DIFFERENT CREEP BEHAVIOUR AND MICROSTRUCTURE OF ECAP ALUMINIUM WITH THE IDENTICAL ECAP HISTORY

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Abstract

Experiments were conducted on extremely coarse-grained Al (99.99%) to evaluate the effect of equal-channel angular pressing (ECAP) on microstructure changes and creep behaviour. ECAP was conducted at room temperature with a die that had an internal angle of 90° between the two parts of the channel. The subsequent extrusion passes were performed by route A (no rotation between subsequent passes) up to 2 ECAP passes. Creep tests in tension were performed on the as-pressed samples at 473 K and applied stress 15 MPa.

Microstructures of samples were examined by means of transmission electron microscope (TEM) and scanning electron microscope (SEM) equipped with an electron back-scatter diffraction (EBSD) unit. It was found that the ultrafine-grained Al specimens with the same ECAP history showed the scatter in the creep properties. The crystallographic orientation of grains and misorientation angles of its boundaries in structure were analyzed on the crept specimens to explain their different creep behaviour. In this work the microstructure changes within grains with different crystallographic orientations and near their high-angle boundaries of coarse-grained state in the sample after different ECAP passes were studied. Mutual comparison of the results of microstructural characterization of microstructure of as-received coarse-grained state and the state after different ECAP passes were performed. It is concluded that the scatter in creep properties could be influenced by inhomogeneity of ECAP microstructure.

1. INTRODUCTION

The methods of severe plastic deformation plastic deformation (SPD) change initial microstructure by fragmentation of original grains. The microstructures formed using SPD are ultrafine-grained structures containing mainly high-angle grain boundaries. During SPD the new grain boundaries are formed [1,2]. Many experiments were performed on polycrystals [3,4]. The sliding process in polycrystals is influenced by the presence of grain boundaries and crystallographic orientation of different grains. The investigation of deformed polycrystals need not always fully recognize the influences of different orientations of the grains and the original grain boundaries on the evolution of UFG structure. On the contrary, in single crystals the dislocation glide is not blocked by grain boundaries there is only one crystallographic orientation in the beginning. Single crystals subjected to SPD are materials where all grain boundaries are formed from only deformation at room temperature.

In this time only a few experiments concern the effect of initial structure on the evolution of ultrafine-grained structure [5,6]. The most of works have studied single crystals however only after 1 ECAP pass. However by using single crystals for severe plastic deformation it is not possible to describe the roles of the initial high-angle grain boundaries. In the report [7] the Cu bicrystals with different grain boundary angles with respect to the intersection plane were subjected to one ECAP pass. In was found that the bicrystals after 1 ECAP pass displayed quite different deformation behaviours due to their different initial GB directions and the specific crystallographic orientations of the two component grains.
The aim of this work is the study of microstructure heterogeneity creating during ECAP pressing and its influence on the creep behaviour.

2. EXPERIMENTAL MATERIAL AND PROCEDURES

The experimental material used in this investigation was an extremely coarse-grained Al 99.99%. The cast material had initial grain size ~ 5 mm. The initial cast ingot was cut into the billets with cross-sections of 10x10 mm$^2$. The ECAP pressing was conducted at room temperature using a die that had a 90° angle between the channels. The subsequent extrusion passes were performed by route A up to 2 passes. In the route A the sample is pressed repetitively without rotation. This route was used because the analysed places (HAB of original grains) are situated always in the shear plain and can be more easily identify. Microstructure was examined by scanning electron microscopy (JEOL 6460) equipped by electron back-scatter diffraction (EBSD) unit.

Constant load tensile creep tests of ECAPed samples were conducted at 473 K under constant applied stress 15 MPa on samples processed by route B. For comparison purposes, same creep tests were conducted on coarse-grained aluminium.

3. RESULTS

Microstructure after 1 ECAP pass

Fig. 1 shows the microstructure inside of the original grain situated of the upper part of the billet. The microstructure is heterogeneous. There are arias which contain small relatively equiaxed subgrains with the size between 2-4 µm. Nevertheless the most of the microstructure is created by large subgrains which are elongated in the pressing direction. In this place there were measured by EBSD ~ 3 % of HAGB.

