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HOMOGENEITY OF THE CRYSTALLOGRAPHIC TEXTURE AND DEFORMATION BEHAVIOR IN Cu AND Ti UNDER SEVERE PLASTIC DEFORMATION

JEDNORODNOŚĆ TEKSTURY KRYSTALOGRAFICZNEJ I POSTĘP PROCESU DEFORMACJI W Cu I Ti PODDANYCH SILNEMU ODKSZTAŁCENIU PLASTYCZNEMU

The paper presents the results of experimental studies of the evolution of the homogeneity of the crystallographic texture and deformation behavior in bulk Cu and Ti billets subjected to the different numbers of equal-channel angular pressing (ECAP). It is found that the 1st pass during ECAP of pure Cu and Ti results in the formation of the pronounced preferred orientation of crystallites. Increase of the number of ECAP passes is accompanied by the formation of pronounced texture maxima which are orderly arranged in the pole figure. The intensity of texture maxima corresponding to the central part of the billet is the highest. The heterogeneity of the deformation behavior grows significantly after the 1st ECAP pass as compared to the initial state, but it reduces with the increasing number of ECAP passes.

Keywords: Ti, Cu, texture, heterogeneity, deformation behavior

Artykuł przedstawia wyniki badań eksperymentalnych nad rozwojem jednorodności tekstury krystalograficznej I postępu deformacji w prętach Cu I Ti poddanych cyklicznemu odkształceniu metodą przeciskania przez kanał równo-kątowy (ECAP). Stwierdzono, że w czystej Cu i Ti podczas pierwszego przepustu ECAP formuje się wyraźna uprzywilejowana orientacja krystalitów. Wraz ze wzrostem liczby przepustów kształtują się składowe tekstury, które są coraz bardziej stają się wyraźniejsze w postaci maksimów na figurze biegunowej. Największa intensywność tekstury występuje w obszarach zlokalizowanych w centralnej części przekroju poprzecznego odkształcanego pręta. Jednorodność postępującej deformacji po 1-wszym przepuście ECAP zwiększa się znacząco w porównaniu ze stanem wyjściowym z tym, że po każdym następnym przepuście zostaje osłabiana (szczególnie w Ti).

1. Introduction

Severe plastic deformation (SPD) has been recently enjoying popularity among researchers, as it allows producing bulk ultrafine-grained (UFG) materials with an average grain size of several tens or hundreds of nanometers. Unique mechanical and physical properties are typical of these materials [1].

The SPD process is known to be accompanied by formation of crystallographic texture. The texture development character depends on the stress-strained state which satisfies the prevailing conditions in the particular part of a billet [2–4]. The microstructure changes along with changes in the grain size, dislocation density, misorientations between neighboring grains, etc. Therefore, it is important to study the processes of crystallographic texture formation, as it is one of the determinants in the deformation behavior of material and, consequently, in the formation of heterogeneity of mechanical properties.

Equal-channel angular pressing (ECAP) is especially popular among SPD techniques. It enables producing bulk UFG billets without any residual porosity [1, 5, 6]. The character of the obtained crystallographic textures strongly depends on some SPD parameters. They are as follows: route, mode, strain degree, strain rate, temperature, etc. [1].

The processes of texture formation and deformation behavior of metals subjected to ECAP and their heterogeneity across the billet were studied in a number of papers [3, 7, 8]. According to [8] the character of formation of the crystallographic texture in the ECAPed Cu and Ti billets is different. The intensity of texture

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maxima is lower in the top and bottom parts of a billet than in its central part for both Cu and Ti [8].

Recent experimental studies demonstrated that the deformation behavior of the samples cut out from different zones of bulk ECAPed Ti billets was heterogeneous to some extent [9].

This paper exhibits the results of comparative experimental investigations of the regularities of formation of the crystallographic texture homogeneity and deformation behavior in the billets of pure Cu and Ti subjected to ECAP.

2. Experimental procedure

The experiments were carried out using commercially pure Cu (99.99%) and Ti (99.95%). The dimensions of the billets subjected to ECAP were 60×8×8 mm^3. ECAP was conducted at room temperature in case of Cu; in case of Ti the temperature was 450°C. The velocity was 6 mm/s. The angle of channels intersection was 90°.

