A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
Volume 51 2006 Issue 1

J. POSPIECH* M. OSTAFIN** , R. SCHWARZER**

# THE EFFECT OF THE ROLLING GEOMETRY ON THE TEXTURE AND MICROSTUCTURE IN AZ31 AND COPPER

# WPŁYW GEOMETRII WALCOWANIA NA TEXTURĘ I MIKROSTUKTURĘ STOPU AZ31 I MIEDZI

The destabilization phenomena in texture and microstructure caused by the change of the deformation path are considered in an AZ31 magnesium alloy. The study, based on individual grain orientation measurements in the SEM by COM/EBSD, is a continuation of earlier investigation on copper. The phenomena in materials caused by the destabilization provide new information about the mechanism of plastic deformation and its structure-texture effects which are valuable for the solving basic problems of controlling mechanical properties.

*Keywords*: magnesium alloy AZ31, copper, texture, microstructure, rolling, COM/EBSD measurements in the SEM, deformation path, destabilization

Przedmiotem pracy jest zjawisko destabilizacji w teksturze i mikrostrukturze wywołane zmianą drogi odkształcenia w stopie magnezu AZ31 i w miedzi. Badania oparte na pomiarach pojedynczych orientacjach techniką COM/EBSD w SEM, stanowią kontynuację wcześniejszych prac nad miedzią. Zjawiska w materiałach wywołane destabilizacją dostarczają nowych informacji cennych dla rozwiązania podstawowych problemów sterowania właściwościami mechanicznymi.

## 1. Introduction

Earlier investigation of copper [1-5] has shown that even a small additional plastic deformation after a change of the deformation geometry can cause a strong change in the global texture. Individual grain orientation measurements have revealed a close interconnection between the changes in texture with significant changes in the microstructure. These effects in texture and microstructure are constrained by the change of local stresses leading to the change of the geometry of the active slips. The consequence is a drastic destabilization of the dislocation structure which eliminates strain hardening [6].

Plastic deformation becomes heterogeneous by often inducing localization in the form of deformation bands or shear bands. The changes in texture and microstructure caused by the change of the path of plastic deformation are characterized by strong dynamics. These effects of destabilization are analyzed in the present paper for a hexagonal metal such as the magnesium alloy AZ31 and compared with results obtained for copper. The experiment was performed for rolling with the change from reverse to cross (after rotation by 90° around ND) or diagonal (after 45° around ND). The effects of destabilization in texture and microstructure were analysed by measuring individual grain orientations in the SEM by automated crystal orientation mapping (COM/EBSD).

## 2. Effects of destabilization in copper

Effects of the change of the deformation geometry on texture and microstructure were described earlier for polycrystalline copper alloys (with Al or Ge) [6, 7] and for polycrystalline [2-5] and monocrystalline pure copper [1]. These effects occur as significant changes in the texture and microstructure which are the stronger the larger the grain size is and the higher the samples have been deformed before the deformation path is changed. These effects of destabilization of the substructure develop with high dynamics. This is manifested by results of previous investigations which were performed for pure copper by channel-die compression of monocrystalline samples [3]

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* INSTITUTE OF METALLURGY AND MATERIALS SCIENCE, POLISH ACADEMY OF SCIENCES, 30-059 KRAKÓW, 25 REYMONTA ST., POLAND
** INSTITUTE OF PHYSICS, TU CLAUSTHAL, CLAUSTHAL-Z., GERMANY

