Materials Letters 83 (2012) 175–178

Contents lists available at SciVerse ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

Uniform fine microstructure and random texture of Mg–9.8Gd–2.7Y–0.4Zr magnesium alloy processed by repeated-upsetting deformation

H. Zhou [a], B. Ye [a,b], Q.D. Wang [a,b,*], W. Guo [a]

[a] *National Engineering Research Center of Light Alloy Net Forming, Shanghai Jiao Tong University, Shanghai 200240, China*
[b] *Key State Laboratory of Metal Matrix Composite, Shanghai Jiao Tong University, Shanghai 200240, China*

ARTICLE INFO

Article history:
Received 14 April 2012
Accepted 30 May 2012
Available online 13 June 2012

Keywords:
Severe plastic deformation (SPD)
Magnesium alloys
Repeated-upsetting (RU)
Microstructures
Texture

ABSTRACT

Mg–Gd–Y is a new type of high performance magnesium alloy with high specific strength at both room and elevated temperature. A recently developed multiple compression severe deformation, repeated-upsetting (RU) processing is applied to further improve both strength and ductility. The microstructure and texture evolution of Mg–9.8Gd–2.7Y–0.4Zr Mg alloy large plate processed by RU are investigated, which are critical to provide a fundamental understanding of the improvement. Reasonably equiaxed spatially uniform microstructure is obtained with a grain size of 2.5–3.0 μm. Randomized texture is achieved through 3D material flow by grain rotation due to imposed shear strain and Mg alloys specific tensile twinning. Reasonably stable {0002} basal texture along horizontal directions is related to tensile twinning mechanism.

1. Introduction

As a typical representation of high performance magnesium alloy, Mg–Gd–Y alloy exhibits higher specific strength at both room and elevated temperature and better creep resistance than conventional Al and Mg alloys, including WE54, the best high performance commercial alloy [1]. Nevertheless, due to their hcp structure and low stacking fault energy, Mg alloys generally present limited ductility and strength at ambient temperature [2]. It has been demonstrated that the ductility enhancement in magnesium could be achieved by grain refinement typically by large plastic deformation and recrystallization [3]. However, conventional plastic deformation techniques such as extrusion [4] or rolling [5] induce strong texture in the final product leading to mechanical anisotropy such as tension–compression asymmetry [6]. The mechanical anisotropy limits wider application of wrought magnesium alloys under typical product design scheme.

One way to modify and weaken the strong textures in wrought Mg alloys is to perform non-conventional processing. In the case of extrusion, various novel techniques have been developed in recent years such as equal-channel angular extrusion (ECAE) and cyclic extrusion compression (CEC). It was found that the Mg alloys processed by ECAE, showed increased elongation in combination with a reduced yield strength due to the changed texture and the refined grains [7].

We developed a new type of SPD processing named repeated-upsetting (RU) [8]. It has been demonstrated that RU can improve the tensile strength and elongation of AZ31 alloy to 304 MPa and 28% after 5 passes via route B [8], which is one of the best combinations of strength and ductility among SPD processed AZ31 alloy [9]. For a typical Mg–9.8Gd–2.7Y–0.4Zr (wt.%) alloy, the extruded properties (yield strength of 201 MPa and elongation of 6.3%) were much improved to 271 MPa and 11.8% in tension and 262 MPa in compression without showing the yield asymmetry. However, the evolution for microstructure uniformation and texture randomization during RU is not clear. The objective of this work is to investigate microstructure evolution and texture behavior of a more hard-to-deform Mg–Gd–Y magnesium alloy [10] during RU processing.

