Materials Science & Engineering A 708 (2017) 104–109

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Damping capacity of pre-compressed magnesium alloys after annealing

Yujie Cui[a], Jiaxiang Li[b], Yunping Li[c,*], Yuichiro Koizumi[a], Akihiko Chiba[a]

[a] Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan
[b] Department of Materials Science and Engineering, Central South University, Changsha 410083, China
[c] State Key Lab for Powder Metallurgy, Central South University, Changsha 410083, China

ARTICLE INFO

Keywords:
Magnesium alloy
Damping capacity
Twin boundary
Annealing

ABSTRACT

We systematically studied the effect of annealing on damping capacity of pre-deformed magnesium alloy and demonstrated the close relationship between damping capacity and twin boundary mobility. The damping capacity of pre-compressed AZ31 alloy can be improved by annealing for short period as a result of increased twin boundary mobility. In contrast, the damping capacity will be deteriorated after prolonged annealing in pre-compressed AZ91 alloy, which is ascribed to the stabilization of twin boundary by significant segregation and precipitation. In addition, we firstly succeeded to distinguish the damping capacity contributed by TB motion from that by dislocation motion in Mg alloys. This study provides the strategy to enhance damping capacity by improving twin boundary mobility after appropriate annealing, the time of which depends on the alloying element concentration.

1. Introduction

Damping material has attracted a lot of attention and can be applied in many fields, such as anti-vibration and noise-reduction components in automobile and aeroplane [1–9]. Pure magnesium exhibits extraordinarily high damping capacity, while it is significantly reduced after alloying in order to improve its mechanical property [10–15]. This reduction of damping capacity is attributed to the restriction of dislocation motion by solute atoms which concurrently accounts for the enhanced mechanical property in Mg alloys. Therefore, from the viewpoint of dislocation motion theory, it is difficult to obtain Mg alloys with both high strength and high damping capacity.

To solve this problem, $\{10-12\}$ tensile twins were introduced in Mg alloys by pre-compression since twinning represents an important deformation mode in hexagonal close-packed (HCP) Mg alloys and the alternative growth and shrinkage of twins can absorb the vibration energy and are effective to enhance damping capacity without sacrificing mechanical property [16–19]. Moreover, a short-time annealing (250 °C for 100 s) has been reported to further improve damping capacity of pre-compressed AZ31 alloy. This was ascribed to the increased twin boundary mobility (TBM) accompanying with the decrease of dislocation density and change in twin interface structure during annealing [16]. However, this finding seems to contravene the recent research by Somekawa et al. [20], who demonstrated that the segregated solute atoms at the twin boundary after annealing at 250 °C for 2.5 h deteriorate the damping capacity in Mg-Gd alloy because these segregated solute elements pose a hardening effect on the motion of twin boundary [21–23].

To date, although annealing has been proved to pose a significant effect on damping capacity of twin-containing Mg alloys, there is still a lack of systematic research on the effect of annealing on damping capacity of different Mg alloys. Our recent research [24] indicates TBM can be regulated by annealing time which depends on the alloying element. In the present study, we verified the close relationship between TBM and the corresponding damping capacity in Mg alloys AZ31 and AZ91 during annealing. The damping capacity can be enhanced after appropriate annealing depending on the alloying element concentration in Mg alloys. In addition, for the first time, the damping capacity contributed by TB motion is distinguished from that by dislocation motion.

