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M. OSTAFIN[*, **], J. POSPIECH[**], R.A. SCHWARZER[*]

THE EVOLUTION OF DEFORMATION TEXTURE IN COPPER BY UNIDIRECTIAL AND BY CROSS ROLING

EWOLUCJA TEKSTURY ODKSZTAŁCENIA W MIEDZI PODCZAS WALCOWANIA JEDNOKIERUNKOWEGO I WALCOWANIA KRZYŻOWEGO

The change of the deformation path has a strong effect on the formation of cold-rolling texture. In particular, the texture stabilized during rolling becomes unstable and disintegrates when the rolling direction is changed in the last stitches from unidirectional or reverse rolling to pseudo-cross rolling by rotating the sample through an angle of 90° or 45° about the normal direction. In addition to global texture, the microstructure is also specifically changed on a grain-size level.

The change of the path of plastic deformation leads to a destabilization of the substructure which was formed during the primary step of rolling in one direction. In investigations on electrolytic copper distinct changes of texture and microstructure have been found depending on the deformation process. The orientation density function (ODF) shows that the reverse rolled starting sample of copper in this investigation contains only one component in the $C=\{112\}\langle 111\rangle$ position. By rotation about ND through 90° or 45°, the C component changes into the unstable $C90=\{112\}\langle 110\rangle$ or $C45=\{112\}\langle 914\rangle$ position, respectively, which almost disappears with progressive deformation.

The effect of the mode of rolling on texture evolution has been studied in detail on a macroscopic scale by X-ray pole-figure measurement as well as on a grain-specific scale by individual grain orientation mapping (ACOM, "Automated EBSD") in the SEM. The statistical distributions of grain orientations (pole figures, ODF), misorientations across grain boundaries (MODF) and Σ grain boundaries are considered.

Zmiana drogi odkształcenia silnie oddziaływuje na teksturę walcowania. W szczególności tekstura ustabilizowana podczas walcowania staje się niestabilna i ulega rozpadowi, gdy w ostatnim etapie walcowanie jednokierunkowe lub rewersyjne zamieniamy na walcowanie poprzeczne obrotem próbki dookoła KN o 90° lub 45°. Równocześnie z teksturą globalną

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[*] INSTITUTE OF PHYSICS, TU CLAUSTHAL, CLAUSTHAL-Z., GERMANY

[**] INSTYTUT METALURGII I INŻYNIERII MATERIAŁOWEJ IM. A. KRUPKOWSKIEGO, POLSKA AKADEMIA NAUK, 30-059 KRAKÓW, UL. REYMONTA 25

obserwowane są specyficzne zmiany w mikrostrukturze w skali wielkości porównywalnej z wielkością ziarna.

Zmiana drogi plastycznego odkształcenia doprowadza do destabilizacji substruktury, która została uformowana w początkowym etapie jednokierunkowego względnie rewersyjnego walcowania. W badaniach nad elektrolityczną miedzią wytworzone zostały znaczne zmiany w teksturze i mikrostrukturze w zależności od procesu odkształcenia.

Funkcja gęstości orientacji (ODF) pokazała, że próbka do badań w stanie początkowym przed walcowaniem rewersyjnym zawiera tylko jedną składową w położeniu C={112}<111>. Po obrocie dookoła KN o 90° względnie 45°, składowa C przechodzi w niestabilne położenie odpowiednio C90= {112}<110> względnie C45={112}<914>, które zanikają ze wzrostem odkształcenia.

Wpływ sposobu walcowania na ewolucję tekstury badano szczegółowo zarówno w skali makro przez pomiar rentgenowskich figur biegunowych jak i w skali rozmiaru ziarna przez odwzorowanie indywidualnych orientacji ziarn techniką ACOM (automatyzowane EBSD) w SEM.

Rozpatrywano rozkłady statystyczne orientacji ziarn (figura biegunowa, ODF), dezorientację w poprzek granic ziarn (MODF) i granice specjalne Σ.

1. Introduction

It is well known that plastic deformation of a crystalline material produces a specific texture in the material. The type of texture depends on the mode, speed and degree of deformation. Textures which develop during unidirectional (or reverse) rolling can be well approximated by simple geometrical models (e.g. Taylor type models), but textures induced by a general deformation process cannot yet be predicted reliably. The development of texture during deformation is also accompanied by the mutual interaction of texture and microstructure and, in addition, by specific changes of the microstructure which are not taken into account in simple geometrical models. Therefore it seems that texture formation cannot be tackled by a simple geometrical simulation.

