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Effect of post-heat-treatment in ECAP processed Cu–40%Zn brass

H.S. Kim, W.Y. Kim, K.H. Song*

Korea Institute of Industrial Technology, 7-47, Songdo-Dong, Yeonsu-gu, Incheon, 406-840, Republic of Korea

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ABSTRACT

This study evaluated the grain refinement and mechanical properties of Cu–40%Zn brass processed by equal channel angular pressing (ECAP). The samples were repeatedly pressed to strains as high as 4 at a temperature of 250 °C using route C. Recrystallization heat-treatment was carried out at 350 °C for 20 min. To evaluate the grain boundary character distributions and mechanical properties of ECAP materials, electron backscattered diffraction, Vickers microhardness, and tensile tests were used. Increased passes in ECAP led to notable grain refinement, from 13 μm in the initial sample (350 °C/180 min heat-treated material) to 300 nm after 4 passes. The post-heat-treated material after ECAP also sustained refined grain size (2.4 μm in the α phase and 4 μm in the β′ phase) than that of initial state, which resulted in an increase in tensile strength with no decrease in elongation. Furthermore, coincidence site lattice boundaries derived from annealing twins were more developed than those of the initial material. This paper discusses the enhancement of mechanical properties in terms of grain boundary character distributions development.

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1. Introduction

Brass is widely used in many industrial products, such as lead frames, connectors, valves, pipes and so on, because of its excellent mechanical properties, including outstanding corrosion resistance, good formability, and suitable strength [1–3]. However, to improve the pressure tightness, strength, and machinability, lead has been used as an additive due to its low cost [2,4]. Recently, the use of lead in alloys has been strictly regulated due to its health effects; thus, lead-free brass is required to prevent health hazards. In addition, industry has been anticipating new applications for brass, specifically, electronic parts such as lead frames and connectors. Therefore, lead-free brass with optimized strength and conductivity, as well as minimized environmental and health concerns, is desirable. ECAP is an effective method for enhanced grain refinement, and mechanical properties such as microhardness and tensile strength [5–8]. Also, post-heat-treatment after ECAP is effective to develop the mechanical properties [9,10]. Therefore, in this study, ECAP via route C and post-heat-treatment on lead-free Cu–40%Zn brass were applied, and microstructural and mechanical properties were evaluated in terms of GBCDs.

2. Experimental procedures

The material used in this work was commercial-grade Cu–40%Zn brass (hot extruded bar). For ECAP, commercial grade Cu–40%Zn brass was machined to 10 mm in diameter and 100 mm in length and heat-treated at 350 °C for 180 min, which used as an initial material. ECAP was carried out at 250 °C via route C, which rotates the sample to 180° clockwise along its longitudinal axis and repeatedly processes it up to 4 passes. A closed die made of tool steel with a cross-channel angle (Φ) of 90° between the vertical and horizontal channels and an outer corner angle (Ψ) of 20° was used for ECAP, as schematically shown in Fig. 1. ECAP samples were subsequently annealed at 350 °C for 20 min to obtain recrystallized microstructures.

To investigate the microstructures, ECAP samples were machined to 10 mm × 10 mm at transverse direction (−Y plane in Fig. 1(a)), and a solution of $K_2Cr_2O_7$ (2 g), H_2O (100 mL), and H_2SO_4 (8 mL) was used to mechanically polish and etch the sample surfaces. For EBSD analysis, samples were further polished by VibroMet, GBCDs on annealed materials were investigated by EBSD. Also, EBSD data were acquired using a field-emission gun scanning electron microscope (FEG-SEM) operated at 20 kV. To investigate deformed microstructures, such as those resulting from 1 pass and 4 passes via route C, transmission electron microscopy (TEM) analysis was used. For TEM analysis, discs of 3 mm in diameter were mechanically polished to 80 μm and then twin-jet polished using a solution of nitric acid (20 mL) and methanol (80 mL) under 8 V at −40 °C.

