etienne. The critical point of the experiment was that a split sample was used (fig. 1) in order to perform the analysis on 3 perpendicular surfaces, including an internal surface normal to the rolling direction (RD). Since the channel-die apparatus was used to simulate rolling, reference will be made to the equivalent rolling, transverse and normal directions (RD, TD, ND, see fig. 1). All surfaces were electropolished and a 500 x 500 µm grid of microhardness indentations was applied on the 3 surfaces shown in fig. 1. The orientations of the grains inside the grid were determined by indexing the Kikuchi pattern formed by EBSD prior and after deformation. Although the indentation deformation limited the experiment to a strain of 0.5, this enables the reorientations of near-cube grains and their surrounding neighbours to be followed during hot PSC.

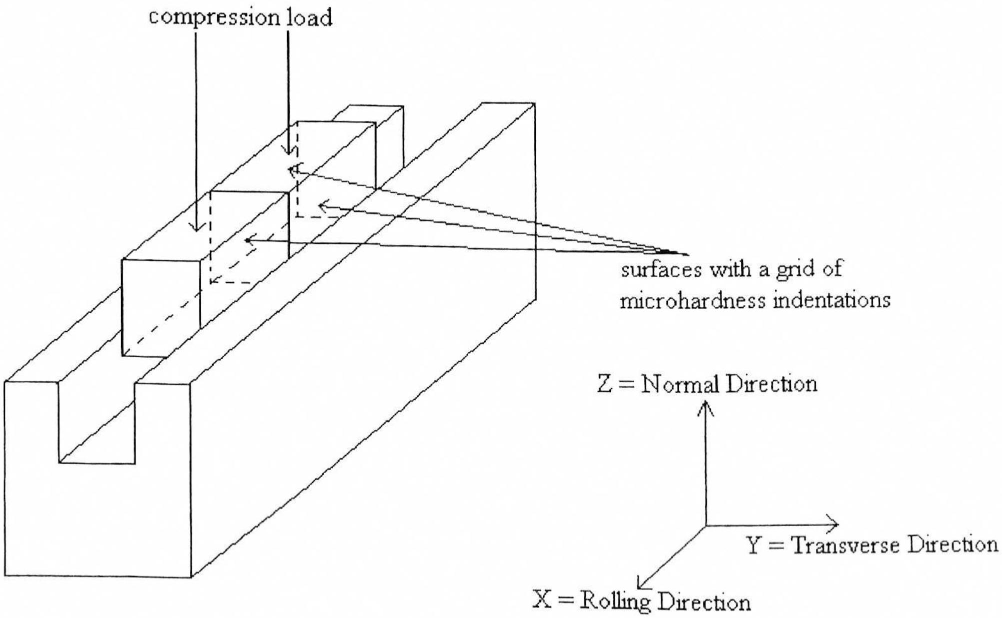

Figure 1 : Schematic drawing of the split sample experiment (channel-die compression test).

3. CUBE VOLUME FRACTION EVOLUTION

For each of the 4 alloys, a number of samples were selected to measure the macroscopic textures by X-ray diffraction. In each case, 3 pole figures were measured on the compression face located at mid-thickness, enabling the calculation of the complete orientation distribution function (ODF). As a reference, we also measured the initial textures of the 4 alloys prior to deformation. In the case of the 1% Mg alloy, texture measurements were performed both at mid-thickness and on the sample surface, leading to a total of 47 calculated ODFs. Volume fractions of the typical texture components were then evaluated assuming a 17.63° dispersion (see [7] for details).

Only the cube component is of interest in the present paper. We therefore focused on the evolution of the normalised cube volume fraction which is obtained by dividing the calculated cube volume fraction by the initial cube volume fraction (prior to deformation). This normalised volume fraction is plotted as a function of ln(Z) in figs. 2 and 3 for strains of 0.5 and 1 respectively, where Z is the Zener-Hollomon parameter $\dot{\varepsilon}\exp(Q/RT)$ and the activation energy is taken to be 156 $kJmol^{-1}$.

