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Microstructure and Crystallography of β Phase Formed through Electric Current Pulse (ECP) Treatment in Cold-Rolled Cu-40%Zn Alloy

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Abstract: Most of the studies on phase transformation in metallic materials have focused on transformations during cooling processes due to the easiness of the conservation of the product phase. However, for phase transformation happening during heating processes, the experimental investigations have been indirect if the product high temperature phase could not be preserved to the convenient observation temperature, for example the room temperature. The high density Electric Current Pulse (ECP) treatment allows the phase transformation during heating process and the preservation of the high temperature phase to the room temperature, offering possibilities for direct experimental examinations. Thus, in the present work, a cold-rolled Cu–40%Zn alloy was ECP treated and the microstructure of the product phase and the transformation orientation relationship were investigated. Results show that during the ECP treatment, the high temperature beta phase with BCC structure formed in the parent alpha phase with FCC structure. Especially, two kinds of orientation relationships could be detected between the parent alpha phase and the product beta precipitates. The one is the Kurdjumov-Sachs orientation relationship (K-S OR), and the other is the Nishiyama-Wasserman (N-W). In addition, the amount of beta precipitates obeying the K-S OR is more than that of precipitates obeying the N-W OR. The results of this work provide new fundamental information on phase transformation of metallic materials.

Introduction

The high density electric current pulse (ECP) treatment can realize ultra-rapid heating (the heating rate about 10^6–10^7 K/s) [1] and cooling [1-4] of a bulk material and has been extensively applied in phase transformations [1-10]. It is firstly reported that instead of conventional quenching martensitic transformation from β-Ti to α-Ti, unusual martensitic transformation from α-Ti to β-Ti could be achieved simply by using ECP treatments [6]. It evidences that the ECP treatments would provide a promising method to investigate the high temperature product phase at the room temperature.

In recent years, some studies have focused on the heating phase transformation in Cu-Zn alloys [1, 3, 9, 10] and revealed that the high temperature β phase nucleated from the α phase obeyed the orientation relation of 44.3°<114> [9], which is close to the Kurdjumov-Sachs orientation relationship (K-S OR) [9, 10] under the ECP treatment. However, the relationship between the parent phase and the high temperature product phase induced by ECP and the orientation relationships are still not clear in the heating phase transformation process.

Thus, in the present work we investigated in detail the crystallographic high-temperature phase and the phase transformation orientation relationship between the parent phase and the product phase of the heating phase transformation by the high density electric current pulse in a cold-rolled Cu-40%Zn alloy.

Experimentals

The materials used in the present work is the cold-rolled 33% Cu-40%Zn alloy sheet (300×150×1mm) with a composition of Cu of 60.8 in mass% and Zn of 39.1 in mass%. Dog-bone-shaped samples were cut out of the center part of the cold-rolled Cu-40%Zn alloy sheet by the electro-spark discharge technique, as shown in Fig. 1. Then, a sample was treated using electric current pulses with a current density of 12.15kA/ mm^2. Fig. 1 shows a schematic illustration of the experimental arrangement. For comparison, the cold-rolled sample was also examined for reference.

The microstructural examinations and crystallographic orientation investigations were performed in a field emission gun scanning electron microscope (SEM, Jeol JSM 6500 F) with an EBSD acquisition camera and the Aztec online acquisition software package (Oxford Instruments). During the EBSD measurements, the “beam-control” mode was used under an accelerating voltage of 15 kV. The EBSD data were analyzed with the Channel 5 software (Oxford Instruments). The nano scaled microstructural and crystallographic features of the constituent phases were analyzed using a Philips CM 200 transmission electron microscope (TEM) operated at 200 kV. The TEM is equipped with a LaB6 cathode, a Gatan Orius 833 CCD camera, and homemade automatic orientation analysis software – Euclid’s Phantasies (EP) [11, 12]. TEM thin films were prepared by electro polishing with a solution of 20 % (volume fraction) nitride acid in methanol, using a Struers Tenupol-5 twin-jet electropolisher.