To evaluate the mechanical properties, Vickers microhardness and tensile tests were used. For microhardness test, samples were machined to 10 mm × 10 mm on transverse direction and polished with abrasive paper. Vickers microhardness was carried out on cross sections of the materials with a load of 9.8 N and a dwell time of 15 s. Tensile test samples were used to evaluate the longitudinal tensile strength of the ECAP and recrystallized materials, as shown in Fig. 1(b).

3. Results

The microstructures of commercial grade Cu–40%Zn brass and the ECAP initial material are shown in Fig. 2. Commercial Cu–40%Zn brass had a small amount of deformation, exhibiting elongated grains with an average grain size of 13 μm in the α phase and 10 μm in the β′ phase, as shown in Fig. 2(a). The ECAP initial material was annealed at 350 °C for 180 min, removing elongated grains in

* Corresponding author. Tel.: +82 32 850 0395; fax: +82 32 850 0410.
E-mail address: skhyun7@nate.com (K.H. Song).

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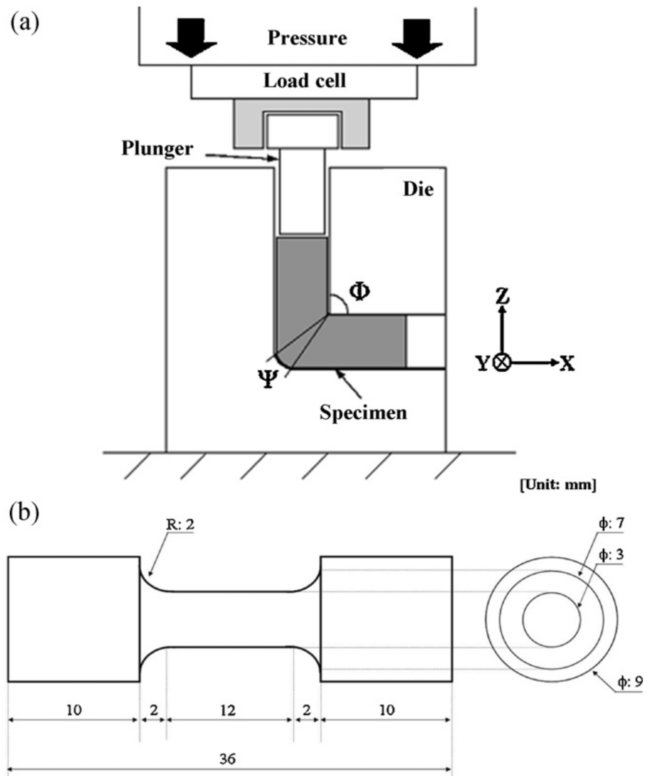

Fig. 1. Schematic of (a) equal channel angular pressing (ECAP) and (b) longitudinal tensile test sample. Φ and Ψ in (a) indicate the cross-channel angle and outer corner angle, respectively.

the microstructure, as shown in Fig. 2(b). The average grain size of the initial material was 13 μm in the α phase and 17 μm in the β′ phase, which was slightly larger than the grain size in the β′ phase of commercial Cu–40%Zn brass.

The microstructures of the samples processed by ECAP are shown in Fig. 3. At 1 pass via route C, the grains were elongated in the deformation direction, as shown in Fig. 3(a). However, grain size in the α phase and β′ phase could not be identified due to its severely deformed structure. For 2 passes via route C, the elongated microstructure along the deformation direction was restored to its original state due to its deformation mode, similar to that of the initial material, as shown in Fig. 3(b). Application of repeated ECAP caused the elongated and restored microstructures, as shown in Fig. 3(c) and (d), respectively. However, it is difficult to identify the grain size in microstructures by optical microscopy (OM).

TEM was used to identify the microstructures of ECAP materials (Fig. 4). The sample that was pressed for 1 pass was composed of grains ranging from 500 nm to 1 μm, including a large number of dislocations, as shown in Fig. 4(a). The sample processed for 4 passes using route C had grains ranging from 100 nm to 500 nm in size; thus, it was more refined than the 1-pass sample, as shown in Fig. 4(b).

