Materials and Design 49 (2013) 209–219

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Hot tensile deformation and fracture behaviors of AZ31 magnesium alloy

Jiao Deng [a,b], Y.C. Lin [a,b,*], Shui-Sheng Li [a,b], Jian Chen [c], Yi Ding [a,b]

[a] School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China
[b] State Key Laboratory of High Performance Complex Manufacturing, Changsha 410083, China
[c] School of Energy and Power Engineering, Key Laboratory of Efficient and Clean Energy Utilization, Changsha University of Science and Technology, Changsha 410076, China

ARTICLE INFO

Article history:
Received 6 November 2012
Accepted 9 January 2013
Available online 20 January 2013

Keywords:
Magnesium alloy
Plastic deformation
Fracture morphology
Deformation mechanisms

ABSTRACT

The hot tensile deformation and fracture behaviors of the hot-rolled AZ31 magnesium alloy were studied by uniaxial tensile tests with the temperature range of 523–723 K and strain rate range of 0.05–0.0005 s^{-1}. Effects of deformation parameters on the strain hardening rate, strain rate sensitivity, microstructural evolution and fracture morphology were discussed. The results show that: (1) The flow curves show a considerable strain hardening stage and no obvious diffuse necking stage under the relatively low temperatures (523 and 573 K). (2) The elongation to fracture increases with the increase of the deformation temperature. But, the sharp drop of the elongation to fracture under 723 K and 0.0005 s^{-1} results from the synthetical effects of the grain growth, inverse eutectic melting reaction ($\alpha + \beta = L$) and the incipient melting of α matrix. (3) For the case with the deformation temperature of 623 K and relatively low strain rates, the fracture mechanism is the combination of the void coalescence and intergranular fracture. (4) Under the deformation temperature of 723 K, the fine recrystallized grains experienced a rapid growth and the deformation mechanism is the dislocation creep with the help of inverse eutectic liquid phase. (5) The presence of proper amount of liquid phase on the grain boundary changes the deformation mechanisms, and makes great contribution to the high ductility. However, it will deteriorate the material ductility if the amount of liquid phase is too much.

1. Introduction

Magnesium alloys are widely used in a variety of technology-related applications, especially in automotive products [1]. The preferential disposition towards the selection and use of magnesium alloys is always attributed to its light weight, high specific strength and fatigue strength, and fine cutting performance, etc. [2,3]. Due to the hexagonal close-packed (HCP) structure, magnesium alloy has a poor plastic deformation capacity at room temperature [4]. However, the magnesium alloys can be extremely ductile and readily formable under high temperatures and moderate strain rates [5]. When temperature is increased, the critical shear stress of non-basal plane slip system is reduced because of the increase of the amplitude of the atomic vibration, and then some potential non-basal plane slip systems, such as the prismatic and pyramidal plane, are promoted by the thermal activation [6].

It is well known that the dynamic recrystallization (DRX) can refine the grain during the hot deformation. As an important softening and grain refinement mechanism, the DRX has a great significance to the control of microstructures and the improvement of mechanical properties. Dynamic recrystallization behaviors of Cu-bearing HSLA-100 steel [7], AISI 410 martensitic stainless steel [8], 17-4 PH stainless steel [9], 42CrMo steel [10] were studied. Mandal et al. [11–13] investigated the kinetics, mechanism and modeling of microstructural evolution during dynamic recrystallization in a titanium-modified austenitic stainless steel. The state of stress does not alter the mechanisms of DRX nucleation but hinder the kinetics of DRX during plane-strain deformation [14]. Lin et al. [15–17] investigated the microstructural evolution during DRX in the alloy 42CrMo steel and obtained the general mechanisms of DRX. i.e., with the increase of the deformation temperature, the dynamic recrystallization easily occurs and the microstructures become more and more homogenous. But, the grains also easily grow up because of the enhancement of the grain boundary diffusion and migration when the deformation temperature is high enough [15]. It is popular understood that more substructures can be generated in the initial grains when strain rate is higher, which will produce more nuclei per unit volume of the grains. This mechanism can make the grain finer when strain rate is higher [16]. When the strain rate is decreased, the dynamic recovery rate increases and the dynamic recovery proceeds adequately or the recrystallization occurs during deformation. However, there is not sufficient deformation energy for complete recrystallization, and then the recrystallization degree is small [17]. Mandal et al. [18] pointed out that the extent of DRX increases with increasing strain rate and temperature. The acceleration of DRX with strain

* Corresponding author at: School of Mechanical and Electrical Engineering, Central South University, Changsha 410083, China. Tel.: +86 013469071208.
E-mail addresses: yclin@csu.edu.cn, linyongcheng@163.com (Y.C. Lin).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.01.023

Table 1
Chemical compositions of AZ31 magnesium alloy (wt.%).

Al	Zn	Mn	Si	Cu	Ni	Be	Fe	Mg
3.19	0.81	0.334	0.02	0.05	0.001	0.02	0.005	Bal.

Table 2
The repeatability errors for the elongation to fracture under different deformation conditions (%).