Some possibilities to better understand and to control texture formation are offered by studying the effect of a change of the deformation path. Textures which are formed, e.g. by cross or by clock rolling, differ from those known from unidirectional rolling. The change of the deformation path causes destabilization of the earlier formed structure. As a consequence, significant changes in texture and microstructure are observed already at a relatively small amount of additional deformation which proceed with high dynamics. In single crystals of copper with the initial orientation {112}<111>, a fragmentation (splitting) of the structure into symmetrical areas [1] occurs, whereas in polycrystalline copper alloys (CuGe8, CuAl5) new generations of twins and also localization of plastic deformation in the form of shear bands are observed [2, 3]

Since recently detailed studies of the development of texture and microstructure on a grain- specific scale are possible by Automatic Crystal Orientation Measurement in the SEM (ACOM, EBSD) [4]. In the present paper, earlier investigations on polycrystalline copper [5, 6] have been continued with emphasis laid on the effect of a change of the rolling direction. Some results are shown which demonstrate the effects of several percent additional deformation exerted by diagonal rolling at the angle of 45° to the primary rolling direction.

2. Experimental techniques

The investigation was carried out on recrystallized electrolytic copper. The grain size of the sample was about 60 μm, that is about half of the average grain size in a previous similar study [6] where the grain size was about 110 μm. After reverse rolling up to 62% reduction, four complementary lots of the sample were rotated about the normal direction (ND) by 90° (cross) and by 45° (diagonal), respectively, and next additionally rolled up to 10% and 20% reduction in thickness.

For each of these samples global and local textures have been determined. The global texture, described by the *O*rientation *D*ensity *F*unction (ODF), were calculated from X-ray pole figures, measured by means of a Bruker GADDS area detector. Local texture measurement was performed by evaluating backscatter Kikuchi patterns using the ACOM technique in the SEM [4]. To describe the microstructure, *C*rystal *O*rientation *M*aps (COM) were constructed from single orientation measurements on rectangular fields by ascribing distinct colours to particular grain orientations in the measured points. All these investigations were carried out in the longitudinal planes of the samples. The measured single orientations after recalculation into misorientations were used for the statistical analysis of Σ grain boundaries.

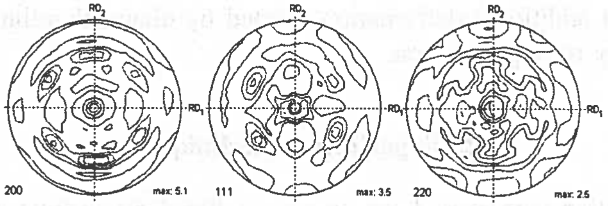
3. Texture and microstructure after the change of the rolling direction

In Fig.1 the recalculated (220), (111) and (200) pole figures are plotted from two samples which had been deformed first by reverse rolling in one direction up to 62% and then — after rotation of the samples about the ND by the angles 90° and 45°, respectively — additionally rolled in this new direction. It can be noticed that the orthorhombic symmetry in the pole figures is almost fulfilled.

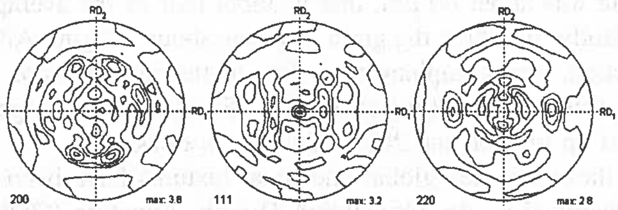
On Fig. 2 the ODF for the sample rolled up to 62% is shown. It contains only one texture component located at C ={112}<111> and is thus different from the typical rolling texture which usually contains the characteristic β fibre.

The microstructure image of this sample from ACOM measurement in the longitudinal plane shows grains elongated in the rolling direction and forming band clusters of varying width. If the sample (the sample's coordinate system) is rotated about the ND by an angle of 45° then the C component which is located at (112)[-1 -1 1] shifts into the C45 = (112)[1 -9 4] position. This is visible by the change of the ODF from Fig. 2a to Fig. 2b.

A relatively small amount of deformation by rolling in the diagonal direction (diagonal rolling) introduces significant changes in the texture. As can be seen on Fig. 3a, the additional rolling reduction of 10% leads to a total disintegration of the C45 component. At the same time new components, which are {001}<530> and near



a) cross rolled to 20% additional reduction.



b) diagonal rolled to 20% additional reduction.

