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Three-dimensional microstructural analysis of fragmentation behavior of platelet Al_3Ti particles in Al-Al_3Ti composite deformed by equal-channel angular pressing

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ABSTRACT

The fragmentation of platelet Al_3Ti particles in an Al-Al_3Ti composite by equal-channel angular pressing (ECAP) is investigated using three-dimensional (3D) microstructural evaluation and crystallography. The Al-Al_3Ti composite comprises coarse platelet Al_3Ti particles in an α-Al matrix. The ECAP of this composite is performed for up to 4 passes under processing routes A, B_c, and C. Route B_c produces the smallest Al_3Ti particle fragments in comparison with the fragments produced under routes A and C. This is because that route B_c produces the largest number of shearing directions and shearing planes. Platelet Al_3Ti particle fragments in the specimen deformed by ECAP under route A are homogeneously distributed along the deformation axis. In contrast, in the specimens deformed by four ECAP passes under routes B_c and C, the Al_3Ti particle fragments are gathered into several groups. The fragment groups have a length similar to the initial length of the platelet Al_3Ti particles. These spatial distributions of particle fragments can be explained by material flow of α-Al matrix during ECAP. Moreover, from 3D microstructural evaluation and crystallographic analysis of the Al_3Ti particle fragments, it is found that the Al_3Ti particles are preferentially fragmented on the twin boundary plane of $\{112\}_{Al3Ti}$. Therefore, it is concluded that fragmentation of a platelet Al_3Ti particle by ECAP occurs along the twin boundary plane after twin deformation.

1. Introduction

When a metal-based composite containing solid particles is subjected to severe plastic deformation (SPD) processing, such as equal-channel-angular pressing (ECAP) [1–14], high-pressure torsion (HPT) [15–19], or accumulative roll bonding (ARB) [20–22], the particle distribution in the composite changes drastically [4–23]. This is because the matrix around the particles in the composite is severely deformed during SPD. It is well known that the Young's modulus of the metal-based composite containing large solid particles follows mixture law. On the other hand, if the metal-based composite contains small solid particles, its yield stress follows Orowan mechanism. Therefore, precious evaluations for the size, the shape and the spatial distribution of the particles in the deformed composites are important.

Although changes to the particle distribution in metal-based composites during plastic deformation have been reported previously [4–24], the number of reports concerning SPD of composites is limited [23]. Tan and Zhang investigated the effects of secondary deformation processing, such as rolling or extrusion, on the particle distribution of an 8090 Al alloy (Al-2.54%Li-1.49%Cu-0.91%Mg-0.13%Zr) composite containing granular SiC particles [24]. According to their study [24], the secondary deformation processing can improve the homogeneity of the granular SiC distribution in the 8090 Al alloy composite. In addition, they suggested that the size of the SiC particles in the composite must be larger than a critical size for homogeneous distribution. Sabirov et al. performed ECAP on a 6061 Al alloy composite containing granular Al_2O_3 particle clusters, and they discussed the resulting distribution behavior of the granular Al_2O_3 particles [7]. As a result, they concluded that applying ECAP to the 6061 Al alloy composite leads to increase in the homogeneity of the granular Al_2O_3 particles in the alloy matrix. On the other hand, Han et al. investigated particle distribution in Ti-based composite containing both TiB and TiC particles deformed by ECAP [12]. In their study, they found that the homogeneity of TiB and TiC particles in the composite is increased by ECAP. Furthermore, it has been reported that ECAP for Al alloy-based composite with 6061 matrix and graphite particles improves homogeneity of the graphite

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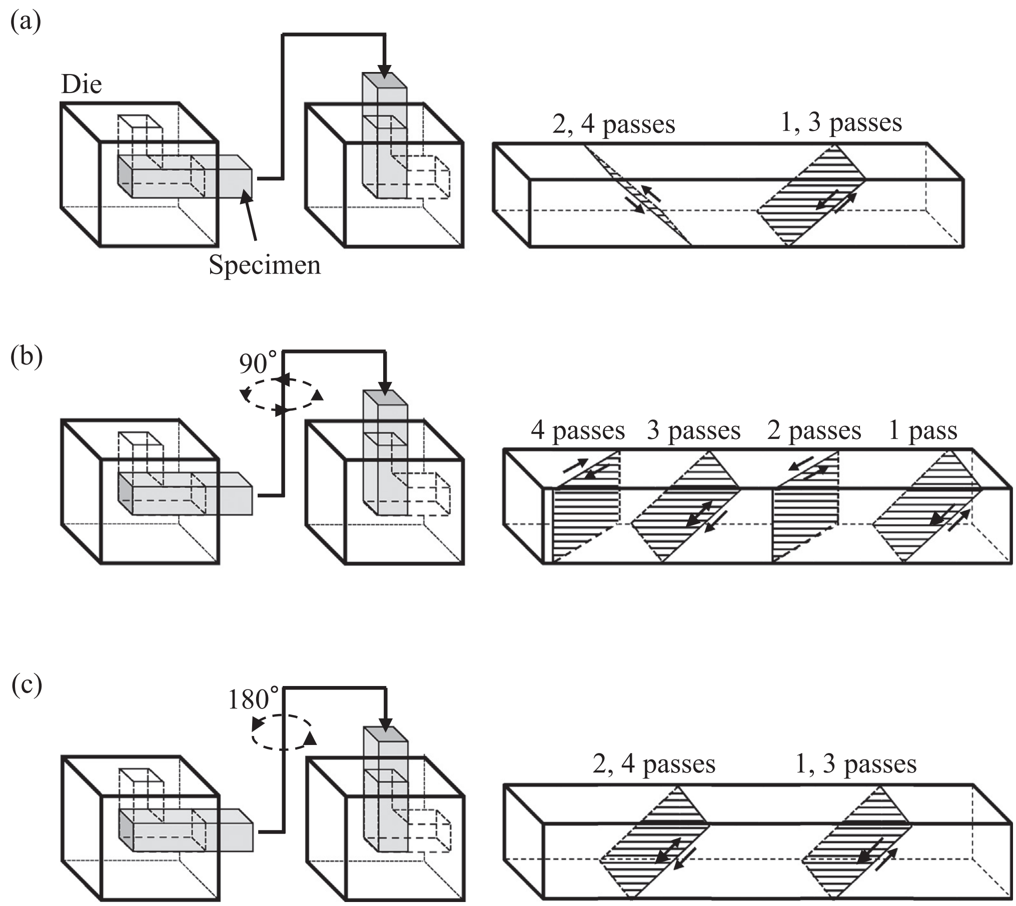

