The occurrence of shear banding in a millimeter scale (123)[634] grain of an Al-4.5% Mg alloy during plane strain compression

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Abstract

The appearance of localization in shear bands during plane strain compression (PSC) of an Al-4.5% Mg alloy is investigated, with emphasis on a millimeter scale S-orientated grain in the longitudinal section of the specimen, upon which a gold microgrid was deposited. In order to justify this focus, attention is also paid on smaller grains of other areas. The microgrid technique allows the local strain field at various steps of deformation to be followed and in-plane components to be plotted over the selected region. Electron back scattered diffraction analysis was also used to gain an insight into the crystallography of local lattice rotations. One can then predict the potentially activated slip systems according to the Schmid law with Taylor’s hypothesis, and assert the initial crystallographic feature of shear banding. This provides the opportunity to gain a more complete understanding, assuming a grain scale effect, of the mechanisms involved in the occurrence of shear banding in this alloy, and to reveal its influence on the rolling texture.

Keywords: Shear bands; Deformation maps; Crystalline orientation; EBSD; Channel-die

1. Introduction

Over the last decades, metallurgists and mechanists have been studying the occurrence of shear banding without gaining a clear understanding of this metallographic curiosity as it was first referred to [1]. Usually observed in cold rolling [2–4], cold rolling often simulated by plane compression (PSC) [5], it is also expected in stamping [6] and tensile testing [7].

Shear bands form as planar sheets parallel to the transverse direction (TD) and inclined, in average, at 35° to the rolling direction (RD). Inside these heterogeneities, there is a strong localization of the deformation, whereas in the matrix the deformation is supposed to nullify. It has also been reported that this so-called bifurcation is preceded by microshear banding and refinement of substructure by the formation of ultrafine crystallites [3,4].

In parallel to this, models based on continuum mechanics have been developed in an attempt to predict the occurrence and the characteristics of shear banding. Most of these have approached the problem in two ways. The first approach considers modeling shear banding as a bifurcation, so the displacement field takes a specific form between two planes and the compatibility with the stress state is studied [8–10], whereas the second is based on energetic considerations [11]. The main difficulty is that the majority of these models are concerned by a homogeneous stress state before localization. This is in contrast to the approach of other works which attempt to improve prediction of texture through a more accurate description of grain interaction and grain subdivision—which involves an inhomogeneous strain and stress state. Besides, these analysis rarely introduce dimension parameters.

The purpose of this paper is to increase the amount of experimental data on the occurrence of shear banding, and to discuss the mechanism that could explain the appearance of such a phenomenon. Attention is focussed on a specific domain where shear banding was...
initially observed, while keeping in mind the specificity of the selected area by gathering results from other regions and from the literature. In accordance with previous studies on the influence of grain size [12], the more precocious bands were found in a millimeter scale grain, and the techniques used in the present study enable both quantitative and qualitative characterization. \( R, T \) and \( N \), respectively refer to rolling, transverse and normal directions.

2. Techniques and procedures

2.1. Alloy, specimen and mechanical test

Experiments were carried out at room temperature on an Al-4.5\% Mg alloy, where the grain size is found to be \( \sim 100 \mu m \) — grain sizes at the surfaces were found of the order of mm—as sketched in Fig. 1(a). The sheet was prepared in several stages: the as-cast material was aged for 6 h at 480 \( ^\circ C \), and for 6 h at 540 \( ^\circ C \), then hot rolled at 500 \( ^\circ C \) to 67\% reduction, and annealed for 12 h at 550 \( ^\circ C \) to produce initial equiaxed grains of uniform size. The main impurities were: 0.28 Fe, 0.17 Si and 0.012 Mn. Due to the heat treatment, precipitation was relatively uniformly distributed even though important precipitation was seen on grain boundaries. The sheet was machined into rectangular samples of dimensions \( 10 \times 10 \times 7 \) mm.

PSC experiments were performed in a presently well known device called Channel-die [13]. Samples were deformed by 10\% steps according to the height after each stage and in order to change the lubrication (Teflon). The deformation strain rate was \( \dot{\varepsilon} = 5 \times 10^{-3} \) s\(^{-1}\).

