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Effect of lead on the crack propagation and the mechanical properties of Brass processed by ECAP at different temperatures

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ABSTRACT

The effect of equal channel angular pressing on the microstructure and the mechanical properties of a 60–40 brass alloy and a brass alloy containing 2.5 wt% Lead was investigated. The process was carried out at 300 °C and 400 °C through the route C up to two passes. The microstructure of the specimens was evaluated using optical microscopy and scanning electron microscopy. It was found out that, after the second pass, some cracks appeared in the specimens at both temperatures. The investigations confirmed the existence of the liquid lead flow in the phase boundaries and crack walls at 400 °C, leading to the deeper crack formation, as compared to the specimen at 300 °C. Mechanical properties were evaluated through micro-hardness and tensile tests at room temperature. The results showed that the highest hardness and tensile strength corresponded to the specimen processes at 300 °C after two passes. In order to ensure a deeper study of the mechanical behavior of the specimens, dislocation density was measured using X-ray diffraction pattern; a drop of dislocation density at 400 °C was revealed.

1. Introduction

Nowadays, the Cu-Zn brass alloy due to its suitable mechanical properties and good corrosion resistance is widely used in such industrial applications as pipes, valves and inner components of ships. Improvement of machinability and mechanical properties are two of the most important approaches considered to develop the applications of this alloy. Adding Lead is one of the improvement methods for the machinability; it is mainly used in the brass alloys. This element, by helping the formation of small chips in machining, can reduce the manufacturing costs [1]. Few reports are available on the mechanical properties and the deformation behavior of two phase Leaded- brass alloy through the deformation processes [2]. The equal channel angular pressing process is very effective to improve the mechanical properties of alloys with a rod-shape. The die used in this process contains two crossed channels with the same diameter. While the specimen is passed through the intersection channels, the severe shear stress application increases mechanical properties through hardening and strong grain refinement [3–15]. The mechanical properties of two phase brass alloy at high strains and under ECAP process has not been studied extensively [16–18]. The low stacking fault energy of 60–40 brass alloys prevents the easy deformation. The lead addition can make the deformation even more difficult by pinning the grain boundaries. This can greatly justify the lack of studies on the effect of the deformation process on the properties of the Leaded-brass alloy. The effect of the ECAP process on the behavior of this alloy has only been reported by Dutkiewicz et. al., [19]. However, they did not refer to the mechanical properties and the microstructure variations obtained by ECAP process. In this research, the mechanical properties and the deformation behavior of the 60–40 brass alloy and the Leaded- brass alloy processed by ECAP have been investigated. Also, the effect of Lead phases formation at the grain boundaries and the interface of the alpha and the beta phases on the fracture mechanisms has been analyzed.

It is worth mentioning, the using of lead in large quantities leads to environmental hazards. It is known that lead is cheap and then it was used in some critical applications such as some aircraft connections and ship fuel tanks. In this study, it is found that this element can also cause rapid failure. Therefore, it is suggested the lead removal from the chemical composition of the alloy; instead of lead, lead free brass processed by ECAP was used. ECAP resulted in the materials properties modifications such as the enhancement of the strength and grain refinement leading to also improve the machinability.

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Table 1
Nominal composition of brass alloys.

Elements		Cu	Zn	Pb	Other
Weight (%)	Leaded brass alloy	59. 11	38.27	2.49	Bal.
	60–40 brass alloy	60.17	39.82	0.003	Bal.

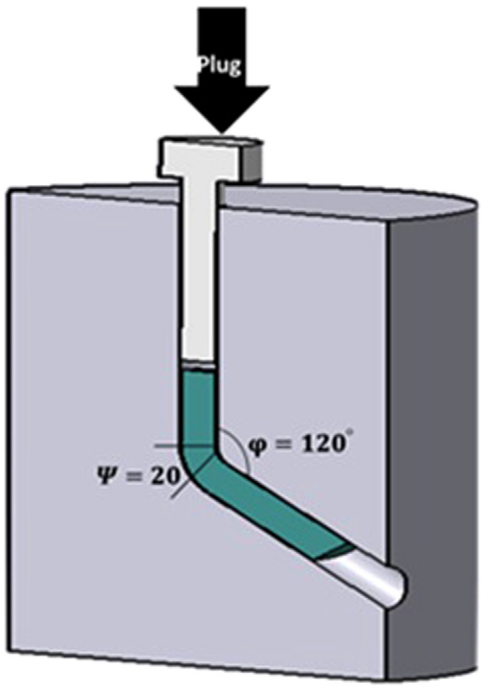

Fig. 1. Schematic of ECAP die.