2. Experimental procedure

Extruded rods of Mg alloys AZ31 (Mg-3.1Al-0.9Zn-0.45Mn, mass%) and AZ91 (Mg-8.9Al-0.89Zn-0.42Mn, mass%) (Obtained from Osaka Fuji Corp., Japan and the process conditions for them are the same) were used as-received. Cylindrical samples with a dimension of $\Phi 15 \times 50$ mm were cut from the extruded rods. Prior to the pre-compression at room temperature, all samples were subjected to solution treatment at 400 °C for 2 h, followed by water quenching to room temperature to obtain twin-free samples (ST samples). The pre-compressions were carried out at room temperature along the extrusion

* Corresponding author.
E-mail address: lyping@csu.edu.cn (Y. Li).

http://dx.doi.org/10.1016/j.msea.2017.09.096
Received 11 March 2017; Received in revised form 19 June 2017; Accepted 20 September 2017
Available online 28 September 2017

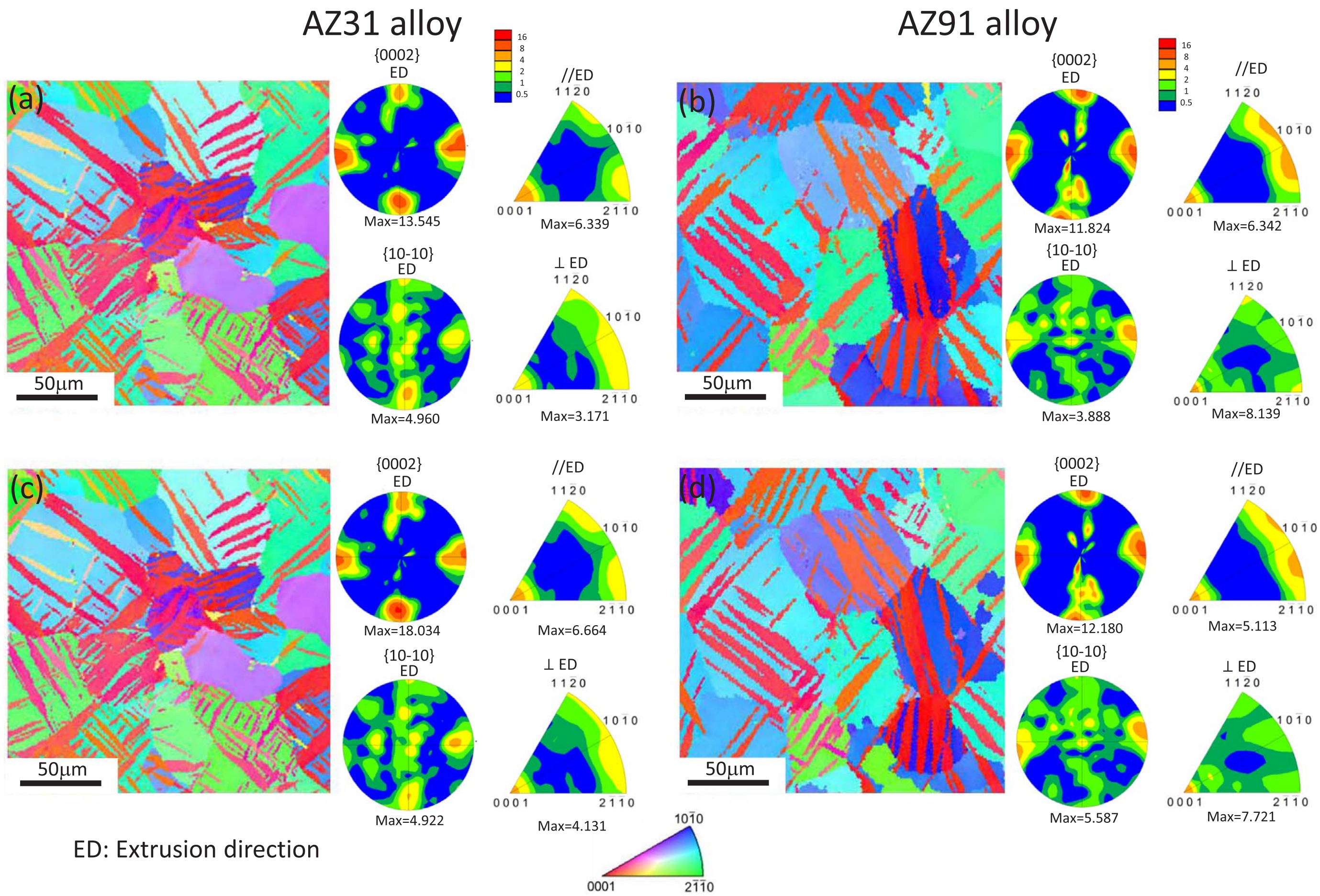

Fig. 1. Inverse polar figures and polar figures of (a) AZ31 alloy, and (b) AZ91 alloy compressed at a strain of 4% under a strain rate of 0.001 s^{-1}, (c) AZ31 alloy and (d) AZ91 alloy after annealing at 250 °C for 5000 s.

direction (ED) to an engineering strain of 4% under a strain rate 0.001 s^{-1} using the computer-aided THERMECMASTOR-Z hot-forging simulator (Fuji Electronic Industrial Co., Japan).

The subsequent annealing treatments were carried out at 250 °C for 100–5000 s immediately after the compressive tests. The damping capacity was measured in terms of the internal friction with an internal friction measuring system (EG-HT, Nihon Techno-Plus Co. Ltd, Osaka, Japan) at room temperature, using the resonant vibration method with vibration strain amplitudes ranging from 0.01% to ~0.15%. In addition, in order to distinguish the motion of dislocation from the motion of TBs accounting for the damping capacity, the damping capacity of ST samples and twin-containing samples was measured at different frequencies using a dynamic mechanical analyzer (Q800, TA instruments, USA) under the dual-cantilever mode. The vibration frequency was ranging from 1 to 130 Hz.

