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# Effect of texture symmetry on mechanical performance and corrosion resistance of magnesium alloy sheet

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## ABSTRACT

The strong asymmetric c-axis//transverse direction (TD) preferred orientation of the Mg-3Li-3Al-1Zn alloy sheet could induce different deformation mechanisms when the sheet was loaded along different directions. Consequently the related poor planar isotropy in mechanical properties may further deteriorate the sheet formability. More unfortunately, this type of texture component would give rise to poor corrosion resistance owing to a large amount of $\{10\bar{1}0\}/\{11\bar{2}0\}$ crystallographic planes with high surface energy were exposing to the sheet surface. Appropriate pre-deformation was carried out on the sheet to tailor the initial asymmetric distribution of basal poles to be symmetric. The results indicated that the introduced symmetric weak basal texture significantly improved the planar isotropy of the sheet as well as enhanced its comprehensive mechanical performance. The absolute strength of the modified sample was enhanced and the Erichsen value increased up to ~80% compared with the as-extruded sheet. Besides, the immersion tests and electrochemical polarization tests suggested that the re-orientation of the prismatic planes through pre-deformation could effectively enhance the corrosion resistance of the sheet simultaneously. The evolution of the microstructure, texture, mechanical properties and corrosion resistance during this study were investigated in detail.

## 1. Introduction

Magnesium alloys, owing to a number of advantages they offer, have received much attention in the automotive and electronics industries [1–3]. In recent decades, magnesium alloys have been studied intensely from a variety of perspectives. However, there are still two main problems restricting their further applications. One is the poor formability at room temperature, which is mainly due to the insufficient operable slip systems [4,5]. Especially for the wrought magnesium alloys, the existing strong texture induced during primary processing can further deteriorate the comprehensive mechanical properties and devalue the materials [6–8]. The other is its unsatisfied corrosion resistance. The high corrosion susceptibility of magnesium alloy, even in natural environment, provides a strong barrier on their commercial use [9–11].

Massive studies have been made to solve these above two issues [11–14]. Nevertheless, few achievements have been reported based on the enhancement of both the mechanical properties and corrosion resistance concurrently. Currently, microstructural modification by the equal channel angular extrusion (ECAE) seems to open up the possibility [15–17]. The microstructural refinement of magnesium alloy during ECAE can lead to efficient improvement in mechanical performance due to a more evenly deformation behavior [18]. Besides, the acquired ultra-fine grain size and the break-up of second phase particles with more uniform distribution achieved through ECAE were examined lead to increase in corrosion resistance [16,19]. However, ECAE process was limited in industry due to unmanageable and costly, as well as not suitable to fabricate wide Mg alloy sheets. In addition to the microstructure, the crystallographic orientation, which is usually regarded as an important factor to control the mechanical performances, can remarkably influence the corrosion, dissolution and oxidation responses of Mg alloys as well [20–23]. The relationship between crystallographic orientation and corrosion response is believed to

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relate to the binding energy of the surface atoms of Mg alloy. For the magnesium alloy sheets, the surface energy of (0002), $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$ are quite different owing to varying degrees of atom close-arrangement, further give rise to different corrosion rates at different crystalline planes [20,24]. Thus, it is wondered an appropriate texture optimization could be another possible way to optimize the mechanical properties and the corrosion resistance of Mg alloys simultaneously.

In last several years, the investigation about the role of Lithium (Li) element in Mg alloys' performances is always a hot topic [25–27]. Li element can be considered as a special texture modifier for Mg, which can alter the texture feature markedly owing to its effective modification on the c/a ratio [28]. In our team, Li et al. found that with 3 wt.% Li addition in Mg-3Al-1Zn (AZ31) alloy, the extruded texture was transformed from typical basal texture into a prismatic texture and the texture intensity decreased ~50% compared with the Li-free AZ31 alloy [27]. The texture weakening is beneficial to improve the uniaxial mechanical performances, while the multiaxial sheet formability such as the stamping formability is still limited and not improved that much, which is believed mainly due to the asymmetric distribution of the basal poles caused by the asymmetric texture [29]. Last but not the least, it should be noted that the poor corrosion resistance of the Mg-Li alloy is another difficult issue. Since the Li element is more active than Mg element, thus Li addition can further deteriorate the corrosion resistance of the Mg alloy rapidly [30,31]. What makes it even worse is that the $\{10\bar{1}0\}$ and $\{11\bar{2}0\}$ prismatic planes with high surface energy were nearly parallel to the sheet surface, which would further conduce to deteriorate the corrosion resistance of the extruded sheet.

Since such a special asymmetric c-axis//TD texture rarely appeared in the conventional AZ series alloys, and there hardly any effective process has been reported to deal with it related unsatisfied mechanical properties and corrosion resistance. This study proposes the “texture symmetry” concept to try to optimize the mechanical properties and the corrosion resistance. We provide a simple but effective method to improve both these two performances though special grain re-orientation by employing the pre-straining process. The introduction of symmetric weak basal texture is in favor of improving both of the ductility, strength and sheet formability. Besides, the re-orientation of the $\{10\bar{1}0\}/\{11\bar{2}0\}$ crystalline planes significantly enhanced the corrosion resistance of the Mg-3Li-3Al-1Zn alloy sheet.

