

Impact of Texture on r -value and its Measurement in Magnesium Alloy Sheets

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ABSTRACT

The impact of texture on r -value and its measurement in magnesium alloy sheets has been studied using digital image correlation and electron backscatter diffraction techniques. Two magnesium alloy sheets with distinct textures were used in the present study, namely, AZ31 with a strong basal texture and ZE21 with a randomized texture.

It is well known that a conventionally processed AZ31 magnesium sheet has strong basal texture, necessitating contraction and double twinning to accommodate thinning strain. The strain distribution on the sheet surface evolves nonlinearly with strain, impacting the measured r -value. In particular, the normal approach to measuring r -value based on average strains over the gauge section leads to the erroneous conclusion that r -value increases with deformation. When the r -value is measured locally at any point inside or outside the neck, the r -value is shown to have a constant value of 3 for all strain values. In contrast, in ZE21 magnesium alloy sheet containing 2 wt.% zinc and 1 wt.% cerium, a random texture can be obtained using an annealing schedule reaching full recrystallization of the material. This material exhibits more uniform deformation and much longer tensile elongation. There is then no discrepancy between the r -value measured locally and globally and the r -value is close to 1.

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INTRODUCTION

Magnesium alloy sheets have been well recognized to be utilized in the automotive industry for further structural lightweighting in the near future due to their low density, superior specific tensile strength and rigidity compared to steel and aluminum alloys. However, it is also well known that the formability of wrought magnesium alloys at room temperature is inferior to that of steel and aluminum alloys. This is due to magnesium's hexagonal closed packed crystal structure and the resultant lack of active slip systems, especially at room temperature [1-2]. General deformation therefore requires twinning to be activated which has a deleterious effect on ductility.

The anisotropy of plasticity in Mg alloys affects yield asymmetry between tensile and compressive deformation, the r -value (width to thickness strain ratio), and forming limit diagram, amongst other properties [3, 4, 5, 6, 7, 8]. Most studies in the literature on the relationship between the mechanical properties and deformation mechanisms have relied on macroscopic stress-strain measurements and uniform strain assumptions along the tensile gage length (common in

studies of cubic metals such as steel and aluminum) to interpret microstructural observations. However, we reported recently [9] that the strain distribution on the sheet surface in AZ31 alloy sheet evolves nonlinearly with strain, impacting the measured plastic strain ratio, r -value. The results show that the r -value should be measured at "points" rather than over the "gage length" in Mg alloys with a strong basal texture like AZ31.

In this contribution, the impact of texture on r -value and its measurements in two magnesium alloy sheets, AZ31 and ZE21 with distinct textures is further studied using digital image correlation for local deformation measurements on specimen surface coupled with electron backscatter diffraction for texture measurements.

EXPERIMENTAL

Two magnesium alloy sheets with distinct textures were used in the present study, namely, AZ31 with a strong basal texture and ZE21 with a random texture.



2mm thick AZ31 rolled sheet material with nominal composition of 3 wt. % Aluminum and 1 wt. % Zinc was used in the present study. The material was annealed at 350 °C for 30 minutes in a furnace and air cooled to obtain a fully recrystallized microstructure. The resulting structure has an average grain size of 16 µm [9]. ZE21 rolled sheet material with nominal composition of 2 wt.% Zn and 1 wt.% Cerium was annealed at 400 °C for 1 hour in a vacuum furnace and air cooled to obtain a stable microstructure and optimal mechanical properties. The average grain size was 40µm. Details of thermal mechanical processing and microstructural evolution will be reported elsewhere.

Electron backscatter diffraction was used to measure the initial texture of both AZ31 and ZE21. The EBSD measurements were conducted on the specimen surface plane in a LEO 1450 scanning electron microscope operating at 20kV equipped with a TSL EBSD camera at a step size of 0.1 µm.

Uniaxial tensile samples were machined according to ASTM standard B557-10 [10] with a gage length of 20 mm and larger transition radius ensuring fracture within the gage length. The tensile tests were conducted at room temperature at a nominal strain rate of 6×10^{-4} /s. An extensometer of 20 mm was used to measure the tensile strain during testing. A commercially available optical strain measurement system, Aramis^{TD} [11], based on digital image correlation, was used to measure the surface strain during uniaxial tensile tests. The images were taken at a rate of 1 image per second with a camera shutter time less than 0.1 second. A facet size of 15 pixels and step size of 13 pixels were used for the strain calculation. This was calibrated to be equivalent to a gage length of 0.30mm.

The influence of the inhomogeneous deformation on mechanical properties of the material is determined using the plastic strain ratio, r-value, which is commonly defined as [12-13]

$$r = \frac{\varepsilon_w}{\varepsilon_t} = - \frac{\varepsilon_w}{\varepsilon_t + \varepsilon_w} \quad (1)$$

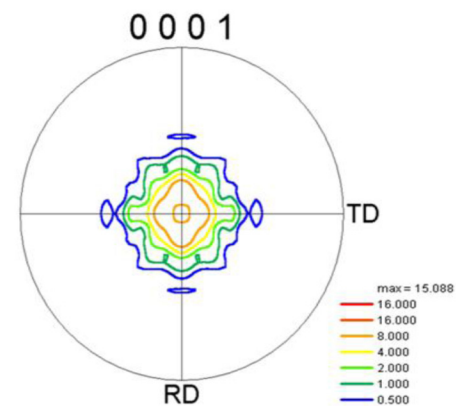
where ε_l , ε_w , ε_t are longitudinal, width and thickness strains, respectively.

Thickness strain is difficult to measure using an extensometer during standard tensile testing. Two extensometers are usually used over a certain gage length in the longitudinal and width directions. Using the assumptions of constant volume in plastic deformation and uniform strain distribution over the gage length, the r-value is determined based on measurements of longitudinal and width strains using Equation (1) [13].

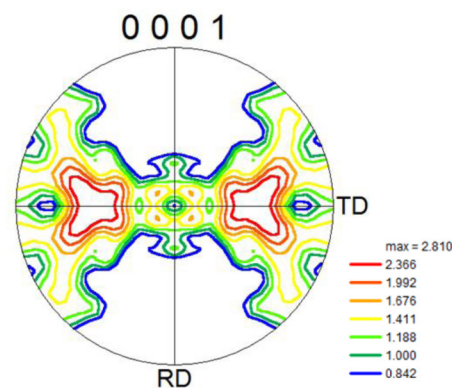
RESULTS AND DISCUSSION

The EBSD maps taken on the specimen surface planes were used to construct pole figures of AZ31 and ZE21 alloy sheets (Fig. 1). It is seen in Fig. 1(a) that AZ31 has a strong basal texture (peak intensity of 16) after annealing while ZE21 has a random texture and weak basal texture (peak intensity of 2.8) (Fig. 1(b)). The latter results are consistent with the observations in literature on Cerium containing Mg alloy sheets [14-15].

The engineering stress - engineering strain curves of AZ31 and ZE21 sheets pulled along the rolling direction (RD) are shown in Fig. 2. The data shows that there is an early onset of diffuse necking in both materials followed by prolonged post necking deformation. It is noted that ZE21 has a much lower yield stress and ultimate strength but a slightly longer elongation compared to AZ31.



(a)



(b)

Figure 1. Pole figures of (a) AZ31 (b) ZE21.