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ROLE OF SHEAR BANDS IN FORMING THE TEXTURE IMAGE OF DEFORMED COPPER ALLOYS[1)]

ROLA PASM ŚCINANIA W KSZTAŁTOWANIU OBRAZU TEKSTURY ODKSZTAŁCANYCH STOPÓW MIEDZI

The paper shows that the development of texture in deformed copper alloys depends on macroscopic localisation of plastic flow induced by shear bands. Investigations carried out on CuZn30, CuNi25, CuSn5P alloys comprised thier cross-rolling, structural observations and precise measurements of texture. It has been found that the shear bands, generated during rolling, „cut out" in the material blocks of macroscopic size which while undergoing mutual displacement, determine its texture.

Praca dowodzi, że rozwój tekstury w odkształcanych stopach miedzi uzależniony jest od makrolokalizacji plastycznego płynięcia spowodowanej przez pasmach ścinania. Badania przeprowadzone na stopach CuZn30, CuNi25, CuSn5P obejmowały ich krzyżowe walcowanie oraz obserwacje strukturalne i precyzyjne pomiary tekstury. Stwierdzono, że pasma ścinania generowane podczas walcowania „wycinają" w materiale bloki o makroskopowej wielkości, które ulegając wzajemnym przemieszczeniom decydują o jego teksturze.

1. Introduction

It is widely accepted that the texture of a metallic material is a structural property which in the case of its deformation undergoes evolutionary changes into more and more distinct states. The implicit assumption is that the change of the dominating mechanism of plastic flow, disturbing the monotonic development of the material structure and texture, relates only to advanced deformation process. On the other hand, there exists convincing experimental documentation [1] indicating that a change of

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the deformation path leads not only to activation of other slip systems, but first of all, to destabilisation of the substructure, being connected with the phenomenon of the change of the deformation path. As a consequence, there takes place a change in the deformation mechanism from a multi-system, fine slip (homogeneous deformation) into localised plastic flow in the shear bands. Even a small deformation induced after a change of rolling direction leads to rapid reorganisation of the substructure, accompanied by essential changes of texture [2-7] recorded irrespectively of the preservation or loss of the stability of the reference system.

The effect of applying various sequences in the realisation of the rolling deformation on the evolution of the final texture was investigated in the study [5] by defining the state of texture after completion of the process with orthogonal change of the rolling direction. Unfortunately, the measurements carried out „ex post“ do not allow to estimate the origin and the course of changes occurring in the texture only by describing them, using to that end the concepts of „ideal orientation“, „a component“ and „volume fraction“ occupied by the given orientation.

The aim of investigations presented in this study was to identify the effect of a sequential change of the deformation path on the structural changes and on texture in copper alloys. To examine the texture there have been applied procedures, which enable the analysis of the morphology of a pole figure and the technique of trace analysis. This allowed to associate the results of structural and textural observations which was the principal research tool in the present study.

2. Experimental

The investigations were carried out on three copper alloys (Table 1), cast in a continuos way on flat bars of 400 mm × 13 mm cross-section.

TABLE 1

Materials used in the investigations

Denotation	1	2	6
Type of alloy	CuZn30	CuNi25	CuSn5P

The alloys were rolled at ambient temperature with orthogonal changes of the strain direction (Fig. 1), imposing the true strain equal to 0.8 at the first stage, 1.0 at the second stage and 1.5 at the third, i.e. the last stage, respectively. In each pass of the given stage of rolling the identical position of the rolling plane was retained and the ratio l/h (coefficient of the shape of the rolling gap) was kept within the recommended limit 1.4 – 2.6, quarantining that there was no difference in the texture of the rolled band through its thickness. With orthogonal change of the rolling direction, which occurred twice, the sample was turned in the rolling direction in such a way that its rolling direction (RD) and its sense at the first and the third stage were identical. Moreover, the surfaces of morphological observations could be identified on a stereographic projection made on the rolling plane.