2. Materials and methods

Fig. 1a and b shows the deformation scheme of the repeated-upsetting. RU is ready for thickness reduction to fabricate industrial scale thin plates, which is different from reported typical SPD process (further principle details concerning RU are reported in Ref. [8]). The plate in this study has a height of 100 mm and a cross-section area of $20 \times 100\ mm^2$. In order to facilitate the description of spatial grain size distribution, an X–Y–Z coordinate system is defined (Fig. 1a), where the press direction is along the Z-axis (ND), horizontal deformation direction is the Y-axis (ED) and the direction perpendicular to the paper is the X-axis (TD). During the process the plate is sheared and upset into a reversed-T-shaped channel in the die by a plunger as shown in Fig. 1b. The plate has the same dimension as the horizontal channels without dimension change between passes. After each pressing, the plate is picked out from the bottom, rotated and reinserted into the channel for the next pass.

* Corresponding author at: National Engineering Research Center of Light Alloy Net Forming, Shanghai Jiao Tong University, Shanghai 200240, China. Tel.: +86 21 54742715.
E-mail address: wangqudong@sjtu.edu.cn (Q.D. Wang).

0167-577X/$ – see front matter
doi:10.1016/j.matlet.2012.05.129

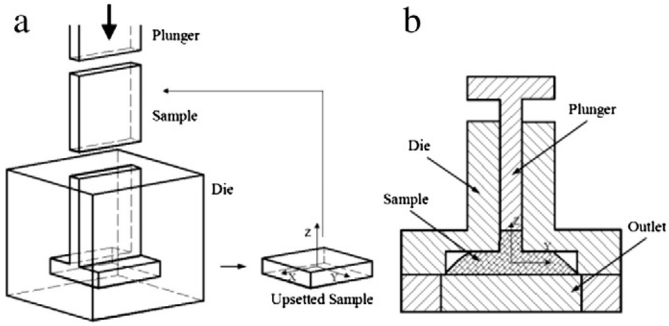

Fig. 1. Process diagram of RU: (a) schematic diagram of 1st pass, (b) die schematic of the cross-section perpendicular to the X-axis.

The cast ingots with a diameter of 180 mm were homogenized at 500 °C for 10 h followed by quenching into hot water (i.e. T4 treatment). The ingot was hot extruded (pre-deformation) into sheet with dimensions of $30 \times 150\ mm^2$ on the cross section and extrusion ratio of 5.65:1 at 400 °C. Following extrusion, repeated-upsetting was carried out at 350 °C for 4 passes via route A [8] with a constant processing speed of 5 mm/s. The microstructure was characterized using optical microscopy (OM). Grain size measurement was facilitated by direct analyzing optical images of etched sample, which showed equivalent grain structure observed by EBSD [1]. Texture from samples before and after RU processing was measured by Philips X′ Pert System equipped with the ATC-3 texture goniometer.

3. Results and discussion

For the cast-T4 specimen, the average grain size is ~139.2 μm. Owing to the poor formability of cast-T4 Mg–Gd–Y alloy, extrusion at 400 °C was carried before the RU processing. Typical RU processed microstructure from the central part of plate is shown in Fig. 2. The microstructure before RU process is relatively homogeneous with a mean grain size of ~11.2 μm shown in Fig. 2a. Fig. 2b shows the initial grains surrounded by lots of fine recrystallized grains as band, and the recrystallized fine grain size is about 3 μm. On average, the grain size after RU-1pass is ~14.3 μm. With the increase of strain, the size of fine grain is little affected by upsetting passes, while the coarse grains are refined continuously by the dynamic recrystallization (DRX) occurring along the fine grain bands (shown in Fig. 2c). The intersection of fine grain bands leads to the formation of close area in sample, and the mean grain size is ~6.9 μm after RU-2passes. Fig. 2d reveals that all grains of RU-4passes are reasonably equiaxed. A homogeneous fine microstructure is reached with a mean the grain size of ~2.8 μm.

To further quantitatively characterize microstructure uniformity and refinement, the spatial distribution of the grain size measurements for Mg–9.8Gd–2.7Y–0.4Zr alloy after RU process is shown in Fig. 3. The $100 \times 100 \times 20\ mm^3$ sample is meshed along the X and Y axes with 10 by 10 divisions. These 3-D displays provide a simple pictorial representation of the grain size distribution throughout the cross-sectional plane at the center of each cell.