Results and Discussions

Fig. 2 (a) and (b) show the EBSD micrographs of the cold-rolled Cu-40%Zn alloy, where the α grains are in gray represented with the EBSD band quality indices and the β ones are in color according to their crystallographic orientations. It can be seen that the cold-rolled microstructure is mainly composed of α phase (about 97.2%) with a small quantity of β phase (about 2.8%). The β phase is located at the α grain boundaries and triple-junctions, forming bands along the cold-rolled direction. Within the α grains, many dark traces with different orientations could be observed, as shown in Fig. 2 (b). Fig.2 (c) displayed the disorientation angle distribution of the α grains. It is seen that the amount of low angle disorientation (< 5°) is very high, indicating that the α grains may contain large amount of crystal defects, such as dislocations.

TEM examinations revealed that the α matrix possesses large amount of dislocations, as shown in Fig. 3. We supposed that the dark traces appeared in the α grain interiors in the EBSD micrographs (Fig. 2 (b)) should be the bands containing high density dislocations. Further analysis by TEM showed that they are mainly $<10\bar{1}>\{111\}_\beta$ dislocations that are typical of FCC metals.

Fig. 4 shows the EBSD micrographs of the cold-rolled Cu-40%Zn alloy after ECP treatments, where the α grains are in gray represented with the EBSD band quality indices and the β ones are in color according to their crystallographic orientations. Comparing with the cold-rolled sample (Fig. 2 (b)), one can find that numerous fine β precipitates formed at the α grain boundaries and in the α grain interiors. This result shows that the high-temperature β precipitates can be preserved to the room temperature. Hence, the α phase with FCC structure transformed to the high-temperature β phase with BCC structure under the high density electric current pulse treatment. In addition, the β precipitates are distributed inhomogeneously and prefer to precipitation along the bands in the α grain interiors, as shown Fig. 4. This means that deformed bands offer the preferential nucleation sites for the β precipitates. It also indicates that the defects (dislocations) in the α grains are favorable for the precipitates of the high-temperature β phase during the heating phase transformation.

With crystallographic analyses, we found that the high-temperature β phase in the α grains possess two ORs with the surrounding α phase. One part of the β precipitates respect the Kurdjumov-Sachs OR (K-S OR), being specified as $\{111\}_\alpha//\{110\}_\beta$, $<\bar{1}10>_\alpha//<\bar{1}11>_\beta$, and the other part the Nishiyama-Wasserman OR (N-W OR), being specified as $\{111\}_{\alpha}//\{110\}_{\beta}$, $<11\bar{2}>_{\alpha}//<\bar{1}10>_{\beta}$,. Such results have not been reported for the ECP induced α to β phase transformation in the cold-rolled Cu-40%Zn alloys.

Table 1 shows the detailed results of the ORs and the corresponding angular deviations from the exact OR of the β precipitates. The results were obtained from the examination on a large number of randomly selected β precipitates in the ECPed sample. It is seen that most β precipitates respects the K-S OR whereas much less β precipitates obeys the N-W OR. That proves there are some selection rules between the K-S OR and the N-W OR during α to β phase transformation. We consider that the crystal defects in the initial α phase may play an important role on the selection of phase transformation ORs. In-depth analysis is on going.

Summary

In the present work, the α to β heating phase transformation induced by electric current pulses (ECP) was investigated in the cold-rolled Cu–40%Zn alloy. The ECP induced fine β precipitates were retained to the room temperature. The precipitates prefer to form along the deformation zones or bands in the α grains. The K-S and N-W ORs were detected between the α phase and the β precipitates during the heating phase transformation. Moreover, most β precipitates respects the K-S OR whereas much less β precipitates obeys the N-W OR. The results of the present work offered new information on the heating transformation orientation relationships in the cold-rolled Cu–40%Zn alloy.