2.2. Microgrid and deformation maps

Microgrid techniques have been reviewed [14]. After a microscopic examination preparation, PMMA (poly(methyl methacrylate))—whose thickness was made uniform by centrifugation—was laid onto the sample surface to produce a regular pattern of longitudinal and normal lines using the electron beam. After developing, gold was evaporated onto the area of interest. A final dissolution allowed to exhibit a 1 mm\(^2\) gold grid with a 5 \( \mu m \) step and a linewidth between 0.5 and 1 \( \mu m \) to be usually obtained. Four grids are deposited onto the longitudinal section of the specimen (Fig. 1(b)).

High resolution images (4\( k \times 4k \)) at the initial state and then at each step of deformation were recorded using scanning electron microscope (SEM). The regular pattern of gold and its evolution with compression enabled the local field displacements and the gradient of the transformation tensor \( F \), to be determined. The software Correlmanuv and SEM images provided the coordinates of a set of points—intersections of lines—which when computed, gave some components of the strain field. Thus, the Green–Lagrange \( E \) or Euler–Almansi \( A \) tensors, and the rigid body rotation (RBR) tensor \( R(F = RU, \) polar decomposition where \( U \) is the right pure deformation tensor) could be computed from \( F \) [7,15,16]. Rey and coworkers [7] succeeded in computing six \( F \) components using a classical stereographical method involving the acquisition of at least two SEM images of the same area with a different acquisition orientation. This study deals with a plane analysis. So, the RBR is limited to a single parameter, i.e. the angular rotation around TD axis. The RBR and lattice rotation may be strongly linked, but one may occur when the other does not.

![Fig. 1. Sample shape and orientation, PSC device (channel-die). RD\(_0\), TD\(_0\), ND\(_0\): sheet axis; RD, TD, ND: PSC axis. The hatched domain on (a) is a 100 \( \mu m \) grain size area whereas the surrounding volume is composed of millimeter grain size. On (b) is indicated the position of the microgrids (1.4).](image-url)
2.3. **EBSD analyses**

Lattice orientation was acquired at each stage, using electron back scattered diffraction (EBSD), with a JEOL 6400 and JEOL 6500 (field emission gun, FEG), coupled with HKL software Channel 4 and 5. The FEG enabled a reduction of the electron beam diameter to 20 nm. This allowed an analysis of the shear band microstructure, which has been almost exclusively examined to date with the transmission electron microscope (TEM). With a conventional SEM, we succeeded in acquiring lattice orientation up to 19% compression, with a high rate of indexing, in spite of hardening and increasing dislocation density. Then, even with a FEG, surface relief lead to a significant decrease in the lattice orientation acquisition. All experiments using the FEG were carried out after an additional polish, which gave an estimated reduction in thickness of about 200 μm.

3. **Results**

3.1. **Observation of shear bands**

As previously mentioned, shear banding is believed to occur earlier with an increasing grain size. Even if there is no real localization (Fig. 2(a)) of the deformation, the deformation is heterogeneous at about 10% compression. In fact, the selected area is in bending. A uniform deformation would have transformed each initial square shape in a rectangular form.

As illustrated in Fig. 2(a), the hatched lines that follow the grid reveal the global flexion of the grain. This behavior shows the importance of the surrounding grains during accommodation of deformation. One should predict an homogeneous shearing—$E_{RN}$—of the grid for an S—determined by EBSD—orientated single crystal.

Besides, the localization in bands becomes obvious at 19% ($\varepsilon = 0.24$), whereas the macroscopic phenomenon is generally expected at a reduction of 40% in this alloy. Fig. 2(b) shows 10 or so shear bands inclined between 20 and 35° to the RD. They do not cross the studied area completely, but end at a larger accommodation zone. More relevant is the fact that a deflection (Table 1) in the intragranular band orientation can be seen.

The orientation of the shear bands appears to remain relatively constant, when the deformation is uniform. Thus, taking into account the global bending, the observed area may be divided into three domains (Fig. 2(a)), and EBSD measurements will confirm this assumption. In the domain A, there is an average band inclination of 35° with respect to the RD; in the domain B, the orientation is approximately 28°, and in the domain C, this average value is found to be 24°. So, between the first two identified zones, A and B, the mean band inclinations show a deflection of 7°. The same kind of deflection is seen between the B and C, 4°.