The crystallographic texture in the initial state, after 1, 2 and 4 passes along the route B_C (rotation of the billet around the longitudinal axis by 90° clockwise between subsequent passes) was analyzed in the cross-sectional plane for different zones of the billet (Fig. 1). The X-ray analysis of the pole figures (PF) was carried out with the help of the Philips X'Pert diffractometer equipped with the texture goniometer ATC-3. The angle interval was 0–75°; the azimuth interval was 0–360° with the step 5°. The diameter of the X-rayed zone was 0.6 mm.

Fig. 1 shows the allocation scheme of the points to investigate the homogeneity of formation of the crystallographic texture and deformation behavior in Cu and Ti billets.

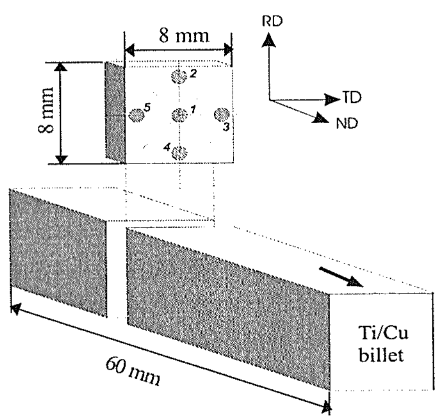

Fig. 1. The allocation scheme of the points for the investigation of the homogeneity of the crystallographic texture

To obtain the experimental stress-strain curves, microsamples with a diameter 1.5 mm and initial gauge length of 7.5 mm were cut out along the longitudinal axis in 5 points of the cross section of the billet (Fig. 1). The mechanical properties were defined during tension on the INSTRON 1185 testing unit. The strain rate was 10^{-3} s^{-1} for Cu and Ti samples; the tension was conducted at room temperature.

3. Simulation results and their discussion

3.1. Analysis of the homogeneity of the crystallographic texture in Cu

As is seen from Fig. 2, where direct and inverse pole figures are shown, the texture in the cross section of a Cu billet in the initial state is heterogeneous. The intensity of main texture maxima is rather high, but as it follows from the pattern of direct PF the orientation of texture maxima is spread. At the same time, after the first and the subsequent ECAP passes (Fig. 3, 4) there are observed pronounced maxima on the PF. Their arrangement is rather ordered.

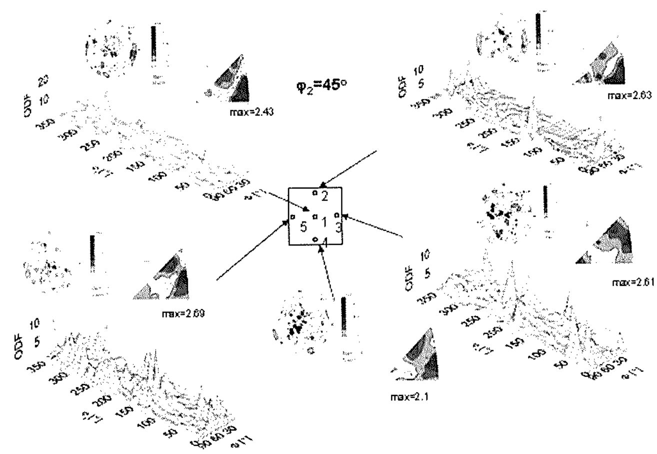

Fig. 2. PF (111) and RPF (001) in the as-received Cu

A completely formed texture can be described with the components $(111)[\bar{1}\bar{1}2]$, $(111)[11\bar{2}]$, $(1\bar{1}1)[110]$, $(\bar{1}1\bar{1})[\bar{1}\bar{1}0]$, $(1\bar{1}2)[110]$, $(\bar{1}12)[\bar{1}\bar{1}0]$ and (001)[110]. The intensity of texture maxima on the PF which corresponds to the central part of the billet is maximum (Fig. 3, 4). On the whole the PF pattern is quite the same after different number of passes. This enables assuming that it is defined by the character of the material flow during the last ECAP pass. The crystallographic texture of Cu subjected to the 1st and subsequent ECAP passes are identical and characterized by the prevailing components {110}<111> (Fig. 3, 4).