Fig. 3 shows the grain size distribution after 1, 2 and 4 passes of RU processing, respectively. It is apparent from Fig. 3a that the grain size distribution of the sample after 1 pass of RU process is inhomogeneous and exhibits a wave-type distribution of spanning 5–15 μm along the Y axis, in agreement with Fig. 2b. As for the sample after 2 passes, the fluctuation of the wave is drastically reduced to about 2 μm and the grain size exhibits 5–8 μm. It can be noted that the coarse grain positions (Y = 0, 50 and 100 mm) after 1 pass disappeared. In addition, it is remarkable that the grain sizes are distributed homogeneously over the whole cross-sectional plane after 4 passes of RU with an average grain value of ~3 μm shown in Fig. 3c considering the large sample size. The quantitative grain size distributions are consistent with observations in Fig. 2. A general observation is that the average grain size reduces with increasing numbers of passes. From the RU route characteristics, 3-D material flow was achieved in the sample by multiple passes. Therefore, enough strain imposed on each face of the sample may lead to observed microstructure uniformity and refinement with RU passes.

The texture evolution represented by inverse pole figures (IPFs) during RU processing of Mg–9.8Gd–2.7Y–0.4Zr alloy is illustrated in Fig. 4. The density of poles in Fig. 4a–c indicates that the texture is dominated by the grains with pyramidal $\{11\bar{2}0\}$ plane parallel to the as-extruded plate plane. These grains have both TD and ED components. Fig. 4d–f shows significant texture changes of extruded plates after RU processing. The strong $\{11\bar{2}0\}$ intensity in ND IPF transformed into equal $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$ component. However, the {0002} texture still shows relatively weak as its as-extruded condition. As shown in Fig. 4e and f, both the ED and TD components of

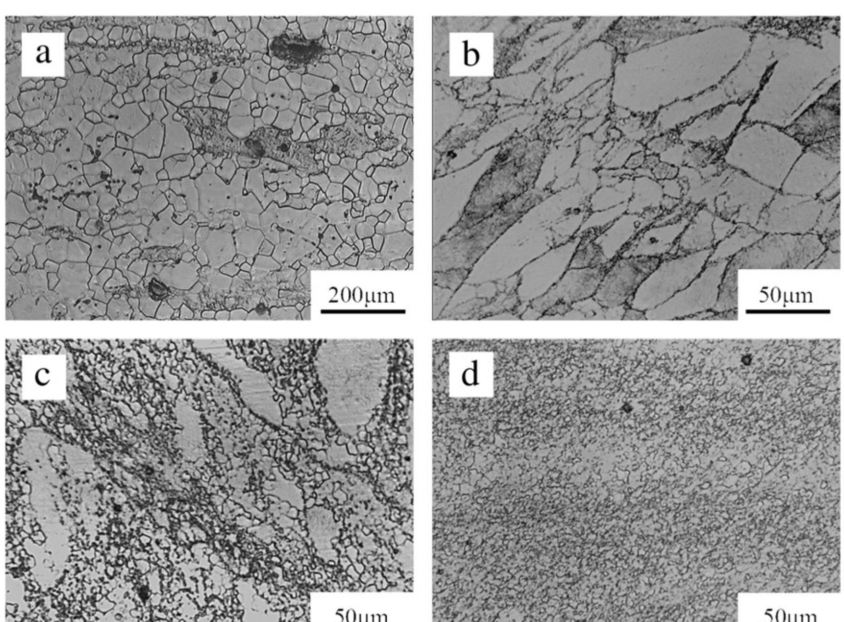

Fig. 2. Microstructures of Mg–9.8Gd–2.7Y–0.4Zr alloy: (a) as-extruded, (b) RU-1pass, (c) RU-2pass and (d) RU-4pass.