Discontinuous Dynamic Recrystallization during Accumulative Back Extrusion of a Magnesium Alloy

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Abstract

The study of nucleation mechanism of new grains during severe plastic deformation of magnesium alloys is of great importance to control the characteristics of final microstructures. To investigate the role of discontinuous recrystallization, a wrought AZ31 magnesium alloy was deformed by accumulative back extrusion process at 330 °C. The obtained microstructures were studied using optical and field emission microscopy as well as electron back scattered diffraction techniques. The results demonstrated that the fine and ultrafine grains formed along the prior grain boundaries yielding a bimodal structure. The EBSD analysis showed that the new grains exhibit a similar basal texture to deformed grains, which may confirm the operation of strain induced boundary migration mechanism.

Keywords: Microstructure; DRX; ABE; EBSD

1. Introduction

The development of magnesium alloys with ultrafine-grained structure is attracting much practical interest. This is explained by the fact that considerable lowering of the grain size counteracts the limited formability of these alloys at low temperatures. The latter may assist in exploiting the benefits of high specific strength of magnesium alloys [1]. A preferred method for obtaining submicrocrystalline structure in magnesium alloys is a process employing high degrees of deformation without changing the total size of the specimens i.e. severe plastic deformation (SPD) [2-4, 3, 4]. Because of quite poor workability of magnesium alloy, hot working is often used to deform magnesium alloys. Grain refinement during hot deformation is resulted by dynamic recrystallization [5, 6, 7].

To understand dynamic recrystallization (DRX) and to compromise the grain size distribution of final microstructure, it is necessary to study the grain refinement mechanisms contribute during SPD processing of magnesium alloys. While it is generally accepted that the grain refinement mechanism involves the combination of mechanical shear, accumulation of strain and/or dynamic recrystallization during SPD, it remains arguable and unclear, given that the existing models may not be directly applicable in magnesium alloys in all of the processes. Quite rare research dealt with the fundamental of grain refinement in magnesium alloys during SPD processes [8-11].

The results reported by Su et al. [9] showed that the grain refinement mechanism for Mg during equal channel angular pressing (ECAP) is by a combination of mechanical shearing and subsequent continuous recovery, recrystallization and growth of grains and subgrain cells to produce refined and equiaxed grains within one ECAP pass. A main characteristic of grain refinement during multiple forging (MF) of a magnesium alloy was reported to be directly associated with grain splitting due to the formation of microbands that develop in various directions [11]. Such microbands intersect each other during hot MF, resulting in continuous subdivision of coarse grains into misoriented fine domains. Further deformation leads to increase in the number and misorientation of these boundaries and finally almost full development of fine equiaxed grains in high strain. However, Figueiredo and Langdon [8] believed that the nature of grain refinement in magnesium alloys is dependent upon the initial grain structure prior to ECAP. They proposed a model for DRX in magnesium alloy during ECAP which is based on the

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principles of dynamic recrystallization in which necklace-like distributions of fine grains are nucleated along the grain boundaries and along twin boundaries. However, fundamental study of grain refinement mechanism of the SPD processes still remains to be investigated.

Grain boundary bulging and subsequent discontinuous DRX has often been found to be an important nucleation mechanism in magnesium alloys during conventional deformation5. This research was initiated to investigate the possible role of discontinuous DRX during severe deformation of AZ31 magnesium alloy. This was conducted by applying accumulative back extrusion (ABE) at 330 °C. Moreover, the orientation relationship between DRX grain and parent grains was explored using EBSD analysis.

2. Experimental

The experimental alloy used in this work was a hot- rolled plate, 22 mm in thickness with a nominal composition of Mg–2.9%Al–0.85%Zn-0.7%Mn (wt.%). Cylindrical specimens for ABE processing were machined with the dimensions of H8×Φ18 mm2, the deformation axis of which was selected to be parallel to the initial rolling. Our earlier reports provided detailed experimental information on the processing of the AZ31 alloy by ABE12. Briefly speaking, the first step of ABE consists of the back extrusion of work piece into the gap between the inner punch and the die. In the second step the back extruded material is forged back to the initial cross section by the outer punch. ABE process was conducted at a ram speed of 10 mm/min and temperature of 330 °C. The as-processed work pieces were then sectioned along the extrusion direction and mechanically ground with SiC papers of grit sizes down to 4000. Polishing was done by colloidal silica slurry containing particles of 0.05 µm. Then for optical the specimens were etched with a solution composed of 4 gr picric acid, 10 ml water, 10 ml acetic acid and 70 ml ethanol for about 3s. The microstructures of the as-received and deformed specimens were studied by the use of optical microscopy and scanning electron microscopy (Zeiss Ultra Plus microscope operated at 5 kV). Information about grain orientation and texture was obtained by use of the electron backscattered diffraction (EBSD) technique. Recrystallized and unrecrystallized grains were differentiated on the basis of grain size and morphology.

