Materials Science and Engineering A 527 (2010) 5984–5989

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Factors influencing tensile ductility of ultrafine-grained Mg–3Al–1Zn alloy sheet at elevated temperatures

W.J. Kim*, B.H. Lee

Dept. of Materials Science and Engineering, Hongik University, 72-1 Mapo-gu, Sangsu-dong, Seoul 121-791, Republic of Korea

ARTICLE INFO

Article history:
Received 11 May 2010
Received in revised form 27 May 2010
Accepted 27 May 2010

Keywords:
Mechanical characterization
Magnesium alloys
Thermomechanical processing
Grain refinement

ABSTRACT

Tensile elongation behavior of ultrafine-grained (UFG) Mg–3Al–1Zn (AZ31) alloy sheet (with a mean grain size of 1 μm) produced by high-ratio differential speed rolling was studied at elevated temperatures, and factors influencing the ductility were evaluated. The UFG AZ31 showed an obvious advantage in ductility enhancement below 473 K, but the maximum forming temperature was limited due to high thermal instability of the UFG AZ31 microstructure. There was a pronounced effect of grain coarsening during the sample heating and deformation on strain-rate sensitivity and strain hardening. The tensile elongation behavior of UFG AZ31 with high density of thermally stable (Al, Mg)$_2$Ca particles was compared with that of UFG AZ31 to see what happens if grain coarsening is well suppressed in UFG AZ31 alloy.

1. Introduction

Grain refinement can be an effective way of enhancing the formability of Mg alloys at elevated temperatures because the contribution from grain boundary sliding on total deformation increases as grain size decreases. In recent years, grain refinement of Mg alloys via severe plastic deformation (SPD) [1–3] has attracted great attention. Among wrought Mg alloys, AZ31 alloy has been most widely used for hot deformation processes as it has good strength–ductility balance and high corrosion resistance. Achievement of ultrafine-grain (UFG) size in AZ31 alloy using SPD methods is, however, challenging because there is a lower limit processing temperature due to its hexagonal close packed (HCP) crystal structure with limited slip systems below 473 K, and the corresponding alloy composition lacks second phase particles that can promote particle-stimulated nucleation and inhibit rapid grain coarsening during plastic deformation. Recently, the authors reported a novel method for fabricating UFG AZ31 Mg alloy sheets using a high-ratio differential speed rolling (HRDSR) technique, where non-preheated sample was deformed by intensive shear straining in the hot rolls of which rotational speeds are largely different at the upper and lower rolls [4]. In the present work, tensile elongation behavior of this UFG AZ31 alloy at elevated temperatures was examined and analyzed to find deformation parameters which promise enhanced forming capability of UFG AZ31 compared to conventionally grain sized AZ31. As thermal instability was high in the UFG AZ31 alloy, grain growth during the sample heating and deformation yielded a pronounced effect on ductility.

2. Experimental methods

The material used in this study was a 110 mm wide and 2 mm thick AZ31 (nominal composition of 3 wt.% Al, 1 wt.% Zn, 0.3 wt.% Mn, balance Mg) sheet. The as-received sheet had a mean grain size (d) of 9 μm and a typical basal fiber texture with intensity of 7.5 [4]. Rolling was conducted under non-lubricated conditions. The diameters of the upper and lower rolls were identical (400 mm) and the ratio of upper to lower roll speed was set at 3. A cold sample was fed into the hot rolls, preheated at 473 K, and a total thickness reduction ratio of 73% was achieved by two-step rolling: the sheet was rolled to 1.65 mm in thickness, cooled in air, and then rolled again to the final thickness of 0.55 mm (hereafter, denoted as UFG AZ31). A detailed description of the processing procedure can be found in Ref. [4].

Tensile specimens were cut from the sheets with 5 mm gauge length lying parallel to the rolling direction. They were tested at temperatures of room temperature (RT) and 423, 448, 473, 498, 523 and 548 K in air at a fixed initial strain rate of 1×10^{-3} s^{-1}. For comparison purposes, a commercially available AZ31 sheet with a thickness of 0.5 mm (hereafter, denoted as FG AZ31) was prepared and tested in tension under the same experimental conditions. To determine the variation in strain-rate sensitivity (m) with temperature, strain-rate change (SRC) tests were conducted at each temperature at which the crosshead speed was periodically changed between 0.005 mm s^{-1} and 0.01 mm s^{-1} (near a strain rate of 1×10^{-3} s^{-1}) until true strain reaches 0.37. Approximately 3%

* Corresponding author. Tel.: +82 2 320 1468; fax: +82 2 325 6116.
E-mail address: kimwj@wow.hongik.ac.kr (W.J. Kim).

