Available online at www.sciencedirect.com

ScienceDirect

Scripta Materialia 87 (2014) 1–4

Scripta MATERIALIA

www.elsevier.com/locate/scriptamat

Microyielding and damping capacity in magnesium

Hiroyuki Watanabe,[a,*] Tadaaki Sawada,[b] Yasuyoshi Sasakura,[b]
Naoko Ikeo[b] and Toshiji Mukai[b]

[a]*Osaka Municipal Technical Research Institute, 1-6-50 Morinomiya, Joto-ku, Osaka 536-8553, Japan*
[b]*Graduate School of Engineering, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe 657-8501, Japan*

Received 14 May 2014; revised 6 June 2014; accepted 9 June 2014
Available online 18 June 2014

The damping capacity and mechanical response under uniaxial tension and compression were examined for specimens of extruded magnesium inclined by 0°, 15° and 30° relative to the extrusion direction. It was found that both the microyielding under uniaxial deformation and the occurrence of strain-dependent damping capacity pertain to the same physical event: the breaking away of basal $\langle \mathbf{a} \rangle$ dislocations from weak pinning points and the subsequent sweeping motion of dislocations between strong pinning points.

Keywords: Magnesium; Internal friction; Elastic behavior; Plasticity; Microyielding

Magnesium alloys have great potential as structural materials, because they are the lightest of all structural alloys. Additionally, pure magnesium and some magnesium alloys are well known to have high damping capacity [1]. Therefore, material damping using these materials is a prominent method of controlling vibration and noise in vehicles when weight reduction is of primary importance, and in biomedical applications where the high damping capacity can absorb the vibration and stress at the implant–bone interface and thus increase the osseointegration of orthopedic implants [2].

Recently, the deformation behavior of magnesium at low strain has attracted attention in efforts to understand the mechanism for the initiation of microscopic yielding [3]. Tensile tests have demonstrated that the yield point in magnesium is not reached abruptly, but rather there is gradual yielding when the specimens are deformed above the proportional limit [4].

To date, the mechanical properties at low strain, where microyielding may occur, have been characterized in various ways such as uniaxial tensile/compressive testing [3,5–10], cyclic loading [11–15] and damping testing [16,17]. To reveal the activity of dislocations and twinning/detwinning behavior at low strain, the properties obtained have been analyzed from the viewpoint of microstructural evolution by means of post-mortem microscopic observations [8,9,11], in situ observations employing neutron diffraction [12–15] coupled with computer simulation using, for example, the elastoplastic self-consistent (EPSC) model [5,6], and observations of acoustic emissions [8–10]. At present, with the aid of EPSC simulation, it is suggested that the initiation of microyielding in magnesium alloys is due to the activity of basal $\langle \mathbf{a} \rangle$ slip [5–7]. However, further complementary evidence would help reach a concrete conclusion.

Damping properties are usually characterized at low strain near microscopic yielding. The damping capacity of pure magnesium has already been reported for a single crystal, and it has been measured along various crystallographic directions [18,19]. The results suggest that high damping capacity is attained for crystals with a high Schmid factor (R) for basal $\langle \mathbf{a} \rangle$ slip, but not for crystals with a low Schmid factor, and is well explained by the model proposed by Granato and Lücke (G-L) [20,21]. The effect of crystallographic texture on damping capacity has also been examined qualitatively in polycrystalline magnesium and its alloys [19,22]. It is likely that alloys with texture having a high average Schmid factor for basal $\langle \mathbf{a} \rangle$ slip are preferable for attaining high damping capacity. However, the relationship between damping capacity and texture has not been quantitatively investigated, and it has been unclear so

---

* Corresponding author. Tel.: +81 6 6963 8157; fax: +81 6 6963 8145; e-mail: hwata@omtri.or.jp

http://dx.doi.org/10.1016/j.scriptamat.2014.06.004

far whether the quantitative relation found for the single crystal can indeed be extended to textured polycrystalline magnesium. This is because it has been difficult to calculate the average Schmid factor for a given slip system of a polycrystalline material. A recent development of electron backscattering diffraction (EBSD) in conjunction with scanning electron microscopy (SEM) has allowed grain structures to be quantitatively characterized in the context of the distribution of the Schmid factor. With the advent of the SEM-EBSD technique, the effect of texture on damping capacity in polycrystalline magnesium can be re-examined quantitatively and more fully.

In this study, the damping capacity and uniaxial tensile/compressive response at low strain were examined simultaneously in extruded pure magnesium. The authors intended to clarify the deformation mechanism at low strain around microyielding by quantitatively correlating the texture and damping capacity. This is because both uniaxial deformation and flexural vibration during damping measurement probably pertain to the same physical event [17]. The present study presents further evidence that the microyielding is initiated by the activation of basal $\langle \mathbf{a} \rangle$ slip.

The material used in this study was 99.95% pure magnesium, received as an extruded round bar with a diameter of 40 mm. The microstructures consisted of equiaxed, recrystallized grains, as shown in Figure 1a.