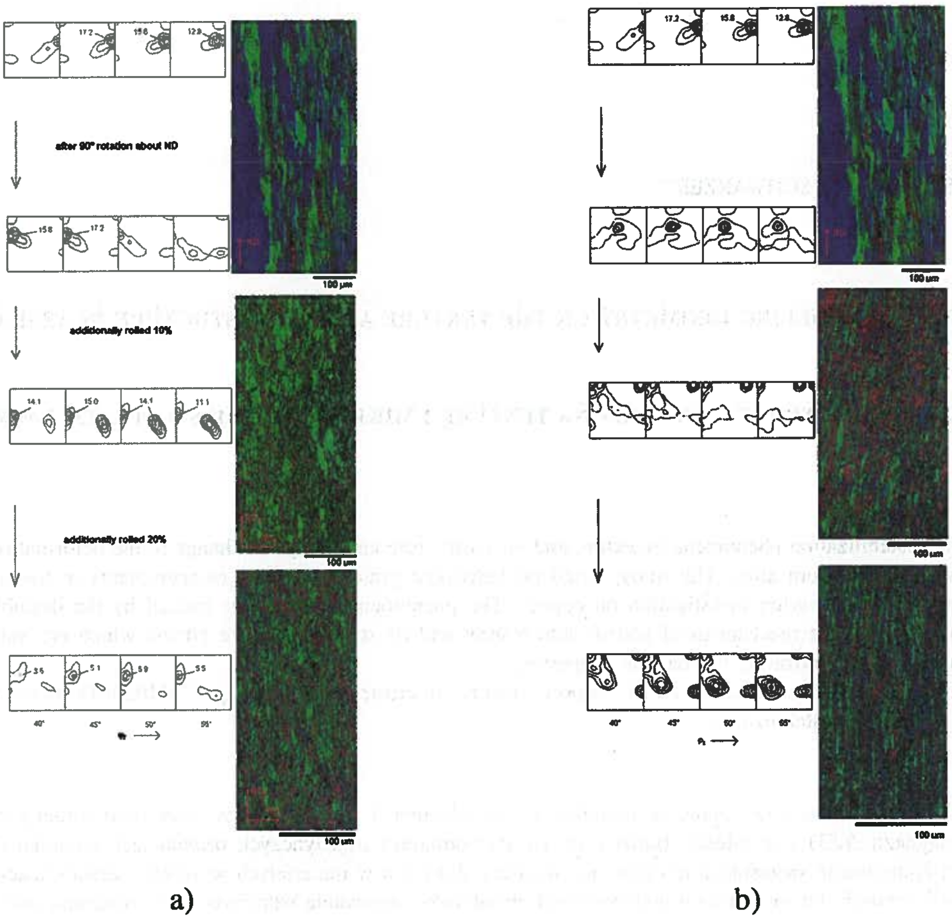


Fig. 1. ODF plots around the C position and the corresponding crystal orientation map of a Cu sample rolled up to 62% reduction and then rolled to additional 10% and 20% reduction in thickness a) after 90° rotation about ND, b) after 45° rotation about ND

and by rolling of polycrystalline samples with average grain sizes of 110 $\mu$m respectively 60 $\mu$m [4]. Investigations on single crystals allowed a closer elucidation of the interrelated changes in texture and microstructure. The destabilization after the change of the deformation path led to a fragmentation of the matrix in symmetrically equivalent elements [1] and thus to a reduction of the influence of the form effect during deformation. The observed texture changes, as an effect of destabilization, are not typical and cannot yet be obtained by simulation calculations based on Taylor models.

As an example of the previous investigations on copper, the changes of the texture and the corresponding microstructure of a polycrystalline sample rolled up to 62% reduction in thickness and an average grain size of 60 $\mu$m are shown on Fig. 1. The texture contains one component, C = {112}<111>, and is presented in the ODF space of Euler angles in sections of constant $\varphi_2$ angles around the C position (i.e. $\varphi_2$ = 40°, 45°, 50°, 55°). After rotation by 90° and 45° about ND, cross and diagonal respectively, the samples are additionally rolled to 10% and 20% reduction. Rotation of the sample brings the C position into the positions C90 = {112}<110> respectively C45 = {112}<941> which are unstable against the changed rolling geometry. The ODFs on Fig. 1 show that the additional (cross and diagonal) deformation shifts and disintegrates the old unstable components C90 and C45. At the same time distinct tendencies of creation of new components near {111}<uvw> are observed. The comparison with the COM map manifests the links between the texture changes and a strong grain fragmentation. The crystal orientation map on Fig. 1a shows a typical microstructure for the longitudinal plane of a metal sheet after unidirectional rolling. The grains are elongated in the rolling direction and form strings of varying width. After additional rolling up to 10% the microstructure became rather homogeneous with large elongated grains between small fragmented elements. On Fig. 1b the microstructure after diagonal rolling is shown. In this case the grains are elongated parallel to the new rolling direction (RD). After 10% additional deformation week traces of the former arrangement of grains are visible, but after 20% deformation only grains elongated parallel to the final RD are observed.

In Fig. 2 the (200), (111) and (220) pole figures are plotted for a sample deformed by rolling up to 62% reduction and then additionally rolled in diagonal direction to 20% reduction. One can recognize that in the pole figures the orthorhombic sample symmetry is almost fulfilled. Phenomena observed in the texture and microstructure during additional rolling of polycrystalline material can be compared to the phenomena observed in monocrystals [1]. During deformation after the change of the rolling direction in the polycrystalline material a fragmentation of grains and, at the same time, a change in texture with preservation of the orthorhombic sample symmetry was observed. In the monocrystalline material it was directly shown that in the occurring fragmentation of the matrix its fragments are connected by the orthorhombic sample symmetry relation.