Fig. 1. Schematic illustrations of processing route (left) and shearing patterns (right) of ECAP routes (a) A, (b) B_c, and (c) C. In shearing patterns, hatched planes and arrows present slip planes and slip directions, respectively.

particles [14]. Similar results were reported for other metal-based composites deformed by ECAP [5,11,13], HPT [15,16,18,19], and ARB [20–22]. Thus, it is known that plastic deformation of a metal-based composite can improve the homogeneity of solid particles within the composite.

However, these current investigations focused on metal-based composites containing only granular particles. When a composite containing platelet-shaped particles is severely deformed, the distribution behavior of the platelet particles due to SPD is different from that of granular particles. In our previous studies [9,10], we investigated the effects of two ECAP processing routes on the distribution of platelet Al_3Ti particles in an Al-Al_3Ti composite by two-dimensional (2D) and three-dimensional (3D) microstructural observations. In those studies, the Al-Al_3Ti composites were deformed by ECAP under routes A and B_c. Fig. 1(a), (b), and (c) show the processing routes and shearing patterns for routes A, B_c, and C, respectively [1–3]. In route A, the specimen is pressed repetitively without rotation, which can give shear deformation from two directions. In contrast, route B_c is done by rotating the specimen 90° in the same direction, which imposes a homogeneous strain through 4 passes. In the previous studies [8–10], the platelet Al_3Ti particles were severely fragmented by ECAP. Moreover, when ECAP was performed on the Al-Al_3Ti composite for up to 4 passes under route A, the fragmented Al_3Ti particles became aligned along the deformation axis. In contrast, when ECAP was performed on the Al-Al_3Ti composite with 4 passes of ECAP under route B_c, the fragmented Al_3Ti particles gathered into randomly distributed groups. Thus, the application of ECAP to the Al-Al_3Ti composite containing platelet Al_3Ti particles did not improve the homogeneity of the Al_3Ti particles. Clearly, ECAP has different effects on the distribution of granular and platelet particles.

Although the spatial distribution of Al_3Ti particle fragments in the Al-Al_3Ti composites deformed with ECAP was reported in our previous study [9,10], the mechanism of the distribution of the Al_3Ti particle fragments is not clear. Also, the fragmentation mechanism of an Al_3Ti particle during ECAP is unclear because no quantitative analysis for the Al_3Ti particle fragments in the deformed Al-Al_3Ti composite was performed. To make these mechanisms clear, quantitative evaluations of the size, the volume, and the crystal orientation of the fragmented Al_3Ti particles by a combination of 3D observations by serial sectioning and crystallographic analyses by electron backscattered diffraction (EBSD) are necessary.

In this study, the distributions of the platelet Al_3Ti particles in Al-Al_3Ti composites deformed by ECAP are investigated using both 3D microstructural observation and crystallographic analysis. Based on the obtained results, the distribution and fragmentation mechanisms of the platelet Al_3Ti particles in the Al-Al_3Ti composites deformed by ECAP are discussed.

2. Experimental Procedure

2.1. Specimen Preparation

Specimens for ECAP were fabricated from a commercial Al-5mass%Ti alloy ingot. This alloy contains platelet Al_3Ti particles with volume fraction of 11% in an α-Al matrix. The Al-5mass%Ti alloy ingot was melted at 800 °C and then poured into a mold with an inner diameter of 15 mm and depth of 180 mm. Final sizing of the cast Al-5mass%Ti alloy specimens (hereafter, Al-Al_3Ti specimens) was done by a machine lathe. The final specimen size was 10 mm in diameter and 60 mm in length.