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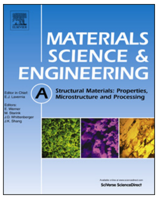

Damping and dynamic recovery in magnesium alloys containing strontium

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ABSTRACT

This article reports evidences related to the effect of strontium on damping and dynamic recovery of novel extruded magnesium alloys. Dynamical mechanical analyses demonstrate a significant plateau region on storage/loss moduli, as well as damping values. Post-mortem electron back scatter diffraction and kernel average misorientation analysis showed that these experimental results are related to both changes in texture and crystallographic recovery due to twinning and pronounced slip activity at higher temperatures.

1. Introduction

The demand for fuel efficient, yet high performance vehicles, is currently being addressed among other ways by research and development on lightweight metallic materials [1–3]. On this subject, crystallographic texture engineering achieved by intelligent processing and alloying has led to the widespread use of light structural alloys made of aluminum (Al) [4,5]. Beyond Al alloys, magnesium (Mg) with its density of 1.7 g/m^3 (which is 33% less that of Al) is one of the lightest structural metallic materials. Common Mg alloys [6–8] have higher specific strength compared to many aluminum alloys and several types of steels [9,10]. In this framework, significant efforts have been made to characterize the mechanical behavior of Mg alloys under various loading conditions [11–14]. However, less attention has been given to the quantification of the dynamic properties of Mg alloys at high temperatures, which is critical in manufacturing. With this aim, Dynamic Mechanical Analysis (DMA) was utilized in this investigation to demonstrate the effect of strontium (Sr) on the storage/loss moduli and damping of novel Mg alloys at various temperatures, which was subsequently correlated to distinct crystallographic changes.

The mechanical behavior of hcp Mg alloys at room temperature is mostly controlled by the activation and development of a limited number of slip systems including basal slip of $1/3\langle 11\bar{2}0\rangle$ or $\langle a\rangle$ type dislocations, as well as deformation twinning. Besides the possible incorporation of non-basal slip $\langle a\rangle$ dislocation on prismatic and pyramidal planes which only offers two more independent slip systems; deformation twinning plays a key role in accommodating strain along the *c*-axis [15,16]. The activation of such mechanisms greatly depends on both texture [6,16] and temperature [17]. In fact, the Critical Resolved Shear Stress (CRSS) of non-basal slip systems, which can result into straining along the *c*-axis and therefore enhance overall ductility is much higher than the CRSS of basal slip at room temperature [8]. At higher temperatures ($>180\ ^\circ$C) non-basal slip is dominant and therefore higher formability can be achieved [8].

Mg–Al–Sr alloys have a well-earned reputation for creep resistance [18–20]. Their enhanced creep performance has been attributed to the formation of thermally stable Al_4Sr precipitates which suppress the formation of the low melting point $Mg_{17}Al_{12}$ and reduce the Al concentration in Mg solid solution [19,20]. Consequently, it has been proposed that the high creep resistance of this type of Mg alloys is mostly related to the absence of the low melting point β-Mg_{17}–Al_{12}, to the minimization of Al super saturation in the primary Mg matrix [19] and to the thermal stability of the Sr intermetallics due to the low solubility of Sr in Mg. Although the effect of Sr addition on precipitation, deformation and texture evolution has been thoroughly investigated [7,20,21], the dynamic mechanical properties of these alloys have not been investigated. This article shows that such properties are related to the reported energy dissipation of Mg alloys[22].

2. Experimental procedure

Extruded Mg AZ31 bars and Sr–10Al master alloys were used to produce designated alloy compositions. The melt was prepared

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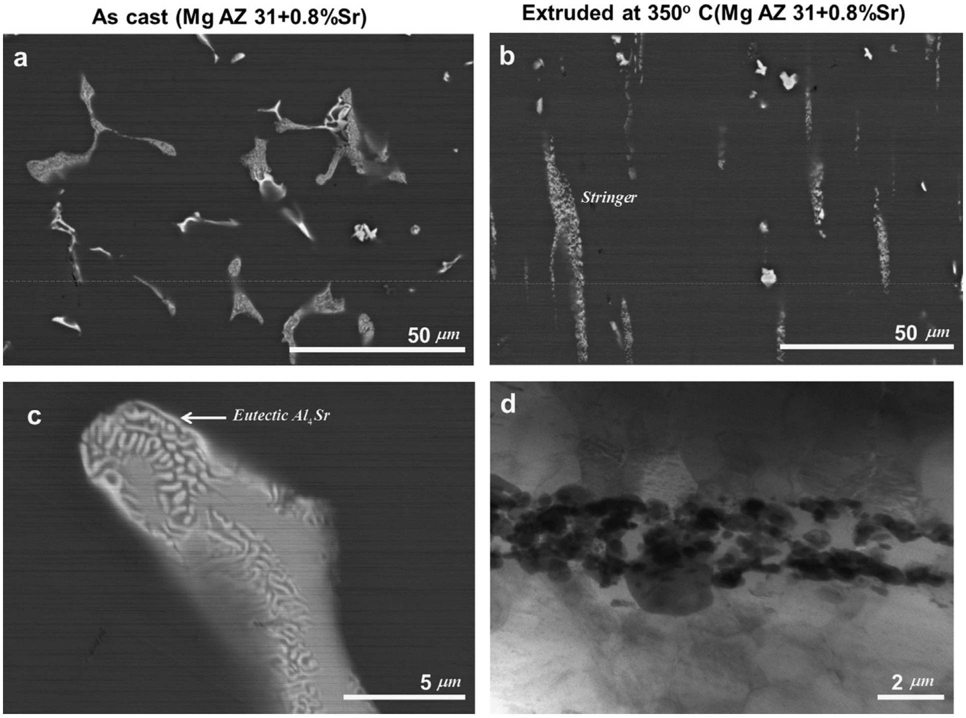