3. Result and Discussion

The initial structure exhibited an average grain size of 25 µm. Microstructural observation after middle stage of ABE processing showed that preferential nucleation along prior grain boundaries. As depicted in Fig. 1, the grain size distribution is bimodal including large areas of new fine grains coexisting with discrete and well-defined large grains that appear to correspond to the inner core areas of some of the larger initial grains. Based on FESEM results (Fig. 2), it was demonstrated that the new grains contain fine and ultra-fine grains ranging from 0.4 to 1.5 µm.

Grain refinement in magnesium alloys is reported to be characterized by the nucleation of fine grains along the pre-existing grain boundaries. This is attributed to the development of stress concentrations at the boundaries and the subsequent activation of both basal and non-basal slip processes [6]. The latter is consistent with the conclusion that the production of homogeneous three dimensional microstructures in magnesium alloys requires the activation of both non-

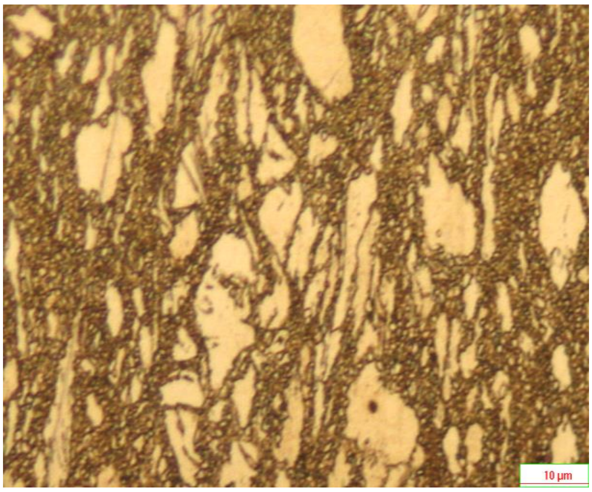

Fig. 1. Optical microstructure showing bimodal grain distribution obtained after middle stage of ABE.

basal and basal slip and with experimental observations showing that non-basal slip is activated more easily in the interiors of the grains of magnesium alloys when the grain size is reduced [12]. The driving force for nucleation on grain boundaries is usually presumed to arise from a difference in dislocation content on opposite sides of the grain boundary. This could result directly from the deformation process, because it is known that the dislocation storage rate may be dependent on grain orientation and also could be different in the boundary regions. The latter may be promoted in magnesium, due to their inherent anisotropy in activation of slip systems. New grains originate at theold grain boundaries, but, as the material continue to deform, the dislocation density of the new grains increases, thus reducing the driving force for further growth, and the recrystallizing grains eventually cease to grow. This type of dynamic recrystallization, which possesses clear nucleation and growth stages, can be classified as a discontinuous process.

The mechanical properties of final product in processing of magnesium alloy are usually dictated by size distribution as well as texture of recrystallized grains [13, 14]. The magnitude of the final grain size can be rationalized in terms of the effects of the various parameters on the nucleation and growth processes. Any factor such as a high

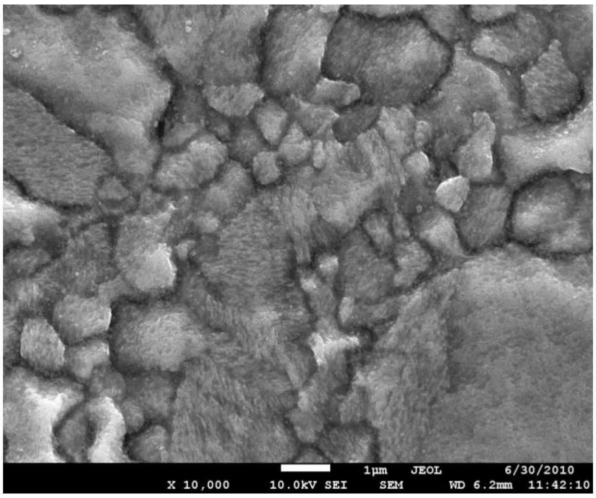

Fig. 2. SEM micrograph showing recrystallized grain along prior grain boundaries during ABE.

strain or a small initial grain size, which favors a large number of nuclei or a rapid nucleation rate, will lead to a small final grainsize [16]. However, quite rare studies may be found in the literature dealing with the texture of DRX grain in magnesium during SPD processing.

To analyze the relation between recrystallization texture of discontinuously DRXed grain and the initial deformation texture EBSD maps were provided of deformed AZ31 alloy (Fig. 3.a). The maps of DRX grains and parent grains were isolated (Fig. 3.b and c) and related pole figures were obtained separately (Fig. 3.d and e). The deformed parent grains exhibit a basal texture where the c-axis aligned perpendicular to ED-TD plane and axisymmetric distribution of prismatic and pyramidal planes was seen. As can be obviously realized from Fig. 3, the discontinuously DRXed grains follows the same orientation to the old grains from which they have grown. This close relationship was considered by Humphrey [15] as a characteristic feature of strain induced grain boundary migration (SIBM) mechanism. Thus, one may infer that the new grains observed along grain boundaries were nucleated through SIBM.