To understand the mechanical response at room temperature of the extruded magnesium, both damping and uniaxial tensile/compressive properties were characterized. Three types of specimens were taken from the extruded bar along different directions. For the 0° specimen, the longitudinal axis was parallel to the extrusion axis. For the 15° and 30° specimens, the longitudinal axes were inclined away from the extrusion axis by 15° and 30°, respectively. Because all specimens were taken from the same bar, all specimens had the same grain size and the same dislocation configuration.

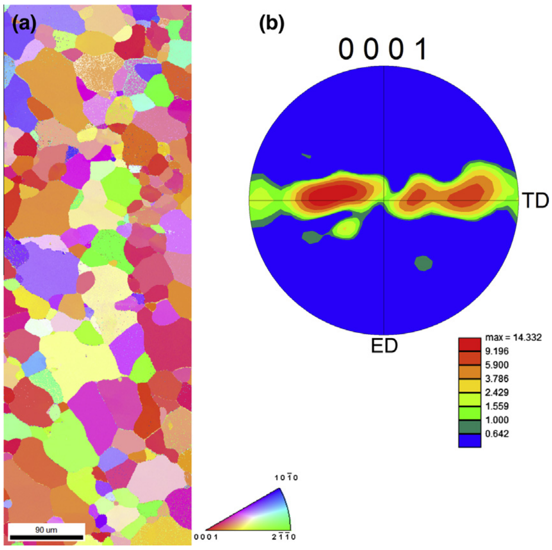

Figure 1. (a) Typical inverse pole figure map and (b) (0001) pole figure of extruded magnesium. The cross-sectional plane parallel to the extrusion direction was examined and the extrusion direction is vertical in (a).

The damping capacity of the extruded magnesium was measured at the fundamental resonant frequency in flexure employing a decay method for rectangular specimens in a cantilever holder. The specimens had rectangular shape with a length of 60 mm, a width of 7 mm and a thickness of 1.8 mm. The resonant frequency in the experimental apparatus was 13–14 Hz. The damping capacity was specified by the loss factor, η, of free vibration, which is related to the logarithmic decrement, δ, by $\eta = \delta/\pi$.

Tensile and compressive tests were conducted at an initial strain rate of $5 \times 10^{-4}\ \mathrm{s}^{-1}$. The tensile specimens had a gauge length of 12 mm and a diameter of 3 mm, and compressive specimens had a height of 34 mm and a diameter of 17 mm (except for the 0° specimen, which had a height of 80 mm and a diameter of 35 mm). Strain was measured using an extensometer for each specimen.

The texture of the extruded magnesium was characterized by SEM-EBSD analysis. The texture analysis showed that most of the basal planes lie parallel to the extrusion axis, as shown in Figure 1. The distribution of Schmid factors in the present material was characterized using the EBSD data.

Nominal stress (σ)–nominal strain (ε) curves at low strains for the specimens examined in this study are shown in Figure 2a–c. The slope of the initial proportional regions agreed with the dynamic Young's modulus of the 15° specimen ($E = 44$ GPa), which was determined employing the free–free transverse vibration method.

Deviation from linearity (arrows in Fig. 2a–c), or microyielding, occurred at $\varepsilon = \pm 2.7 \times 10^{-4}$ for the 0° specimen and the proportional limit decreased with inclination angle. After the smooth elastic–plastic transition, nearly linear strain hardening behavior was

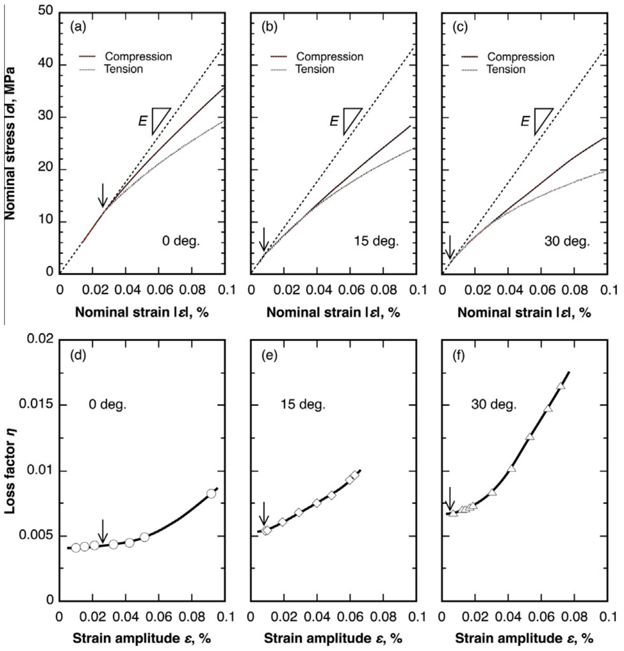

Figure 2. (a)–(c) Stress–strain curves and (d)–(f) variation in the loss factor with the strain amplitude of extruded magnesium inclined by 0° (a, d), 15° (b, e) and 30° (c, f) relative to the extrusion direction. The broken lines have a slope equal to the dynamic Young's modulus of magnesium ($E = 44$ MPa).