Fig. 1. Recalculated (2 0 0), (1 1 1) and (2 2 0) pole figures from XRD measurement on copper samples which had been rolled in reverse mode to 62% reduction, then rotated about ND and rolled again

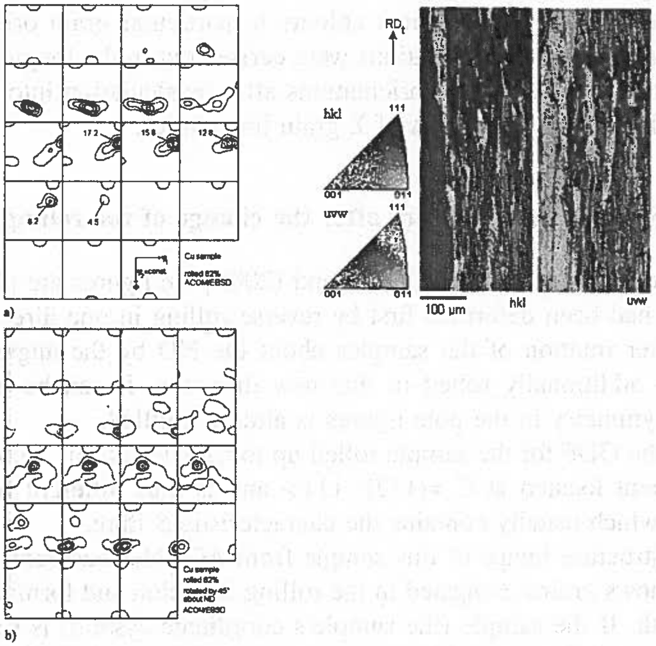


Fig. 2. ODF and COM microstructure of a copper sample with 60 μm initial average grain size, a) after reverse rolling to 62% reduction and the corresponding ACOM microstructure, and b) the ODF from a) after rotation of the sample reference frame by 45° about ND

{111}<211>, are observed to appear, stimulated by the activities of the pair of co-planar slip systems DVI and DI (with some superiority of the former and the AIII, Schmid

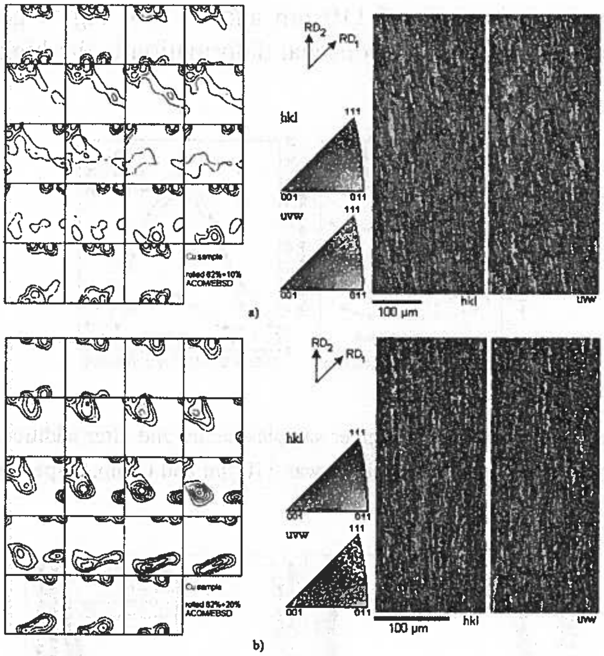


Fig. 3. ODF and COM microstructure of a copper sample with 60 μm grain size reverse rolled to 62% reduction, a) additionaly diagonal rolled to 10% reduction and the corresponding image of the microstructure, b) additionally diagonal rolled to 20% reduction and the corresponding microstructure

convention) and by another pair of co-linear slip systems AII and BII, respectively. These two components become stronger and dominant in the texture after the next step of rolling to 20% additional reduction in thickness. This texture formation is manifested by comparing the ODFs in Fig. 3a and Fig. 3b.

The microstructure of the diagonal rolled samples shows that the grains are elongated parallel with the new rolling direction (45° from the former rolling direction). But after 10% additional reduction (Fig. 3a) some traces of the former arrangement of grains are still visible. After 20% additional reduction of thickness only grains elongated parallel with the final rolling direction are observed (Fig. 3b). At both stages of diagonal rolling (10% and 20%) the grains are much smaller than those after reversal rolling.