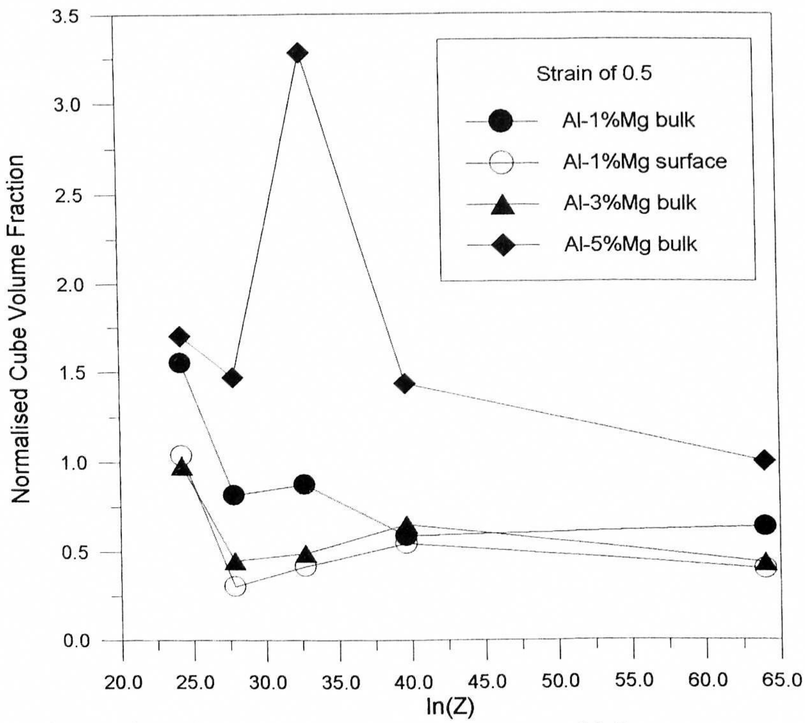

Figure 2 : Normalised cube volume fraction vs ln(Z) at a strain of 0.5.

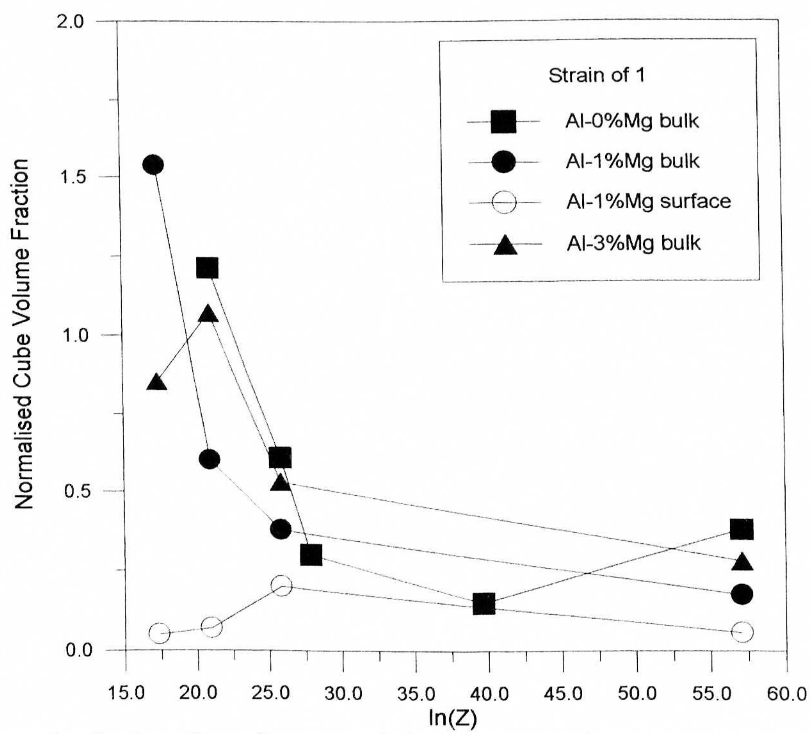

Figure 3 : Normalised cube volume fraction vs ln(Z) at a strain of 1.

Figs. 2 and 3 exhibit the following major tendencies :

- the points corresponding to the 5% Mg alloy are not always consistent with those of the other alloys : this is probably due to rapid recrystallization before quenching which modifies the textures. For reading convenience, the 5% Mg points have been omitted in fig. 3 (normalised volume fractions of the order of 3 or 4).
- as a general trend, the normalised cube volume fraction decreases when Z increases.
- the strain has little effect on the normalised cube volume fraction.
- the cube volume fraction is considerably lower at the surface compared with the grains located in the bulk. This could be due to friction effects.
- for the 0, 1 and 3% Mg alloys, the Mg content has little effect on the normalised cube volume fraction (but this is not the case if absolute volume fractions are considered).

4. LOCAL REORIENTATIONS

For strains up to 0.5, the EBSD technique combined with the use of a split sample with grids of microhardness indentations on 3 perpendicular surfaces allows to measure the orientations of the grains inside the grid before and after deformation. An initial cube-oriented grain and its surrounding neighbours were selected for a number of samples from the 1, 3 and 5% Mg alloys. The chosen strain rate was 1 s^{-1} and the deformation temperature range 20-500°C was covered. A 15° dispersion around the exact cube orientation was accepted for the selection of "cube" grains before deformation. Examples of the results obtained are given figs. 4 and 5.