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Figures

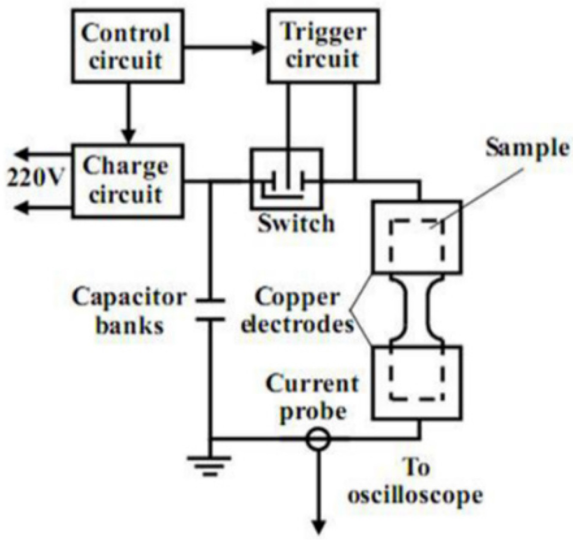

Fig.1 A schematic illustration of experimental arrangement for ECP.

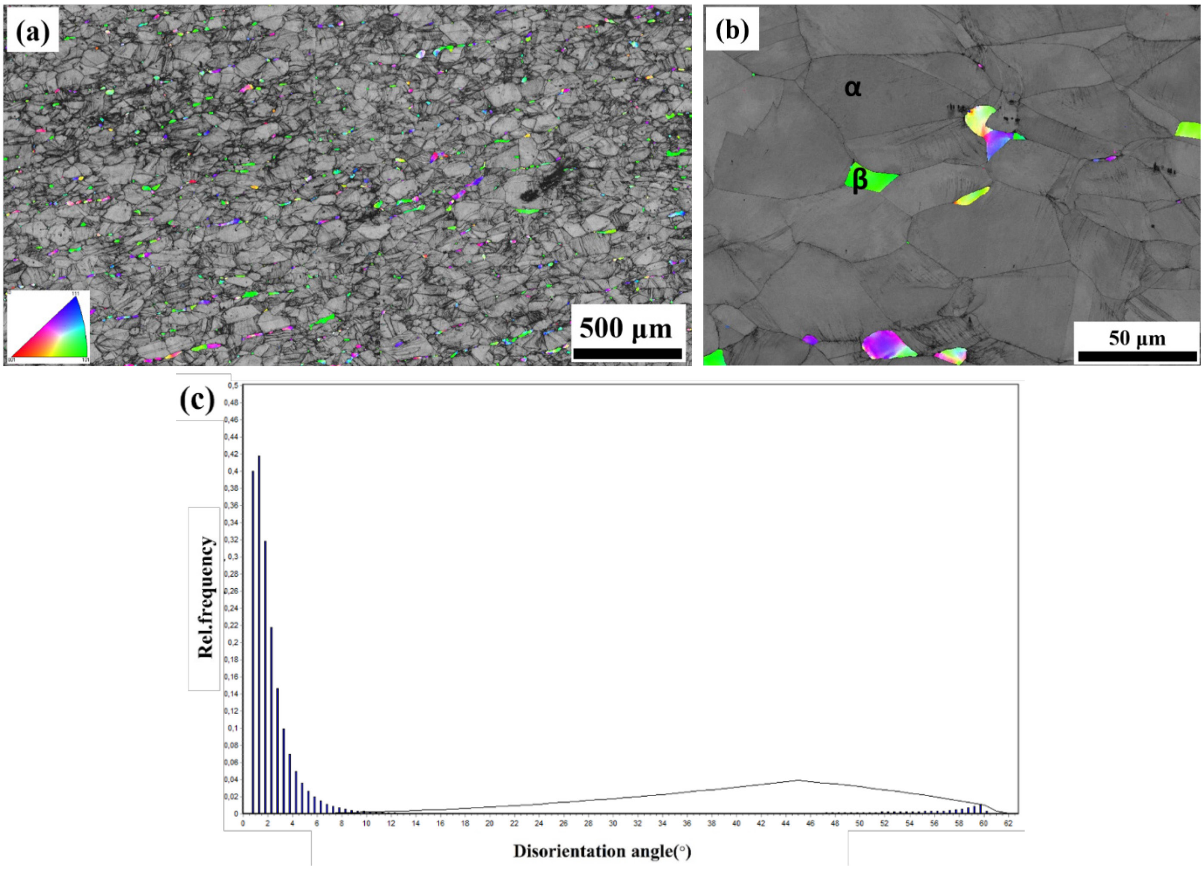

Fig.2 (a) and (b) SEM-EBSD micrographs of Cu-40%Zn alloy after ECP treatments where the α grains are in gray according to the EBSD band quality indices and the β phase in color according to its crystallographic orientation with respect to the X0 axis (X0 inverse pole figure (IPF) micrograph). (c) Disorientation angle distribution of α phase of the cold-rolled Cu-40%Zn alloy. The black line represents the theoretical random orientation of α phase.