Fig. 5 shows phase maps and misorientation angle distributions, obtained by EBSD, for 4-pass ECAP samples that were subsequently recrystallized. The recrystallized material showed the equiaxed grain structure, consisting of grains with an average size of 2.4 μm in the α phase and 4 μm in the β′ phase, as shown in Fig. 5(a). Also, the material was perfectly recrystallized, with the high-angle grain boundaries accounting for more than 92% of the high angle grain boundaries, as shown in Fig. 5(b). Especially, more than 46% of the distribution was composed of 60° in grain angles; these high angle grain boundaries were identified by the presence of an annealing twin boundary, which is usually observed in fcc metals that have a low stacking-fault energy.

Fig. 6 shows changes in the CSLB fraction. Commercial Cu–40%Zn brass accounted for 27% of the total CSLB fraction, and the $\Sigma3$ boundary primarily contributed to the total fraction, occupying more than 25% in fraction, however, $\Sigma9$ and $\Sigma27$ boundaries occupied 2% of the total fraction. ECAP and recrystallization heat-treatment markedly increased the CSLB fraction. Consequently, the total CSLB fraction increased to 54%, including a $\Sigma3$ of 43% and $\Sigma9$ and $\Sigma27$ boundaries of 7%.

The distribution of Vickers microhardness is shown in Fig. 7. Commercial Cu–40%Zn brass and the initial material had microhardnesses of 130 HV and 101 HV, respectively. However, Vickers microhardness was significantly increased by ECAP, which was gradually increased with increased passes of ECAP. As a result, Vickers microhardness increased from 184 HV for 1 pass to 210 HV for 4 passes (Fig. 7).

Tensile properties are shown in Fig. 8. The tensile strength of the treated samples markedly increased compared to that of the initial material and was gradually increased with increased passes of ECAP, similar to Vickers microhardness. The yield strength of the material processed by ECAP increased from 469 MPa for 1 pass to 544 MPa for 4 passes, which was an increase of nearly 340% compared to the initial material. In contrast, elongation decreased with increased passes of ECAP. In addition, the material that was recrystallization heat-treated after ECAP showed increased tensile and yield strength compared to the initial material, with similar elongation. The yield strength significantly increased from 165 MPa for the initial material to 304 MPa for ECAP and annealed material.

4. Discussion

ECAP at 250 °C on Cu–40%Zn brass effectively refined the grain size, which was accelerated with increased passes of ECAP. Initially, the grain size was 13 μm in the α phase (Fig. 2(b)); however, it was markedly refined from 1 μm for 1 pass to 300 nm for 4 passes,

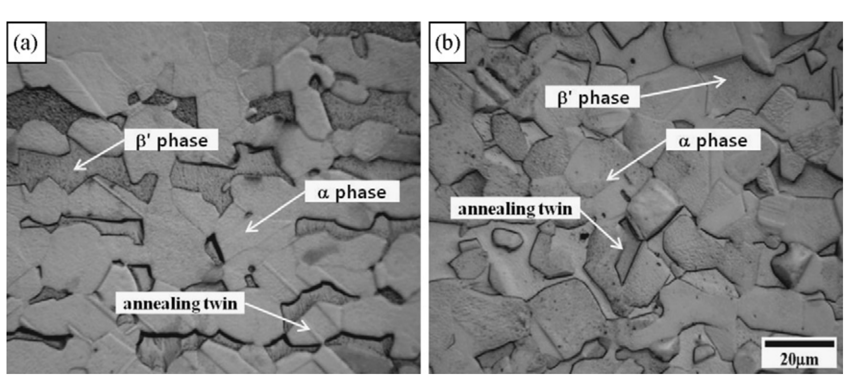

Fig. 2. Microstructures of (a) commercial Cu–40%Zn brass and (b) the initial material annealed at 350 °C for 180 min.

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