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Superplastic properties of Pb–62%Sn eutectic alloy after equal channel angular pressing (ECAP)

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ABSTRACT

Billets of Pb–62%Sn alloy were subjected to equal channel angular pressing up to various numbers of pressings of 1, 4, 8 and 16 passes via route B_C at room temperature in order to investigate its superplastic properties. These samples were pulled to failure in an Instron machine at a temperature of 413 K at initial strain rates ranging from $1.0 \times 10^{-3}\,s^{-1}$ to $2.0 \times 10^{-2}\,s^{-1}$. The initial grain size was ~14 μm and the grain sizes corresponding to 1, 4 and 8 passes were 10.7, 9.2 and 8.4 μm, respectively. At a strain rate of $1.0 \times 10^{-3}\,s^{-1}$, which is rather close to the optimum superplastic region II in this material, for 8 passes the elongation to failure increased from 2330 to 3000%, which can be considered to be optimum number of pass for attaining highest ductility.

1. Introduction

Grain refinement by severe plastic deformation (SPD) has been known as a potential tool for high strain rate or low temperature superplasticity (Valiev et al., 2000, 2006). Among them equal channel angular pressing (ECAP) is extensively investigated because of the advantages such as scale-up with easiness, preservation of original shape and controllable strain accumulation by simple repetitive shear etc. (Gubicza et al., 2007; Langdon, 2007; Xu et al., 2007). In this reason a variety of Al and Mg alloys etc. were investigated using ECAP method (Xu et al., 2007; Figueiredo and Langdon, 2006). Until now most of the studies were focused on enhancement of superplastic properties from single phase non-superplastic metals. Recently Zn–22%Al two phase alloy, one of the famous superplastic materials, was studied in order to observe the effect of the process in the respect of the change in superplasticity such as optimum superplastic condition and grain boundary sliding mechanism through additional grain refinement (Kumar et al., 2006). Lee and Langdon reported the strong tendency of high strain rate superplasticity after ECAP in Zn-22%Al alloy from $10^{-2}\,s^{-1}$ to $1\,s^{-1}$ in optimum strain rate, which was attributed to grain size reduction and efficient phase mixing effect (Lee and Langdon, 2001).

Current study was motivated to observe if Pb–62%Sn, another well-known two phase superplastic material, showed similarly enhanced behaviour by employing ECAP method. In this paper eutectic two phase superplastic Pb–62%Sn alloy was studied to investigate the effect of processing parameter on grain refinement and its superplasticity. As described below, this material exhibited the dependence on the number of pressings on grain size reduction. Also, the superplastic properties were fairly enhanced.

2. Experimental procedure

The material used in this investigation was a commercial Pb–62%Sn eutectic alloy obtained in superplastic condition. Cylindrically shaped billets with a diameter of 9.3 mm and total length of ~63 mm were machined for ECAP. The detailed description on ECAP facility was well addressed in (Lee and Langdon, 2001). Fig. 1 shows the utilized ECAP facility and schematic illustration of the experimental procedure. In the

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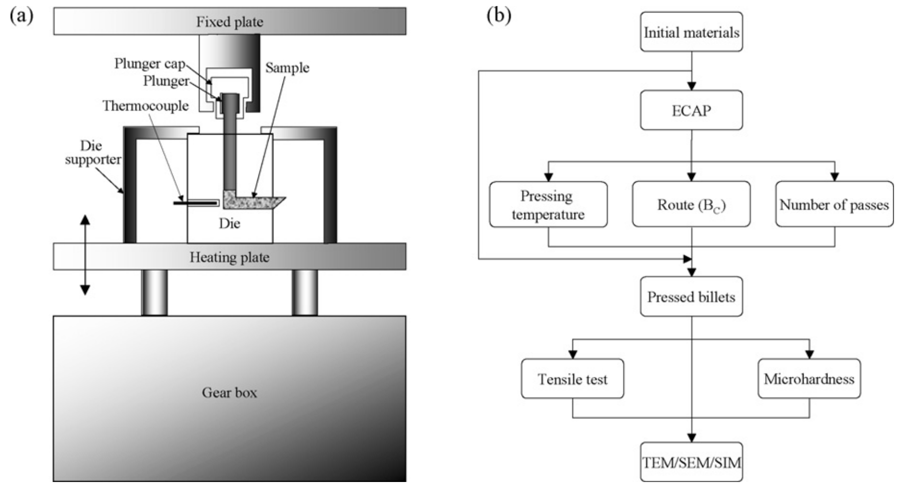

