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T-shaped equi-channel angular pressing of Pb–Sn eutectic and its tensile properties

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Abstract

Equi-channel angular pressing (ECAP) of a Pb–Sn eutectic alloy up to six passes in a T-shaped die, rather than a conventional L-shaped die, was studied for grain refinement. The effect of ECAP on the hardness and tensile properties was studied. Microstructure predominately changed in the early part of the ECAP process and became equiaxed and uniformly distributed in both the longitudinal and the transverse sections after four passes. There occurred substantial softening over the first two passes—hardness of 10 Hv, yield strength of 14.2 MPa and tensile strength of 16.3 MPa in the as-cast condition decreased upon two passes to 6 Hv, 9.7 MPa and 13.0 MPa, respectively. The ductility (% elongation) increased drastically from <50% in the as-cast condition to 150% upon two passes, and further increased to 230% after four passes. Various tensile properties and concurrent microstructural evolution were used to develop a mutual relationship among them.

Keywords: Equi-channel angular pressing; Grain growth; Ductility; Constitutive relationship

1. Introduction

Equi-channel angular pressing (ECAP) is one of the severe plastic deformation processes where the material is subjected to simple shear. Using the technique of ECAP, one can impose intense strain without any change in the cross-sectional area of the sample. This is used to achieve considerable grain refinement in the material, typically within sub-micrometer and even nanosize ranges [1]. These fine grains provide the opportunity for superplastic behavior with a high percentage elongation at relatively lower elevated temperature and faster strain rate.

The conventional L-shaped die consists of two channels equal in cross-section and intersecting at an angle near the centre of the die [2]. The material is made to enter one of the channels and exit through other channel without any change in cross-sectional area, while being subjected to simple shear. Since there is no change in cross-sectional area, the sample can be repeatedly pressed to obtain a large cumulative strain.

Numerous reports have been published describing microstructures and textures produced through ECAP processing. This has included various materials such as aluminum and its alloys [3–5], copper alloys [6–8], magnesium alloys [9], pure nickel and its alloys [10,11], low carbon steel [12–14], pure beryllium [15], pure titanium and its alloys [16–18] and Zn–Al alloys [19]. In all these cases, the pressing was carried out using L-shaped die. It was thought that if the material of selected cross-sectional area could be divided to flow in two channels, but maintaining the same cross-section as the inlet, it could go through more severe mechanical working. In this case, 12 mm × 12 mm incoming sample gets into two interconnected horizontal channels, as will be described later. No attempt seems to have been made to extrude the material using a T-shaped die, where the material is placed in one channel and is made to exit from two channels without any change in the cross-section of the sample. Hence, in the present study, a T-shaped die was designed and fabricated for this new ECAP process. To study this new approach, a Pb–Sn eutectic alloy was selected and the study incorporates evaluation of microstructures and the mechanical properties with progress in ECAP. Selection of this model material is owing to the fact that it is easy to deform and it exhibits superplastic characteristics even at room temperature.

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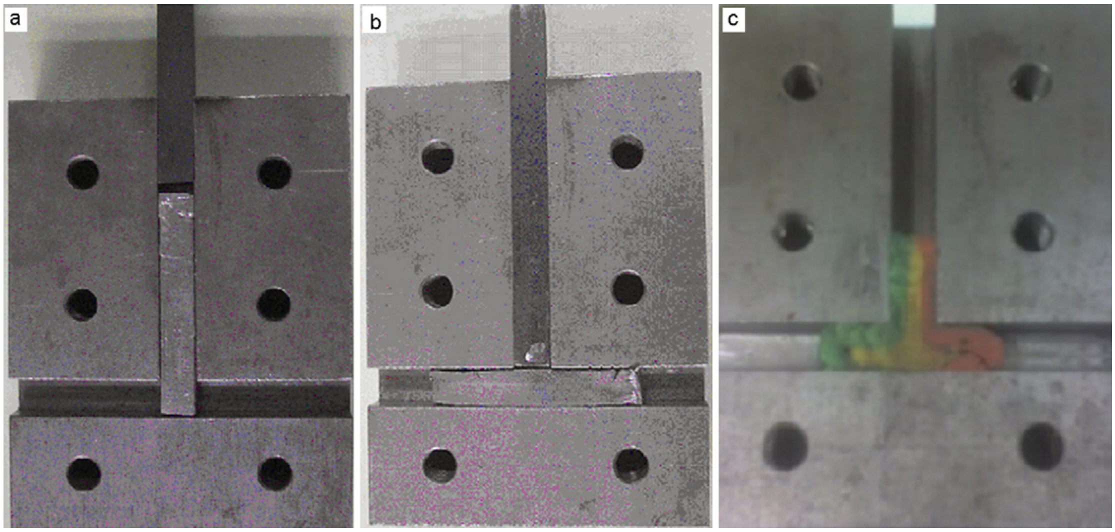

Fig. 1. T-shaped ECAP die with sample and plunger: (a) before pressing; (b) after pressing; (c) pressing of plasticine at intermediate stage. The top plane plate and bolts are not shown for inner clarity.

