

Three-point bending behavior of a ZEK100 Mg alloy at room temperature

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ABSTRACT

Three-point bending and tensile tests were performed on rare earth containing ZEK100 at room temperature and various displacement rates (1.0, 5.0, 10.0, 20.0 and 50.0 mm/min). The bend was either parallel to the rolling direction (RD specimens) or the transverse direction (TD specimens). The TD specimens presented higher bendability than the RD specimens. For the TD specimens, fracture did not occur at low displacement rates of 1.0, 5.0 and 10.0 mm/min, but occurred at 20.0 and 50.0 mm/min. Fracture occurred in the RD specimens at all the displacement rates. Cracks were observed in both the compression zone and the tension zone. Tensile tests in the RD and the TD show that the ductility in the TD is about three times as much as in the RD, leading to the better bendability in the RD specimens. The initial texture was examined by X-ray diffraction (XRD) and the results show that the (0001) basal texture was weakened and spread along the TD due to the addition of the rare earth elements. In-situ electron backscatter diffraction (EBSD) analysis was performed when the specimen was being bent, and the results show that $\{10\bar{1}2\}\langle 10\bar{1}\bar{1}\rangle$ twinning was activated in both the compression zone and the tension zone, different from highly textured AZ31 sheets. Our results indicate that the ZEK100 Mg alloy still presents anisotropy in the tensile properties and in the bending behavior, despite the weakened basal texture.

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1. Introduction

Due to their low densities, magnesium (Mg) and its alloys are deemed as potential structural materials for automotive and aerospace applications where fuel efficiency is a priority. With the low symmetry hexagonal close-packed (HCP) crystal structures, Mg alloys present mechanical behaviors that vastly differ from metals with cubic structures in that: (1) they have a limited number of easy slip systems; (2) profuse twinning is activated and plays a crucial role in the mechanical properties [1–6]; (3) they have a high propensity of texture that is developed during processing [7]. Conventional wrought, i.e., rolled or extruded Mg alloys present a strong basal texture with the basal planes of the grains being nearly parallel to the rolling direction (RD) or extrusion direction (ED). The basal texture leads to anisotropic deformation behavior in wrought Mg alloys, which affects their room temperature formability.

It has been expected that weakening or randomizing the basal texture in Mg alloys might lead to improved formability. One

approach is to microalloy Mg with rare earth elements to produce the “RE texture”, which usually shows a broader orientation spread or a split in the basal pole along the transverse (TD) direction with a lower intensity [8–13]. The weakened basal texture facilitates the activation of basal slip and $\{10\bar{1}2\}\langle 10\bar{1}\bar{1}\rangle$ extension twins when loaded in the TD, resulting in better ductility in that direction. The weakened texture has been associated with recrystallization during processing in the presence of the RE elements [14], and several mechanisms have been proposed. One of the mechanisms is the formation of shear bands and extension twins during plastic deformation in RE-Mg alloys. Grains that have an unfavorable lattice orientation for deformation twinning are prone to the formation of shear bands [15], which act as nucleation sites for the recrystallized grains [16]. It has also been revealed that retardation of recrystallization process weakens the texture. This retardation can be achieved when RE elements, that are less soluble in matrix, segregate at grain boundaries (GBs) and hinder GB migration [8,17,18]. But Stanford [19] showed that faster recrystallization with the addition of RE, when compared to AZ31, still produces a weakened texture. Particle stimulated nucleation (PSN) is also considered as a vital mechanism for the RE texture in Mg alloys that have precipitates larger than 1.0 μm . Around the large particle in the deformed state,

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the sub-grain boundaries migrate swiftly to form new high angle GBs [8,20]. However, the formation of the RE texture can be a combination of these mechanisms [21].

Previous results show that RE-Mg alloys with a randomized texture present improved ductility and mitigated tension–compression asymmetry and reduce in-plane anisotropy [9]. But little work has been done on the three-point bending behavior of RE-Mg alloys, which is significantly involved in the sheet forming of Mg alloys. In this work, we conducted bending tests on a ZEK100 Mg alloy at various displacement rates at room temperature (RT). We also performed tensile tests and in-situ electron backscatter diffraction (EBSD) analysis. The results obtained shed new insight on the bending behavior of RE-Mg alloys.

2. Experimental method

The material used in this work is ZEK100 (1.0% Zn–0.5% Zr–0.3% RE, and the balance is Mg). The rare earth elements are cesium and lanthanum. More details about the microstructure and texture of this sheet metal can be found in [9]. The as-rolled sheet has a thickness of 1.4 mm. Strips with a dimension of $67 (l) \times 6 (w) \times 1.4 (t) \text{ mm}^3$ were sheared from the as-rolled sheet for three-point bending tests. No heat treatment was conducted before bending. The bending tests were performed on an Instron 5882, and the span distance was 15 mm. To study the strain rate sensitivity of three-point bending, various displacement rates of 1.0, 5.0, 10.0, 20.0 and 50.0 mm/min were used. The bending tests were carried out either

along the rolling direction (RD) or the transverse direction (TD). A specimen with the bend parallel to the rolling direction (RD) is designated as the “RD specimen”, and a specimen with the bend parallel to the TD is designated as the “TD specimen”.