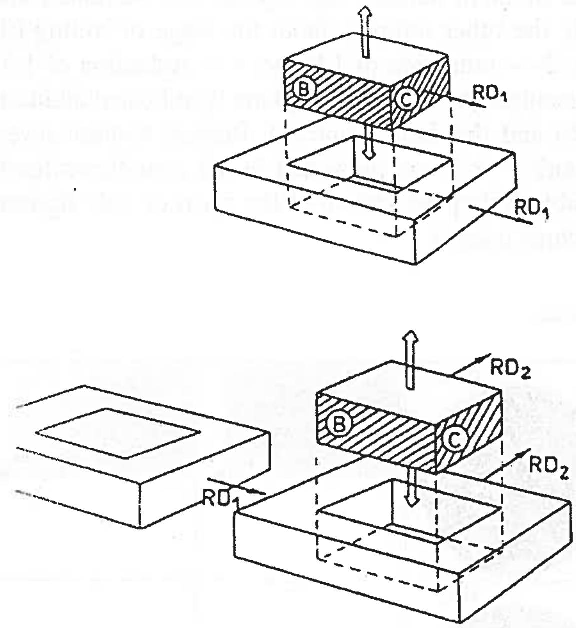


Fig. 1. Scheme of rolling

Structural observations, mainly the topographic ones, were carried out on samples after each stage of rolling, in particular on their front surfaces (perpendicular to RD) and side surfaces (perpendicular to TD) by grinding and polishing them immediately before starting the particular stage.

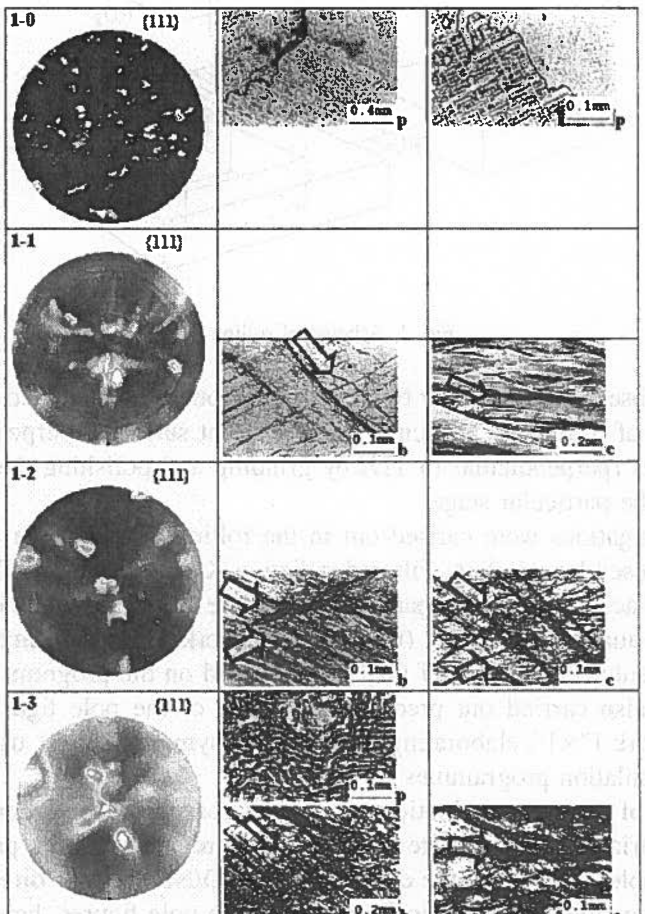
X-ray investigations were carried out in the rolling plane on the central layer of the samples exposed by grinding. Filtered radiation K_α Co was used. The goniometers were controlled according to the patented procedure [8, 9]. The standard qualitative and quantitative analyses of texture (measuring network $5° \times 5°$, symmetrization of the measurement results, calculation of ODF) were based on the program Labotex 2 [10].

