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CREEP BEHAVIOUR OF Mg BINARY SOLID SOLUTIONS

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Abstract

Specimens of cast Mg-0.8 at.%Gd, Mg-2.2 at.%Zn and Mg-2.5at.%Al alloys were tested in compression at an initial strain rate of ~$1.5x10^{-5}s^{-1}$ at room temperature and 180°C. The Mg-Zn alloy, and more so the Mg-Gd alloy, exhibited a largely athermal behaviour, in contrast with the Mg-Al alloy which softened considerably at the higher temperature. The athermal behaviour of the Zn- and Gd-containing alloys can be accounted for by their strong tendency to developing short range order.

Introduction

A plot of the strength of a solid solution versus temperature normally takes the shape of Figure 1. At low temperatures the strength decreases rapidly, whereas at intermediate temperatures it becomes virtually insensitive to temperature. The behaviour can be rationalised by dividing the strength into two components [1-3]:

$$\tau = \tau_i + \tau^*$$

where τ_i is the athermal component of the stress arising from long range stress fields and which cannot be overcome through thermal activation, and τ^* is the thermally activated component connected with short range obstacles that can be overcome by thermal energy. At temperatures above two-thirds of the melting point the flow stress decreases rapidly again, approaching the critical resolved shear stress of the pure metal, a behaviour attributed to an increase in the mobility of the solute atoms. The extent of the athermal regime determines the resistance to dislocation creep of any solid solution [4]. Ideally, the athermal regime should extend well past the service temperature of the alloy.

The strength of a solid solution is determined by a number of solute-dislocation interactions, among them [1-3,5,6]:

- Elastic interactions involving the shear modulus and atomic size misfit (random solid solution effects). These are considered short range interactions, i.e., amenable of thermal activation.
- Short range order (SRO). This is a typical long range, i.e., athermal, hardening mechanism [7].

Random solid solution effects dominate the strength of Mg-Al [8]; SRO, in turn, has been confirmed by x-ray scattering Mg-In, Mg-Gd, Mg-Er and Mg-Sn [9-11], whereas theoretical and experimental evidence suggests that it is present in Mg-Zn alloys as well [8,12]. On a parallel presentation in this symposium [13] thermodynamical arguments are used to rank Mg-based binary alloys considering their relative tendency to develop SRO. Taking Mg-Al, Mg-Zn and Mg-Gd as model alloys, it is predicted that Gd in solution should develop the strongest SRO, hence it should produce the most creep resistant alloy, followed by Zn and Al, in that order. The object of this paper is to present experimental evidence in support of those predictions.

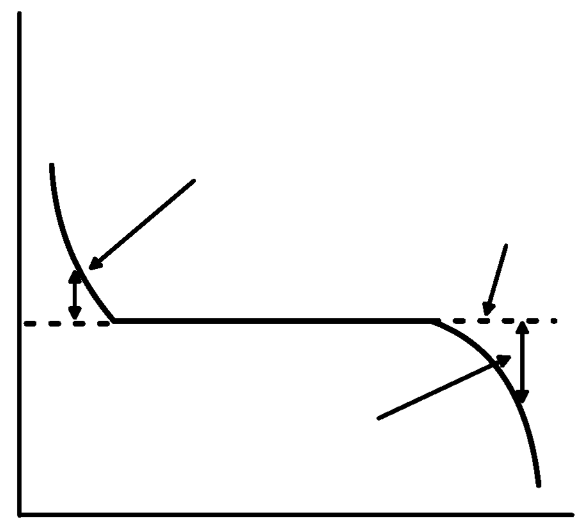

Fig. 1: The temperature dependence of the flow strength (schematic).

2. Experimental Details

Castings with nominal compositions 1.5 at%Zn, 2.5 at%Al and 1 at% Gd were produced. The amount of solute for each alloy was set to approximately match the solubility at 200°C in order to limit precipitation hardening effects during the testing at the higher temperature. The actual compositions are listed in Table 1.

Commercially pure Mg, Zn, Al and a Mg-Gd master alloy (2:3 Gd:Mg) were melted in steel crucibles coated with boron nitride in an electric furnace under a SF6+CO2 protective atmosphere.

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The liquids were stirred mechanically for 20 minutes to ensure the dissolution of the solute and subsequently poured at 735-750°C under an argon atmosphere into steel moulds of size 80 x 80 x 10 mm3, preheated to 300°C. The cast plates were solution heat treated under Ar atmosphere as per the times and temperatures given in Table 1, and quenched into water. Compression tests were carried out on cylindrical specimens, 18 mm in height and 9 mm in diameter, on a screw driven machine at 25°C and 180°C in a temperature controlled chamber. The crosshead speed was 0.016 mm/min for all the tests (initial strain rate = 1.5*10-5s-1).

Table 1. Chemical composition of the alloys studied determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES), and the respective grain sizes and solution heat treatment schedule.

