The effect of a new route on the microstructure and property of 6063 alloy during the ECAP deformation

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Abstract. The microstructures and hardness of 6063 Al alloy subjected to different ECAP route (Bc and the new route) were investigated. These two routes have different rotation scheme of a sample around its long axis between two consecutive ECAP passes: Bc route, by which sample were rotated in the same direction by 90°; the new route, by which sample were rotated in the same direction by 135°. The feature microstructures of the samples subjected to the two routes were investigated by the optical microscopy (OM) and transition electron microscopy (TEM), respectively. In comparison, the pressing by the new route produces more homogeneous microstructure with the higher fraction of high angle boundaries. Furthermore, the hardness results showed that work hardening can be observed and do not depend much on the ECAP route. However, distribution of hardness in cross-sections of samples revealed that processing to total passes number of eight by the new route improves deformation uniformity.

1. Introduction

Equal Channel Angular Pressing (ECAP) is one promising method of Severe Plastic Deformation technique for producing ultra-fine-grained microstructure in metals or alloy[1]. The workpiece can obtain larger plastic deformation and in turn microstructure changes as pressed through the ECAP die consisting of two channels. Due to the channels equal in cross section, the workpiece can be repeatedly processed through the channels. As the workpiece can be rotated around its axis between consecutively pressing, namely, four basic ECAP routes have been developed, such as Bc, A, BA, and C. It can change the shear plane or shear sequence during a series of pressing deformation. To date, many experimental studies have focused on the evolution of microstructure and mechanical properties changes after the martials subjected to ECAP deformation by different routes[2]. The route Bc has been accepted as a better route for producing grain refinement[3]. Nevertheless, the heterogeneity of structure can restrict the ECPAed production available to application[1,4,5]. Previous studies have illustrated that the degree of strain uniformity can be improved by employing back pressure on workpiece in the ECAP processing[1,4], by performing the combined metal forming techniques[5] or choosing the advisable strain route[6]. W.J.Kim and J.C. Namkung[6] had surveyed that effect of ECAP route on the strain uniformity and indicated that route Bc and route C have better effect on the strain uniformity, whereas the route BA and route A produce the lowest strain uniformity.

In this study, it was attempted to alleviate the heterogeneity of the ECPAed 6063 alloy through designing the new route. The effects of the new route and route Bc on the structures and property were investigated.
2. Experimental procedures
The composition in wt.% of the 6063 alloy is Al-0.52Mg-0.49Si-0.09Fe-0.01Ti. Rods 70 mm in long and 15 mm in diameter were machined from the ingot. Prior to ECAP, the rods were annealed at 560 °C for 1 hour followed by quenching in chilled water. The samples were pressed through a ECAP die with an inner corner angle of 90° at room temperature up to eight passes by the new route and Bc route, respectively. The shear strain per pass can be calculated by Segal’s original relationship[1,7] to be 1.05.

The microstructures of annealed and deformed samples were observed by using a polarized light microscope and transmission electron microscopy. These samples were extracted from central regions of the rods, and the structures were observed in the plane lying perpendicular to the pressing direction. The samples were ground and polished following a standard procedure and were etched with solution of 5gHFB acid per 200ml H2O and examined using a polarized light microscope. For the observation of TEM, discs with a thickness about 100 μm were thinned by twin-jet electropolishing unit using a solution of 30 % nitric acid and 70 % methanol at -30 ℃ and 25 V. Vickers hardness tests were conducted with a TUK1102 microhardness tester at a load of 100gf and dwell time of 10s.

3. Experiment results and discussion
Figure 1 shows microstructures for samples after solution treatment and after one-pass ECAP processing at RT. It is apparent in Fig. 1a that the microstructure of as-annealed sample is equiaxed and average grain size is 177 μm. After one pass, the original coarse grains were pronouncedly elongated, as shown in Fig. 1b, and these original coarse grains are still realized. In addition, there is evidence for the formation of deformation bands in some grains. The development of deformed microstructures after further ECAP processing by the new route and route Bc are illustrated in Figure 2. As shown in Fig. 2a and b, after two passes, the original grains are broken-up and nearly don’t be realized. The shear bands appeared in these samples, which associated with the strain gradients introduced by ECAP-induced heterogeneous strain[8]. As the number of passes increases, the strength and frequency of formation of shear bands increase. After four passes, the intersection between high density of shear bands and deformation bands occurred in the samples processed by new route and Bc route. However, processing by the new route led to more homogeneous microstructure than the counterpart of Bc route.

![Fig.1 Microstructures of as-annealed sample and ECAPed after one pass](image-url)
The TEM micrograph associated with SAED pattern of the sample pressed after only one pass was shown in Fig. 3. After further passes, the TEM micrographs and according SAED patterns were shown in Fig. 4. After one pass, there is evidence of parallel-banded substructure formation with the width in the range from 0.26 μm to 1.2 μm. After four passes, the (sub)grain size of samples processed by these two routes is similar about 0.28±0.08 μm. Ultimately, after 8 passes, the microstructure of sample pressed by the new route exhibits the more equiaxed grains with the average size of 0.25±0.06μm (Fig. 4c). The microstructure of sample pressed by Bc route is characterized with the mixture of coarse grains (up to 0.6 μm in width) and fine grains (about 0.11 μm in width). Although there is the same tendency in grain refinement for both routes with increasing pass numbers, the fraction of high angle misorientation of the new route is seemingly higher than counterparts of route Bc based on the more diffused rings of SAED patterns.
Fig. 4 TEM images of samples processed by the new route after (a) four passes, and (c) eight passes, and by Bc route after (b) four passes, and (d) eight passes.

The average microhardness data in the cross-section as a function of the number of passes by the two routes were presented in Fig. 5a, and standard deviations were also shown in Fig. 5b. In Fig. 5a, the similar tendency of hardness for the two routes was observed with the increasing of passes. It suggests that the work hardening of samples processed by ECAP do not depend much on the route during consecutive ECAP passes. However, after high number of passes, the magnitudes of the standard deviations of microhardness for the new route are smaller as compared with counterparts for the Bc route.

Figure 6 shows that contour map of hardness distribution of eight-pass samples processed by the two routes. The normalized hardness in the Fig. 6 is calculated through the relationship:

$$HV_{nor} = \frac{HV - HV_{min}}{HV_{max} - HV_{min}}$$

where $HV_{nor}$ is the normalized hardness, $HV$ measurement value, and $HV_{min}$ and $HV_{max}$ are the minimum and maximum of measurements, respectively. The distribution of normalized hardness in Fig. 6 shows that eight-pass ECAP by new route led to more homogeneous distribution of hardness.
Fig. 6 Normalization of hardness for the eight-pass samples through (a) new route and (b) Bc route.

4. Conclusion
The strain path can affect both the microstructure and its homogeneity. The ECAP processing by the new route produce a more homogeneous UFG microstructure with the higher fraction of high angle boundaries. The two routes led to a similar work-hardening effect as increasing number of passes, but the new route make deformation more homogeneous after eight passes.

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