Microstructure and texture characteristics of ZK60 Mg alloy processed by cyclic extrusion and compression

LIN Jin-bao[1,2], WANG Qu-dong[1], CHEN Yong-jun[3], LIU Man-ping[1], Hans J. Roven[3]

1. National Engineering Research Center for Light Alloy Net Forming and State Key Laboratory of Metal Matrix Composites, Shanghai Jiao Tong University, Shanghai 200240, China
2. School of Applied Science, Taiyuan University of Science and Technology, Taiyuan 030024, China
3. Department of Materials Science and Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway

Abstract: The microstructure and crystallographic texture characteristics of an extruded ZK60 Mg alloy subjected to cyclic extrusion and compression (CEC) up to 8 passes at 503K were investigated. The local crystallographic texture, grain size and distribution, and grain boundary character distributions were analyzed using high-resolution electron backscatter diffraction (EBSD). The results indicate that the microstructure was refined significantly by the CEC processing and the distributions of grain size tend to be more uniform with the increasing of CEC pass number. The fraction of low angle grain boundaries (LAGBs) decreased after CEC deformation, and a high fraction of high angle grain boundaries (HAGBs) (95%) was revealed after 8 passes of CEC. Moreover, the initial fiber texture became random during CEC processing and developed a new texture.
Key words: Cyclic extrusion and compression (CEC); EBSD; ZK60; Microstructure; Texture.

1 Introduction

Magnesium alloys have attracted considerable interest from the automobile industry because of their low density and high specific strength. Nevertheless, to be used for structural components in automobiles, the material should exhibit sufficient ductility as well as an attractive specific strength since components may fail by fracture due to shear or tensile forces [1-3]. Thus, the relatively low strength and ductility of Mg alloys due to the hexagonal close packed (HCP) structure with limited slip systems is a major difficulty that must be overcomed to enable their widespread application [1].

In recent years, it has been demonstrated that the plastic deformation of Mg alloys is strongly influenced by their texture as well as their grain size. The ductility of Mg alloys may be significantly enhanced by texture control and grain refinement through severe plastic deformation (SPD) such as equal channel angular pressing (ECAP) [2], cyclic extrusion and compression (CEC) [1, 3-7] and accumulative roll bonding (ARB). As a kind of continuous SPD processing, CEC seems to be more adaptable for industrial applications. Moreover, it is very suitable for refining grains of hard-to-deform metals such as Mg alloys since it imposes three-dimensional compression stresses during processing [1, 3, 8, 9].

Our previous results demonstrated that the tensile ductility of ZK60 alloy increased with the increase of the CEC accumulated strain. However the strength shows the opposite trend notwithstanding the grain size is reduced [1, 3], i.e. exhibiting a reverse or inverse Hall-Petch Relation. Similar results in CEC AZ31 alloy [9] and ECAP AZ31 alloy [2] were also reported. Its underlying mechanism is complicate and maybe relevant to grain boundary sliding, texture

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Corresponding author: WANG Qu-dong; Tel: +86-21-54742715; E-mail: wangqudong@sjtu.edu.cn

evolution, grain refinement, twinning, dislocation density, and so on. Much more research is needed to investigate the microstructure characteristics of SPD processed metal materials to revealing the relationship between microstructure and mechanical properties. Therefore, the aim of the present study is to investigate the microstructure and crystallographic texture characteristics of an extruded ZK60 alloy subjected to CEC processing using high-resolution EBSD.

2 Experimental procedures

The alloy used in the present study was a commercial ZK60 alloy. It was received in the form of an extruded bar with a diameter of 29.5 mm and then cut into pieces of length 42 mm before CEC processing. The CEC processing was carried out by pushing a billet from one cylindrical chamber having the diameter *D* to another chamber with equal dimensions. The inter-chamber can be considered as an extrusion die having a smaller diameter *d,* as illustrated in Fig. 1 [1]. The die was lubricated using graphite and preheated to 503K before processing. During the final extrusion pass, the opposite ram was removed in order to release the rod. The ram speed was 8 mm/s. All specimens were quenched in water immediately after deformation. In the present study *d* and *D* are 20 mm and 30 mm, respectively.