At present, it cannot be said if this deflection happens after shear banding or before. In fact, shear bands may have occurred with the same orientation, and in this case the misorientation can be explained by differential RBR.

Another basic characteristic of this localization, is its obvious periodicity. Shear bands are regularly spaced at ~200 μm, with an estimated width of 10–20 μm. Therefore, observation in greater detail, leads us to the conclusion that early shear bands could be eventually formed into a periodic decomposition of layers (Fig. 3). Harren et al. [5] found that shear bands in an Al-2.8%Cu alloy were composed of fine 0.1 μm layers—carrying large shear strains—with regular spacings of 0.8 μm. Presently, it is difficult to ascertain whether the lines in Fig. 3 are a result of intense glide along slip systems, or microshearing layers parallel to slip systems.

At 28% ($\varepsilon = 0.36$), another set of shear bands appears (Fig. 2(c)), inclined at about 35° with respect to the RD. It crosses the latter set which is still visible—and
represented with thinner lines—whose inclination decreases due to the material flow and the RBR around TD axis. The strong periodicity is still striking but, at present, the orientation does not appear to shift from one region to another.

Assuming the phenomenon is identical in smaller grains regardless of grain size effect, we now analyze the deformation accommodation in these same grains in a different way. Fig. 4 illustrates this, and reveals sheared layers in 100 μm grains, observed in other regions of the sample. Obviously, the mechanical analysis should allow a grid step size smaller than 5 μm, and the present limitations of EBSD acquisition would be reached with such a scale. Then, using the same assumption, this millimeter grain scale provides the opportunity to extract structural and textural shear banding characteristics with a non-destructive test.

Table 2 tries to emphasize the assumed grain size effect on shear banding by comparing dimension features on a millimeter grain and on a 100 μm grain size (Fig. 4). This result of course lacks quantitative data but is to be compared with other f.c.c. structure metal implying other grain sizes.

3.2. Orientation maps and pole figures

EBSD acquisition was also performed after each state of deformation. In the initial state, the microgrid was laid onto a millimeter scale grain whose orientation is misoriented of 8° from S (1Ì23)[634] with a scattering of less then 5°.

The orientation maps for the 10% compression state shows a precocious grain subdivision. So, orientation maps may be subdivided into various zones (Fig. 5)—identified with mean Euler angles (Table 3)—taking into account the orientation evolution that shift one another and correlated with domain of uniform deformation. From one state to the next, these zones may be not associated; thus, zone 4 of the 10% compression orientation map was not correlated with zone 7 of the 19% deformation map—zone 4 disappears from the analyzed area.
This grain subdivision could lead to the assumption that the whole grain is not submitted to plane strain. Actually, according to the macroscopic path, the deformation state is not dissimilar to PSC, and considering the significant solid angle of the D-type vertex—it means here vertex 49—[17] of the Bishop and Hill polyhedron, the assumption turns out to be legitimate—except on zone 4. To determine the potentially activated slip systems among octahedral slip systems \{111\} \{110\}—according to the Schmid analysis—it will be assumed that the area is under PSC. The discussion that has to take place further is of significant interest, with respect to previous hypothesis. Fig. 6 gives the slip plane trace orientations on the RD-ND and TD-ND sections—one of these traces is obviously correlated with shear band inclination. As reported in Fig. 3, only one of the potentially activated slip systems, or more precisely its trace, is clearly identifiable. The two other slip traces have never been observed in the SEM images except when shear banding occurs. The activation of a single slip system would imply a homogeneous shearing of the microgrid. It follows that the activation, although non-apparent, of other potential activated slip systems cannot be ruled out.

### Table 3

<table>
<thead>
<tr>
<th>Z_1</th>
<th>Z_2</th>
<th>Z_3</th>
<th>Z_4</th>
<th>Z_5</th>
<th>Z_6</th>
<th>Z_7</th>
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Zones are represented on Fig. 5.
Further investigations of a magnified view of Fig. 5, zone (*) (Fig. 7), after a new surface preparation—which resulted in microgrid destruction—gave the lattice orientation development within the inner-band. Whether considering either Fig. 7(a) or (c), the shear bands and their features are easily recognizable. As illustrated by Fig. 7(c), the inner-band structure is not easy to characterize even with a FEG: although the orientation map shown reveals a subgrain structure, such finer measurements within the band are generally not possible due to the high dislocation density. So, this would appear to be a cellular structure, and is probably not as relevant as it seems, and for the time being only the measured orientations in the band will be regarded. Fig. 7(d) shows a misorientation profile taken normal to the shear band sketched in Fig. 7(c); along this 5 μm line, the cumulative lattice misorientation was seen to be 7°.