To study microstructure and texture evolution during three-point bending, electron backscatter diffraction (EBSD) was conducted. Since the as-rolled sheet experienced large plastic deformation during rolling, meaningful data cannot be obtained from the as-rolled specimens. To perform EBSD, one of the specimens was annealed at 300 °C for 1 h inside a furnace filled with inert argon gas. In-situ EBSD was then conducted on the annealed specimen with a specially designed, in-house fixture that enables EBSD scans on a specimen that is being deformed [22]. In conventional EBSD, scans are performed when a specimen is unloaded after deformation. The in-situ capability in this work makes it possible to scan the specimens during bending, i.e., without being unloaded, to examine the microstructure and texture evolution during deformation. The EBSD scans were conducted through the thickness of the sheet specimens using a Zeiss Supra 40 Field Emission Gun Scanning Electron Microscope (FEG-SEM) equipped with an EDAX Hikari EBSD detection system. The through-thickness cross section of the annealed specimen was metallographically polished and then electropolished using a Struers electropolisher and the standard C1 Struers electrolyte (160 mg sodium thiocyanate, 800 ml ethanol, 80 ml ethylene glycol monobutyl ether, and 20 ml distilled water). EBSD scans were performed at two different locations: above and below the neutral axis, i.e., the compression zone and the tension zone, respectively, and with a step size of 0.35 μm . The initial macrotexture of the as-rolled ZEK100 sheet was examined by X-ray diffraction (XRD), using a Regaku SmartLab X-ray diffractometer with a Cu-K α radiation source, 40 kV operating voltage, and a 30 mA current.

To examine the anisotropy in the mechanical properties of the as-rolled sheet, tensile tests were performed along the RD and the TD direction at RT. Dog-bone specimens were machined with a gauge length 25.4 mm. Various displacement rates were used in the tensile tests: 1.0, 5.0, 10.0, 20.0 and 50.0 mm/min.

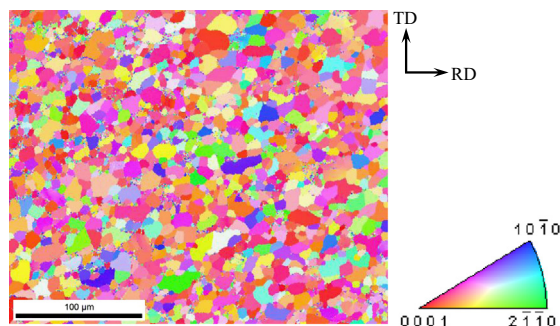


Fig. 1. EBSD IPF map of the initial microstructure of the annealed ZEK100 RD specimen. The average grain size is about 10 μm . The grain size of the as-rolled sheet should be smaller. EBSD step size: 0.35 μm .

3. Results

The grain structure of the annealed specimen is shown in Fig. 1. The grain size is about 10 μm . Grain growth occurred during annealing, so the initial grain size of the as-rolled sheet should be smaller. The initial XRD texture of the as-rolled sheet is shown in Fig. 2. Indeed, the initial texture is randomized to a certain

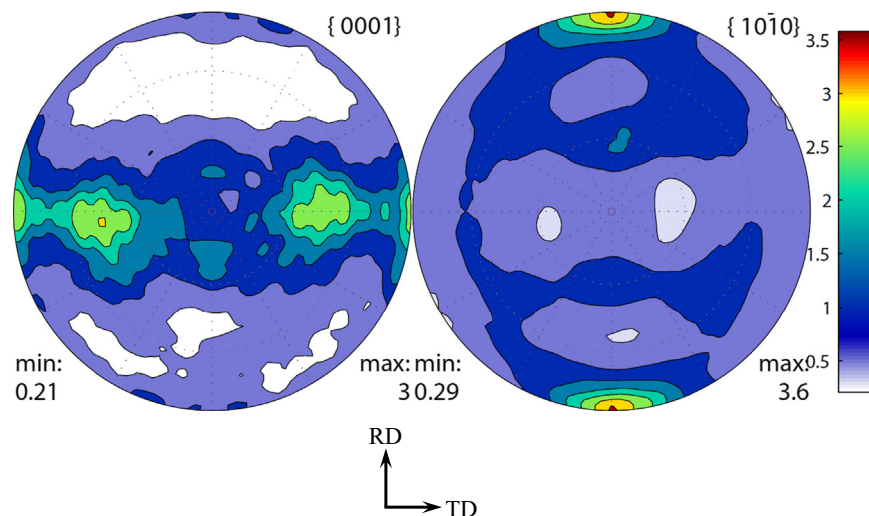


Fig. 2. Pole figure of the as-rolled ZEK100 measured by XRD. The sheet does not exhibit strong basal texture. Instead, two intensity spots appear off the center, indicating weakened basal texture compared with other rolled Mg alloys such as AZ31. The $\{10\bar{1}0\}$ prismatic planes still present a strong pole along the rolling direction.

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