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MICROSTRUCTURE EVALUATION IN AN Al-Li ALLOY PROCESSED BY SEVERE PLASTIC DEFORMATION

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Abstract. Microstructure of Al – 1.6 wt.% Li alloy processed by two methods of severe plastic deformation was evaluated by light and transmission electron microscopy observations and quantitative image analysis. It was found that severe plastic deformation through both equal channel angular extrusion and hydrostatic extrusion results in ultrafine grained structure in Al – 1.6 wt.% Li alloy. The grain size decreases from about 300 μm in the initial state to 0.7 μm after ECAE process and 0.5 μm after hydrostatic extrusion. Severe plastic deformation leads also to gradual change of the grain shape. The grains are more elongated in the alloy subjected to ECAE process in comparison to that hydrostatically extruded.

1. INTRODUCTION

The high stiffness and low density of Al-Li alloy make them particularly interesting for aircraft applications. Their properties may be improved by grain refinement to nanometer scale. To this end various severe plastic deformation methods may be used. Structural changes in materials subjected to severe plastic deformation (SPD) and their effect on properties have been investigated for more than twenty years [1]. The most frequently used techniques, utilizing the effect of SPD on microstructure refinement, include: equal channel angular extrusion (ECAE), cyclic extrusion compression (CEC), high pressure torsion (HPT) or hydrostatic extrusion (HE). Among these methods, only ECAE and HE assure relatively large bulk samples.

Both of these procedures lead to refinement of the microstructure to the submicrometer or nanometer range [2-5]. The aluminium alloy after deformation by HE method shows increase in the yield stress from 340 MPa in the initial state to 515 MPa after the process [4]. During the ECAE process [5], microhardness of the Al-Li alloy increases two times. The microstructure (grain shape and size) of the materials produced via SPD methods strongly depends on the applied technological parameters and method. A. P. Zhilyaev *et al.* [6] examined the grain size in pure nickel after subjecting it to deformation by the HPT and ECAE methods. Both procedures lead to large refinement of microstructure: the average grain size after HPT was measured as ~ 0.17 μm, after ECAE - ~ 0.35 μm. Additionally mechanical properties (hardness, yield stress) changed very strongly as a function of induced deformation.

The main purpose of this work is to compare the microstructure evolution of the aluminium – lithium alloy subjected to severe plastic deformation via ECAE and HE.

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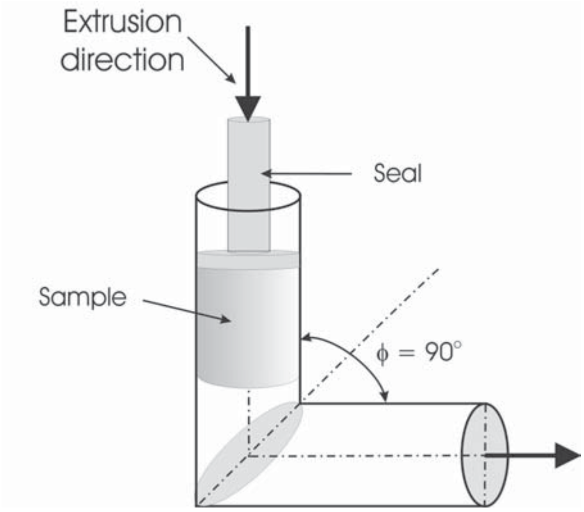

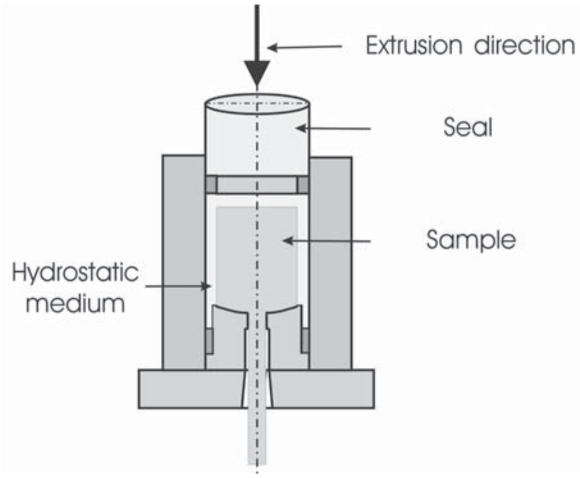

Fig. 1. Principles of ECAE (a) and HE (b) process.

2. EXPERIMENTAL PROCEDURE

The material used in this experiment was an aluminium alloy of the composition: Al – 1.6 wt.% Li. The material of starting diameter ∅ = 26 mm was subjected to plastic deformation up to:

- ε = 4.2 using the ECAE method and
- ε = 3.8 using the hydrostatic extrusion.