Fig. 2 shows the microstructure near the original grain boundary parallel with the pressing direction which is situated near the lower part of the billet. The subgrains are particularly formed near the initial grain boundary and inside of the grains there are only a few small subgrains. In this place there were measured about 6.5 % of HAGB. These HAGB are composed by initial grain boundary and any new HAGB developed during ECAP were observed.
Microstructure after 2 ECAP passes

Fig. 3, 4 show the microstructure situated near the initial grain boundary in the upper part of the billet. The substructure is more or less equiaxed with the subgrain size ~ 3.5 µm but there can be still observed the heterogeneity in substructure (Fig. 3). In the microstructure there was measured ~ 25 % of HAGB. However from Fig. 4 is seen that lower original grain contains the most of HAGB in comparison with the upper grain. Fig. 5 shows inverse pole figure of analyzed microstructure. The upper grain is oriented near pole [101] and lower grain near [001].

The microstructure situated near the initial grain boundary in the lower side of the billet is not homogeneous (Fig. 6). The microstructure can be divided into two parts. The microstructure in the upper part of the Fig. 6 contains subgrains with the mean size of ~ 7.5 µm and microstructure in lower part contains only several subgrains. The HAGB are particularly formed near the boundary of original grain (Fig. 7). The upper initial large grain in the Fig. 7 is oriented near pole [133] and lower initial grain is scattered near pole [115] (Fig. 8).
Creep behaviour

Fig. 9 shows the dependence of time to fracture on the number of ECAP passes. The creep resistance of pure aluminium at 473 K is considerably improved after one ECAP pass in comparison with coarse grained material, however, repetitive pressing leads to a noticeable decrease in the creep properties of the ECAP material. Nevertheless, the creep resistances of ECAPed pure Al was higher even after 12 ECAP passes.

The creep tests show that samples with the same ECAP history processed exhibited the high scatter of creep behaviour.

4. DISCUSSION

It is generally know that the sufficient deformation and elevated temperature lead to the evolution of the new grains. This process is called recrystallization. ECAP can be reduced the new grains only by deformation at
room temperature. Nevertheless the deformation is not always absolutely homogeneous and the heterogeneous structure can be expected also after ECAP.

The extremely coarse-grained Al processed by ECAP exhibited heterogeneity of microstructure. It was found that heterogeneity of microstructure depends on the position of the place in the cross section of the billet. It was observed that in the upper part of the billet the formation of the ECAP microstructure is faster in comparison with the lower part of the billet. The heterogeneity of microstructure is probably influenced by presence an outer arc of curvature and by the frictional effects in the vicinity of the lower die wall. Several works [8,9] found that the presence of an arc of curvature leads to the development of shear zone so that the strain is distributed inhomogenous in cross section of the specimen. However the formation of microstructure in aluminium was influenced also by orientation of the original grains and the presence of the original grain boundary. It was observed that the new ECAP grains are formed easily near the original grain boundary and the interior of the original grains oriented near pole [001] that in other orientations. Miyamoto et al. [6] processed a series of Cu single crystals by 1 ECAP pass. They found that the end orientation, macroscopic heterogeneity and dislocation structures of studied single crystals can be divided into three groups. Their results suggested that the evolution of microstructure relates to the degree of concentration of activated slip systems with respect to the shear plane.

Creep behaviour probably belongs to the fewest examined properties of the ECAPed materials. Our previous experiments [10,11] found that ECAP improves creep resistance of the pure metals (Cu, Al) in comparison to initial material. The samples processed by route B_c exhibited different creep behaviour after the same number of ECAP passes. Sklenicka et al. [12] observed that the processing route had a little apparent effect on the creep behaviour of ECAPed aluminium. On the basis of this result the scatter of creep properties can be also expected at creep tests of samples processed by route A or route C. The microstructure results in this work suggest that the scatter of creep properties of extremely coarse-grained Al after 1-12 ECAP passes can be probably caused by inhomogeneity of the microstructure created during ECAP.

CONCLUSIONS

The orientation of original grains and the presence of initial high-angle grain boundaries in the extremely coarse-grained Al influence the evolution of microstructure during ECAP.

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LITERATURE