2. Experimental procedure

A commercial Pb–Sn alloy ingot was used. The alloy was melted at a temperature of 250 °C and cast in a metal mold to obtain the required dimensions of 12 mm × 12 mm × 100 mm. The chemical analysis determined by using ICP-AES (wt.%) was: 40.17 Pb, 0.016 Fe, 0.071 Cu, 0.041 Al, and balance Sn.

The T-shaped ECAP die in this work consisted of an assembly of two blocks. One block carries the T-shaped channel whereas the second block just covers the channel. The dimensions of the block are 145 mm × 114 mm × 35 mm. The cross-sectional dimensions 12 mm × 12 mm of the inlet and the outlet channels are the same throughout. The material was placed in one channel of the T-shape and made to exit from the aligned horizontal channels, as shown in Fig. 1(a and b). Shown here is the assembly of the sample and the plunger before and during pressing. A marking was made in the plunger so as to stop ECAP before it could hit the joint at T-section.

As seen in Fig. 1, the inlet channel of the die is symmetric and the exit channel closer to the base is asymmetric with respect to their positions. Since the dimensions of the cross sections of the inlet and the exit channels are the same, no change in the cross-sectional area of the sample at the exit occurs. In view of this, the process can be viewed as equi-channel angular pressing.

Colored layers of plasticine were chosen for pressing as a part of first trial to see the working of the die as well as to examine the flow of the material through the channel of the T-shaped die. Fig. 1(c) shows the deformation of plasticine (color of plasticine not shown here) at an intermediate stage of the pressing. Later, the ECAP for feasibility study was also done with a lead sample. Finally, detailed ECAP was carried out on the chosen Pb–Sn eutectic, which will be described in the present paper. The pressing operation was performed on a hydraulic press of 50 tonnes capacity. Proper alignment was made between the sample and the plunger to facilitate the operation and to avoid the breakage of the die. The samples and the die were lubricated with MoS_2 at each pass for easy removal of the samples after extrusion and also to avoid the frictional effect between the sample and the die during the extrusion.

Firstly, the as-cast Pb–Sn eutectic was subjected to ECAP for one pass. Later, another as-cast sample was subjected to two passes. In this case, the first pass was followed by the second pass by rotating the sample through an angle of 90°. In the similar manner, for four and six passes ECAP was carried out by rotating the sample through 90° after each pass.

Samples of Pb–Sn eutectic subjected to ECAP for one, two, four, and six passes along with the as-cast sample, were mechanically polished and hardness was measured using Vickers micro hardness tester with a load of 25 g held for 15 s on the longitudinal plane of the pressed samples. After the first pass (Fig. 1(b)), there appears to be partial deformation at the centre of the sample in the longitudinal direction. So, effort was made to examine the variation in the hardness throughout the length of the sample with successive passes. For this reason, hardness was measured at different points along the length of the sample from one end to the other.

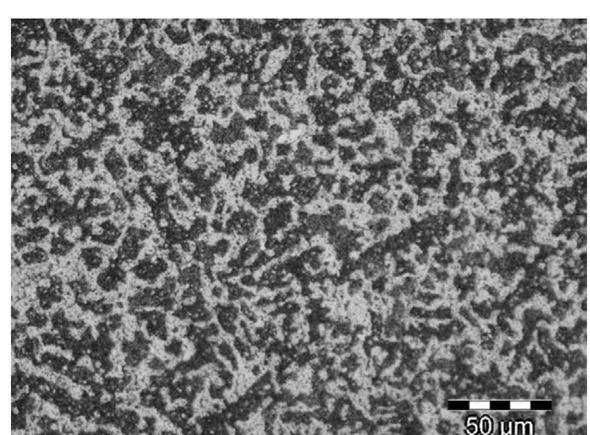

Fig. 2. Optical micrograph of as-cast Pb–Sn eutectic.