Table 4 shows the misorientations between the different zones and ideal orientations, global and local re-orientation are expected to appear. The behavior between zones—with the exception of SB1 and SB2—is not dissimilar. Re-orientation towards the Taylor \{4 4 11\}\langle11 1 8\rangle component was found. Conversely, evidence of lattice rotation in both identified shear bands has been less widely reported. As the bifurcation occurs, the lattice misorientation with Taylor \{4 4 11\}\langle11 1 8\rangle orientation arises. This behavior could imply the existence of a different deformation path from PSC, inside the band.

3.3. Deformation maps

SEM grid images were used to compute the local field displacements [15,16] and the gradient of the transformation tensor $F$—for plane compression with no displacement along the TD. The next step is the calculation of the deformation tensor:

- the Green–Lagrange tensor $E$ in the initial configuration;
- the Euler–Almansi tensor $A$ in the deformed configuration.

The latter gives the shape of the studied area at each step of compression (Fig. 8(d and e)).

The following short example, PSC, may help to increase clarity:

$$F = \begin{pmatrix} \lambda & 0 \\ 0 & 1/\lambda \end{pmatrix}, \quad R = I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}, \quad U = F,$$

$$E = \frac{1}{2} (F^T F - I) = \frac{1}{2} \begin{pmatrix} \lambda^2 - 1 & 0 \\ 0 & (1/\lambda^2) - 1 \end{pmatrix},$$

$$A = \frac{1}{2} (I - (FF^T)^{-1}) = \frac{1}{2} \begin{pmatrix} 1 - (1/\lambda^2) & 0 \\ 0 & 1 - \lambda^2 \end{pmatrix}.$$ 

So, here:

$$E_{RR} = -A_{NN} = \frac{1}{2} (\lambda^2 - 1) \quad \text{and}$$

$$E_{NN} = -A_{RR} = \frac{1}{2} \left( \frac{1}{\lambda^2} - 1 \right).$$

Fig. 7. Focus on zone (*) (Fig. 5) and on a shear band: (a) misorientation map to the initial state in grey scale; (b) pole figure of zone (*); (c) focus on a band, black regions are non-indexed area (high densities of dislocations); (d) misorientation profile along the line represented on (c). Those orientation maps was obtained with a FEG MEB.
At 10% deformation (Fig. 8(a)), the Green–Lagrange deformation maps show a non-significant dispersion of component values. One may quote the opposite RBR and shear component between the left and right side of the domain—in agreement with the global bending.

At 19% (Fig. 8(c)), as shear banding occurs, local component values increase strongly in the band of

<table>
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<th>Z.1</th>
<th>Z.2</th>
<th>Z.3</th>
<th>Z.4</th>
<th>Z.5</th>
<th>Z.6</th>
<th>Z.7</th>
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Fig. 8. Deformation maps: (a) RBR (%) component at 10%; (b) RBR (%) component at 19%; (c) $E_{RR}$ (%) component at 19%; (d) $A_{RR}$ (%) component at 19%; (e) $A_{RR}$ (%) component at 27%. In the last map, the second band appears in white because deformation values there are out of range.
localization. Nethertheless, some values must be considered with care: in most of these cases, the determinant of \( F \) is not equal to 1, consequently, the deformation is not really plane strain, and components are locally false within the band. It is known that when large deformations are concerned, trace(\( E \)) is not necessarily zero; the conservation of the volume is assured by the condition \( \det(F) = 1 \).

At 19% (Fig. 8(b)), the RBR maps show an important opposite rotation between bands and matrix. This observation is then used to quantify average component values for matrix and shear bands, at each state of the transformation (Table 5). For this study, the bands are regions where the RBR is greater than 30°.

Regarding the mean values as true, attention is focussed on two surprising results. At first, the deformation is not concentrated in the band: the transformation goes on occurring within the matrix. Secondly, the deformation path in the band is more complex than a single shearing.