There was also carried out precise registration of the pole figures {111} in the measuring network $1° \times 1°$, elaborating them without symmetrization, using the authors' own special calculation programmes [8, 9].

The results of texture examination and the microscopic images corresponding too the particular variants of rolling are presented with reference to the primary arrangement of the samples defined by the directions RD/TD/ND (ND — direction normal to the plane of projection). For technical reasons on the pole figures there have not been given the particular values of relative intensities. Nevertheless, after measurements with the step $5° \times 5°$, a complete elaboration of ODF was made, and the results of these calculations are presented as the particular numerical values.

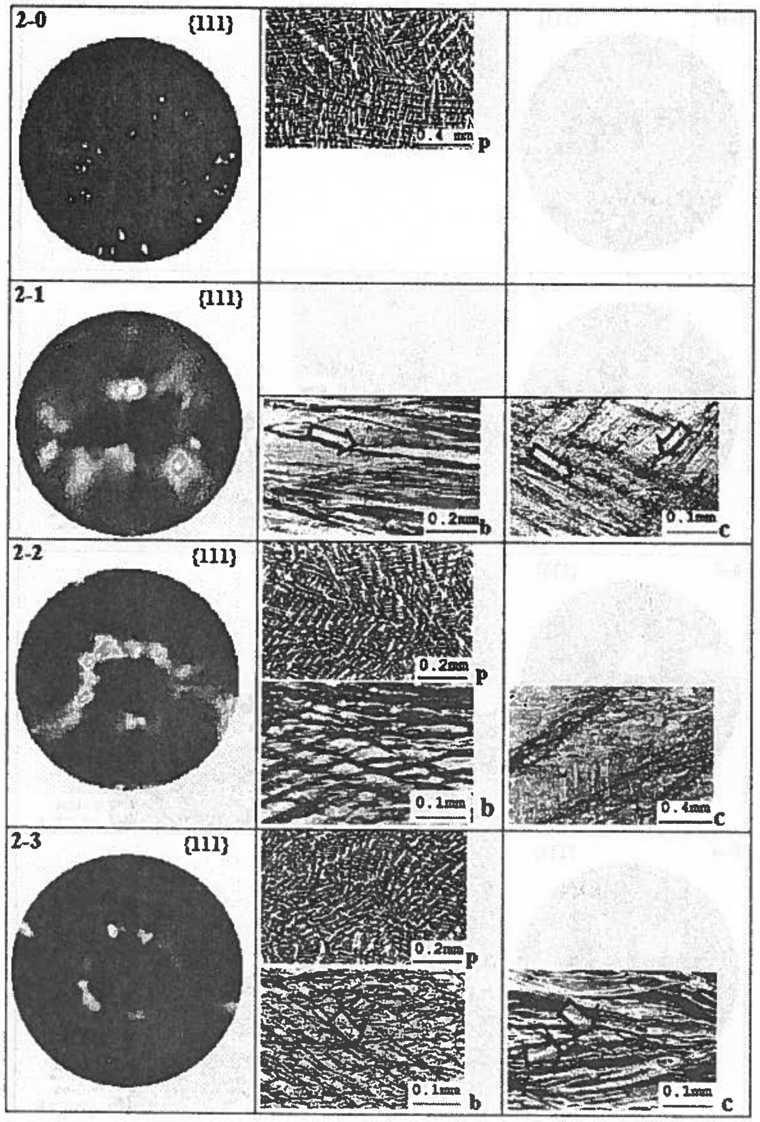
Measurements with the step 1° × 1° were used to present the morphology of the pole figure by the grayscale. The denotations used to the present results are composed of two digits. The first of them denotes the type of the examined alloy (in accordance with Table 1), while the other informs about the stage of rolling (0 — initial state, 1 — reduction of 0.8, 2 — reduction of 1.0 and 3 — reduction of 1.5). When structural observations are presented, the observation plane is indicated additionally: rolling plane (p), lateral plane (b) and the front plane (c). Precise textural investigations made in the measuring network 1° × 1° are presented in the actually realised measuring range, i.e. up to 80°. In Table 2 they are shown in the form of pole figures together with the corresponding structure images.