The principles of these methods are shown in Fig. 1. During ECAE process, a sample is pressed through a die containing two channels (circular in cross – section) intersecting at an angle of 90°. As a result of the pressing, the sample undergoes simple shear, but it retains the same cross section area. Thus, several cycles of pressing can be repeated. In the present experiment, the sample was subjected to four passes of ECAE. After each pass, the sample was rotated by 90° around its longitudinal axis. In HE method, a sample in the container is surrounded with the pressure medium. During extrusion the penetrating seal compresses the pressure medium until the sample starts to extrude. Due to negligibly small friction, high deformation homogeneity and very high strain rate are assured.

The microstructural evolution of the alloy was observed using transmission electron microscope and optical microscope with a polarized light beam. In both cases the observation was done on the plane perpendicular to the extrusion direction. The mean grain size (d_{eq}) and the grain elongation (a) were determined by a computer aided stereological analysis.

3. RESULTS

The microstructure of Al – 1.6 wt.% Li alloy in the initial state (Fig. 2a) consists of very large, equiaxed grains. Their mean equivalent diameter is about 300 μm. Large imposed strain leads to gradual change of the microstructure, as it is presented in Fig. 2b, c. On this figure, some differences between microstructures resulted from two methods of severe plastic deformation can be seen. After ECAE process, deformed and highly elongated grains are visible (Fig. 2b), whereas after HE the microstructure is equiaxed (Fig. 2c).

TEM images of the investigated alloy subjected to large plastic strains are shown in Fig. 3. These observations have revealed that, during ECAE process, the original grains are partitioned by extended boundaries (Fig. 3a). These boundaries separate the cell – blocks, which deform by different slip systems. They have been termed geometrically necessary boundaries (GNBs) [7] since they take account of the differences in lattice rotation between adjacent parts of the crystal. Dislocation cells within each cell – blocks are separated by incidental dislocation boundaries (IDBs). This subdivision of grains by well-defined dislocation boundaries leads to a refinement of the initial microstructure. In the investigated Al – 1.6 wt.% Li alloy, the microstructure after four passes of ECAE consists of elongated subgrains. Analysis of selected area electron diffraction (SAED) pattern indicates low misorientation

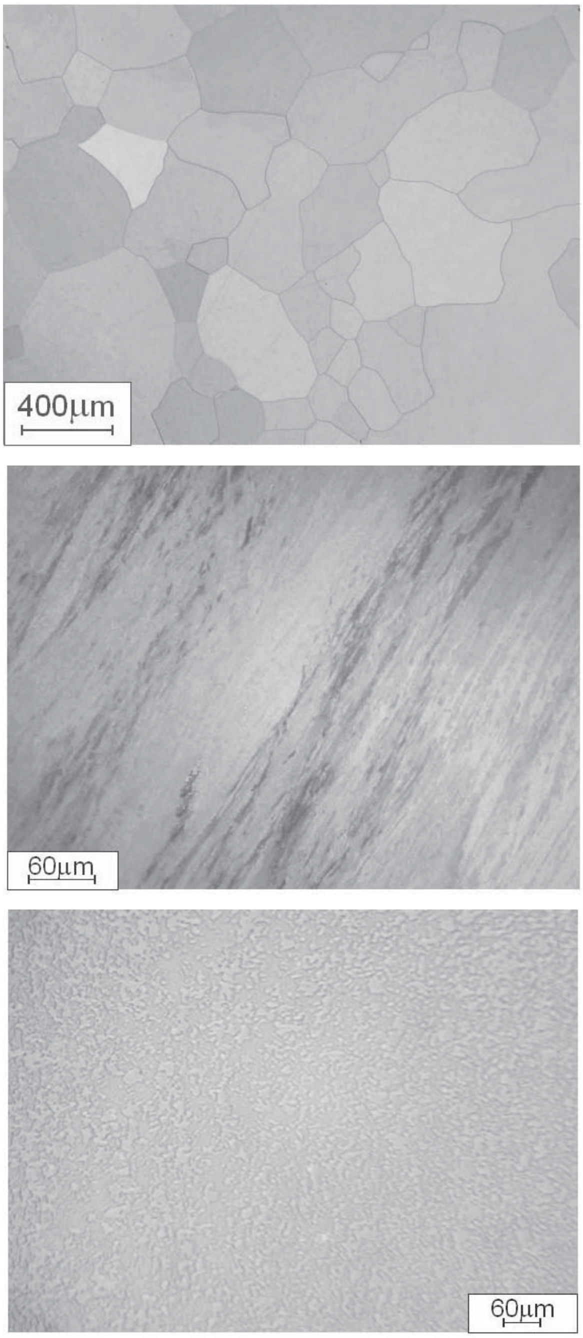

Fig. 2. Microstructure of Al – 1.6 wt.% alloy: initial state (a), after ECAE (b), after HE process (c) (light microscopy).

