Materials Science & Engineering A 567 (2013) 101–109

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

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

Effect of inhomogeneous deformation on anisotropy of AZ31 magnesium sheet

Jidong Kang [a,*], David S. Wilkinson [b], Raja K. Mishra [c], Wei Yuan [d], Rajiv S. Mishra [e]

[a] CanmetMATERIALS, 183 Longwood Road South, Hamilton, Ontario, Canada L8P 0A5
[b] Department of Materials Science and Engineering, McMaster University, 1280 Main Street West, Hamilton, Ontario, Canada L8S 4L7
[c] General Motors Research and Development Center,30500 Mound Road, Warren, MI 48090-9055, USA
[d] Center for Friction Stir Processing, Department of Materials Science and Engineering, Missouri University of Science and Technology, Rolla, MO 65409, USA
[e] Center for Friction Stir Processing, Department of Materials Science and Engineering, University of North Texas, Denton, TX 76203, USA

ARTICLE INFO

Article history:
Received 18 July 2011
Received in revised form
24 July 2012
Accepted 24 August 2012
Available online 5 September 2012

Keywords:
Magnesium alloy
Plastic deformation
r-Value
Necking
Friction stir processing

ABSTRACT

Inhomogeneous plastic deformation in AZ31 magnesium sheet has been studied during uniaxial tensile testing using digital image correlation and electron backscatter diffraction techniques. Large strain gradients develop on the sheet surface parallel and perpendicular to the loading direction while very little deformation occurs in the thickness direction. This lack of thinning leads to an abrupt fracture following the development of a premature but extensive diffuse neck but without any localized neck. The strain distribution on the sheet surface evolves nonlinearly with strain, impacting the measured plastic strain ratio, *r-value*. The results show that *r*-value should be measured at "points" rather than over the "gage length" in Mg alloys. Friction stir processing modifies the basal texture and thus significantly improves the forming limit for in-plane plane strain path.

1. Introduction

There is increasing interest in utilization of magnesium alloys in automotive applications due to their low density, superior specific tensile strength and rigidity compared to steel and aluminum alloys [1–2]. However, it is well recognized that the formability of wrought magnesium alloys at room temperature is inferior to these competitors. The poor formability of magnesium alloys is due to their hexagonal close packed crystal structure and the consequent lack of sufficient active slip systems at room temperature [1–2], requiring that twinning be used to enable general shape change in a polycrystal. Because twin activation is stress-state dependent, Mg alloys also exhibit significant plastic anisotropy resulting in asymmetry between tension and compression in terms of yield stress, and plastic strain ratio (*r*-value, i.e. width to thickness strain ratio) for example [3–8]. Most published studies on the relationship between the mechanical properties and deformation mechanisms have relied on macroscopic stress–strain measurements and assume uniform strain over the tensile gage length (common in studies of cubic metals such as steel and aluminum) to interpret microstructural observations. In this paper we question the validity of this assumption when applied to Mg alloys.

The influence of the inhomogeneous deformation on mechanical properties is revealed from a measurement of the plastic strain ratio, the so-called *r*-value, which is commonly defined as [9–10]

$$r = \frac{\varepsilon_w}{\varepsilon_t} = -\frac{\varepsilon_w}{\varepsilon_l + \varepsilon_w} \tag{1}$$

where ε_l, ε_w, and 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 and the incompressibility criterion along with the assumption of uniform strain distribution over the gage length is used to determine the *r*-value [10]. In practice, when two extensometers are not available, high elongation strain gages are used instead [11] or one simply measures the specimen width at a given axial strain [12].

Usually *r*-values are constant once the strain is at relatively large, e.g. at strain of 10–15% and beyond (depending on the materials) [9–10]. However, it has been reported that for AZ31 magnesium sheets, *r*-values increase with increasing global strain [11–12]. This has posed a challenge to numerical modeling and

* Corresponding author. Tel.: +1 905 645 0820; fax: +1 905 645 0831.
E-mail address: jkang@nrcan.gc.ca (J. Kang).

0921-5093/$ - see front matter © 2012 Crown Copyright and Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2012.08.117