Table 2a



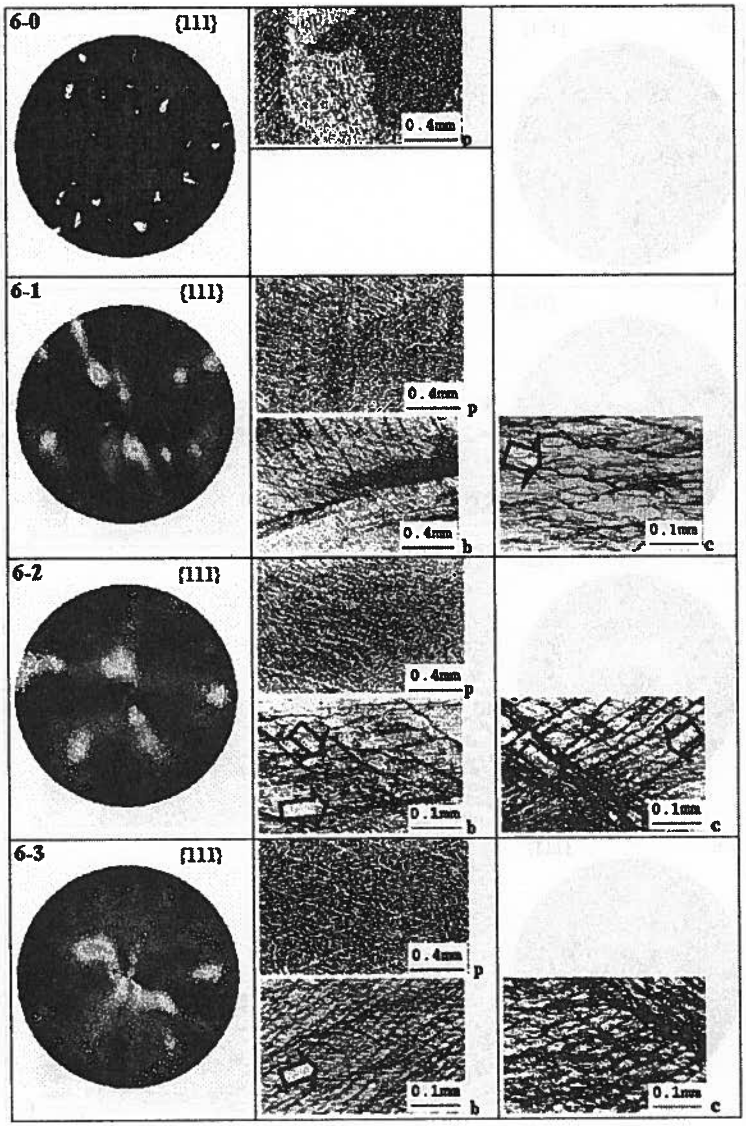
Tab. 2a. CuZn30 alloy. Set of textures (pole figures {111}) and structural observations (p — rolling plane, b — lateral plane, c — front plane)

Table 2b



Tab. 2b. CuNi25 alloy. Set of results as in the Tab. 2a.

Table 2c



Tab. 2c. CuSn5P alloy. Set of results as in the Tab. 2a.

For comparison, in Table 3 there are presented the results of the qualitative and quantitative analyses of texture carried out in the standard procedure (measurement 5°x 5°, symmetrization of the results, ODF calculation, quantitative estimation).

