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Comparison of microstructure and mechanical properties of pure copper processed by twist extrusion and equal channel angular pressing

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ABSTRACT

Commercially pure copper sample was subjected to severe plastic deformation (SPD) processing via applying twist extrusion (TE) and equal channel angular pressing (ECAP) at room temperature. It was found that in the same accumulated strain (~ 2.4), TE decreased the mean grain size more than ECAP did. Moreover, the microstructure produced by TE was more homogeneous than that obtained by ECAP. The results of the tensile test showed that the strength properties of the TEed sample were higher than those of the ECAPed one. However, in the same strain value the ductility of the ECAPed specimen was higher than that of the TEed sample.

1. Introduction

SPD techniques have attracted much attention in the past two decades [1]. Several different SPD processing techniques are available but most emphasis to date has been placed on the techniques of ECAP [2] and High pressure torsion (HPT) [3]. In ECAP processing materials are used in various forms of rod, bar or even sheet, while in HPT method sample shape is limited to thin disks. TE [4] is an another conventional SPD technique which is similar to HPT processing but it is performed on billets with an arbitrary cross-section (except for circular). It was shown that during TE processing each physical cross-section of a billet is deformed in the same way as a thin disk during HPT processing is [5]. The comparison of ECAP and HPT methods has been done previously [6–9]. However, there is not enough information on the comparison of ECAP and TE techniques. Therefore, the aim of the present work was to compare the microstructure and mechanical properties of pure copper samples processed by ECAP and TE techniques.

2. Experimental procedure

The material used in this study was commercially pure copper (99.96%). The large billets with the dimensions of $18 \times 32 \times 70$ mm^3 and $18 \times 18 \times 70$ mm^3 were machined for TE and ECAP, respectively. To conduct the TE technique, a die with a twisted channel with a rotation angle (α) of 90° and a slope angle (β) of 60° was used. ECAP processing was carried out by using a die having a channel with an internal angle of $\Phi = 110°$ and an outer arc of curvature of $\Psi = 20°$. The microstructure of the samples was characterized by optical microscope of Olympus. Transmission electron microscopy (TEM) micrographs were obtained by utilizing a Philips CM200 microscope operated at 200 kV. The misorientation data were collected using a Hitachi S-4300SE field emission scanning electron microscope (FE-SEM). For texture examinations all samples were cut in the size of 10×10 mm^2 and they were tested using a Philips X-ray diffraction meter. The pole figure of (111) plane was investigated. The tensile tests were carried out at room temperature with the strain rate of 3×10^{-3} s^{-1} using a Santam STM-20 testing machine.

3. Results and discussion

Fig. 1(c) shows that by performing the first two passes of TE the grains are elongated according to the vortex flow pattern of TE [10]. Comparision of Fig. 1(d) and (e) illustrates that by performing the third pass of TE, the grain refinement achieves the saturation limit. Therefore, employing the fourth pass does not change the microstructure. However, in case of ECAP, conducting the fourth pass of ECAP decreases the mean grain size but not as much as the previous passes did. Furthermore, there are some coarse grains