Fig. 1 – Schematic illustration of (a) ECAP facility and (b) experimental procedure.

present experiments, samples were pressed for total of 1, 4, 8 and 16 passes via route B_C at room temperature where route B_C is the rotation of the sample by 90° in the same sense between passes. After completing ECAP tensile specimens were machined with different gauge lengths. Tensile specimens made from the billets for 1, 4 and 8 passes had a gauge length of 3 mm and tensile specimens from 16 pass billets had a gauge length of 2 mm. These samples were pulled to failure in an Instron machine at a temperature of 413 K at initial strain rates ranging from $1.0 \times 10^{-3}\,s^{-1}$ to $2.0 \times 10^{-2}\,s^{-1}$. The microstructure and the grain size measurements were conducted using a Cambridge scanning electron microscopy (SEM) operating at an accelerating voltage of 20 kV. Energy dispersive X-ray spectroscopy (EDS) analysis was used to identify the two different phases in the Pb–62%Sn alloy. The samples were prepared by conventional metallographic technique, subsequently followed by chemical etching with an appropriate etching solution. The measurements for microhardness were conducted using a digital microhardness tester FM-1e from Future-Tech Corp. equipped with a Vickers diamond indenter with a face angle of 136°. Loads of 100 and 50 gf were used with the dwelling time of 10 seconds for all measurements.

3. Results and discussion

The mechanical results are listed in Table 1 and elongation to failure is plotted as a function of strain rate in Fig. 2(a). Inspection of Fig. 2(a) shows that there was no evidence of displacement of optimum strain rate to a higher value. It was reported that the optimum strain rate for superplasticity of this material was at a strain rate of less than $\sim 1.0 \times 10^{-4}\,s^{-1}$ (Ma and Langdon, 1994). However, at a strain rate of $1.0 \times 10^{-3}\,s^{-1}$, which appeared to be rather close to the optimum superplastic region II in this material, the elongation to failure at 4 passes (1500%) was significantly less than that of the unpressed specimen (2330%).

The reduction was almost 40% of elongation to failure compared to the unpressed specimen. At 8 passes, the fracture elongation again increases to 3000%, and finally it saturates at the same elongation at 16 passes. According to this trend, the initial passage of pressing up to 4 passes does not appear to enhance the elongation to failure. Therefore, it is assumed that the number of pressing up to 8 passes is optimum and enough to evolve the microstructure for superplasticity and more than 8 passes do not affect the ductility of this material. Although the ductilities obtained here are not as good as those reported earlier by Ma, it would be valuable to make a direct comparison of the current data before and after straining since all datum points were obtained in the same experimental conditions. According to the current results, it is indicated that ECAP of Pb–62%Sn has a moderate effect on the improvement of ductility as described above.

Under conditions of high strain rates such as $\sim 10^{-2}\,s^{-1}$, the elongations to failure are consistently low which reflects the presence of region III. True stress versus true strain curves were plotted at a strain rate of $1.0 \times 10^{-3}\,s^{-1}$ for unpressed and 4, 8 and 16 passes in Fig. 2(b). It is apparent that the ultimate tensile stress (UTS) drops after 4 passes. And also yield

Table 1 – Mechanical properties of Pb–62%Sn alloy pulled to failure at 413 K after ECAP

Number of pressings	Initial strain rate (s^{-1})	Elongation to failure (%)	UTS (MPa)
0	1.0×10^{-3}	2330	7
	2.0×10^{-3}	1330	10
	6.7×10^{-3}	460	17
	2.0×10^{-2}	280	20
4	1.0×10^{-3}	1500	6.0
	3.3×10^{-3}	610	12
	1.0×10^{-2}	350	15
8	1.0×10^{-3}	3000	6
	3.3×10^{-3}	810	12
	1.0×10^{-2}	490	16
16	1.0×10^{-3}	3060	6.0
	2.0×10^{-3}	1791	8
	6.7×10^{-3}	1359	14
	2.0×10^{-2}	490	20.