TABLE 3

Illustrative results of the quantitative qualitative texture analyses of CuZn30 alloy

Variant	1-0		1-1		1-2		1-3	
Component	V [%] Volume fraction	Rest [%]	V [%] Volume fraction	Rest [%]	V [%] Volume fraction	Rest [%]	V [%] Volume fraction	Rest [%]
{4 11 10}<1 − 44>	4.42							
{1 1 2}<−1 − 32>			10.56					
{0 1 1}<6 − 55					16.48			
{0 1 1}<3 − 11>							39.41	
{1 1 0}<1 − 12> brass-type			3.80		5.88		11.37	
{1 1 2}<11 − 1> metal-type	3.47						5.35	
{3 2 3}<1 − 31>							5.22	
{1 3 2}<6 − 43> S1	4.68		8.54		6.20		6.52	
{2 3 1}<3 − 46> S2	4.68		8.54		6.20		6.52	
{2 1 3}<3 − 64> S3	4.68	73.40	8.54	39.58	6.20	35.63	6.62	12.56
{2 3 1}<−34 − 6> S4	4.68		8.54		6.20		6.62	
{1 2 2}<2 − 21>					6.69			
{1 2 3}<41 − 2> R			10.37					
{1 1 0}<001> Goss-type			1.17		3.10			
{1 1 0}<1 − 11>					7.41			

3. Analysis and interpretation results

Analysis of the morphological features of pole figures revealed in the accurate texture measurements requires taking into consideration the actual conditions of the investigations, in particular the so-called „representativeness of the sample" and the meaning of the signal registered in the course of such measurements. Hence, at the beginning, it is necessary to state that:

— Bragg's law defines the geometrical condition for the occurrence of diffraction on a definite crystallographic plane of {hkl} type,

— In diffractometric measurement using a textural goniometer, the spatial distribution of poles of the tested type (e.q. {111}) is registered. The pole figure is their stereographic projection made on the external (outside) plane of the sample.

— Worsening of the perfection of the crystal and diminishing of the mosaic blocks result in the change of the width of diffraction peak.

— Irrespective of the size of the monocrystal (grain in a polycrystalline material), if it is found in the field of the radiation beam, when Bragg's condition is satisfied, there will occur the diffraction effect, irrespective of the size of the object.
— A perfect monocrystal causes the formation of a rather small textural peak due to its width, however of great intensity. An imperfect monocrystal causes greater scattering of the peak at its base and its low intensity.
— The real morphology of textural peak provides information whether the polycrystalline aggregate is composed of many perfect monocrystals with similar positions (orientation) of poles, of the tested type, or whether it is a set of monocrystals of low perfection and similar orientation.
— The measurement is realised with same definite size of the measurement network. The mutual relations between the actually occurring morphological features of the pole figure and the angular size of the applied measurement network determine the possibility of the detection of phenomena, their subsequent analysis including the correctness of ascribing the ideal orientation.

It should be also noted that in the present study the investigations of texture were carried out on the central layer of the sample, while the microscopic observations were made on its outside surface. Thus the revealed features of the structure do not refer to the identical element of the sample. In particular, the shear bands visible on the particular surfaces of rolled samples inform exclusively about their spatial arrangement, although they are associated with the morphological feature of the pole figure.

Recently there has been observed interest in local, efficient research tools used in measurement of local orientations in SEM or TEM (EBSD or CBED techniques) which are accepted as identifying the texture changes induced by inhomogeneous deformation.

In this way there are analysed the particular places of the area of linear size of about 250 — 300 μm, and the pole figure is formed as a result of combining single orientations. The situation is different in the case when the texture is examined by the diffractometric technique in which the measurement is based on a signal generated on atomic scale (diffraction takes place on crystallographic planes) and it covers the macroscopic area of sample of linear size of the order of some or some tens of millimetres. It is just this complete area, being one fragment of the sample, that is reflected in the pole figure. Hence registration mode on macroscopic scale is referred to macroscopic, morphological observation of the sample surface. The presence of deformation twins situated in individual grains (monocrystals) or lattice reorientations being the result of accommodation processes occurring on the scale observed in the mentioned electron-microscopic techniques is of vital importance but only in the case of analysis concerning the microscale.