Fig. 8(d and e) show Euler–Almansi components \( A_{RR} \)—elongation—in the deformed configuration and give visual informations on the intense shearing that occurs within this area. These maps clearly reveal that RBR of the whole grain would have been more significant without shear banding.

As summarized in the previous table, the average compression component \( E_{NN} \) for each step, is in complete agreement with the macroscopic deformation.

4. Discussion

4.1. Crystallographic or non-crystallographic phenomenon

The sequence of events that leads to macroscopic shear banding has been well documented. According to Korbel and Martin [18], firstly microbands are observed, with directions that coincide with a common trace of crystallographic \{111\} slip planes, and when these encounter grain boundary, if they cross, they may become macrobands. In Al–Mg alloy, microbands are 0.1–0.2 μm in thickness, whilst macrobands are 5 μm in width and over.

From a dimensional viewpoint, the bands observed in the present study, may not be regarded as microbands. However, one may expect a grain size effect on the microshear banding scale, and on dislocation clustering, or ‘high dislocations density islands’ dimension. Therefore, it is of interest in the present study to wonder if the banding is similar to that found in smaller grains (Fig. 4). In our opinion, both are identical: the only difference is probably the amount of energy to be dissipated and, due to grain size, the volume involved in this dissipation. The opposite side of the microgrid at 10% compression can be seen as two bodies with an opposite RBR. As, in plane compression, assuming an isotropic material, macroscopic RBR is prevented by boundaries conditions, the implied energy must be dissipated differently from rotation, an as cracking way.

In spite of this ‘question of scale’, there is no doubt in the directional coincidence between the first set of bands and one peculiar slip plane—\{111\}—trace; this involves a deformation accommodation by the two coplanar slip systems (111)[011] and (111)[101] in the inner-band. The ‘resultant’ shearing (111)[112] has also been observed in a Copper oriented Al single crystal, deformed under plane stress conditions for cold rolling [19].

Moreover, this correlation justifies the observed band deflection from one identified zone to another. It should be pointed out that this deflection did not occur after the band appearance: the lattice misorientation—and so the slip plane trace deflection—had already been established with EBSD measurements after 10% compression. In this particular case, the precocious occurrence may also be justified by the \{111\} plane orientation: its trace is about 30° to RD and it is slightly misoriented from the TD (Fig. 6). In zones 5–7, the slip traces containing the TD are inclined of 33, 24 and 26°, respectively with respect to RD, for average measured values of 35, 28 and 24°. The disagreement between traces and measurements may be closely connected with the experimental procedure, and with an inaccurate estimation of the average lattice orientation.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Average Green–Lagrange components at each state in the global studied area, in the shear bands and outside the shear bands (matrix)</th>
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<tr>
<td></td>
<td>19%</td>
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<tr>
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<td>Global</td>
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<tr>
<td>( E_{RR} ) (%)</td>
<td>32</td>
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<tr>
<td>( E_{NN} ) (%)</td>
<td>-18</td>
</tr>
<tr>
<td>( E_{RN} ) (%)</td>
<td>-3</td>
</tr>
<tr>
<td>RBR (%)</td>
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</table>
The second shear set still coincides with the (111) plane, as indicated by the misorientation EBSD map in Fig. 7: in the matrix, there is no dramatic re-orientation of the lattice—the orientation is still close to S component. Material flow can occur without any lattice rotation: the global inclination of the first set of bands decreases while the lattice rotation is weak, involving a light shift in slip plane traces.

Otherwise, band features are definitely identical in quite homogeneous constraint domain. Therefore, regarding shear banding as a bifurcation of the deformation path with an initial homogeneous stress state, would appear to be a legitimate assumption.

As a consequence, it is suggested that shear banding—microshear banding—occurs more sensitively along {111} plane containing the TD axis. The occurrence slip plane should be the one whose plane trace orientation on RD–ND is nearest to 45°—a high intensity shearing direction, according continuum mechanics for a plane strain path of transformation.

