



# Grain refinement of magnesium alloys processed by severe plastic deformation

Yong-jun CHEN<sup>1,2,3</sup>, Qu-dong WANG<sup>1</sup>, Jin-bao LIN<sup>4</sup>, Man-ping LIU<sup>5</sup>, Jarle HJELEN<sup>2</sup>, Hans J. ROVEN<sup>2,6</sup>

1. National Engineering Research Center of Light Alloy Net Forming,  
Shanghai Jiao Tong University, Shanghai 200030, China;

2. Department of Materials Science and Engineering, Norwegian University of Science and Technology,  
Trondheim 7491, Norway;

3. ERC for Revolutionizing Metallic Biomaterials, North Carolina A&T State University,  
Greensboro, NC 27411, USA;

4. School of Applied Science, Taiyuan University of Science and Technology, Taiyuan 030024, China;

5. School of Materials Science and Engineering, Jiangsu University, Zhenjiang 212013, China;

6. Center for Advanced Materials, Qatar University, Doha POB 2713, Qatar

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**Abstract:** Grain refinement of AZ31 Mg alloy during cyclic extrusion compression (CEC) at 225–400 °C was investigated quantitatively by electron backscattering diffraction (EBSD). Results show that an ultrafine grained microstructure of AZ31 alloy is obtained only after 3 passes of CEC at 225 °C. The mean misorientation and the fraction of high angle grain boundaries (HAGBs) increase gradually by lowering extrusion temperature. Only a small fraction of  $\{10\bar{1}2\}$  twinning is observed by EBSD in AZ31 Mg alloys after 3 passes of CEC. Schmid factors calculation shows that the most active slip system is pyramidal slip  $\{10\bar{1}1\}$   $\langle 11\bar{2}0 \rangle$  and basal slip  $\{0001\}$   $\langle 11\bar{2}0 \rangle$  at 225–350 °C and 400 °C, respectively. Direct evidences at subgrain boundaries support the occurrence of continuous dynamic recrystallization (CDRX) mechanism in grain refinement of AZ31 Mg alloy processed by CEC.

**Key words:** magnesium alloys; grain refinement; continuous dynamic recrystallization (CDRX); electron backscattering diffraction (EBSD); cyclic extrusion compression (CEC)

## 1 Introduction

Magnesium alloys are the lightest metal structural materials and are much lighter than aluminum alloys and steel [1,2]. They are used in various applications which include national defense, automobiles, etc, due to their low density, high specific strength and excellent machinability [3,4]. There are increasingly strict demands for Mg alloys at both strength and ductility, especially for the activation of big projects including lunar excursion, high speed traffic tools and electronic automobiles. However, most Mg alloys generally present limited ductility and strength at ambient temperature, which severely limits their industrial application.

Grain refinement by severe plastic deformation (SPD) is a well-known method to improve both strength and ductility of metals [5]. According to the Hall–Petch relationship and Taylor factor, the yield strength of metals is associated with not only grain size but also number of slip systems. Therefore, the contribution of grain refinement on the strength of Mg alloys is much greater than the other metals with more slip systems, e.g., face-centered cubic (FCC) and body-centered cubic (BCC) metals [6]. Among all available SPD methods [7], cyclic extrusion compression (CEC) is very suitable for grain refinement of Mg alloys due to its characteristics of continuous deformation and special stress condition. The CEC method was designed originally for fabricating pure Al and its alloys [8,9]. Our group has extended its

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**Corresponding authors:** Qu-dong WANG; Tel: +86-21-54742715; E-mail: [wangqudong@sjtu.edu.cn](mailto:wangqudong@sjtu.edu.cn); Hans J. Roven; Tel: +47-73594966; E-mail: [hans.roven@material.ntnu.no](mailto:hans.roven@material.ntnu.no)

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application to Mg alloys [10–12]. In our recent works, we have studied the microstructure evolution of AZ31 Mg alloy after CEC 1–7 passes [10], the effect of the second phase on the microstructure evolution of AZ series Mg alloys [11], and a proposed compound grain refinement mechanism including rotational dynamic recrystallization (RDRX) and continuous dynamic recrystallization (CDRX) [12]. However, we have not presented any solid evidence for the suggested CDRX of Mg alloys processed by CEC. Moreover, the effect of extrusion temperature on the grain refinement of Mg alloys is still unknown.

This present work aims to bring more insight in the grain refinement of AZ31 Mg alloy during CEC at 225–400 °C and provide solid evidence for the suggested CDRX.