## 2. Experimental

The as-extruded Mg-3Li-3Al-1Zn (Mg-2.93 wt.% Li-2.61 wt.% Al-0.78 wt.% Zn-0.32 wt.% Mn, denoted as LAZ331) alloy sheet with 120 mm in width along the transverse direction (TD), 2000 mm length along extrusion direction (ED) and 1.8 mm in thickness, was cut into 120 mm × 50 mm (TD×ED) rectangular specimens for pre-straining process. Uniaxial pre-stretching process was carried out on a CMT6305-300 KN electronic universal testing machine along the length of the rectangular specimens. The specimens were then pre-stretched by 5% along TD. The principle of making samples please refer to [29]. Subsequently, some of the pre-strained samples were annealed at 180 °C for 5 h to remove the dislocations while retain the deformation texture, the others were annealed at 300 °C for 1 h to obtain a fully recrystallized microstructure. For the sake of brevity, the former can be defined as PRS (pre-stretched followed by stress relieving annealing) sample and the latter as PA (pre-stretched followed by recrystallization annealing) sample. Dog bone tensile samples 10 mm in gage length, 3 mm in gage width were machined from the as-extruded LAZ331 sheet, the PRS specimen and the PA specimen along three different directions tilting of 0°, 45° and 90° to ED to evaluate the mechanical properties. The speed of the tensile test was set as 1.5 mm $\text{min}^{-1}$. In tensile test, three samples were tested for each condition and the average value was then obtained. Meanwhile, square samples with 50 mm × 50 mm were machined from the various specimens for Erichsen tests. The Erichsen tests were carried out using a hemispherical punch with a diameter of 20 mm to examine the sheet formability of the various samples at room temperature. The X-ray phase and macro texture analysis was carried out by Rigaku D/Max 2500. The micro grain orientation of the various samples was revealed by EBSD analysis using a HKL Channel 5 system (Oxford system equipped in a FEI Nova 400 FEG-SEM).

Square samples with dimensions of 15 mm × 10 mm (length × width) were cut from the as-extruded sheet, PRS specimen and PA specimen to examine the corrosion response by employing a hydrogen evolution method in 3.5 wt% NaCl solution at 25 °C. The square specimens were cold-mounted in an araldite disc with one side of the specimen surface exposed. The exposed surface area for the following corrosion testing was set as 1.5 $\text{cm}^2$ (15 mm × 10 mm). Prior to corrosion tests, the exposed surface of the various samples was polished gingerly on 400–2000 sandpapers to reduce the effect of surface roughness on corrosion response. Corrosion rate was estimated by evaluating the hydrogen evolution. Furthermore, Corrosion products were then removed using a cleaning solution containing 200 g $\text{l}^{-1}$ $CrO_3$, 10 g $\text{l}^{-1}$ $AgNO_3$ and 20 g $\text{l}^{-1}$ $Ba(NO_3)_2$ at room temperature, and the surface morphologies with corrosion products removed were then characterised by scanning electron microscopy (SEM, TESCAN VEGA) to study evolution of the corrosion attack. Electrochemical measurements were performed on a Parstat 2273 electrochemical workstation. Potentiodynamic polarisation curves were recorded at a scan rate of 1 mV $\text{s}^{-1}$ after 10 min of stabilization at open-circuit potential (OCP). Corrosion current density ($I_{corr}$) and corrosion potential ($E_{corr}$) were estimated by Tafel fitting. During the corrosion tests and the electrochemical measurements, at least three replicates were performed for each test to ensure reproducibility of the results.

## 3. Results

### 3.1. Microstructure and texture analysis of the as-extruded LAZ331 sheet

Fig. 1 shows the microstructure and grain orientation distribution of the as-extruded LAZ331 sheet. The average grain size is measured to be ~35.0 μm. It is worth noting that the 3 wt.% Li-added AZ31 sheet exhibits an unconventional non-basal texture with their basal poles deflecting to TD completely. Such a texture feature is rarely reported in the AZ series alloys while it is universal in the wrought titanium alloys [32]. Furthermore, in addition to the asymmetric distribution of basal poles, there also exists a near $<10\bar{1}0>$//ND preferred orientation of prismatic planes, according to the $\{10\bar{1}0\}$ pole figure. Thus, the extruded LAZ331 sheet shows an extremely asymmetric texture distribution.

### 3.2. EBSD results of the as-extruded sheet, PRS sample and PA sample

The EBSD orientation maps of the three samples are shown in Fig. 2. Unlike the traditional extruded AZ31 alloy sheet (grains mainly in red color, represents the basal planes nearly parallel to extrusion direction), the grains in the as-extruded LAZ331 sheet are mainly in blue or near blue color, which indicates that the c-axis of the majority grains are parallel to TD and the basal planes are perpendicular to the extrusion direction, as shown in Fig. 2 (a). This