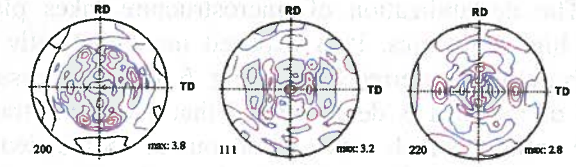


Fig. 2. (200), (111) and (220) pole figures of a Cu sample rolled to 20% additional reduction after 45° rotation around ND

## 3. Investigations of the magnesium alloy AZ31

Magnesium and magnesium alloys have a hexagonal crystal lattice with dense packing arrangement of the atoms (c/a = 1.624) which is connected with a strong anisotropy of the material. Magnesium and its alloy AZ31 are characterized by low deformability at room temperature which is due to the small number of operating slip systems. Plastic deformation takes place essentially only by {0001}<11-20> slip along **a** with the Burgers vector 1/3<11-20> in the basal plane. Slips with the Burgers vectors <c + **a**> on the pyramidal planes are practically not activated at room temperature because the critical resolved shear stress is too high as compared to that of basal slip. Plastic deformation can be supported by twinning, but it is only one-sided and moreover cannot be activated by compression stress along the c axis. Only at elevated temperatures, from about 200°C and higher, the critical resolved shear stress for <c + **a**> slip undergoes a considerable reduction. When temperature increases above 200°C, dislocation climb is activated as a further mechanism, and also twinning is more intense. A sudden increase in the deformability is observed. This means that cold plastic deformation is extremely difficult because of the insufficient number of slip systems.

Rolling of semi-finished products for sheets, deep drawing, and profile production by extrusion are the most important applications of metal forming in industrial technology as well as in basic investigations. Thus a special interest in such processes exists also in the case of magnesium alloys. There are not many publications dealing with texture development in hexagonal metals. The texture of rolled (or channel-die deformed) pure magnesium and AZ31 alloy, as described in literature, has the form of a strongly exposed fiber with the c axis aligned almost parallel to the normal direction of the sheet, or with the c axis deviating about 15° from the rolling direction. There is no information in the open literature about the here considered subject concerning the effects in texture and microstructure caused by the change of the deformation path.

## 4. Experimental procedures

The material was an AZ31 magnesium alloy containing (in wt.): 3.0-3.5% Al, 0.45- 0.80% Zn, 0.17-0.40% Mn, balance Mg in the form of an ingot after squeezing and annealing. The AZ31 samples were rolled reversely and uni-directionally up to 65% reduction at 380°C, and next additionally rolled transversely and cross up to 11% reduction at 180°C.

Individual grain orientation measurement was performed by evaluating backscatter Kikuchi patterns with the COM/EBSD technique in the SEM [9, 10] which enables a precise local analysis of the phenomena under study [7]. The textures were measured on rectangular fields in the longitudinal plane point by point in steps of about 0.5 $\mu$m at the rate of >10 points per second. The field sizes comprised 300 × 300 measured points on regular scan grids of about 0.2 mm in the ND and 0.6 mm in the rolling direction (RD). The crystal orientation maps (COM) were constructed by attributing colours to the pixels characteristic for the particular grain orientations in the measured points. "Images" of the microstructure were thus produced which revealed the detailed grain structure in quantitative orientation contrast. The results of the investigation were analysed by means of the global texture described by the ODF which was calculated from COM data, using the series expansion method with $L_{max}$ = 34. The ODF is presented in the space of Euler angles in the interval $\Phi_1$ (0, 180), $\Phi$ (0, 90), $\varphi_2$ (0, 60) defined by the hexagonal crystal and triclinic sample symmetry.