0921-5093/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.msea.2010.05.090

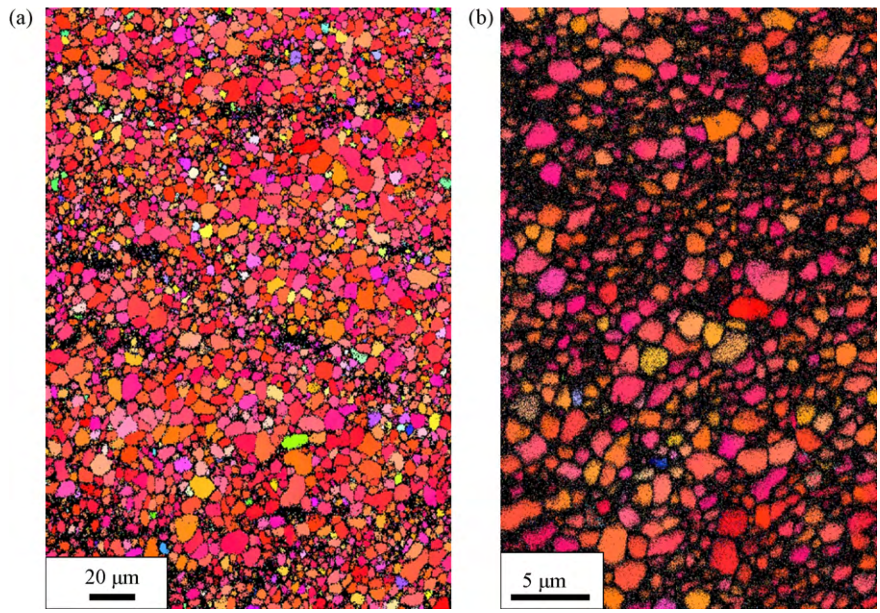

Fig. 1. EBSD images of (a) FG and (b) UFG AZ31.

plastic strain was given between the two speeds. In addition to SRC tests, tensile elongation-to-failure tests were conducted to evaluate tensile ductility at various temperatures at a fixed strain rate of $1 \times 10^{-3}\,s^{-1}$. In tensile testing, the tensile jig was preheated and then the sample was mounted onto the sample holder. It took only 5 min to reach the designated temperature again. Then, the sample was allowed to equilibrate in temperature for an additional 5 min before initiating straining. A rapid temperature increase to the target temperature is important to conserve the UFG microstructure before tensile loading is initiated, which will be discussed later.

The electron back-scattering diffraction (EBSD) analysis for the FG was performed with a step size of 1000 nm. For the SP sheet, the step size was 50 nm. The cross-sections of the sheet containing the normal direction (ND) and rolling direction (RD) were examined. TSL version 5.31 was used as the analysis software.

3. Results and discussion

Fig. 1(a) and (b) shows the electron back-scattering diffraction (EBSD) images for FG AZ31 and UFG AZ31, taken at their middle layers, respectively, showing that both microstructures consist of equiaxed grains. The mean grain size (d) of FG AZ31 is 3.4 μm. The microstructure of the UFG AZ31, which is reasonably homogeneous along the thickness direction, shows equiaxed grains with $d = 1$ μm. The (0 0 0 2) pole figures of FG AZ31 and UFG AZ31 obtained from EBSD analysis are shown in Fig. 2(a) and (b), respectively. The pole figures show that the textures of both materials are ND (normal direction)//{0 0 0 1} basal fiber textures. The texture intensity of UFG AZ31 is, however, noticeably higher than that of FG AZ31 (30 vs. 14). As the microstructure of UFG AZ31 retains strong basal fiber texture, it is suggested that grain refinement by HRDSR proceeds by continuous dynamic crystallization.

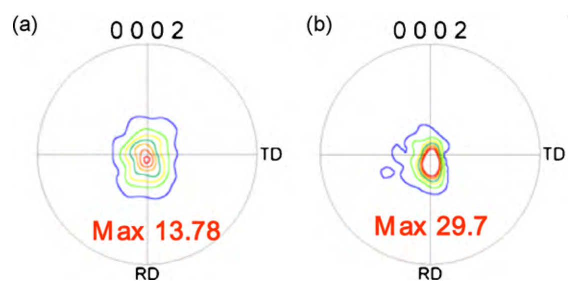

Fig. 2. The (0 0 0 2) pole figures of FG AZ31 and UFG AZ31 obtained from EBSD analysis.

Fig. 3(a) and (b) shows the true stress–true strain curves for FG AZ31 and UFG AZ31 at different temperatures at a fixed strain rate of $10^{-3}\,s^{-1}$. Strain-rate sensitivity m values of FG AZ31 and UFG AZ31 were measured near a strain rate of $1 \times 10^{-3}\,s^{-1}$ using

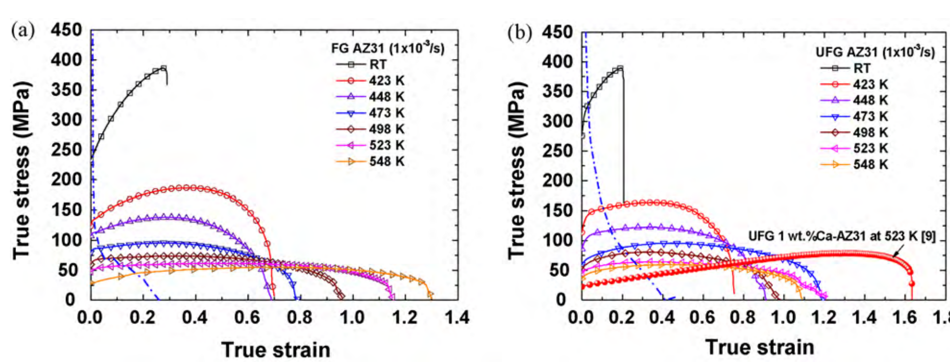

Fig. 3. True stress–true strain curves of (a) FG and (b) UFG AZ31 in tension at various temperatures. The dashed curves represent the Hart's necking criterion (Eq. (1)) at 473 K.