Materials Science & Engineering A 689 (2017) 395–403

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Ameliorating the mechanical properties of magnesium alloy: Role of texture

Qinghang Wang[a], Bin Jiang[a,b,*], Aitao Tang[a,**], Shaoxing Ma[a], Zhongtao Jiang[c], Yanfu Chai[a], Bo Liu[d], Fusheng Pan[a,b]

[a] *State Key Laboratory of Mechanical Transmissions, College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China*
[b] *Chongqing Academy of Science and Technology, Chongqing 401123, China*
[c] *Research Institute for New Materials Technology, Chongqing University of Arts and Sciences, Chongqing 402160, China*
[d] *Chongqing Chang-an Automobile Co., Ltd., Chongqing 400023, China*

ARTICLE INFO

Keywords:
Differential speed extrusion
Asymmetric shear deformation
Grain refinement
Texture weakening
Formability

ABSTRACT

AZ31 magnesium alloy sheet was fabricated by two different approaches, namely conventional extrusion (CE) and differential speed extrusion (DSE), under the same process conditions and extrusion ratio. The microstructures, textures and mechanical properties of AZ31é magnesium alloy sheets processed by the CE and DSE processes were investigated. It was found that with the DSE process more uniform and finer microstructures were obtained. The DSE sheet exhibited the lower yield strength and yield ratio, but the larger n value combined with the lower r value, which made the DSE sheet achieve an excellent formability. Those results were mainly attributed to a tilted weak texture resulted from the differential flow speed of alloy at the severe deformation zone.

1. Introduction

Magnesium (Mg) alloys possessing qualities of low density, high specific strength and specific stiffness have, over the past decade, created considerable interest in automotive application and aircraft industries to improve fuel efficiency and reduce CO_2 emissions [1]. Mg alloy products mainly focus on strips, bars and profiles fabricated by primary processing, such as hot-extrusion or rolling. However, these products tend to present a strong basal texture whose basal plane is parallel to extrusion or rolling direction, resulting in a poor formability during second processing at room temperature [2,3]. Therefore, tailoring basal texture is considered as an effective way to ameliorate the formability of Mg alloys.

Recently, the severe plastic deformation technologies aiming to refine grains and modify a strong basal texture of Mg alloys have received great attentions. They have been developed rapidly and widely used in preparing the high-performance Mg alloy. These technologies include twist extrusion (TE) [4], simple shear extrusion (SSE) [5] as well as dual equal channel lateral extrusion (DECLE) [6], torsional-equal channel angular pressing (T-ECAP) [7] and high-pressure tube twisting (HPTT) [8]. However, they are only applicable for bulk products limiting the promising of the thin sheets.

Given that the mentioned disadvantage, Chang et al. [9] and Yang et al. [10–12] reported some new extrusion methods to manufacture high-performance thin Mg alloy sheets. Those approaches were collectively entitled as “Asymmetric Extrusion”, such as differential speed extrusion (DSE) [10], trapezoid extrusion (TE) [11] and asymmetric extrusion (ASE) [12]. Inspiration of differential speed extrusion (DSE) derived from differential speed rolling (DSR) which could effectively alter the texture and enhance mechanical properties of the rolled sheets. This change was mainly attributed to an asymmetric shear deformation in the whole thickness of the sheets giving rise to the difference of velocity between the top and bottom surface. The principle of DSE process was that altering a flow passage forms asymmetric shear deformation in the whole thickness of the DSE sheet, causing a grain refinement, a tilted weak basal texture and the improvement of mechanical properties. Yang et al. [10] only focused on the effect of the microstructure and texture characteristics on the final mechanical properties of the DSE sheet, but there was no systematic investigation into the microstructure and texture evolution of a workpiece during the whole extrusion process.

Therefore, the present work was concentrated on the influence of microstructures and texture evolutions of the workpieces during the CE and DSE processes on the final mechanical properties of Mg alloy sheet. Additionally, the formability of both sheets was performed by the Erichsen cupping test.

---

[*] Corresponding author at: State Key Laboratory of Mechanical Transmissions, College of Materials Science and Engineering, Chongqing University, Chongqing 400044, China.
[**] Corresponding author.
E-mail addresses: jiangbinrong@cqu.edu.cn (B. Jiang), tat@cqu.edu.cn (A. Tang).

http://dx.doi.org/10.1016/j.msea.2017.02.067
Received 12 October 2016; Received in revised form 16 January 2017; Accepted 17 February 2017

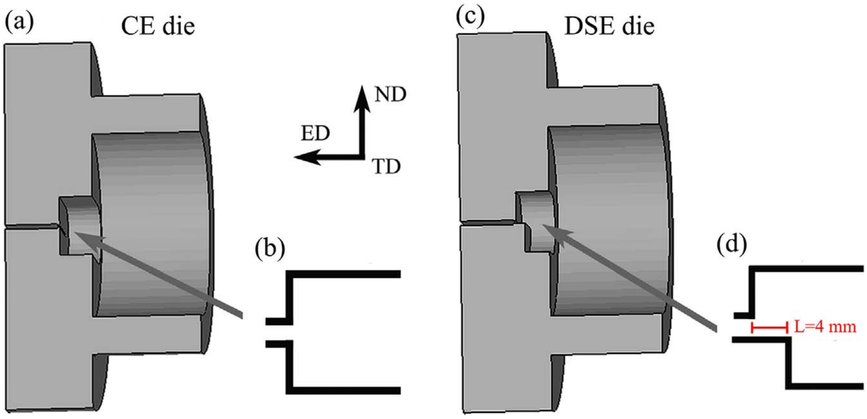

Fig. 1. Schematic sectional view of the extrusion die: (a) the conventional extrusion (CE) die and (c) the differential speed extrusion (DSE) die. Illustration of the flow passage for both dies: (b) the CE die and (d) the DSE die in details [10].