It should be stressed that the application of the technique of precise measurement ($1^\circ \times 1^\circ$) is oriented not only to the improvement of investigations through precise determination of the position of the maximum of the observed strengthening on the pole figure, but first of all, to observation of the morphological features of the peak.

In the presentation of the result in the form of a pole figure a stable reference system was retained irrespective of the changes of the system describing the position.

The texture image revealed in precise measurements using 1° × 1° network and the presented microstructural documentation of the examined copper alloys (Table 2 a-c) indicate that their initial state (after continuous casting) is characterised by chaotic distribution of poles deriving from large grains (dendrites). Also the sharpness of the particular texture peaks visible in each case is evidence of relatively high degree of the perfection of these crystallites. The texture image obtained as a result of rolling reveals single textural peaks with large angles, measuring even some tens of degrees, which is evidence of the presence of agglomerates of imperfect grains with orientations characterised in each of them by a very similar position of one of the poles of the tested type ({111}). This image is a document that it is not possible to identify texture peaks connected by crystallographic angular relations specific for complementary poles and that each of the peaks occupies an area of some ten to twenty or even some tens of degrees. In this situation it is not possible to describe the state of texturing by ascribing the components to the orientation. Hence, it is necessary to accept the presence, in deformed material, of groups of monocrystals although of different orientation, yet connected by (approximately) common pole of {111} type, forming together whole blocks. As a result, in the image of the pole figure, there can be observed texture peaks with large angles and differentiated morphological shapes corresponding to the positions of the groups of poles of ({111}) planes in the space, isolated from each other and not connected by crystallographic relations proper for complementary poles.

It must be noted that the morphology of a pole figure measured by the standard network (5° × 5°) may lead to a non-justified conclusions about the coarse-grained structure of the examined material. Comparison of the observations of the morphology of a pole figure of the initial state and their images of pole figure of the material in the deformed state are also against such a conclusion.

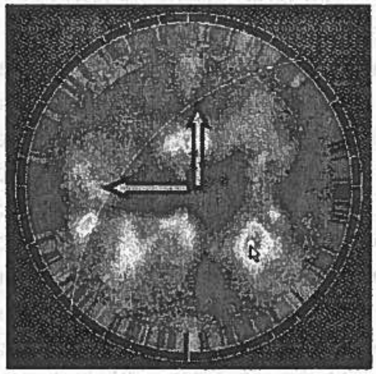
The microscopic observations associated with the results of precise texture test lead to the statement that the change of rolling direction and as a consequence of the appearance of intersecting families of shear bands causes the formation, in the deformed material, of rotating quasi–monocrystalline „blocks" of macroscopic size. The outer appearance of the structure shows also that the shear bands are activated in sequences, which is evidenced by jogs on the „old" bands. The geometric features of the newly forming scatterings of texture peaks, associated with the results of trace analysis, indicate the mode of the realisation of the described rotations of these — cut out by the bands — fraction of the material (quasi- monocrystalline „blocks"). Rotation of the crystallographic lattice, observed in structural investigations [11], carried out in submicroscopic scale, actually affects the morphological features of the peak. Then occurring large misorientations contribute to the total texture observed in the experiment (and the image of the pole figure).

However, from the point of view of the description of texture through ideal orientations, there should be, first of all, taken into account the considerable volume fraction of the material rotated by the action of shear bands.

The trace analysis presented by way of example (Tables 4 a and b) indicates that the pole of a metallographically revealed plane is situated in a registered texture pole.

This confirms the already made assumption about the existence and operation of such „quasi-monocrystaline blocks" of macrocrystalline size.

