Effect of SFE on the evolution of crystallographic texture in Cu-Zn alloys subjected to severe plastic deformation

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Abstract. Within the framework of experimental investigations and computer modeling using the viscoplastic self-consistent (VPSC) model of a material plastic flow, the regularities of preferential orientations formation were established, the proportion of certain texture components was estimated, and existing slip systems (SS) and twinning systems (TS) were identified for equal-channel angular pressing (ECAP) of copper alloys depending on the stacking fault energy (SFE).

1. Introduction

Equal channel angular pressing (ECAP) is the most common method of severe plastic deformation (SPD), which allows the formation of ultrafine-grained (UFG) states with enhanced physical and mechanical properties in various bulk metallic materials [1,2]. The high level of strength properties of these materials is to some extent determined by such parameters as small grain size, predominantly high-angle nature of the grain boundaries misorientations spectrum, high density of deformation defects, and developed crystallographic texture. The latter parameter determines the most important operational properties of metals and alloys, being in many cases the main factor contributing to the achievement of high level of physical and mechanical properties in them.

The nature of the preferred crystallographic orientations formed as a result of plastic deformation depends on the activity of various dislocation slip systems (SS) and/or twinning systems (TS). The activity of SS and TS decisively depends on the value of the material stacking fault energy (SFE), deformation temperature and deformation degree [3]. It is well known that during cold flat rolling of coarse-grained metallic (CG) materials with an FCC lattice, depending on the SFE, two different types of crystallographic texture are formed. In materials with increased SFE, the "copper" type textures \{111\} <112> are mainly formed, and with a decrease in SFE, the transition to a "brass" type texture \{110\} <112> occurs [4].

Analysis of the literature has shown that the effect of SFE on the crystallographic texture formation in UFG materials, the activity of SS and/or TS, the level and anisotropy of strength properties during ECAP has been insufficiently carried out and is an urgent task. Based on the foregoing, the purpose of this paper is to establish the nature of the influence of the SFE on the evolution of the crystallographic texture and establish active SS and/or TS in copper alloys with different SFE under ECAP.

2. Experimental

The Cu-Zn alloys with a content of 10 and 30 wt.% Zn were selected as the material for research in this work. The SFE values of these alloys were \~ 35 mJ·m⁻² and \~ 14 mJ·m⁻², respectively. Prepared samples
of Cu-10 wt.% Zn and Cu-30 wt.% Zn alloys were subjected to four and eight passes of ECAP at T = 150, 300 °C, respectively, in a tooling with an angle of intersection of the channels φ = 90 °, along the BC route [1].

The crystallographic texture formation processes were analyzed using the DRON-3M diffractometer. The incomplete pole figures (PFs) for the crystallographic planes (111), (200) and (220) were taken on a filtered secondary X-ray Cu Kα radiation beam. To construct the complete PFs and the orientation distribution functions (ODFs), as well as to determine the type and volume fraction of ideal crystallographic orientations, the Labotex software was used [5]. Texture studies were performed in the coordinate system shown in figure 1.

3. Results and analysis
Figures 2 and 3 show the texture evolution as a function of ECAP passes number for Cu-10 wt.% Zn and Cu-30 wt.% Zn alloys. As is known, the crystallographic texture in metal materials subjected to ECAP is analyzed with respect to a plane perpendicular to the shear plane (SP) and for a selected shear direction (SD). This coordinate system is the transverse (TD) direction - longitudinal (ED) direction (figure 1).

In this coordinate system, the ideal orientations located on the partial fibers A {111} (parallel to the shear plane) and B <110> (parallel to the shear direction) are well detected. The A {111} and B <110> fibers observed in figures 2 and 3 are typical of metals with the FCC lattice [7]. In the case of a simple shear, fiber A contains components A, A, A and A, while fiber B contains components A, A, B, B and C (figure 2, 3).

ODFs analysis showed that at the initial stage of ECAP (one pass) a simple shear crystallographic texture is formed, at which the A component is the most intense for both alloys (figure 2, 3). In addition to the main simple shear texture components, a subtle Cube orientation can be identified on the ODFs of the alloys (figure 2 and 3). The latter indicates the occurrence of recovery and recrystallization processes, the activation of which is associated with the ECAP at elevated temperatures [3]. It should be noted that the Cube orientation also remains stable with an increase in the ECAP passes number in both alloys. Low value of the SFE led to the emergence of the dominant Brass orientation in the Cu-30 wt.% Zn alloy during the first ECAP pass (figure 3). This type of orientation is absent in the Cu-10 wt.% Zn alloy with the high SFE value (figure 2).
Figure 2. Experimental ODFs of Cu-10 wt.% Zn alloy subjected to ECAP with the different number of passes. Sections $\phi_2 = 0^\circ$ and $\phi_2 = 45^\circ$. Below is a schematic representation of ideal orientations in the Euler angles space.