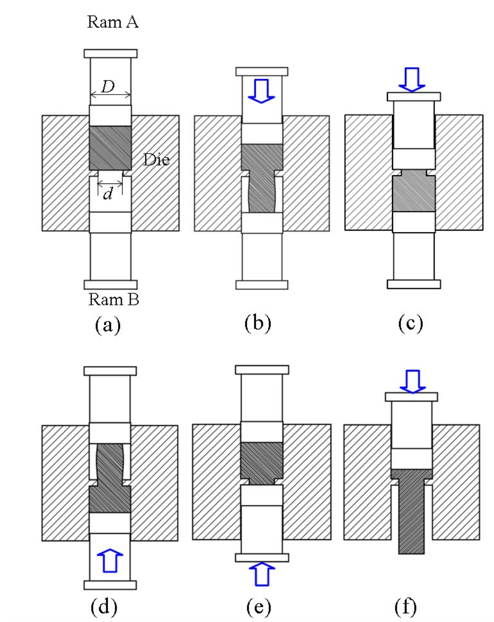

Fig.1 Schematic illustration of the CEC facility and procedure: (a) initial state, (b) extruding by Ram A, (c) end of Ram A involvement, (d) reverse extruding employing Ram B, (e) end of Ram B involvement, (f) final extruding to obtain a rod

EBSD samples were prepared by mechanical grinding and mechanical polishing through 3 μm and 1 μm, final mechanical polishing was performed with a diluted OPS solution (10%). Thereafter, electropolishing was achieved with an AC2 solution using a voltage of 15V for 10-20s at a temperature of -30˚C [5]. The index quality profiles obtained from the EBSD measurements (four scans for each state on zones of 150*150 μm again with a scan step of 1 μm. The electron diffraction analyses were performed in a Zeiss 55VP FEG-SEM equipped with a Nordif EBSD detector and the TSL OIM EBSD software. Scan step of 0.1 μm for CEC samples and 0.3 μm for as-extruded samples were employed.

3 Results and Discussion

3.1 Microstructures

Fig. 2 presents the results of the EBSD mapping in form of an inverse pole figure (IPF) map of as-extruded microstructure and microstructure after CEC 8 passes at 503K. The different colors represent different orientations of the grains. The stereographic triangle left the maps gives color-code employed in these maps. The nearly identical colored grains mean that the misorientations between these grains are not large [10]. Fig. 2a shows that the microstructure of the as-extruded ZK60 alloy is rather heterogeneous and typical incomplete recrystallization. Coarse grains of 50-100 μm in size are elongated along the extrusion direction and fine recrystallized grains in 5-15 μm are distributed among coarse grains. Most grains in Fig. 2a exhibit red color, which means that the {0001} basal planes of these grains are nearly parallel to the paper. After 8 passes of CEC processing (Fig. 2b), the grains are dramatically refined and uniformly distributed due to the dynamic recrystallization [11]. The much more randomly distributed grains colors indicate the grains orientations are changed.

