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# Analysis of high-temperature deformation and microstructure of an AZ31 magnesium alloy

S. Spigarelli [a,*], M. El Mehtedi [a], M. Cabibbo [a], E. Evangelista [a], J. Kaneko [b], A. Jäger [c], V. Gartnerova [c]

[a] *Department of Mechanics, Università Politecnica delle Marche, Via Brecce Bianche, I-60131 Ancona, Italy*

[b] *Department of Mechanical Engineering, College of Industrial Technology, Nihon University, 1-2-1, Izumi-cho, Narashino, Chiba 275-8575, Japan*

[c] *Department of Metal Physics, Charles University, Prague, Czech Republic*

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**Abstract**

High-temperature plastic deformation and dynamic recrystallization of AZ31 extruded (EX) and heat treated (FA) alloy was investigated in the temperature range between 200 and 400 °C. High-temperature straining resulted in partial dynamic recrystallization above 250 °C; in the EX alloy recrystallization was complete at 300 °C, while a moderate grain growth was observed at 400 °C. The peak flow stress dependence on temperature and strain rate are described by means of the conventional sinh equation; the calculation of the activation energy for high temperature in the whole range of temperature deformation gives $Q = 155$ kJ/mol, i.e. a value that was reasonably close but higher than the activation energy for self diffusion in Mg. The microstructure resulting from high-temperature straining was found to be substantially different in EX and FA alloys; in particular, the EX alloy was characterized by a lower flow stress, a higher ductility and by a finer size of the dynamically recrystallized grains. These results are then discussed on the basis of the "necklace" mechanism of dynamic recrystallization.
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*Keywords:* Magnesium alloys; Hot deformation; Microstructure; Recrystallization

## 1. Introduction

Plastic deformation of AZ31 (Mg–3Al–1Zn; wt.%) alloy has been widely investigated, since this material is well suited for sheet production by rolling; a proper control of rolling conditions, in particular, allows to produce a fine grain size due to dynamic recrystallization (DRX). Recent studies of AZ31 [1] analysed the microstructural development occurring during plastic deformation and suggested that DRX initiated at about 300 °C. The lower limit for DRX to occur, on the other hand, had been shifted towards lower temperatures by Tan and Tan [2], who indicated 250 °C, $1 \times 10^{-4}$ s$^{-1}$ to be the optimum straining condition to obtain a fine-grained (6 μm) structure. Other authors analysed the influences of texture and deformation conditions [3,4] and grain size [5,6]. AZ31 sheets suitable of superplastic forming operations could be produced by operating a strict control over straining condition [2,7], but the coarse-grained materials processed in a proper window of temperature and strain rates exhibit considerable ductility, up to 200% at $3 \times 10^{-5}$ s$^{-1}$ and 375 °C [8], as a result of the relatively high strain rate ($\dot{\varepsilon}$), sensitivity ($m$) ($m = \partial \log \sigma / \partial \log \dot{\varepsilon}$) of the flow stress ($\sigma$).

The aim of the present work is to further investigate the hot formability of an AZ31 magnesium alloy in the temperature range between 200 and 400 °C in terms of flow stress and microstructure of the deformed material. In particular, the effect of the initial structure was considered by testing the alloy in as-extruded condition, and by comparing the results with those previously obtained by testing the same material in fully annealed state [9].

## 2. Experimental procedure

The AZ31 alloy was investigated in the as-extruded condition (EX) and after a heat treatment at 500 °C for 2 h in order to achieve a fully equiaxed and coarse grain structure (condition FA) [9]. Torsion tests were carried out on samples machined from the extruded rods. The equivalent stress $\sigma$ and the equivalent strain $\varepsilon$ were calculated using the simplified

* Corresponding author. Tel.: +39 071 2204746; fax: +39 071 2204799.
*E-mail address:* s.spigarelli@univpm.it (S. Spigarelli).

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relationships [10]:

$$\sigma = 3\frac{\sqrt{3}M}{2\pi R^3} \quad (1)$$

$$\varepsilon = \frac{2\pi NR}{\sqrt{3}L} \quad (2)$$

where $R$ and $L$ are the gauge radius and length, respectively, $N$ the number of revolutions and $M$ is the torque. The surface equivalent strain rates were $5\times10^{-2}$, $5\times10^{-1}$ and $5\,\mathrm{s}^{-1}$. Testing temperatures ranged from 200 to 400 °C; additional tests were carried out at 25 and 100 °C. Water jets were used to quench the specimens after rupture, thus avoiding microstructure modifications during slow cooling from the testing temperature.

The microstructure after high-temperature deformation was investigated using optical microscopy along the surface of the gauge length.

## 3. Results and discussion

The microstructure of the alloy is illustrated in Fig. 1. The EX condition exhibits a bimodal distribution of very fine recrystallized and large elongated grains; this microstructure was produced by partial dynamical recrystallization during extrusion of the coarse-grained ingot. After heat treatment the FA condition shows a fully homogeneous and coarser equiaxed microstructure.