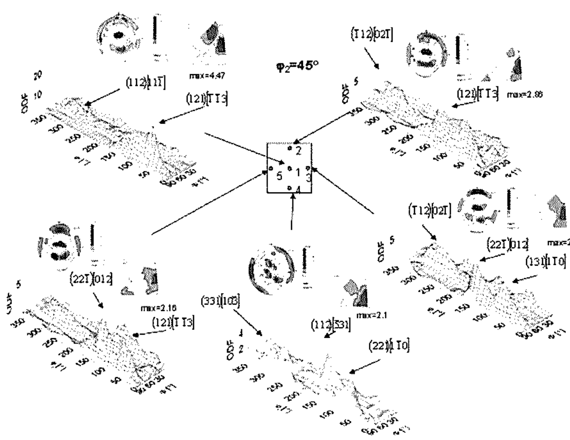

Fig. 3. PF (111) and RPF (001) in Cu after the 1st ECAP pass

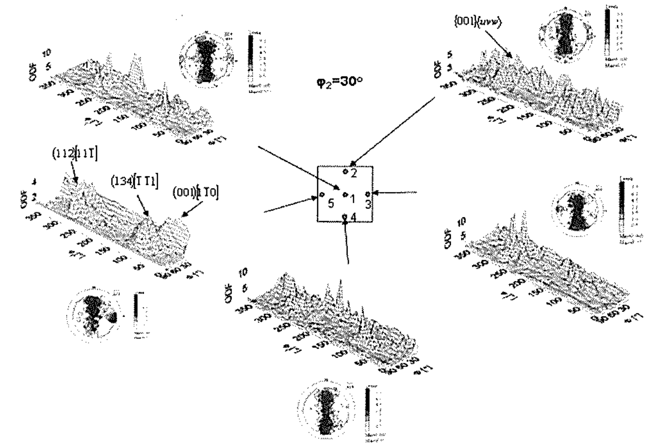

Fig. 5. PF (001) of the as-received Ti

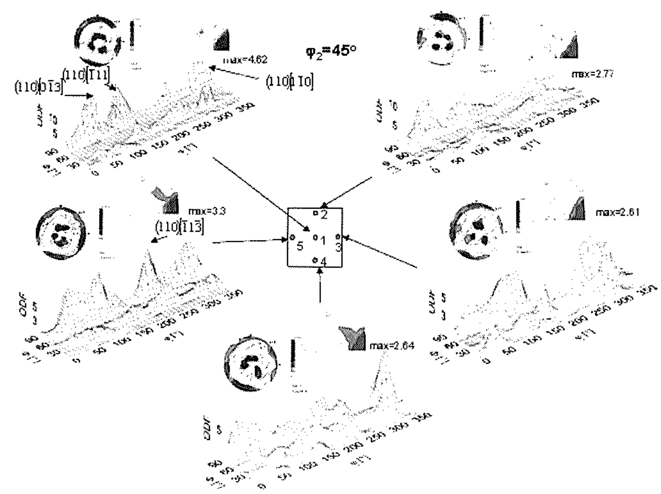

Fig. 4. PF (111) and RPF (001) in Cu after the 4th ECAP pass along the route B_C

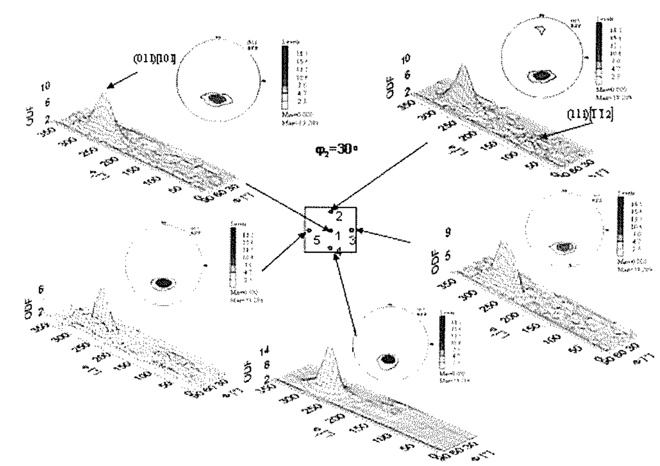

Fig. 6. PF (001) of Ti after the 1st ECAP pass

3.2. Analysis of the homogeneity of the crystallographic texture in Ti

The experimental PF (001) for the as-received Ti (Fig. 5) is similar to the texture of Ti rolled at room temperature [10]. This PF is characterized by the enhanced density of maxima along the rolling direction.