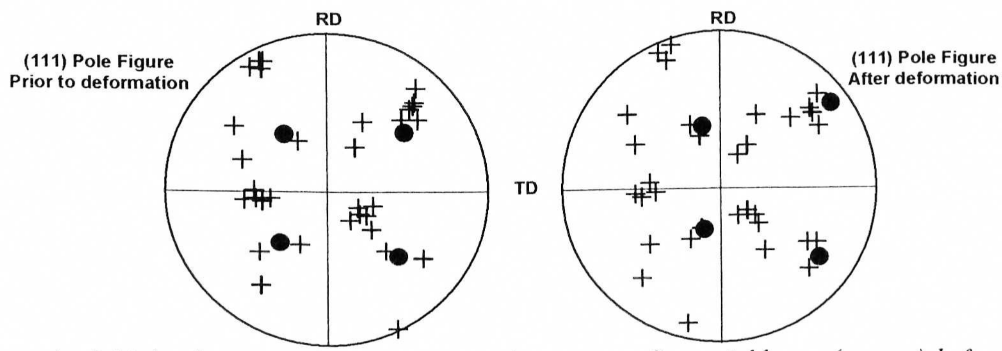

Figure 4 : Initial cube-oriented grain (dots) and its surrounding neighbours (crosses) before and after PSC to a strain of 0.5 at 1 s^{-1} and 20°C (1% Mg). The unstable cube grain rotates towards the Goss orientation.

The orientation changes of the selected cube grains can be roughly sorted into four sets :

- unstable cube grains rotating towards the Goss orientation {011}<100> (fig. 4).
- unstable cube grains with a high rotation rate towards the Brass orientation {110}<112>.
- relatively stable cube grains with a low rotation rate.
- very stable near-cube grains which rotate towards the exact cube orientation. For example, the misorientation between the exact cube orientation and the grain considered in fig. 5 decreases from 15° before deformation to 9° after PSC.

The results are quite different from those predicted from the macroscopic boundary conditions imposed on the sample. It appears therefore that the local boundary conditions imposed by the neighbouring grains, and the subsequent active slip systems and lattice rotations, have a stronger effect on the plastic deformation of near-cube grains than the general deformation conditions (temperature and strain rate).

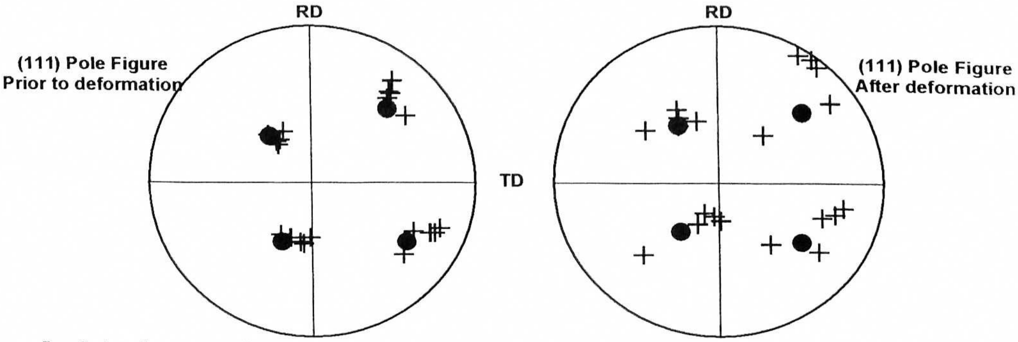

Figure 5 : Initial near-cube-oriented grain (dots) and its surrounding neighbours (crosses) before and after PSC to a strain of 0.5 at 1 s^{-1} and 400°C (1% Mg). The cube grain is stable.

5. CONCLUSIONS

- The use of a split polycrystalline sample combined with the EBSD technique has been used to measure the orientation changes of near-cube-oriented grains during hot PSC.
- The cube texture component is stabilised at low values of the Zener-Hollomon parameter (Z). The corresponding volume fraction decreases with increasing Z.
- The reorientations measured at the grain level differ substantially from the macroscopic texture changes. Local boundary conditions imposed by the neighbouring grains, and therefore the subsequent active slip systems and crystalline rotation rates, are probably quite different from the macroscopic ones that are imposed on the sample.
- The high recrystallization rate of Al-5% Mg after high temperature deformation severely complicates the analysis of the corresponding deformation textures.

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