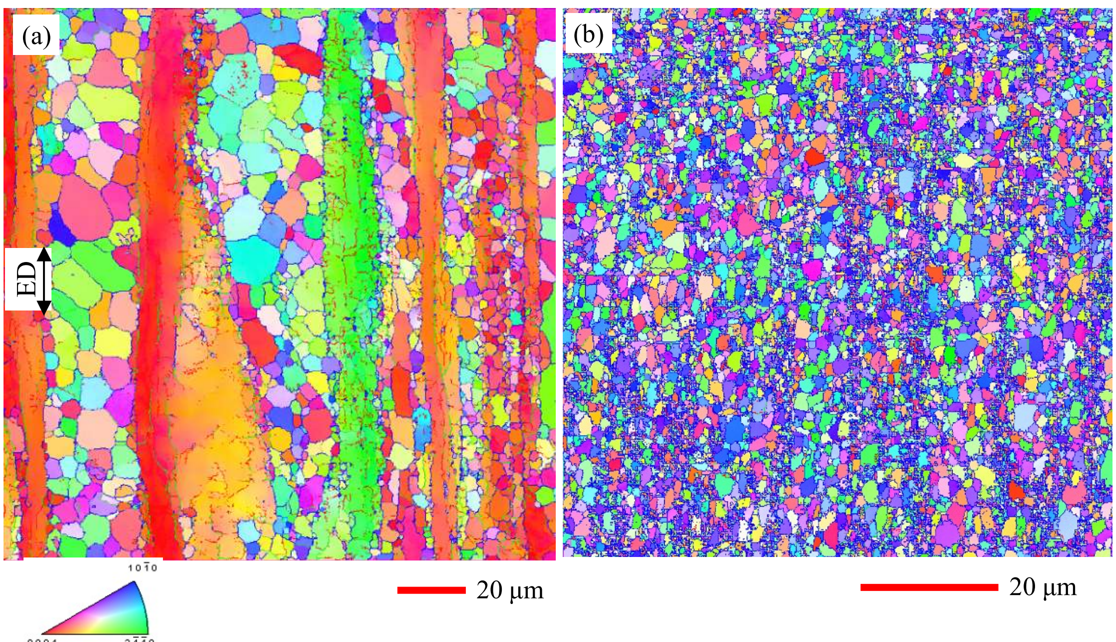

Fig.2 The inverse pole figure maps (IPF) of ZK60 alloy (a) before and (b) after 8 passes CEC processing

3.2 Grain boundaries misorientation

Fig. 3 shows the grain boundaries map of as-extruded and CEC processed alloy. The low angle grain boundaries (LAGBs) are marked by red lines (2^o-5^o) and green lines (5^o-15^o), respectively. The high angle grain boundaries (HAGBs) with misorientation angles beyond 15^o are marked by blue lines. As shown in Fig. 3a, there are numerous LAGBs in the as-extruded material. With the increasing of CEC pass number the grains are gradually refined. The statistics of grain boundaries misorientation are shown in Fig. 4. It can be seen that the number fraction (NF) of LAGBs decreases and the HAGBs increases with the CEC strain increasing. The NF of HAGBs in the as-extruded ZK60 alloy is relatively low (58.1%). After CEC 8 passes, the HAGBs NF dramatically increased to 95.6%, indicating the fact that most of the LAGBs have been evolved into HAGBs during CEC deformation due to dynamic recrystallization process. In addition, two NF peaks could be distinguished around angles 30 ° and 90 °, respectively (Fig. 4a). Similar results have earlier been reported for AZ31 Mg alloy after CEC [5] and ECAP [10]. It could be a strain-induced result of hcp lattice alloy and its formation associated with the plastic deformation mechanism of Mg alloy, especially twinning deformation.