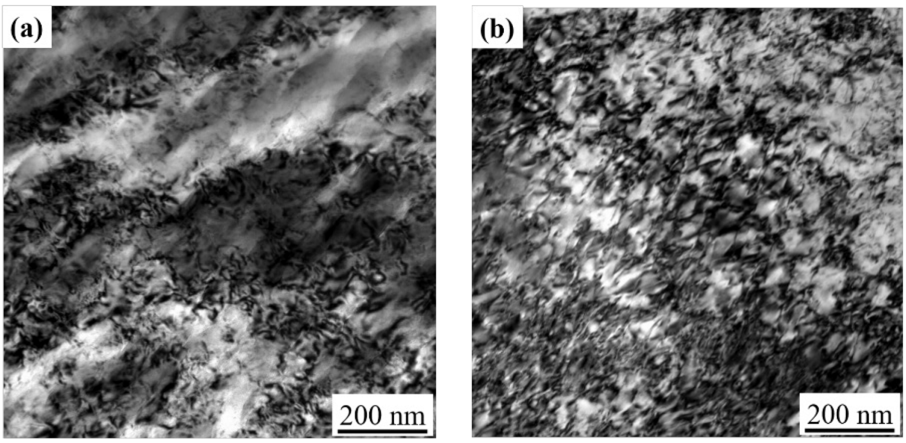

Fig. 3 TEM bright field image showing dislocations in the interior of α grains.

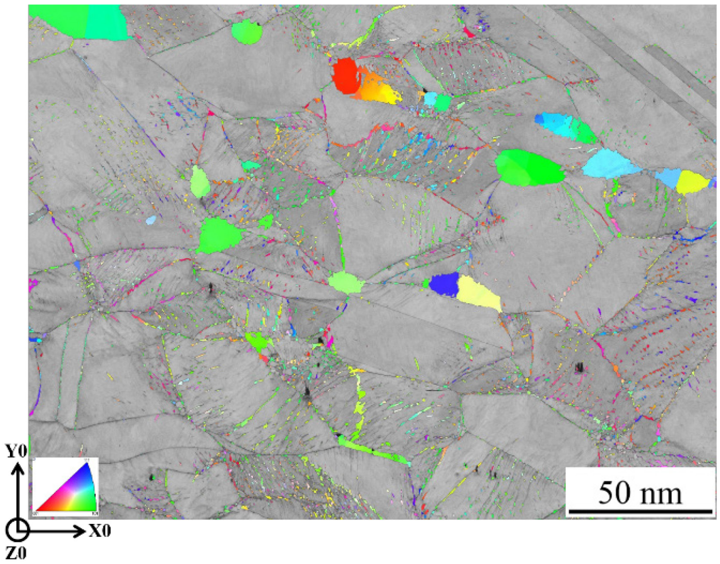

Fig.4 SEM-EBSD micrographs of cold-rolled Cu-40%Zn alloy after ECP treatments where the α grains are in gray according to the EBSD band quality indices and the β phase in color according to its crystallographic orientation with respect to the X0 axis (X0 inverse pole figure (IPF) micrograph). The impulse electric current density j_{max}= 12.15 kA/ mm^2. The electric current direction is in the X0 direction.

Table

Table.1 The amount of β precipitates that obey different transformation ORs (the K-S and the N-W) and the corresponding angular deviations from the exact OR, obtained under j_{max}= 12.15 kA/ mm^2.

Electric Current Density (kA/mm^2)	K-S (<5°)	N-W (<5°)	K-S (>5°)
12.15	80.70%	18.10%	1.2%

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