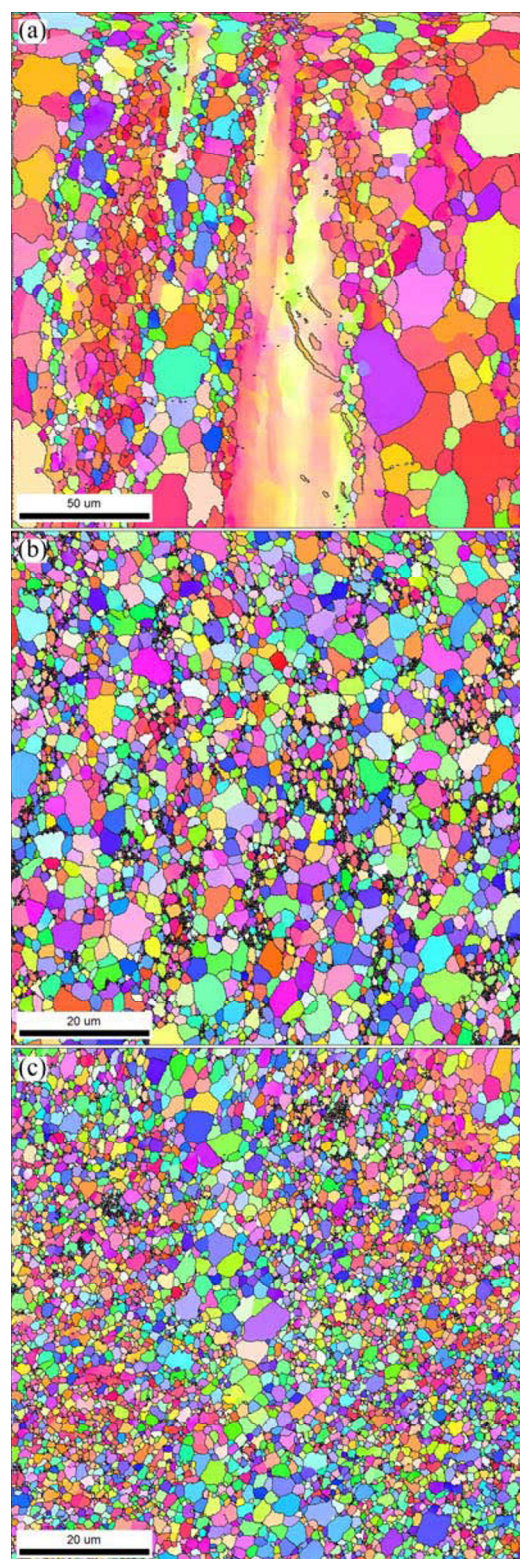
## 2 Experimental

AZ31 Mg alloy (Mg–3.09%Al–1.02%Zn–0.42%Mn, mass fraction) extruded bar and the die were firstly held at 100 °C for 10 min, and were coated with graphite as lubricant. Then, they were kept at targeting temperature for about 2 h. The samples were put into the upper chamber to start the CEC processing cycle. The operation of CEC was detailed in Refs. [9,10]. All samples were quenched in water immediately after CEC deformation to keep the deformed microstructure. Longitudinal section of CEC bar was prepared for optical microscopy, TEM and EBSD observations. Details of the sample preparations for EBSD and TEM can be found in Ref. [11].

## 3 Results and discussion

### 3.1 Grain refinement by increasing strain

In our previous report [10], grain refinement of AZ31 Mg alloy processed by CEC 1–7 passes at 300 °C was studied. Figures 1(a) and (b) illustrate the copies of initial and processed microstructures. It can be seen that a typical heterogeneous microstructure of the as-extruded AZ31 Mg alloy is shown in Fig. 1(a). After CEC 7 passes, the microstructure is reasonably homogeneous and the grains are equiaxed. A mean grain size of 1.77  $\mu\text{m}$  is obtained [10]. With further deformation up to 15 passes, the grain size is slightly reduced but a coarse-grain region is clearly shown in Fig. 1(c). This indicates that the microstructure reaches a dynamic balance between grain refinement by strain and grain growth by high temperature during CEC processing. Hence, it can be concluded that there exists a critical CEC pass to obtain a balance microstructure under a given temperature. This result is in accordance with the effect of extrusion ratio on the microstructure and mechanical properties of AZ31 Mg alloy [13].



**Fig. 1** Orientation maps of AZ31 Mg alloy after CEC at 300 °C: (a) As-extruded; (b) 7 passes; (c) 15 passes

### 3.2 Grain refinement by lowering extrusion temperature

Figure 2 shows the orientation maps of AZ31 alloy processed by 3 passes of CEC at 225–400 °C. The

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