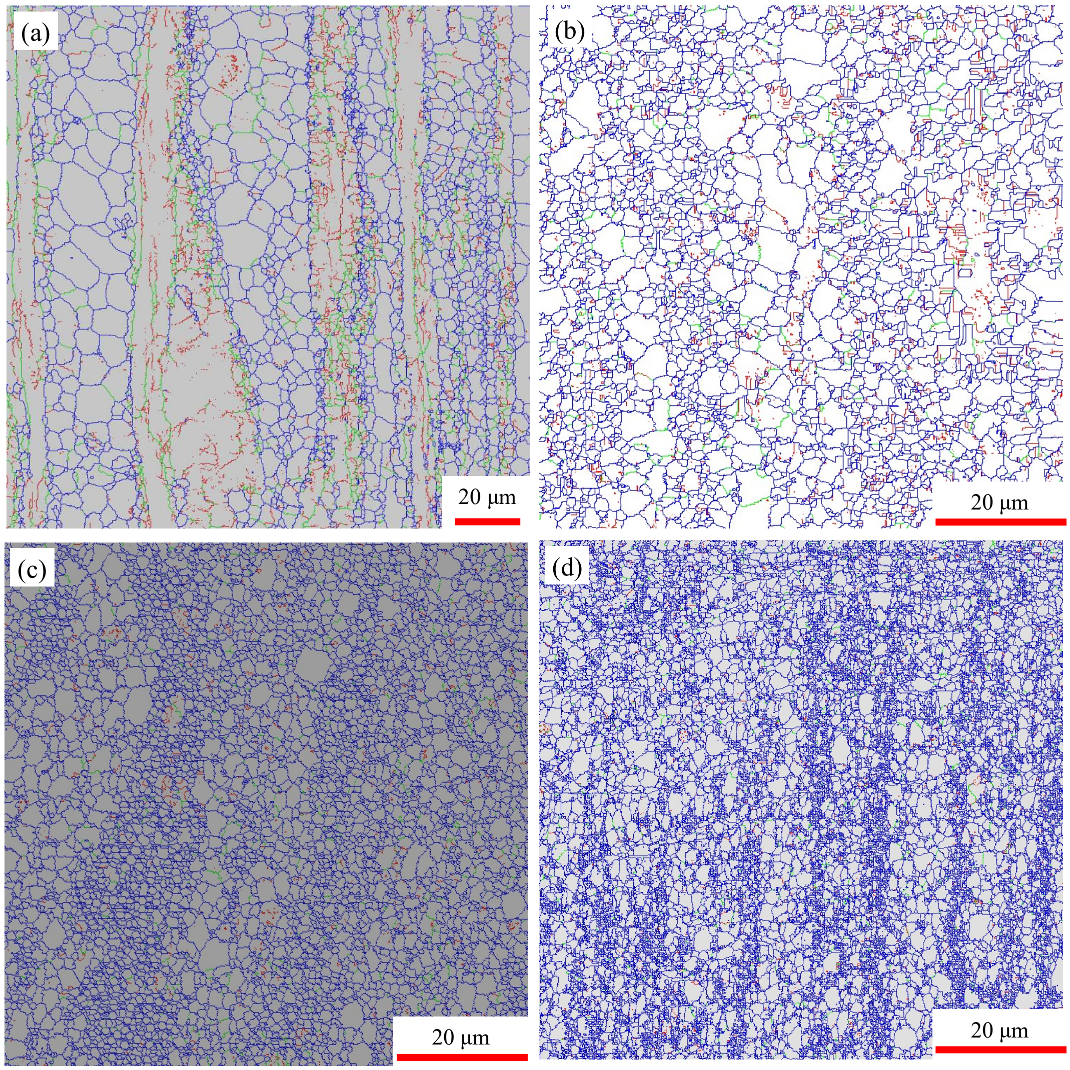

Fig.3 Grain boundary maps of ZK60 alloy after CEC (a) 0 pass, (b) 2 passes, (c) 4 passes, (d) 8 passes