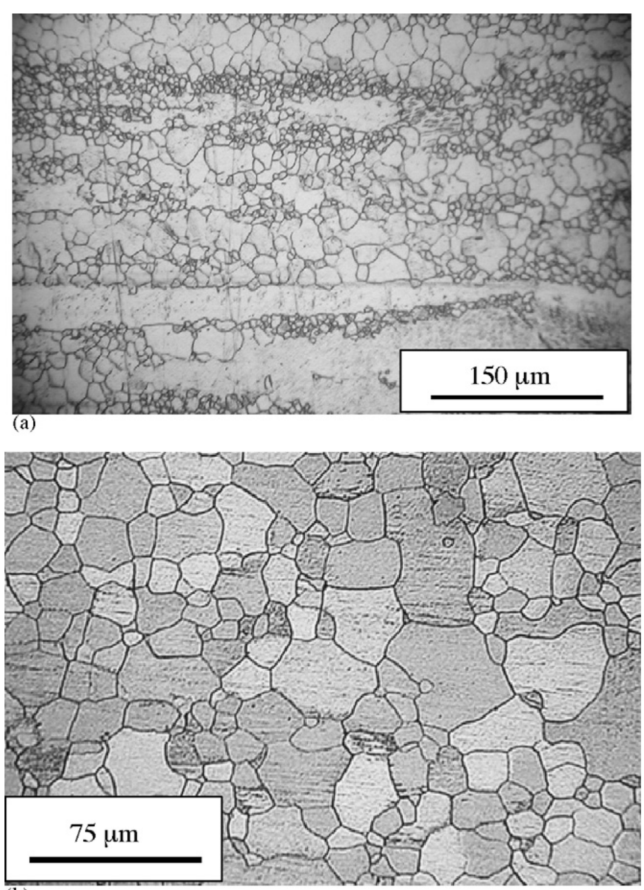


Fig. 1. Optical micrographs of the as-extruded (EX) (a) and heat-treated (500 °C, 2 h, FA) alloy (b).

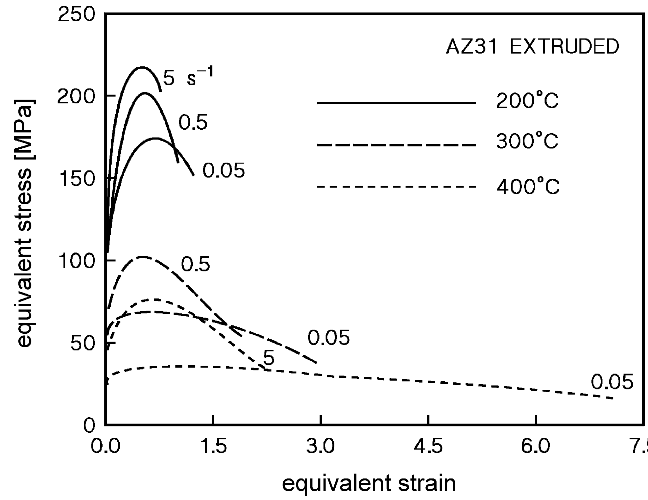


Fig. 2. Representative equivalent stress vs. equivalent strain curves for the EX condition.

Representative equivalent stress versus equivalent strain flow curves at different deformation temperatures and strain rates are shown for the EX condition in Fig. 2. The stress increases to a maximum and then decreases to final rupture. The shape of the flow curves is similar for the FA condition, but the equivalent strain to fracture is substantially lower than in the EX state (Fig. 3).

The temperature and strain rate dependence of the peak stress are shown in Fig. 4. The experimental data are well described by the equation [11]

$$\dot{\varepsilon} = A[\sinh(\alpha\sigma_\mathrm{p})]^n \exp(-Q_\mathrm{HW}/RT) \quad (3)$$

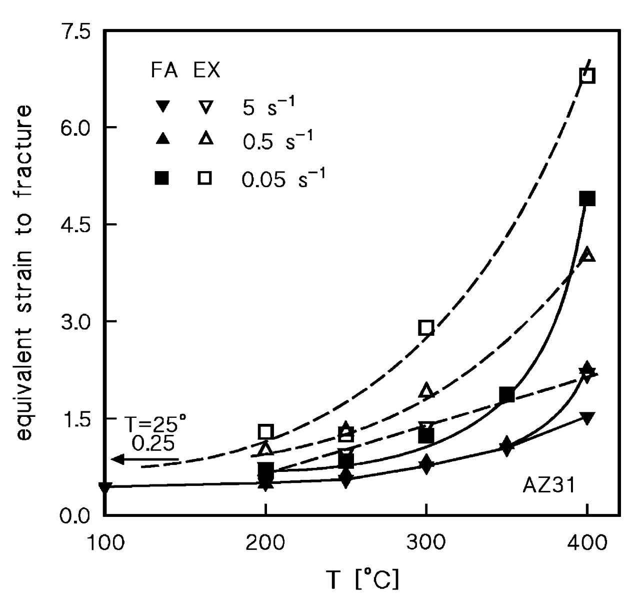


Fig. 3. Equivalent strain rate fracture for the FA and EX conditions.

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