Strain rates (s^{-1})	Deformation temperatures (K)				
	523	573	673	623	723
0.01	4.70	4.49	3.85	4.76	3.83
0.05	4.03	4.61	3.97	4.18	3.84
0.001	4.57	4.85	3.32	4.15	4.20
0.005	3.61	3.90	4.04	3.60	4.11
0.0005	4.73	4.85	4.65	3.16	4.10

rate is attributed to the increased rate of dislocation accumulation during high strain rates and high temperatures [19]. Therefore, the suitable temperature and strain rate should be taken into account to obtain a refined grain.

In order to expand the application scope of magnesium alloys, the superplastic forming properties under the specific deformation temperature and strain rate have drawn much attention of researchers [20–28]. Wei et al. [20] and Watanabe et al. [21] studied the superplasticity of AZ91 magnesium alloy. Kim et al. [22,23] studied the superplasticity of magnesium alloy sheets, and found that the grain boundary sliding (GBS), as well as the apparent climb-controlled dislocation creep, is the main mechanism of superplastic deformation. Liu et al. [24] studied the superplastic deformation process of AZ31 magnesium alloy, and found that the GBS and dynamic recrystallization are the main deformation mechanisms. Mukai et al. [25] investigated the superplastic characteristics of magnesium alloys, and revealed that GBS easily takes place with refined grains. Wu and Liu [26] studied the superplas-

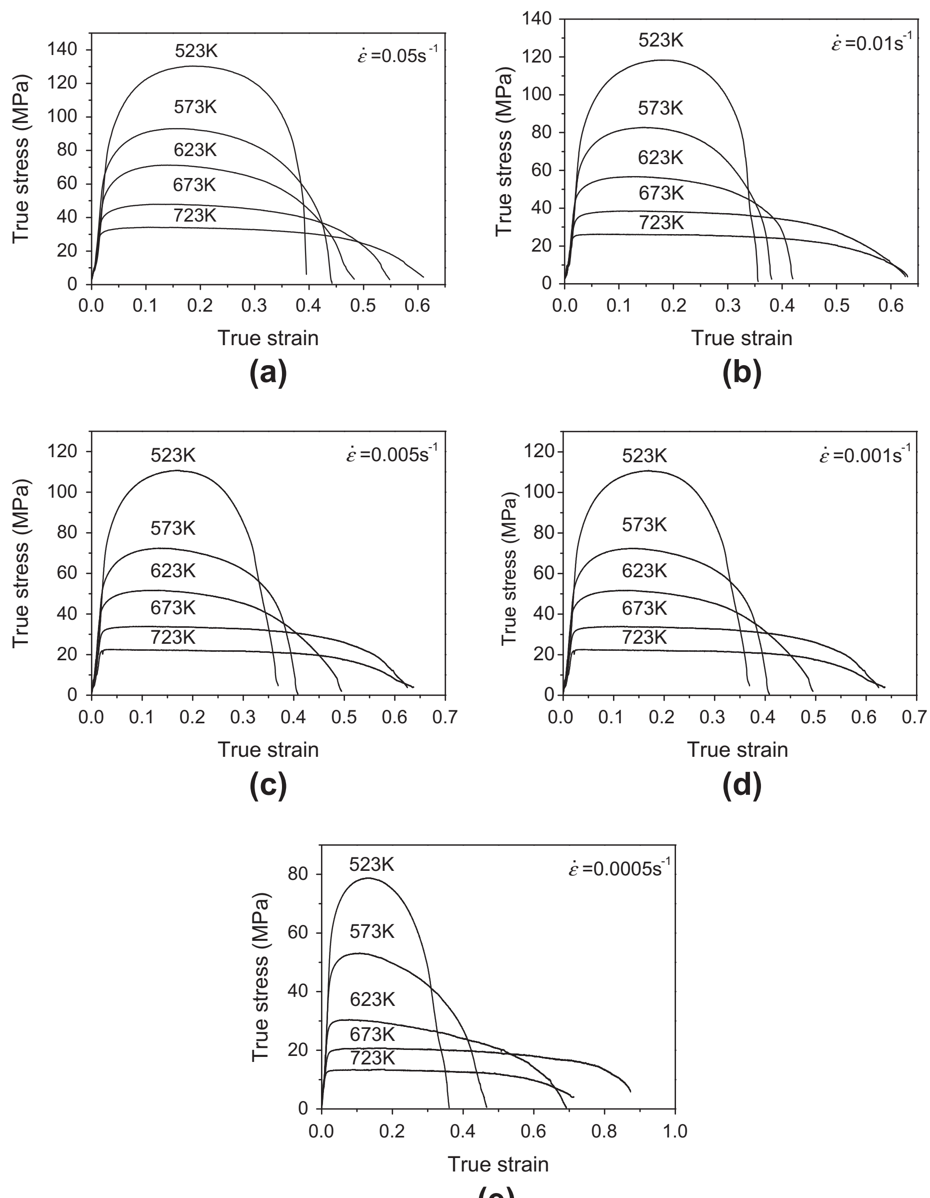

Fig. 1. The typical true stress-true strain curves of AZ31 magnesium alloy with strain rates of (a) 0.05 s^{-1}; (b) 0.01 s^{-1}; (c) 0.005 s^{-1}; (d) 0.001 s^{-1}; (e) 0.0005 s^{-1}.