An increase in the number of ECAP passes to two led to significant changes in the location and intensity of the detected texture components. In particular, there is a suppression of the A component in the Cu-10 wt.% Zn alloy and $A$, $C$ components in the Cu-30 wt.% Zn alloy. The volume fraction of the $A^*_2$ component decreases in both alloys. Components $B/B^*$ become the most intense for the Cu-30 wt.% Zn alloy, which is typical for a material with the low SFE [8]. At the same time, a decrease in the SFE value leads to the significant increase in the Brass component (figure 3). Brass orientation also becomes intense in the Cu-10 wt.% Zn alloy after two passes of ECAP. It can be considered that this fact indicates the texture transition of the predominant orientations from those which are characteristic of copper texture to the orientations characteristic of brass. However, in an alloy with the lower SFE, the texture transition occurs after the first pass.

After four passes of ECAP, the most intense texture components are $A^*_1$ component for Cu-10 wt.% Zn alloy, $A^*_2$ component for Cu-30 wt.% Zn alloy and $B/B^*$ components for both alloys (figure 2, 3). The enhancement of the $B/B^*$ components usually occurs due to the tendency of the alloy to twinning, as noted in [8]. Components $A/A^*$ are practically absent in both alloys. The intensity of orientation of the Brass type in alloys gradually increases in comparison with two passes of ECAP.
Figure 3. Experimental ODFs of Cu-30 wt.% Zn alloy subjected to ECAP with the different number of passes. Sections $\varphi_2 = 0^\circ$ and $\varphi_2 = 45^\circ$. Below is a schematic representation of ideal orientations in the Euler angles space.

ODF analysis after eight passes of ECAP showed the presence of stable orientations observed after four passes of ECAP (figure 2, 3). The intensity of the $B/B\!/g_{3365}$ components remains high for an alloy with the low SFE, while the $A$ and $A\!/g_{3365}$ components are suppressed in favor of the Brass orientation. The Brass orientation is dominant in both alloys (figure 2, 3).

Thus, it can be concluded that both a decrease in the SFE value by alloying the Cu-Zn alloys system and ECAP leads to a decrease in the proportion of $A\!/A\!$ components and an increase in the proportion of $B/B\!$ components. C and Cube components remain stable. At the initial stages of ECAP, a texture transition of predominant orientations occurs from those characteristic of copper texture to those characteristic of brass, at high deformation degrees the Brass type orientation becomes dominant.

To establish the reasons leading to such crystallographic texture changes, the contribution of SS and/or TS active during ECAP in the alloys under investigation was estimated within the framework of the VPSC model.

Figure 4 shows the activity of existing SS and/or TS depending on the ECAP passes number for the investigated alloys. The modeling results showed that in the Cu-10 wt.% Zn and Cu-30 wt.% Zn alloys, the most active SS are the $\{111\} <110>$ octahedral slip systems.
At the initial stages of ECAP, the lower SFE value corresponds to a lower activity of SS \{111\} <110> and an increase in the contribution of TS \{112\} <110> (figure 4). An increase in the ECAP passes number is accompanied by an increase in the twinning processes activity. During the first and second passes of ECAP, the twinning processes activity is low. However, in the Cu-30 wt.% Zn alloy with the lower SFE, starting from the third pass, and in the Cu-10 wt.% Zn alloy, starting from the fourth pass, the twinning processes activity during ECAP slightly increases.

The activity of SS \{110\} <110> is low in both investigated alloys, but their activity increases with an increase in the ECAP passes number (large deformation degrees).

4. Conclusions

As a result of the experimental investigations and computer modeling of the texture formation processes during ECAP of the Cu-Zn alloys with different SFE, the following conclusions can be drawn. Both the decrease in the SFE value by alloying and ECAP lead to the decrease of the A/Â texture components and the increase of the B/B components, which is associated with the tendency of the material to twinning. The C and Cube components remain stable. In an alloy with the lower SFE, the texture transition of the preferred orientations from those characteristic of copper texture to those characteristic of brass occurs already after the first pass. With the further increase in the deformation degree, the Brass-type component becomes dominant. This fact is explained by the activation of twinning processes.

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