## 5. Destabilization effects in the AZ31 alloy

The results of this investigation are presented by pole figures and ODFs. Fig. 3 shows the (0002) and (10-10) pole figures and ODFs for AZ31 samples rolled up to 65% reduction in thickness at 380°C. The ODF is plotted in the space of Euler angles ($\varphi_1, \Phi, \varphi_2$ ) in sections of constant angular steps of $\Delta\varphi_2 = 5°$. The texture has one component in the form of a fiber with the c axes of the grains aligned nearly parallel to the normal direction (ND) of the rolling plane. The fiber contains a weak maximum near (0001) <10-10> which, together with the fiber axis, deviates by 15° from the RD. The basic lattice plane is thus slightly declined from the rolling plane. The texture component which is situated in the center of the pole figure corresponds to a texture maximum near $\Phi = 0$ in the Euler space, i.e. in the area where the deformation of the space is largest (Fig. 3b). For a clearer exposition of the texture changes due to destabilization, the fiber was therefore transferred to the least deformed area of the Euler space by a 90° rotation of the Euler angle coordinate system about the transverse axis. The fiber axis which was localized in this way near $\varphi_1 = 90°$, $\Phi = 90°$, now runs parallel along the $\varphi_2$ axis (Fig. 3c). The transfer in which the RD is exchanged by the ND has obviously only of geometric character, and the c axes of the grains remain nearly parallel to the ND.

In Fig. 4 the (0002) pole figures of the AZ31 sample, after successive stages of the experiment, are plotted: a) after conventional rolling up to 65% reduction, b) then after rotating the RD into the TD (i.e. after 90° rotation of the sample about the ND), c) after additional rolling up to 11% reduction along the TD, d) after cross rolling up to 11% reduction. The results show that after additional rolling of the sample along the TD, the texture has returned to the previous form of a fiber, the same type of texture as before the change of the deformation path, but the fiber has now rotated with the sample coordinate system to a symmetrically equivalent position according to the relation $\varphi_1' = 180° + \varphi_1$, which is a 180° rotation about the ND of the sheet plane.

The texture changes are demonstrated by three successive pole figures in Fig. 4. The last one (the fourth in the row) corresponds to the sample after cross rolling. Below in Fig. 5 the corresponding ODFs are shown in the standard (not transferred) form.

The destabilization of microstructure takes place with high dynamics. It is exposed more distinctly by ODFs in the transferred form in Fig. 6. In the successive plots of Fig. 6 it is demonstrated that additional transverse rolling, which was carried out at 180°C, led to dramatic texture effects. Fig. 6b shows the texture after rotating the RD of the sample into the TD. Fig. 6c

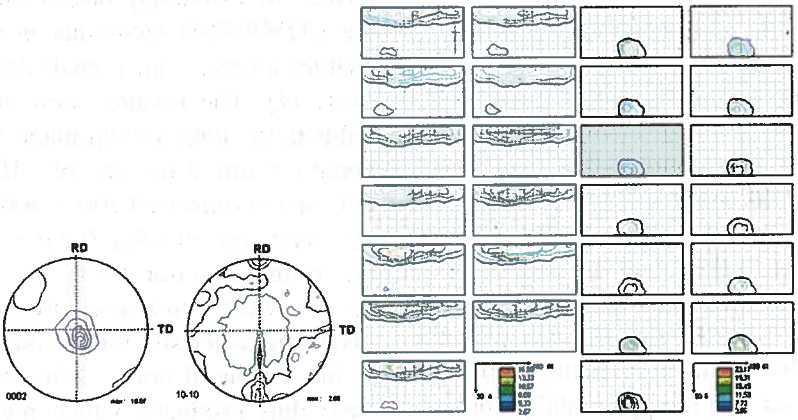


Fig. 3. a) (0002) and (10-10) pole figures for an AZ31 sample rolled up to 65% reduction at 380°C and the corresponding ODF b) in the standard form, c) after rotation by 90° around the ND axis of the sample

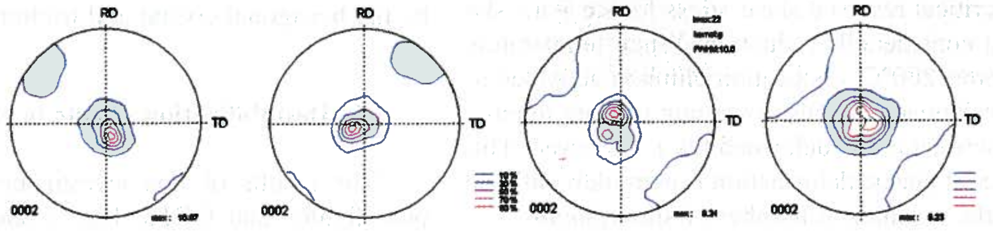


Fig. 4. (0002) pole figures of an AZ31 sample: a) after rolling up to 65% reduction at 380°C, b) next after rotating the sample by 90° about the ND, c) after additional rolling up to 11% reduction along the TD at 180°C, d) after cross rolling up to 11% reduction at 180°C

