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Enhancement of mechanical properties and corrosion resistance of magnesium alloy sheet by pre-straining and annealing

Junjie He [a], Bin Jiang [a,b,*], Jianyue Zhang [a], Qing Xiang [a], Xiangsheng Xia [c], Fusheng Pan [a,b]

[a] National Engineering Research Center for Magnesium Alloys, Chongqing University, Chongqing 400044, China
[b] Chongqing Academy of Science and Technology, Chongqing 401123, China
[c] No. 59 Institute of China Ordnance Industry, Chongqing 400039, China

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ABSTRACT

Pre-straining and annealing processes were carried out to enhance the mechanical properties and corrosion resistance of AZ31 sheet by modifying the microstructure and texture. The results showed that by a small tensile deformation along the weak basal textured orientation, the pre-strained AZ31 samples showed higher strength and improved anisotropy after annealing. Furthermore, because the texture reinforcement effect obtained by the pre-deformation was retained during annealing, the corrosion resistance of pre-strained and annealed specimens was enhanced compared with the as-extruded sheet, which was characterised by the evolved hydrogen and the immersed surfaces. This study suggested that appropriate pre-straining accompanied annealing was a potential technique to improve the comprehensive properties of the magnesium alloy sheets.

1. Introduction

Magnesium alloys, owing to their series of advantages such as low density, high specific strength and excellent camping capacity, are regarded as one of the most promising green engineering material of 21st century [1–3]. It is well known that wrought magnesium alloys have much better integrated mechanical properties than their casting counterparts and thus are prized in the research flied of magnesium alloys [4]. However, there are two major problems extremely limiting their commercial applications to date. One is the relatively low strength and ductility of wrought Mg alloys compared with aluminum alloys as well as the poor anisotropy. The low ductility and poor anisotropy are mainly due to their close-packed-hexagonal (HCP) structure, which can only initiate a limited number of slip systems at room temperature [5–8]. The other is the unsatisfied corrosion performance of most wrought Mg alloys, which is mainly attributed to the high reactivity of Mg element, and the oxidation film subsequently formed on the surface of Mg alloys is usually not pyknotic to protect the matrix [9–11]. Thus, many extruded or rolled products would be easily oxidized in ambient environmental without providing efficient protection.

Much attention has been paid to solve these two issues. As always, efforts have been made towards the development of a relationship correlating the grain size of Mg alloys and corresponding mechanical properties as well as corrosion response [12–15]. The grain refinement may significantly improve the strength of Mg alloys according to the Hall–Petch relationship [16–18], and the ductility as well. Many reports also suggested that the effective grain refinement would lead to an increase in corrosion resistance [12,19]. For example, through the severe plastic deformation (SPD), the acquisition of fine microstructure and the break-up of second phase particles with more uniform distribution can greatly improve both mechanical properties and the corrosion resistance [12,20,21]. Nevertheless, The SPD process is usually unmanageable and costly, as well as not suitable to some Mg-based drip moldings. Meanwhile, micro-alloying is an effective method in Mg to achieve the improvement on both the strength and corrosion performance simultaneously [22–24]. By the addition of alloy elements, e.g. Ca, Y, La, the grains of Mg alloys can be refined significantly, which benefits their mechanical properties. On the other hand, alloying elements can enhance the corrosion resistance by improving the protection nature of the surface film. However, the micro-alloying of Mg alloys is uncontrolled for the formation of second phase, which would increase the corrosion rate by micro-galvanic acceleration of the α-Mg matrix. In general, the relationship between mechanical properties and the corrosion performance is difficult to coordinate, and thus more practical treatments are in need of carrying out to solve the two problems synchronously.

Recently, Xin et al. [25] suggests that the texture has significant

* Correspondence to: Sha-zheng-street 174#, Sha-ping-ba District, Chongqing, China. Fax: +86 23 65111140.
E-mail address: jiangbinrong@cqu.edu.cn (B. Jiang).

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influence on the corrosion rate of AZ31 Mg alloy sheet in 3.5% NaCl. In their research, the corrosion rate of AZ31 dramatically increased with the drop of (0 0 0 1) texture intensity and the rise of (1 0 1 0)/(1 1 2 0) texture intensity. It should be noted that the texture evolution also has obvious effect on the mechanical properties of magnesium alloys [4,26,27]. Therefore, regulate and control the texture seems to be a potential way to improve the comprehensive properties of Mg alloy sheets.

In this present work, pre-straining by suitable small deformation along the weak basal textured orientation was carried out on the AZ31 thin sheet to tailor the macrotexture. It was proved that the strength of the sheet was enhanced without obviously sacrificing the ductility, and the corrosion rate of the pre-strained and annealed sample in the 3.5% NaCl solution was significant decreased compared with the as-extruded sheet.