2. Materials and methods

The as-received AZ31 (Mg-2.78 Al-0.63 Zn-0.21 Mn in wt%) cast billets with 85 mm in diameter were cut into ingots with Φ 80 mm×60 mm. The billets then were homogenized at 400 °C for 12 h and cooled in air to obtain supersaturated solution. The AZ31 Mg alloy billets were extruded into the CE and DSE sheets with 1 mm in thickness and 60 mm in width at 430 °C with an extrusion ratio of 101:1. The extruded sheets were allowed to cool naturally in air after exiting the dies. The schematic section of flow passage in CE and DSE dies was shown in Fig. 1 [10]. The DSE die was equipped with a different parallel flow passage length (L=4 mm) [10].

Specimens remaining in the CE and DSE dies were split after extrusion processes. The longitudinal sections of specimens were etched or electro-polished, and observed using Optical Microscopy (OM) and electro backscatter diffraction (EBSD). The sample preparation for EBSD consisted of grinding on SiC papers of grit size 400, 600, 800, 1000, 1200, 2000 and electro-polishing at a voltage of 20 V for 120 s at a temperature of −10 °C with a special electrolyte named as AC2. The analyses of EBSD were done in a FEI Nova 400 FEG-SEM equipped with an EBSD detector. EBSD was performed at the operating voltage of 20 kV, 15 mm working distance and a 70° tilt. Scan steps for the sample CE and DSE were set as 1 μm. The EBSD data were evaluated by orientation imaging microscopy (OIM, *HKL*-channel 5) software. To support the result of EBSD data, the macro-textures of the CE and DSE sheets from the extrusion direction (ED)-the transverse direction (TD) plane were carried out by X-ray Diffraction (XRD, Rigaku D/Max 2500) using Cu $K_\alpha$radiation at a wavelength of 0.15406 nm.

To investigate the anisotropy of the mechanical properties, tensile specimens with 10 mm in initial gauge length, 6 mm in gauge width and 1 mm in gauge thickness were machined from the CE and DSE sheets in the tensile directions of 0, 45 and 90°. Tensile tests were carried out by a CMT6305–300 kN universal testing machine with a strain rate of 10^{-3} S^{-1} at room temperature. Tensile tests in the different tensile directions were repeated three times to ensure repeatability and to confirm the consistency of the results. However, a representative curve was shown for each test. The Lankford coefficient (*r* value) was examined at a permanent strain of 10% in each tensile direction. The strain hardening exponent value (*n* value) was obtained within a uniform strain using power law regression. The fractured tensile samples of the CE and DSE sheets were observed by the OM in the tensile directions of 0, 45 and 90°.

Erichsen cupping tests were carried out to determine the formability of the CE and DSE sheets using a hemispherical punch with a diameter of 20 mm at a punch speed of 5 mm/min at room temperature. Each sample of Erichsen cupping test was machined into a block with 60 mm in length, 60 mm in width and 1 mm in thickness. The tests were repeated three times for each sheet.

DEFORM-3D simulation was employed to analyze the extrusion process in the present study. In order to clearly demonstrate the metal flow during the extrusion process, 1/2 symmetric geometry model was established. The geometry models of the workpieces (AZ31 alloy), the CE and DSE dies made by Unigraphics NX software were imported to DEFORM-3D system. In this simulation, the workpieces (AZ31 alloy) were set as plastic body, while the dies were defined as the rigid ones. The friction coefficient between workpiece (AZ31 alloy) and die was set as 0.25. The temperature and speed of each extrusion process were set as 430 °C and 10 mm/s, respectively.

3. Results

3.1. Microstructures and textures

EBSD inverse pole figure (IPF) maps and (0002) pole figures of typical locations of the specimen CE and DSE are demonstrated in Fig. 2. Low angle grain boundaries (LAGBs) are defined as boundaries with an angle θ such that $2° < \theta < 15°$ and are indicated in the figures by white lines, and high angle grain boundaries (HAGBs) are defined as boundaries such that $15° \leq \theta$ and are indicated by black lines. It is apparent that from positionIto position II of the specimen CE, coarse and elongated grains gradually are refined and grain boundaries become smoother in Fig. 2a (II). When an AZ31 alloy is extruded from position II to position III, grains are further refined into fine dynamic recrystallized ones in Fig. 2a (III). This microstructural feature is one of the typical characteristics of Mg alloys that underwent complete dynamic recrystallization [13]. This is ascribed to continuous production and absorption of dislocation in low angle grain boundaries, as well as progressive transformation to high angle grain boundaries [14]. As regards to the specimen DSE, the microstructure evolution shows a similar process (Fig. 2b). Compared with the specimen CE, however, the specimen DSE exhibits relative microstructural homogeneity and fine grain size at the corresponding positions. The average grain size of each position for the specimens CE and DSE are summarized in Table 1. This finding indicates that the DSE process is in favor of refining the microstructure of extruded sheet.

Besides the microstructure evolution of extrusion process, the texture evolution is also a significant factor on the mechanical property of Mg alloy sheet. The (0002) pole figures reveal that both the specimens CE and DSE have a typical basal texture feature, despite