4.2. Concentration of deformation

The most salient result of the deformation maps is, that one cannot assume that the deformation is totally localized in bands, when bifurcation occurs (Table 5). The mean values show that in shear bands, the deformation is more intense and that there is not only shearing, but also an important compression and elongation along the band direction. In the matrix, the transformation appear to continue as if there was no bifurcation occurring. The energetic model [11] does take the fact into account, that for all shear bands except those that make angles of 45° with RD, deformation goes on in the matrix.

The deformed configuration given by Euler–Almansi maps, provides another view on the phenomenon of shear banding (Fig. 8). The latter is often seen as a bifurcation event that may be consider using continuum mechanics. However, how not to see, on these deformation maps, a look like fracture [20] along high atomic density plane to prevent macroscopic rotation around TD axis? In tension for instance, localization may imply crack formation, whereas in compressed material cohesion is ensured. The structure involved in the intense shearing, leads to more complex phenomena than simple fracture.

It is not known whether the first to appear is either lattice inflexion—shown by the misorientation profile of Fig. 7—or shear banding. The lattice inflexion in the vicinity of the band, could reveal the attainment of an elastic threshold, and once this limit—depending on the alloy—is reached, intense shearing along a specific direction may occur. However, the same inflexion could be necessary to ensure the transformation continuity on the band border, so that shear banding and inflection would occur simultaneously.

4.3. Texture prediction

Attention is now paid to the lattice re-orientation. As shown in Table 4, with the exception of SB1 and SB2, lattice rotations are not significantly different between the specified zones. Misorientations with ideal common orientations appear to be stable. The decreasing mis-orientation between matrix and the Taylor component must be pointed out: the behavior is well predicted by evolution texture models. Thus, the Taylor component is stable, in texture models of rolling.

Conversely the re-orientation of the lattice within the narrow areas formed by the shear bands, is strongly correlated to the localization phenomenon. As the matrix accommodates the deformation, in order to decrease its misorientation with the stable Taylor lattice orientation, in the inner-band, the lattice misorientation with Copper and Taylor components grows while the misorientation with Brass is stable. Dukham et al. [21] have previously mentioned an increase of the Brass component as strain, and consequently the extent of shear banding, increased. This kind of behavior constitutes a clue for the well known disagreement between experimental and predicted rolling textures. Maurice [13] showed that, whatever the considered model (‘Pancake’, ‘Full Constraints’,…) when octahedral slip systems are concerned, the orientation distribution function calculation never succeed in simulating correctly rolling texture: it means the intensity of Taylor, Copper and S components are always too strong, and, at the opposite, the intensity of the β fiber is too weak.

In an attempt to predict the crystal orientation evolution within the band, a deformation tensor is introduced, under the form, where A is a parameter, in (RD, TD, ND) axis:

\[ \dot{\varepsilon} = \begin{pmatrix} \xi & 0 & -A \xi \\ 0 & -\xi/2 & 0 \\ -A \xi & 0 & -\xi/2 \end{pmatrix}. \]

\( \xi \) depends on the macroscopic rate condition.

This field is in agreement with the assumption that predicts mainly the activation of two coplanar slip systems in the band, involving an intense shearing, and with a significant deformation along the TD axis. Such a field allows, with \( A = 5 \), to predict a lattice orientation in the band, for \( \varepsilon \approx 1 \), misoriented less then 5° from the lattice orientation measurements in SB1 and SB2 (Table 3).

Any evolution texture model for room temperature transformation of f.c.c. structure metals, where Cu-type shear [21] occur, should introduce a bifurcation contribution. Firstly, it requires a bifurcation criterion—the theory of Hill and Hutchinson—, theory developed for
a rigid plastic material with a Bishop and Hill polyhedron yield surface. Secondly, both the dimension characteristics and the texture evolution within the inner-bands, have to be determined in order to establish the bifurcation contribution to the evolution of rolling textures.

5. Conclusion

Evidence of precocious shear banding in a millimeter scale (123)[634] grain of Al-4.5% Mg has been presented and discussed. A parallel with bands in smaller grain and involving a grain size effect has been done. The initial crystallographic feature of the phenomenon has been revealed: shear banding occurs along a {111} plane containing the TD axis. Deformation maps have shown the importance of the deformation within the matrix, when the bands first appear. Compression is not localized within the inner-band. The influence of localization on texture evolution has been confirmed: shear bands appear, at least in this particular case, to stabilize the Brass texture component.

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References