Table 4a



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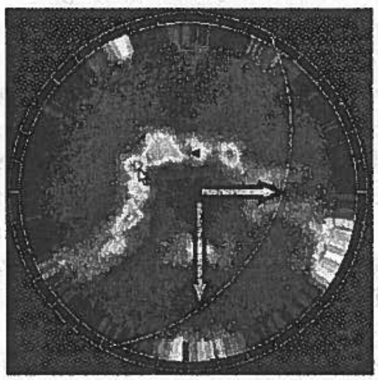

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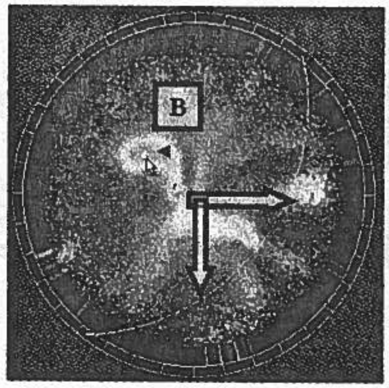
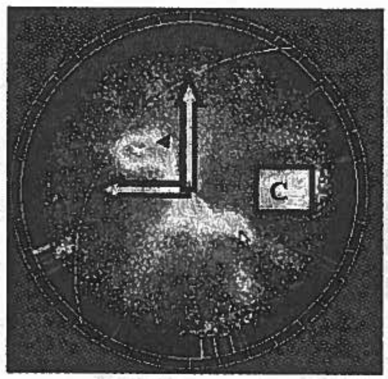
Tab. 4a. Examples of trace analysis of shera bands in a CuNi25 sample. Pole figure{111}. The large circle being a trace of plane visible on the polished section of the front and lateral surfaces. The arrows indicate the angular values resulting from the positions of the traces on the polished section of the front surfaces (horizontal arrow: α) and the lateral surface (vertical arrow: β). The small arrow shows the pole of the thus determined large circle.

(1) Variant 2-1; a $\approx$ 50°, $\beta \approx$ 50°, (2) Variant 2-2; a $\approx$ 55°, $\beta \approx$ 65°

Table 4b



1



2

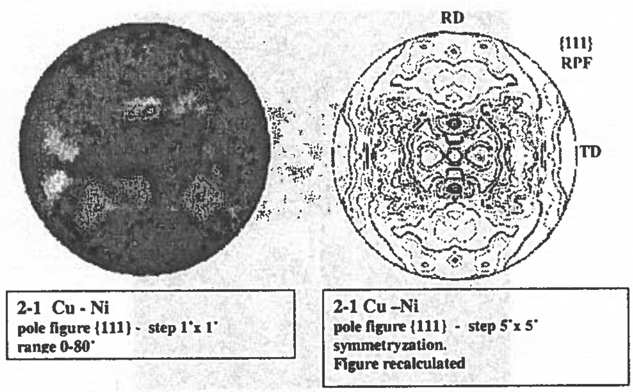
Tab. 4b. Examples of trace analysis of shera bands in a CuSn5P sample; variant 6-3. Pole figure {111}. The large circle being a trace of plane visible on the polished sections of the front and lateral surfaces. The arrows indicate the angular values resulting from the positions of the traces on the polished section of the front surface (horizontal arrow: α) and the lateral surface (vertical arrow: β).

1) a ≈ 65°65°, $\beta \approx 55°$. The small arrow shows the pole of the thus determined large circle, which coincides with the peak B.

2) a ≈ 55°, $\beta \approx 65°$. The small arrow shows the pole of the thus determined large circle, which coincides with the peak C.