2. Experimental procedures

The nominal composition of the as-extruded brass alloys used in this research is shown in Table 1. The materials were supplied by BA-HONAR Company (Kerman, Iran). To improve formability and modify the morphology of grains, the as- received alloy was annealed at 350 °C for 2 h for all specimens. The cylindrical specimens were 20 mm in diameter and 60 mm in height for ECAP process. The schematic of ECAP die used in this research is shown in Fig. 1.

The inner angle and the curvature angle of the ECAP die were 120° and 20° respectively. The process was performed at 300 °C for 60–40 brass alloy and at 300 °C and 400 °C for Leaded-brass alloy up to the second pass through the route C such that specimen was turned 180 degrees after the first pass and re-entered into the die. For convenience, the specimens were numbered. The specimens' numbers are specified in Table 2.

Friction was reduced on the surface of the specimens and in the inner wall of the die by applying the Nano-MoS_2 lubricant after each pass. After process, the specimen's surface was eched in a chloro ferric solution (5% iron chloride, 2 ml hydro choloridric and 95% methanol) to prepare for the analysis. The microstructure of specimens was investigated using an Olympus optical microscope in the pressing direction. To study the mechanical properties, hardness and tensile tests were employed. Micro-hardness tests were performed by employing Horish S135 machine with 50 gr load for 10 s of dual time. The tensile tests were carried out by H50KS Hounsfield machine at room temperature with 2 mm/min rate to study the tensile behavior of specimens following the ASTM standard [20]. Also, a Scanning Electron Microscope was used to investigate the microstructure and the fracture surfaces of tensile specimens. Chemical analysis was done using an X-ray energy dispersive analyzer EDAX (SEM-EDS). The chemical composition was reported by averaging three EDS point analysis per zone.

Table 2
Specimens' number studied in this research.

Process	Leaded-Brass Alloy				60–40 Brass Alloy
	1 Pass at 300 °C	1 Pass at 400 °C	2 Passes at 300 °C	2 Passes at 400 °C	2 Passes at 400 °C
Specimens	1	2	3	4	5

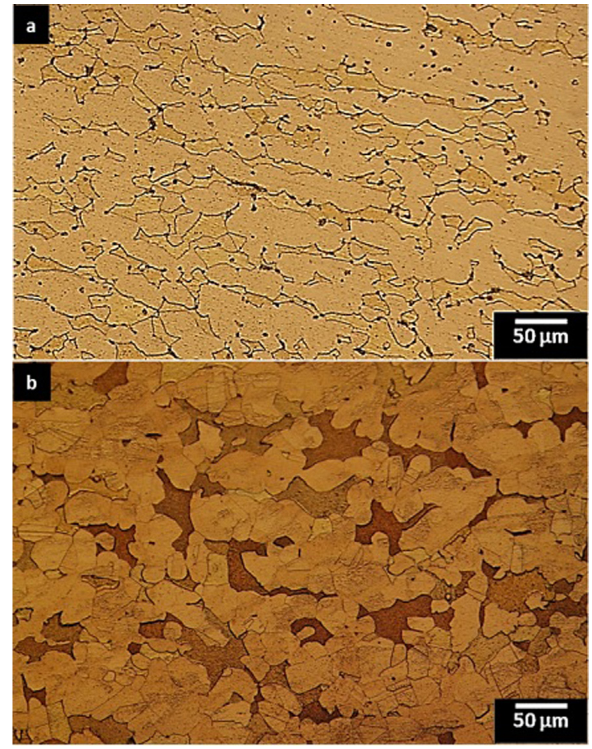

Fig. 2. Microstructure of the annealed specimens; (a) leaded brass alloy and (b) 60–40 brass alloy.

XRD analysis was conducted using a Philips, X′PERT MPD using monochromatic CuKα with a wavelength of 1.541 Å at a scan rate of 1 mV/s. To calculate the values of dislocation density the MAUD software based on the Rietveld method was used [21].

3. Results and discussions

Fig. 2 shows the microstructure of the specimens after annealing at 350 °C.

In these figures, bright and dark areas indicate the α phase with the FCC crystal structure and the β phase with the BCC structure, respectively [22,23]. According to Fig. 2-a, black dots are also apparently concentrated at the phase boundary or the grain boundary of each phase. As mentioned, the investigated Leaded-bras alloy contained 2.5 wt% of Lead. Due to the low solubility of Lead in this alloy, these dots represent Lead particles freely aggregated at the grain boundaries because of the low atomic density of these sites. The aforementioned dots were in the color white in the SEM image (Fig. 3).

SEM-EDS analysis was used to assure the nature of these dots. As shown in Fig. 4, a high density peak of lead was seen indicating the high concentration of Lead in these dots.

Fig. 5 shows the image of specimens after ECAP process. It could be seen that in contrast to 60–40 brass alloy, the deep cracks were formed after two passes at both temperatures in the leaded brass alloy. Of course, more severe cracks could be seen in the specimen processed at 400 °C.