Microstructures of pre-compressed Mg alloys AZ31 and AZ91 before and after annealing at 250 °C for 5000 s were characterized in situ by focusing on the centre of samples with the electron backscatter diffraction (EBSD) instrument equipped with a revised deformation device and data acquisition software (TSL-OIM 5.0, TSL Solutions, Japan). The textures of samples were evaluated by the inverse pole figures (IPFs), which were obtained by scanning all samples over a fixed region of 270 × 270 μm with a step size of 0.38 μm. TEM samples were cut by a focused ion beam (FIB) milling under FEI Helios microscope from an area containing TBs. High-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) was undertaken using a double Cs-corrected G2 60–300 Titan 3 operated at 300 kV. The thin foils for HAADF-STEM imaging were cleaned by PLASMA CLEANER (model 1020) before loading into microscope. The energy dispersive X-ray (EDS) mapping in STEM of TBs was carried out to examine the distribution of solute atoms Al, Zn and Mn.

3. Results and discussions

3.1. Effects of annealing on the damping capacity in Mg alloy AZ31 and AZ91

Extruded Mg alloys AZ31 and AZ91 bars after solution treatment used in the present research demonstrate similar basal plane textures with most of the basal planes being aligned to ED as shown in previous research [22]. To confirm the variation of twin profile of the pre-compressed samples (4%) during annealing, microstructure before and after annealing was conducted by in-situ EBSD. Inverse polar figures (IPF) and polar figures in Fig. 1 show that Mg alloys AZ31 and AZ91 have similar texture, with most of the basal planes being aligned to ED and tensile twinning results in a reorientation of crystals by 86.3°. It is also indicated that annealing at 250 °C even for 5000 s poses ignorant effect on the twin profiles and textures. Moreover, no dynamic recrystallization is observed.

The damping capacity of ST samples and twin-containing samples was measured by EG-HT device. Fig. 2(a) (b) shows the internal friction of the pre-compressed AZ31, AZ91 alloys as a function of strain amplitude at a resonance frequency of 50 Hz. At a strain amplitude of 0.1% as shown in Fig. 2(c) (d), pre-compressed samples exhibit higher internal friction than ST samples in both AZ31 and AZ91 alloy. This increase becomes more significant with the progress of annealing time at 250 °C in AZ31 alloy. In contrast, the damping capacity increases only after a short annealing while decreases significantly after prolonged annealing (5000 s) in the AZ91 alloy.