4. The influence of the grain size on the texture of cross and diagonal rolled copper samples

The texture effects caused by the change of the rolling geometry are influenced considerably by the grain size. This is shown in Fig. 4 by the profiles of the disintegrating {112}<110> texture component caused by additional cross rolling in copper samples with average grain sizes of 110 μm and 60 μm. Fig. 4 gives evidence that the influence on texture by a small additional deformation is the higher the greater the grain size is.

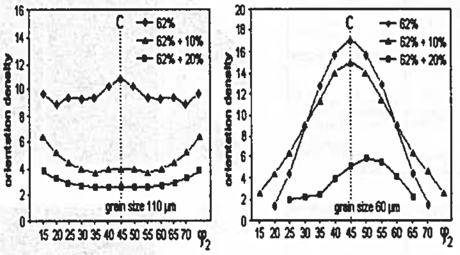


Fig. 4. Profiles of the C90 component in copper samples before and after additional cross rolling. The average grain size before rolling was 110 μm and 60μm, respectively

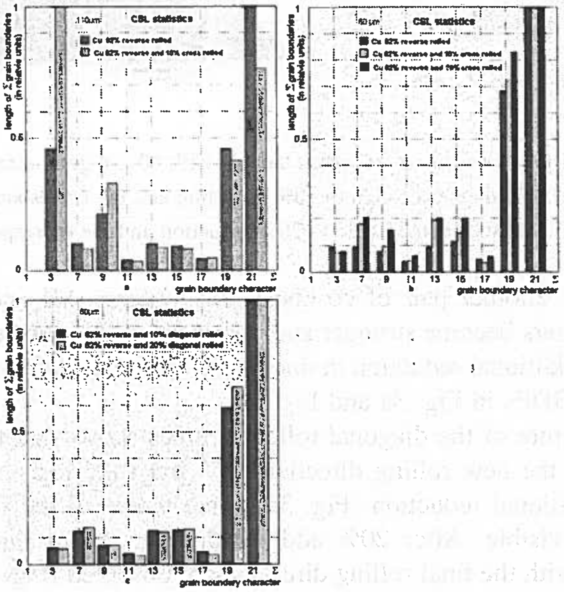


Fig. 5. Statistical distributions Σ grain boundaries calculated from ACOM data for reverse and additional cross or diagonal rolled copper samples with an initial grain size of: a) 110 μm (additional cross) and b) 60 μm additional cross and c) 60 μm additional diagonal. The densities of lengths of the special grain boundaries are normalized to the highest frequency in each sample

From pairs of single orientations measured across grain boundaries, misorientations were calculated. This kind of data enables to select and identify grain boundaries and further inhomogeneities. In the present study the frequency of special grain boundaries (Σ boundaries according to the CSL model under the assumption of the Brandon criterion) have been calculated for samples after diagonal rolling, to complete the previous analysis for samples after cross rolling [5].

Comparing the Σ distributions in Fig. 5 a strong increase of Σ3 grain boundaries (twin relation) can be recognized for larger average grain sizes, whereas the Σ distribution is not much influenced by the kind of additional rolling (cross or diagonal). The character of grain boundaries for the sample of 60 μm initial grain size does not change significantly between 10% and 20% of additional cross nor diagonal rolling.

REFERENCES

[1] Z. Jasieński, J. Pospiech, A. Piątkowski, R.A. Schwarzer, A. Litwora, M. Ostafin, Textural and structural effects of the change of deformation path in copper single crystals in a channel-die test. Archives of Metallurgy and Materials **49**, 11-28, (2004).

[2] J. Pospiech, Z. Jasieński, A. Litwora, A. Piątkowski, The influence of transverse rolling on texture and microstructure; Proc. of 12th ICOTOM, Montreal (Canada); 581 – 586, (1999).

[3] M. Wróbel, M. Blicharski, S. Dymek, J. Gazdowicz, Influence of strain path on texture and microstructure development in polycrystalline Cu and Cu–5 wt% Al alloy; La Revue de Metallurgie **94**, 1045 – 1055 (1997).

[4] R.A. Schwarzer, Automated crystal lattice orientation mapping using a computer-controlled SEM; Micron **28**, 249-265 (1997).

[5] M. Ostafin, J. Pospiech, R.A. Schwarzer, Microstructure and texture in copper sheets after reverse and cross rolling; Solid State Phenomena 105, 309-314 (2005).

[6] J. Pospiech, M. Ostafin, R.A. Schwarzer, Microstructural aspects of cross rolling of copper; Inżynieria Materiałowa **6**, 802-805 (2003).

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