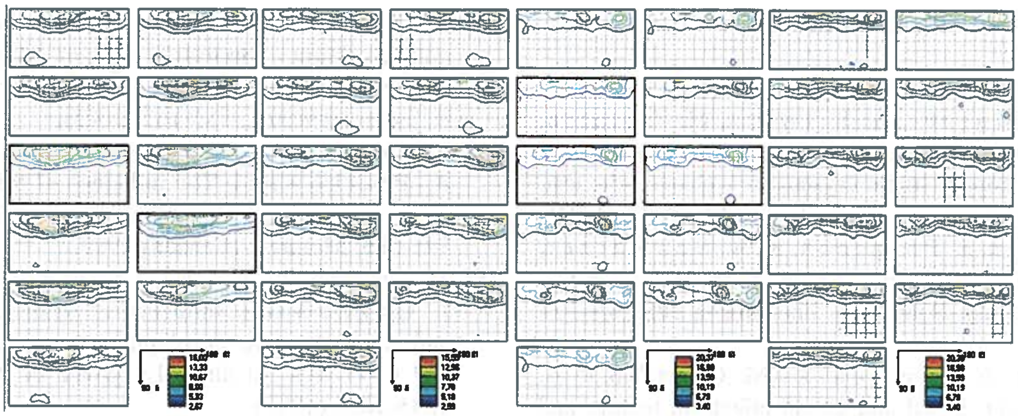


Fig. 5. ODFs in the standard form corresponding to the pole figures on Fig. 4

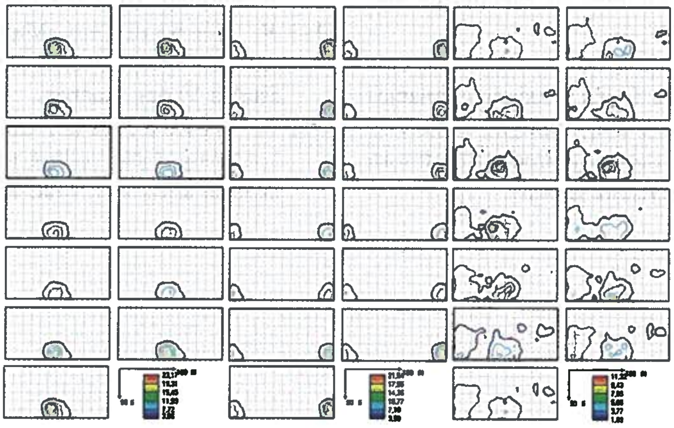
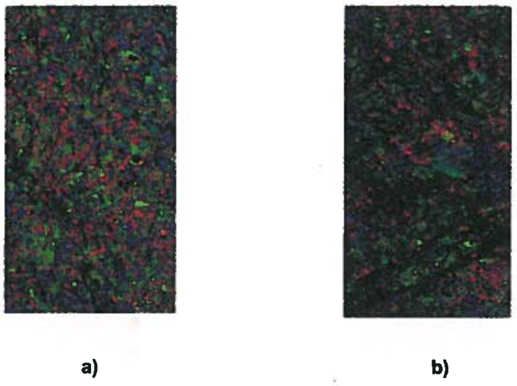


Fig. 6. ODFs of an AZ31 sample plotted in the Euler angle space after rotation of the sample coordinate system by 90° around the transverse direction (TD): a) after rolling up to 65% reduction at 380°C, b) next after rotating the sample by 90° about the ND, c) after rolling up to additional 11% reduction at 180°C



a)

b)

Fig. 7. The microstructure images of an AZ31 samples presented by crystal orientation maps: a) after rolling up to 65% reduction at 380°C, b) after transverse rolling up to 11% reduction at 180°C

shows that only traces of the initial texture outlast additional rolling. In the texture transition from b) to c) at a slightly elevated temperature of 180°C only new basal slip could be activated, either in a <11-20> (single slip) or in a <10-10> (double slip) direction.

On Fig. 7a the microstructures before and on Fig. 7b after additional rolling are shown. The microstructures are fine-grained, but after additional rolling (Fig. 7b) there are some indications of dynamic recrystallization visible.

## 6. Conclusion

Texture and microstructure, stabilized in uni-directional (or reverse) rolling in a polycrystalline material, become unstable after the change of the rolling geometry due to the change of the strain distribution. As a consequence a reorganization of the microstructure and a distinct change in texture is observed. The effects of destabilization are the higher the higher the initial deformation of the sample and the larger the grain size of the material are.

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*Received: 10 January 2006.*