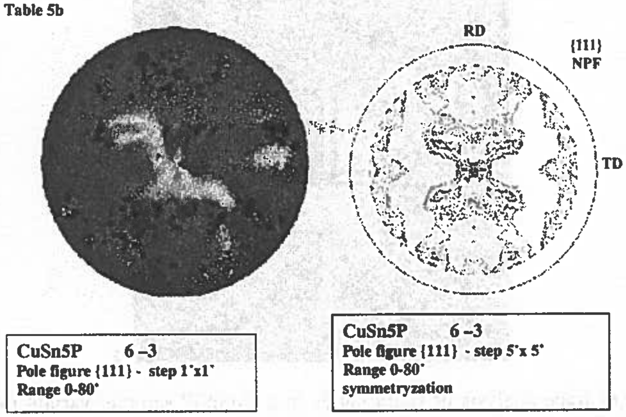
Precise measurements with the application of 1° × 1° network reveal the real morphology of pole figures. The results of measurements carried out in the same cases, applying the measuring network 5°×5°, elaborated mathematically after symmetrization (e.q. Tables 5 a and b) show that symmetrization of the texture image composed in reality of some isolated peaks, can lead to obtaining of pole figures described as an unreal type of texture, although formally it may correspond to a texture type of an alloy or metal. A similar, unreal situation is connected with the so- called „mechanical" symmetrization, resulting from the rolling technique (change of the sense of the rolling direction or the position of the rolling plane).

Table 5a



Tab. 5a. Set of illustrative measurement results of the pole figure — "metal-type texture"

Table 5b



Tab. 5b. Set of illustrative measurement results of the pole figure — "alloy-type texture"

The results of investigations and their analysis presented in this paper are an indication of a close relation between the evolution of the texture of the deformed metal and formation and displacement of whole "quasi-monocrystalline blocks".

It should be noted that the electronmicroscopic techniques based on summing the local orientations [12-14] are an excellent tool for defining the texture of a simple "quasi-monocrystalline block" or the area comprising the neighbourhood area of another block, situated beside. However, even multiplication of such observations by carrying on measurements on many foils, each deriving from a different macroscopic area (as there exists no other technical possibility) will not provide textural information identical with that deriving from a diffractometric measurement, comprising one area, containing many "quasi- monocrystalline blocks" [15].

It is obvious that in each case the test must be carried out in conditions enabling to obtain good resolving power of the spatial positions of the crystallographic planes, guaranteeing a correct relation between the structural properties of the given area and its crystallographic "image".

The coarseness of the materials (alloys) intensifies the textural effects and makes more prominent the consequences of the change of the deformation path realised by cross-rolling. In a fine-grained material, deformed monotonically with the change of the sense of RD and ND directions, the situation described here not only becomes multiplied with respect to the number of registered peaks, but the image of the pole figure may also become symmetrized (through a change of the reference system).

In each case when putting together the results of trace analysis and the image of pole figure, obtained in a precise measurement, one can point to poles of planes revealed in the microstructure as those lying in the particular, local texture peaks. These are the planes of occurrence of shear bands (Table 4). Hence it would be justified to treat them as the „mean" or „statistical" poles {111} of the cut out blocks of the material undergoing displacement.

4. Conclusions

— The tendency of metal to non-homogeneous plastic flow, and, speaking more precisely, to the generation of shear bands in defined geometric configuration is responsible for the formation, in the deformed material, of a texture described as a texture of alloy type (or similar). The bands „cut out" blocks of the material which undergo mutual displacement.

— Change in the spatial arrangement of active shear bands, taking place in the course of deformation, causes the change of the texture.

— The pole of the plane of the occurrence of shear bands can be identified as lying in the textural peak of the figure {111} (i.e. it is a pole near <111> in the given block). This is indicated by the mechanism of rotations, occurring in the course of deformation, of whole, quasi-monocrystalline, macroscopic blocks of material, cut out by the bands.

— Considering the fact that inhomogeneous deformation in the shear bands occurs irrespective of grain size of the material and stacking fault energy, the analysis of the morphology of a precisely registered pole figure may represent a tool to identify the localisation of plastic flow of the material irrespective of the fact whether it occurs autonomously or is externally induced by the change of the deformation path.

— In the case of the occurrence of inhomogeneous deformation, the texture revealed by measurement in the commonly applied procedure, and using a large angular step in the course of registration, cannot be correctly described by such notions as „ideal orientation", "component" or "volume fraction". Such a description is the consequence of multiplying and symmetrization of images occurring as a result of the distinguished textural peaks with large angles.

Acknowledgements

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