As is seen from Fig. 6–7, one maximum is located on the lower part of the PF (001). With the increasing number of ECAP passes, the texture maximum rotates against the axis x. The rotation angle is much higher in case of Ti than that in case of Cu during ECAP. The highest intensity of texture maxima is observed in the central zone of the billet (point 1), whereas the intensity is rather low in the rest of the points (2–5). The distribution of orientations in the PF is axial and is characterized by the components {101}<hkl>.

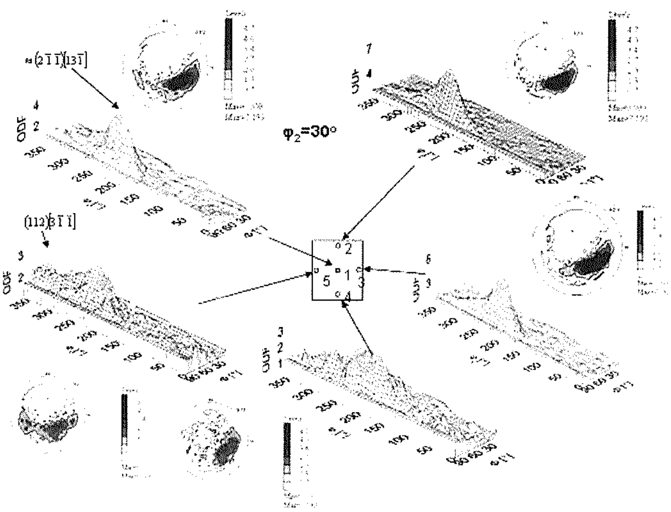

Fig. 7. PF (001) of Ti after the 4th ECAP pass along the route B_C

3.3. Analysis of the homogeneity of the deformation behavior of Cu billets

The experimental true stress – true strain curves for Cu in different structural states are demonstrated in Fig. 8.

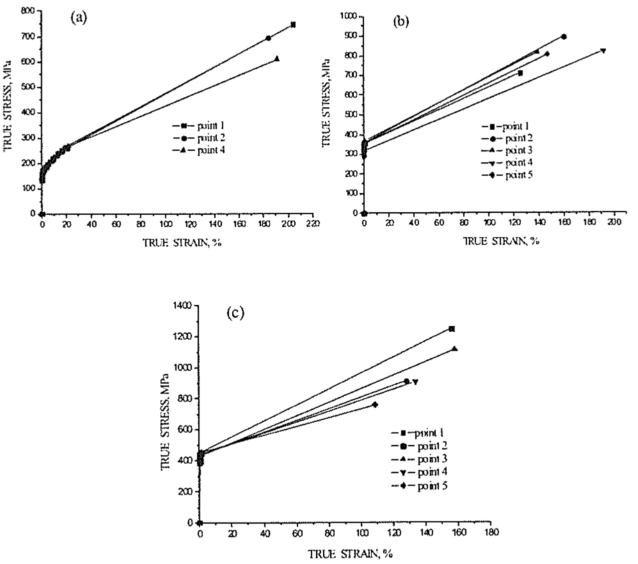

Fig. 8. Experimental true strain σ – true strain e curves for Cu in different cross sections of the billet with different structures: a) initial state, b) after the 1st ECAP pass, c) after the 4th ECAP pass, route B_C. The tensile strain rate $\dot{e}$ = 0.001 s^{-1}. Room temperature

All the tensile curves for the as-received Cu are similar. The slight difference is in different slopes of the curves against the axis e. After the 1st ECAP pass the yield stress of the samples cut out from the lower part of the billet is much lower than the yield stress $\sigma_{0.2}$ during tension of the samples cut out from the upper part of the billet (Fig. 8b). For example, the comparison of the curves shows that the yield stress $\sigma_{0.2}$ is about 380 MPa in the first case, in the second case it is 320 MPa. The latter is, apparently, connected with formation of the zone of less pronounced treatment of the structure which is probably associated with underfilling of the channel zone adjacent to the outer angle in the die-set. There are two significant differences in the deformation behavior of Cu subjected to ECAP as compared to that in the initial state. They are a much higher (by 45%) value of the yield stress and less pronounced states II and III of the strain hardening.