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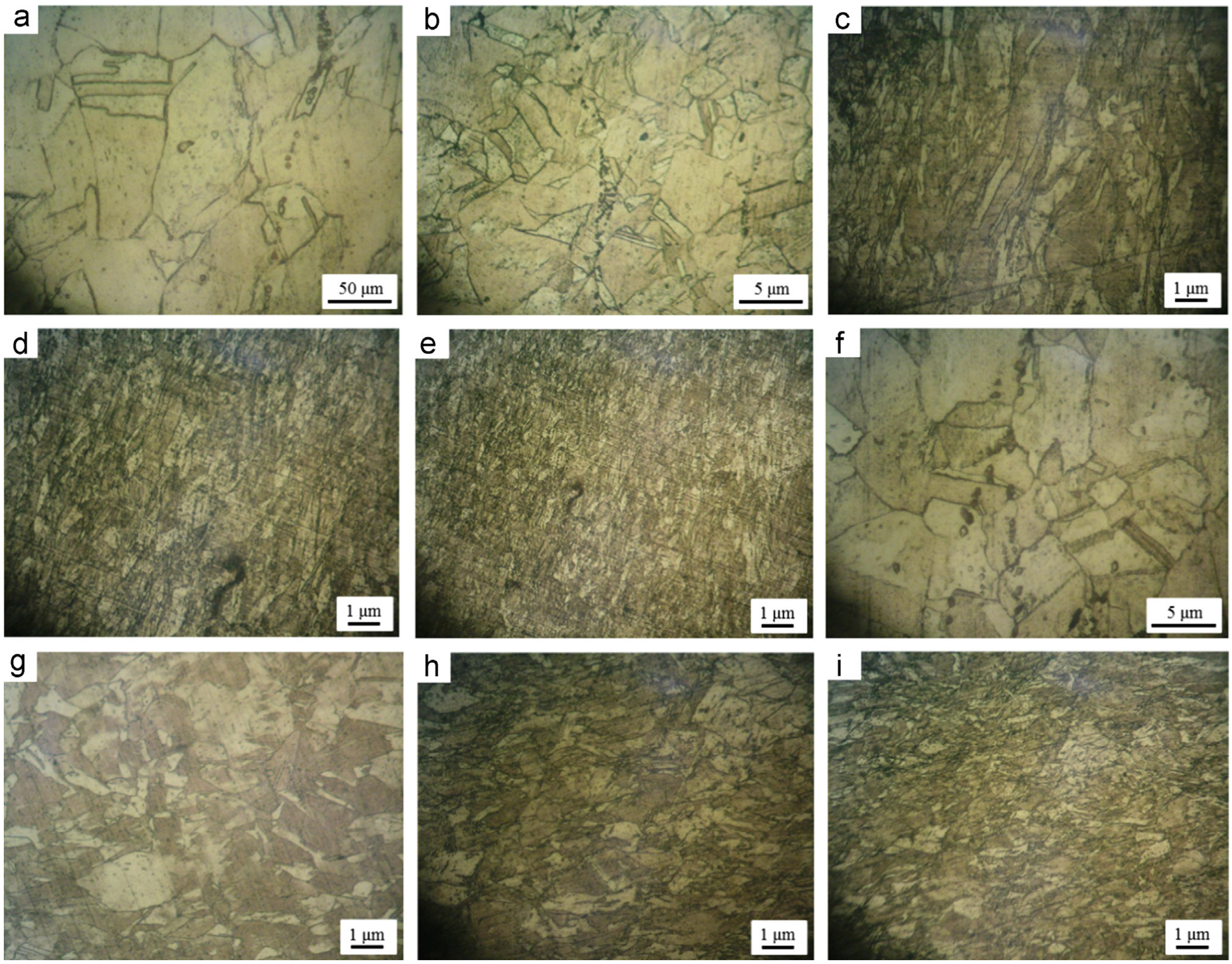

Fig. 1. Optical microscopy micrographs of (a) as-annealed sample, (b)–(e) samples processed by one, two, three and four passes of TE and (f)–(i) samples processed by one, two, three and four passes of ECAP.

indicating that the ECAPed microstructure is not as homogeneous as the TEed one is. The difference between the microstructures obtained by TE and ECAP is attributed to two phenomena. First, though the mode of deformation in TE and ECAP techniques is simple shear, there are two shear planes in TE (unlike ECAP having one shear plane), which results in more grain refinement. Comparision of Fig. 1(c) and 1(h) confirms that in the same accumulated strain (~ 2.4), the TEed microstructure becomes finer in contrast to the ECAPed one. Secondly, the sequential folds and stretches created by TE [11] lead to the microstructural mixing, thus create a more homogeneous microstructure.

Table 1 shows that during the first two passes of TE and ECAP, the fraction of the low angle grain boundaries (LAGBs) is larger. This is definitely resulted from the increase of the dislocation density and, consequently, the formation of the cells and subgrains in the grains. By performing the third pass of TE, the misorientation between the subgrains increases noticeably. According to Table 1, conducting the third pass of TE increases the dislocation density. It then causes large internal stresses most probably acting as the driving force for the cross-slip of the dissociated dislocations which previously could not move due to low stacking fault energy (SFE) of pure copper. As a result, the excessive dislocations relax through the formation of additional high angle grain boundaries (HAGBs) [12].

In contrast, the value of the dislocation density resulted from the third pass of ECAP is lower than that obtained by the third pass of TE. Hence, the fraction of the HAGBs of the ECAPed sample is lower than the TEed one. Comparision of Fig. 2(c) and 2(d) illustrates that the dislocation density of the sample processed by four passes of ECAP is higher than the dislocation density of the specimen deformed by four passes of TE. The reason is that a part of the excessive dislocations was released through the formation of the HAGBs. Therefore, during the fourth pass of TE the fraction of the HAGBs and LAGBs does not change considerably, while during the fourth pass of ECAP the fraction of HAGBs improves.

Table 1
The mean grain size, dislocation density, and percent of the HAGBs and LAGBs of pure copper samples processed by different pass numbers of TE and ECAP techniques.

Processing condition	Pass number	Dislocation density (m^{-2})	Mean grain size (μm)	LAGBs (%) $2^\circ \leq \theta < 15^\circ$	HAGBs (%) $\theta \geq 15^\circ$
TE	1	14×10^{14}	5	65	35
	2	24×10^{14}	0.81	59	41
	3	27×10^{14}	0.68	39	61
	4	22×10^{14}	0.65	38	62
ECAP	1	9×10^{14}	15	70	30
	2	17×10^{14}	1	64	34
	3	24×10^{14}	0.86	55	45
	4	26×10^{14}	0.75	48	52