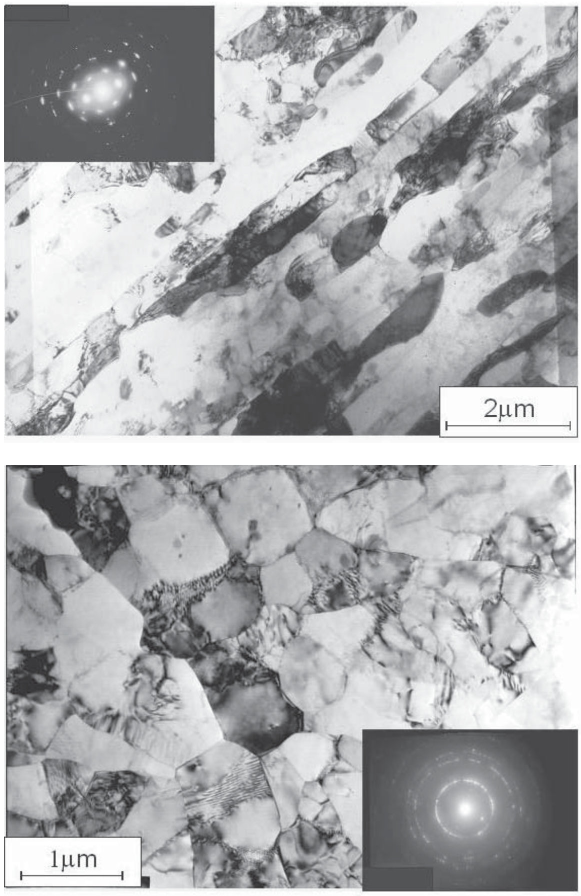

Fig. 3. TEM micrographs and diffraction patterns of the investigated alloy: after ECAE (a); after HE process (b).

angles between neighbouring subgrains (the diffraction spots are only slightly spreaded).

During HE, the stress state is more complex comparing to ECAE. The resulting microstructure consists of nearly equiaxed grains. Within these grains some dislocations are visible. The SAED pattern is different than in the case of ECAE process, the diffracted beams are scattered around rings. This kind of diffraction image indicates that the microstructure contains grains separated by high angle grain boundaries.

The microstructures of Al – 1.6 wt.% Li alloy processed by both ECAE and HE were evaluated quantitatively. The microstructural parameter, such as the grain equivalent diameter (d_{eq}) and grain elongation factor a (defined as d_{max} / d_{eq}) are presented in Fig. 4. It can been seen that severe plastic deformation through both ECAE and HE results in ultrafine grained structure in Al – 1.6 wt.% Li alloy. The mean equivalent diameter decreases from about 300 μm in the initial state to 0.7 μm after ECAE process and 0.5 μm after HE. This suggests that HE is more effective in terms of grain refinement process. Moreover, during severe plastic deformation, the shape of grains changes gradually from equiaxial in the initial state into slightly elongated after HE and much more elongated after ECAE. The

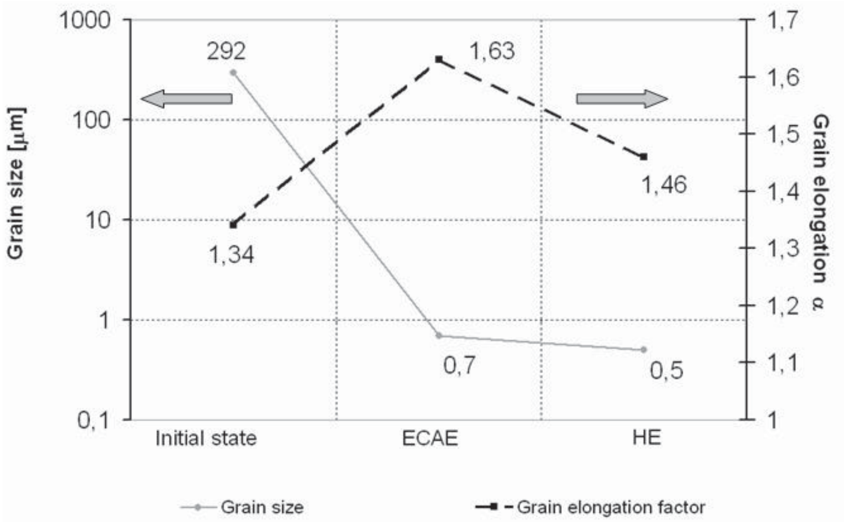

Fig. 4. Grain size and grain elongation factors for Al – 1.6wt. % Li alloy before and after SPD.

grain elongation factor increases from 1.34 to 1.63 after ECAE and 1.46 after HE.

Another parameter that describes the grain microstructure is the misorientation between the neighbouring grains. The information on the range of misorientations may be obtained from the spread of the diffraction spots in the SAED patterns. The comparison of the SAED images for two analysed SPD techniques indicates that the HE is more effective method in generation of high angle boundaries.

4. CONCLUSIONS

- Severe plastic deformation through both ECAE and HE results in ultrafine-grained structure in Al-1.6Li alloy;
- During ECAE process, the grain size has been reduced from 300 μm in the initial state to 0.7 μm after the true strain of ~4, whereas HE leads to the final grain size of 0.5 μm after the same deformation level;
- During severe plastic deformation the shape of grains changes gradually from equiaxial into elongated. The grain elongation factor is higher in the alloy subjected to ECAE in comparison to that hydrostatically extruded.

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