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The effect of extrusion temperature on the development of deformation microstructures in 5052 aluminium alloy processed by equal channel angular extrusion

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Abstract

Commercial 5052 aluminium alloy was used to study the effect of extrusion temperature on the development of deformation microstructures processed by equal channel angular extrusion (ECAE). The extrusion temperatures used were between 50 and 300 °C, and the cumulative equivalent strain was 5.6. Transmission electron microscopy was adopted to characterize quantitatively the metallographical parameters, namely grain size, grain aspect ratio, and boundary disorientation. Raising extrusion temperature causes grain size to increase, grain shape to become more equiaxed-like, and a dramatic increase of low angle boundaries. Both grain and subgrain boundaries with low disorientations are formed at elevated temperatures. Comments on disorientation measuring techniques in transmission electron microscope are also given.

Keywords: Aluminium alloy; Ultrafine-grained structure; Disorientation; High temperature deformation; Equal channel angular extrusion

1. Introduction

Over the last few years, the development of equal channel angular extrusion (ECAE), also called equal channel angular pressing (ECAP), has attracted much attention from the materials community, because of its ability to produce ultrafine-grained metals, and provide novel properties [1]. The basic principle for ECAE is very simple, the tool, see Fig. 1, is a die with two intersecting channels of equal cross-section. A sample of the same cross-section is placed into one of the channels, a plunger then extrudes it into the second channel. Under these conditions, deformation is achieved by simple shear, and the strain imposed to the sample is determined by the intersection angle of the channels [2]. Deformed by ECAE, the sample retains its cross-sectional area so that it is able to repeat the process to many cycles. Therefore, very large plastic strain could be accumulated in the sample. Process route, i.e. strain path, can be varied by

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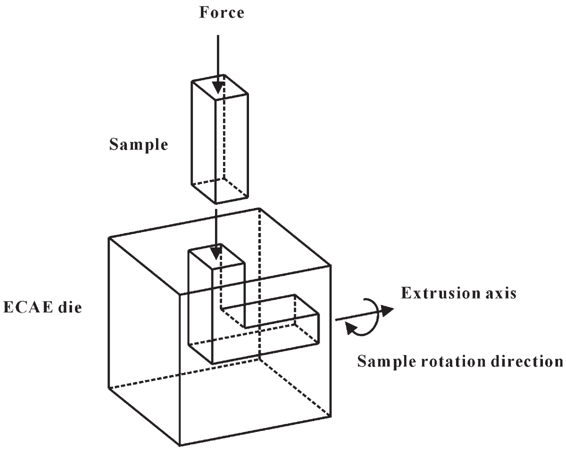

Fig. 1. Schematic configuration of ECAE die.

rotation of the sample between each extrusion pass. In order to produce ideal ultrafine-grained structure, i.e. equiaxed grains with high angle boundaries, processing parameters, like channel angle [3,4], process route [2,5–8], cumulative strain [5,7,9–10], strain rate [11,12], extrusion temperature [13,14], etc. need to be controlled properly.

Among the above mentioned parameters, perhaps extrusion temperature is the least understood processing parameter. Yamashita et al. [13], studied the effect of extrusion temperature on the deformation microstructures of pure Al, an Al–3% Mg alloy, and an Al–3% Mg–0.2% Sc alloy. The channel angle of their die was 90°, and the process route used was B_c [6] which means the samples were rotated 90° between each extrusion pass. They reported that, apart from Al–3% Mg–0.2% Sc alloy, grain (throughout this paper, the usage of grain means an area which is surrounded by low or high angle boundaries, or the mixture of both. Low and high angle boundaries can be grain boundaries, or dislocation walls.) sizes increased, and misorientations of the generated boundaries decreased with increasing extrusion temperature. As for Al–3% Mg–0.2% Sc alloy, due to the formation of coherent Al_3Sc particles, the grain size remained small and the boundary misroientations remained high up to the highest extrusion temperature, i.e. 300 °C. There is one problem in their experimental method for determining boundary misorientation. The way they used to characterize the misorientations of the generated boundaries was to judge the azimuth spread of selected area diffraction (SAD) patterns in transmission electron microscope (TEM). The larger the azimuth spread of the SAD pattern indicates the higher misorientation distribution of the boundaries within the selected area, provided that the number of grains in the selected area is about the same. To compare SAD patterns from different specimens obtained at different extrusion temperatures, Yamashita et al. used the same selected area of 12.3 μm diameter. However, since the grain size was larger at higher extrusion temperatures in their specimens, using the same selected area would select fewer grains at higher temperatures; this will certainly give less azimuth spread of SAD patterns. Their conclusion about the change of misorientation at high extrusion temperatures is, therefore, crude.

Bowen et al. [14] studied the deformation structure of Al–0.13% Mg at different extrusion temperatures. The die they used had 120° channel angle, and the process route was A, which means the samples did not rotate between each extrusion pass. Since their material was purer, the grain size obtained was larger; they were able to use electron backscatter diffraction (EBSD) in scanning electron microscope (SEM) to study the structure. They found the proportion of high angle boundaries remained higher than 60% in specimens extruded up to 200 °C. A boundary with disorientation higher than 15° was defined as a high angle boundary in their paper.

In ECAE, extruding at high temperatures is beneficial for materials which do not have good ductility, since intense shear strain occurs during each extrusion pass, which may cause cracking in these materials. Working at high temperatures will normally improve the workability of the materials, so that preventing the generation of shear cracks [15]. Extruding at high temperatures is also benefited from the lower strength of the materials, which makes extrusion easier. With the advantages mentioned, extrusion at elevated temperature should be explored more thoroughly. Unfortunately, the effect of raising extrusion temperature on the deformation microstructure is not clear yet.

The aim of the present research is to use TEM to characterize quantitatively the deformation