2. Experiment

The as-extruded sheet of AZ31 (Mg–3Al–1Zn wt%) with 100 mm in width in the transverse direction and 0.9 mm in thickness, was cut into 100 mm × 40 mm (length × width) specimens along the extrusion direction for pre-straining (PR) experiments. In the following paragraphs, ED, TD and ND represent the extrusion direction, the transverse direction and the normal direction, respectively. The specimens were pre-stretched by 4% and 7% along ED, and then annealed at 200 °C for 5 h to remove the dislocations but remain the grain orientation. It could be defined the specimens with pre-straining followed annealing as PRA for simplicity. The PR process was carried out on a CMT 6305 – 300KN testing machine with a speed of 1.5 mm min^{-1} at room temperature.

Dog-bone tensile samples of 10 mm gauge length, 3 mm width and 0.9 mm thickness were machined from the as-extruded sheet and PRA specimens with various directions tilting of 0°, 45° and 90° to the ED to examine the mechanical property evolution, respectively. The speed of uniaxial tensile test was 1.5 mm min^{-1}. The microstructures were examined by optical microscopy (OM). The X-ray texture analysis of (0002) pole figure was carried out by Rigaku D/Max 2500.

Square samples with the dimensions of 15 mm × 12 mm × 0.9 mm (length × width × thickness) were cut from the as-extruded and PRA sheet to test the corrosion rate by a hydrogen evolution method in 3.5 wt% NaCl solution at 25 °C. The samples were embedded in resin and to allow only designated surface (15 mm × 12 mm) exposed to the solution. Besides, in order to reduce the effect of surface roughness on corrosion performance, the exposed surface of all the samples was polished successively on 400-1000grit abrasive papers. The surface morphologies of the various soaked samples were observed by using scanning electron microscopy (SEM, TESCAN VEGA).

3. Result and discussion

3.1. Microstructure and mechanical properties of the as-extruded AZ31sheet

The micrograph (ED–ND) and the (0002) pole figure of the as-extruded sheet are revealed in Fig. 1. It shows a homogeneous microstructure and the average grain size is about 20 μm. Fig. 1 (b) indicates that the AZ31 sheet gives a rise to a typical basal texture and the maximum pole density is 8.6. Besides, it also can be seen that the texture distribution is elongated along ED at some level.

The yield strength (YS), the ultimate tensile strength (UTS) and the uniform elongation of the as-extruded sheet are listed in table 1. As a structural material, the applications of the thin sheet may be extremely limited for the low strength, especially the YS of ED, only 148.2 MPa. In addition, the YS exhibit a strong directional anisotropy, which is mainly attributed to the elongated and unsymmetrical texture distribution. As shown in Fig. 1(b), more grains are rotated to ED and the angles of the *c*-axis deviated from ND to ED is generally larger compared with that of ND to TD, which means that the ED of the AZ31 sheet should be the most weak basal textured orientation among the three directions. Previous researches have suggested that grains with weaker basal textured orientation may have a larger Schmidt factor and favor the dislocation of ⟨a⟩ slip [26], this is the reason why the YS of ED is the lowest but the YS of TD is the highest among the three directions. Furthermore, the sheet also performances a low level values of UTS. To sum up, the applications of the thin sheet are seriously hindered by its low strength and poor anisotropy and that are needed to be further improved urgently.

3.2. Microstructure and macrostructure evolution of PRA specimens

Optical micrographs of PRA specimens obtained from the ED–ND plane are demonstrated in Fig. 2. It can be concluded that there was no twin generated in the 4% stretch deformation process according to the Fig. 2(a), for the twin structure can be intactly retained during the stress relief annealing [28]. Although it seems that there is no distinct change in the microstructure, the maximum pole density increases obviously from 8.6 to 16.2. In addition, the orientations of the weak basal textured grains along ED are gradually close to the center of the ED–TD plane and the texture feature becomes more rounded compared with that of the as-extruded sheet. As mentioned before, the weaker basal textured grains may have a priority to participate in the early plastic

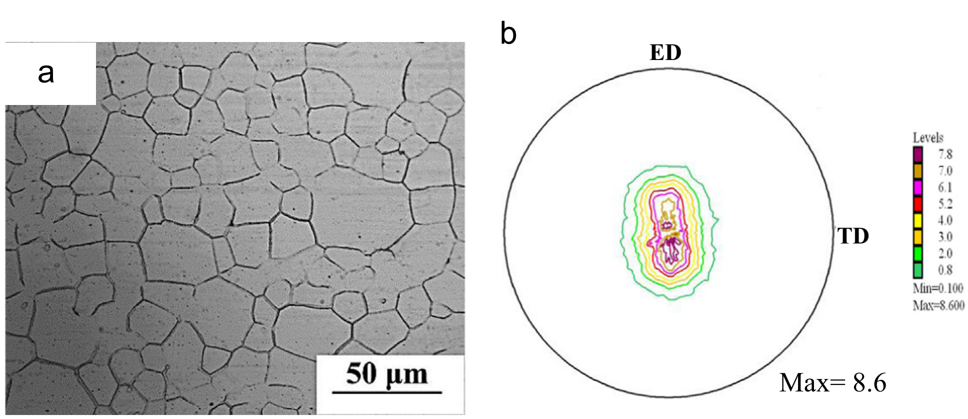

Fig. 1. OM micrograph (a) and (0002) orientation distribution figure (b) of the as-extruded AZ31 sheet.