Fig. 1. Back scattered electron images of AZ31 + 0.8 wt% Sr: (a) as cast Mg–Al–Sr precipitates, (b) a partially transformed Mg–Al–Sr metastable phase to stable Al_4Sr eutectic, (c) the same alloy after extrusion at 350 °C, and (d) TEM image of an Al_4Sr stringer after extrusion at 350 °C.

in a steel crucible using a high frequency induction furnace. Large (8.2 cm diameter, 30 cm length) cylinders were cast in preheated steel dies. In order to study the precipitate structure before and after extrusion, field emission gun scanning electron microscopy (FEG-SEM, Hitachi S-4700, Hitachi high technologies America, Inc., Pleasanton, CA) was used. Fig. 1 demonstrates the back scattered image of AZ31 + 0.8% Sr. The formation of the metastable Mg–Al–Sr precipitates is shown in Fig. 1a. As a consequence of extrusion Mg–Al–Sr becomes elongated along the extrusion direction (Fig. 1b). It is also important to notice that due to the thermal exposure (during cooling to room temperature), the non-equilibrium Mg–Al–Sr precipitate transforms to an equilibrium eutectic phase shown in Fig. 1c by rejection of Mg from precipitate into the matrix. Fig. 1d illustrates the elongated Al_4Sr eutectic phase using bright field transmission electron microscopy (TEM, Philips CM200 operating at 20 kV). The thin foil specimens for TEM were prepared from cross sections of extruded samples containing the extrusion direction (ED-r) by grinding and further thinned by ion milling using a Gatan precision ion polishing system (PIPS).

Three Mg alloys were furthered extruded into cylindrical billets based on AZ31 (Mg–3% Al–1% Zn) with 0, 0.4 and 0.8 wt% Sr. The exact compositions of the AZ31and AZ31 with Sr alloys are listed in Table 1. Billets were extruded to the bars at 350 °C. Note that the details of the extrusion process and texture evolution have been presented previously by the authors [7].

A DMA Q800 (TA Instruments) was used to obtain loss and storage moduli values as a function of temperature from 25 to 400 °C (Fig. 2). Temperature scans with 1 Hz oscillation frequency and maximum displacement of 15 μm were performed at a rate of 2 °C/min. The center of a two-end supported sample was subjected to a sinusoidal load with a ratio of minimum to maximum load equal to zero. A built-in Linear Variable Differential Transformer (LVDT) provided displacement measurements. Sample dimensions were 30 mm length, 10 mm width, and 2 mm thickness along the extrusion direction. The DMA was set up in the single cantilever mode with flexural loading, while the stress created in the centerline never reached yielding.

Table 1
Chemical composition of the alloy.

Alloy	Chemical composition (wt%)				
	Al	Zn	Mn	Sr	Mg
AZ31	3.15	0.89	0.52	–	Balance
AZ31 + 0.4% Sr	2.76	0.79	0.35	0.34	Balance
AZ31 + 0.8% Sr	2.83	0.79	0.33	0.81	Balance

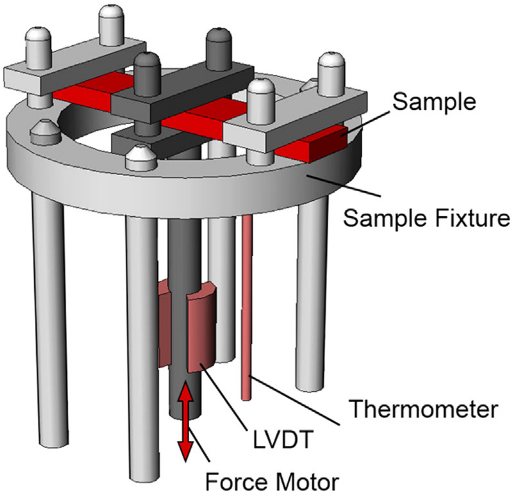

Fig. 2. Single cantilever loading set up. Middle clamp is movable while the sample is fixed at the ends.

In order to correlate underlying microstructural mechanisms including dynamic recovery and texture development during deformation to the observed dynamic mechanical behavior, careful microscopic investigation was conducted by polishing of the lateral side of the long edge of the samples. The details of methodical polishing procedure can be found elsewhere [16].