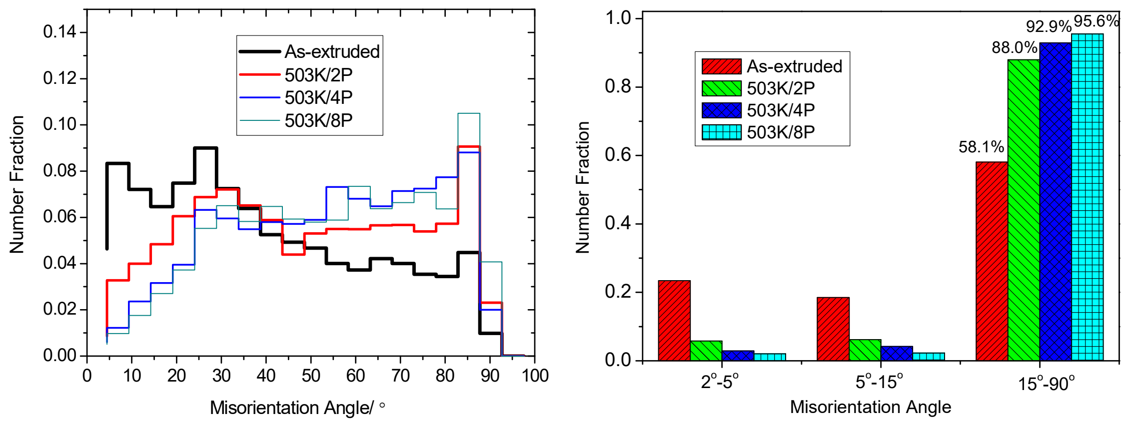

Fig.4 Number faction of misorientationof ZK60 alloy subjected to CEC

3.3. Texture analysis

Fig. 5 shows the EBSD determined {0002} and {10-10} pole figures of ZK60 alloy before and after CEC processing. As shown in Fig. 5a, the as-extruded ZK60 alloy exhibit a strong <10-10> fiber texture, which means that {0002} basal planes and <10-10> directions in most grains are distributed parallel to the extrusion direction (ED); that is why most grains in Fig. 2a exhibit red color. Similar result was observed in as-extruded ZK60 alloy using XRD test [3]. After 2-8 passes CEC, the initial fiber texture vanishes and evolves into a new {10-13}<30-32>+ {10-11}<15-43> texture [3]. The dominant texture did not vary with the number of CEC pass from 2 up to 8. On the other hand, the maximum intensity of both {0002} and {10-10} pole figures declined with the increasing pass number of CEC. This indicates that the grains orientation gradually became more random.

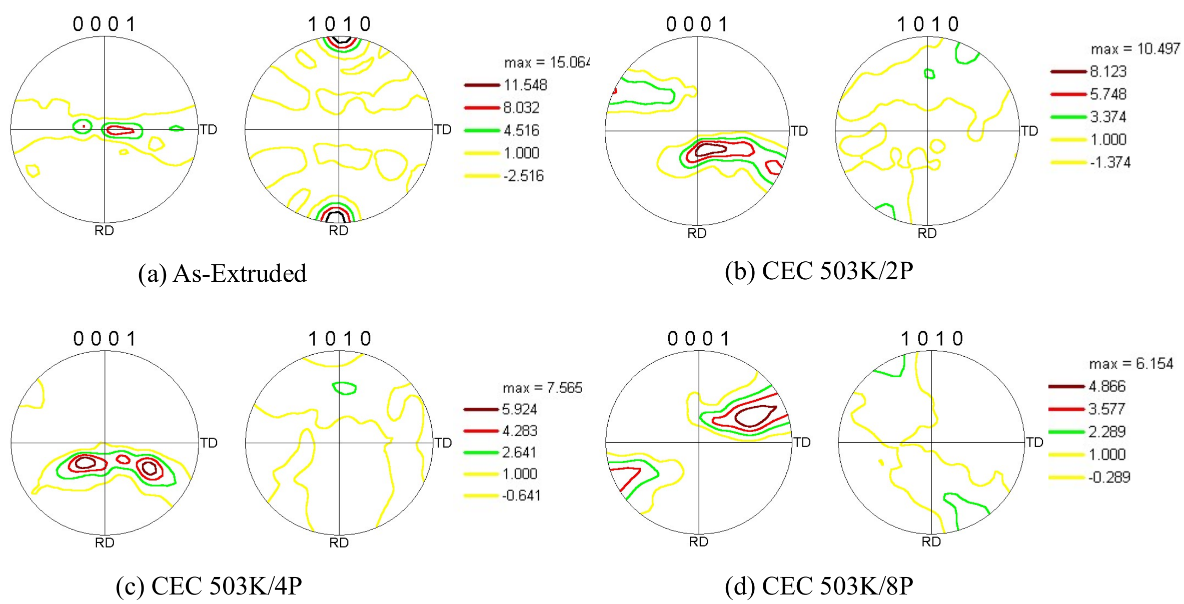

Fig.5 {0002} and {10-10} pole figures of ZK60 alloy before and after CEC: (a) 0 pass, (b) 2 passes, (c) 4 passes and (d) 8 passes

4 Conclusions

The microstructure and texture characteristics of an extruded ZK60 alloy were investigated before and after CEC processing at 503K. The obtained results can be summarized as follows:

(1) The microstructure of ZK60 can be effectively refined by CEC processing. Moreover, the crystallographic orientations were uniformly distributed by CEC deformation.

(2) In the as-extruded alloy, many LAGBs were observed. After CEC deformation, the number fraction of LAGBs decreased and a high fraction of HAGBs (95%) was revealed after 8 passes of CEC.

(3) The initial fiber texture of as-extruded ZK60 alloy became disintegrated and changes into a new texture during CEC deformation. The texture type did not vary with the increasing of CEC pass number, but the pole intensity decreased.

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