3.4. Analysis of the homogeneity of the deformation behavior of Ti billets

The experimental and modeling true strain σ – true strain e curves for Ti in different structural states are presented in Fig. 9.

All the tensile curves for the as-received Ti are similar. The slight difference is in different slopes of curves against the axis e. After the 1st ECAP pass the yield stress is much lower on the tensile curves for the Ti samples cut out from the lower part of the billet than the yield stress $\sigma_{0.2}$ during the tension of the samples cut out from the upper part of the billet. The yield stress $\sigma_{0.2}$ in the first case is about 590 MPa, in the second case it is 630 MPa. The difference is in different slopes of the curves against the axis e. The heterogeneity of the deformation behavior in Cu and Ti in the initial state is less pronounced, while after the 1st ECAP pass it becomes more significant (Fig. 8, 9).

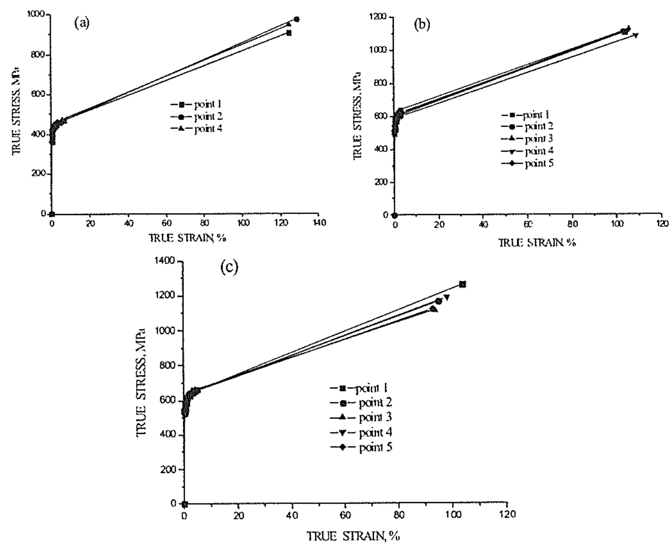

Fig. 9. Experimental true strain σ – true strain e curves for Ti in different cross sections of the billet with different structures: a) initial state, b) after the 1st ECAP pass, c) after the 4th ECAP pass, route B_C. The tensile strain rate $\dot{e}$ = 0.001 s^{-1}. Room temperature

3.5. Comparison of the heterogeneity of the crystallographic texture and deformation behavior in Cu and Ti billets

The study results obtained with the help of the finite element method [2–4] show that the components σ_{11}, σ_{22} and σ_{33} of the tensor of the stress-strained state in the sample reference system (cross-section of the billet) increase when moving from the lower to the upper part of a billet. This phenomenon reflects different formed crystallographic textures. It is seen from Fig. 3 that the finally formed crystallographic texture in the bottom part of the billet (point 4) is smeared. There are some other texture maxima which are not typical of other parts of the billet. This phenomenon reflects microstructural changes which occurred in the ECAPed billet. In [3, 11] it is established that the size of structural elements in the upper and medium zones of the billet is lower than in the lower part and is of lamellar character. The microstructure is much coarser in the lower part and is like the coarse-grained state. Such heterogeneity in the microstructure is reflected on the deformation behavior. It follows from Fig. 8a and 9b that the yield stress is much lower in point 4 than in the rest of the points. Increase of the number of ECAP passes (route B_C) up to 4 resulted in rather low values of the strength and ductility in point 5.

4. Conclusions

The obtained results show that the character of the formed crystallographic texture in Cu and Ti after ECAP differs greatly. In the Ti billet an axial type of texture forms which is described by the components {101}<hkl>. In the Cu billet the texture can be described by the components {110}<111>. The homogeneity of the deformation behavior in Cu and Ti billets after ECAP decreases and then grows with the increasing number of ECAP passes. In Cu and Ti after the 1st ECAP pass an average value of the yield stress $\sigma_{0,2}$ was 350±30 MPa and 600±25 MPa. After the 4th ECAP pass it was 450±10 MPa and 610±20 MPA. In the coarse-grained state it was 175±3 MPa and 444±4 MPa.

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