Recrystallization shares several common characteristics as phase transformation in that the replacement of deformed materials by the nucleation and growth of recrystallized grains, both can lead to a drastic changes in texture18. It is sometimes observed that recrystallization texture components bear crystallographic relationships to the original deformation textures, which may be described by rotations about simple crystal directions. For example, the results obtained by Ion et. al. [7] showed a progressive rotation of the basal planes in the mantle regions near old grain boundaries. This was discussed relying on the occurrence of rotation recrystallization mechanism along grain boundaries. However, it was reported that the texture of the grains that form in Mg-Mn alloy via particle stimulated nucleation (PSN) appears to be random [16].

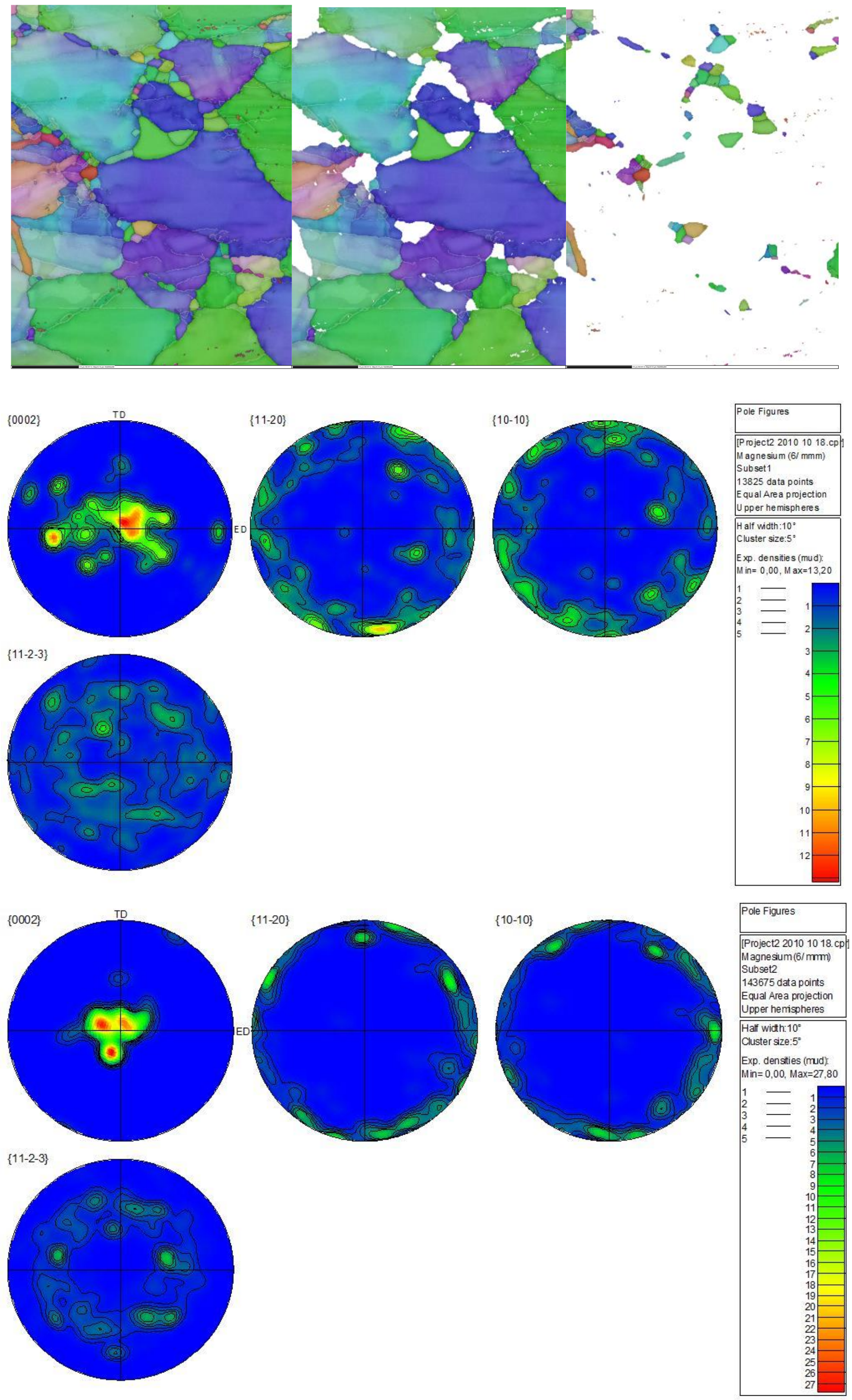

Fig. 3. (a) EBSD image showing the microstructure of AZ31 alloy ABEed at 330 °C, EBSD map with b) excluded parent grains, c) excluded recrystallized grains, d) pole figures of DRX grains, e) pole figures of parent grains.

4. Conclusions

AZ31 magnesium alloy was deformed by accumulative back extrusion technique at 330 °C. Nucleation of fine and ultra-fine grains was realized along prior boundaries during ABE processing. EBSD analysis implied that the new grains may be formed via strain induced grain boundary migration, the texture of which was found to be similar to that of deformed parent grains.

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