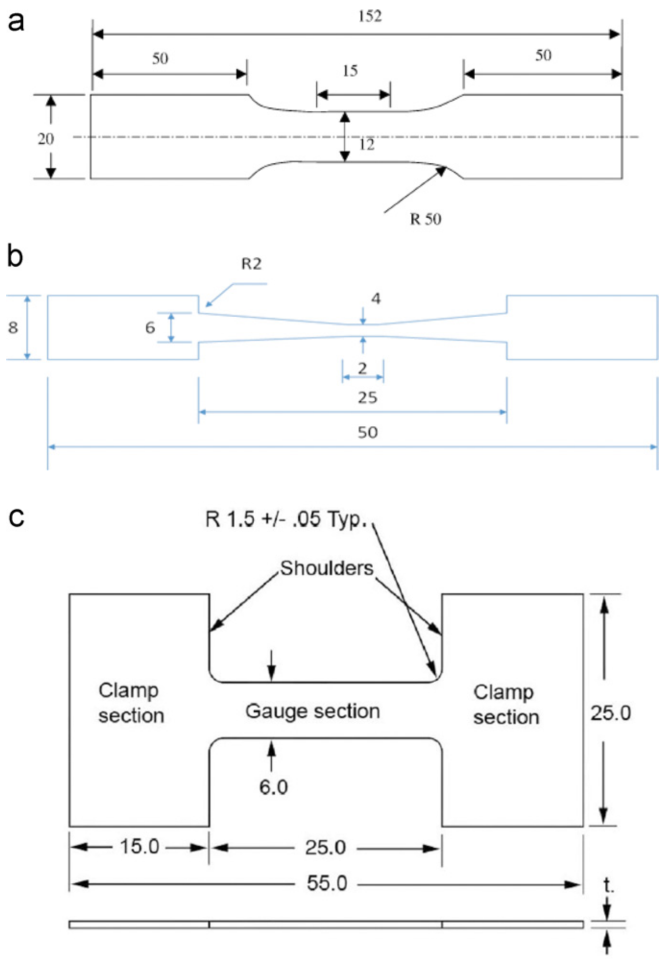

Fig. 1. Tensile samples: (a) uniaxial tensile sample for as received AZ31 materials, (b) tapered tensile sample, and (c) uniaxial tensile sample for friction stir processed materials.

raised questions of the validity of the *r*-value in magnesium alloys.

This study addresses these issues. We present experimental data from simultaneous measurement of local strain and its evolution on the flat surface and the through thickness plane of the tensile sample using the digital image correlation (DIC) technique. Electron backscattered diffraction (EBSD) of the same surfaces is used to determine the nature of twinning accompanying the deformation. The dependence of the inhomogeneity of deformation on the deformation mechanism as well as the influence it has on the measurement of macroscopic *r*-values will also be discussed.

Friction stir processing (FSP) has been used to process magnesium alloys in order to refine the microstructure and enhance strength [13–16]. It has been shown that there is significant modification of the basal texture during FSP [16–18]. In this contribution, we focus our effort on the impact of the texture modification by FSP on *r*-values and include the FSP AZ31 data along with that for rolled AZ31 data to confirm our interpretation.

2. Experimental procedures

A 2 mm thick AZ31 sheet material with a nominal composition of 3 wt% Aluminum and 1 wt% Zinc was used in the present study. The sheets were annealed at 450 °C for 30 min in a vacuum furnace and cooled to obtain a recrystallized starting microstructure. The resulting grain structure has an average grain size of 16 μm. Uniaxial tensile samples were machined according to ASTM standard B557-10 [19] with a gage length of 20 mm and larger transition radius ensuring fracture within the gage length (Fig. 1(a)). The tensile tests were conducted at room temperature at a nominal strain rate of 6×10^{-4}/s. A commercially available optical strain measurement system based on DIC, Aramis[TD] [20], was used to measure the surface strain during uniaxial tensile tests on both the sample surface and through thickness plane simultaneously. A random ink pattern was applied to the sample surface within the gage length using airbrush prior to tensile

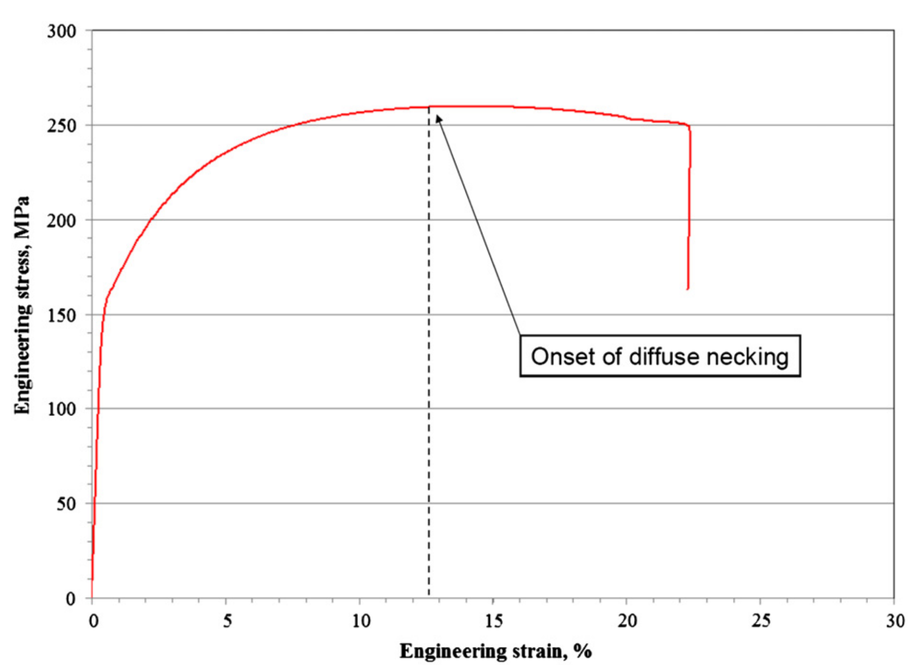

Fig. 2. Engineering stress–engineering strain curve of an AZ31 sheet material.