Alloy	Solute (at.%)	Grain size (µm)	Time (h)	Temperature (°C)
Mg-1.5%Zn	2.2	123	4	470
Mg-1%Gd	0.8	119	4	535
Mg-2.5%Al	-	129	10	413

3. Results

Figures 2-4 show the deformation flow curves of Mg-2.5Al, Mg-2.2Zn and Mg-0.8Gd, respectively, at room and high temperature. Serrated flow was observed in Mg-Zn at room temperature (Fig. 3) and at 180°C in Mg-Gd (Fig. 4). Figure 5 compares the alloys' behaviour at room temperature and Figure 6 at 180°C.

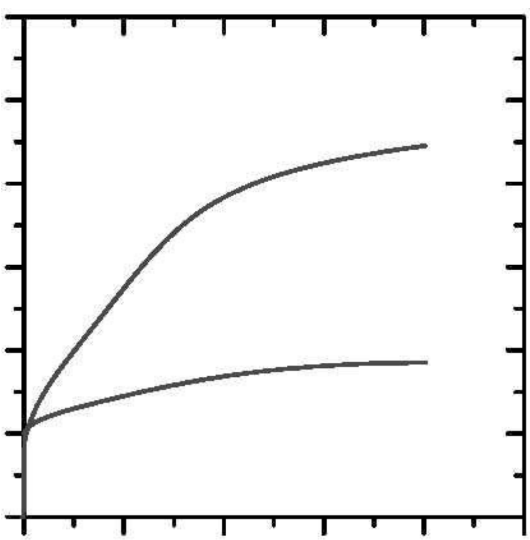

Figure 2. Compressive flow curves of Mg-2.5Al.

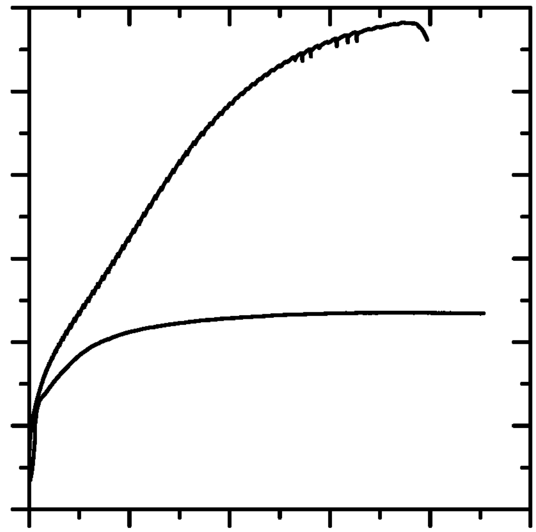

Figure 3. Compressive flow curves of Mg-2.2Zn.

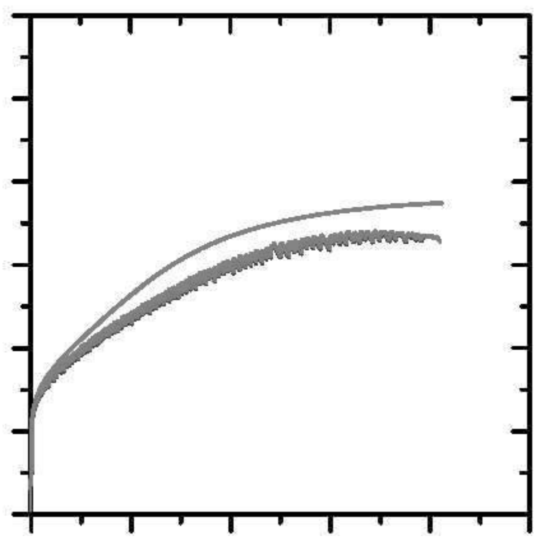

Figure 4. Compressive flow curves of Mg-0.8Gd.

At room temperature all three alloys exhibited an extended linear hardening regime, which reached saturation at about 10 % strain. The saturation stress was largest in the Mg-Zn alloy. At 180°C the loss of strength was very limited in the Mg-Gd alloy, whereas it was extensive in the Mg-Al alloy. The Mg-Zn alloy exhibited a short linear hardening regime, saturating at a strength level which was matched by the Mg-Al alloy at large strains. Figure 7 compares the flow stress at 0.05 strain, showing that the behaviour of the Mg-Gd is nearly athermal, followed by Mg-Zn and Mg-Al, in that order, and line with the expectations from the theoretical analysis of the companion publication [13].

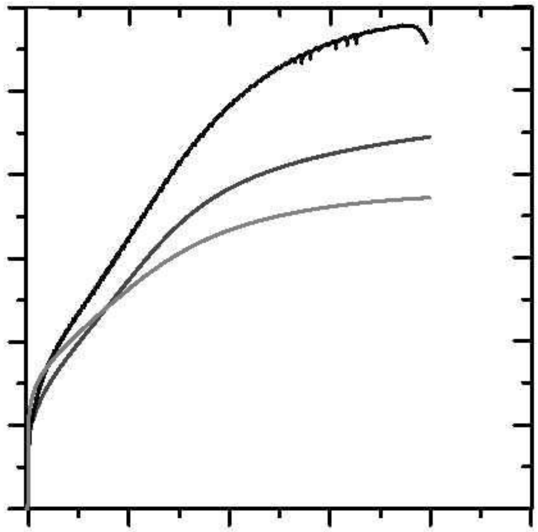

Figure 5. The flow behavior of the alloys studied, at 25°C. The crosses identify the strength values plotted in Figure 5.

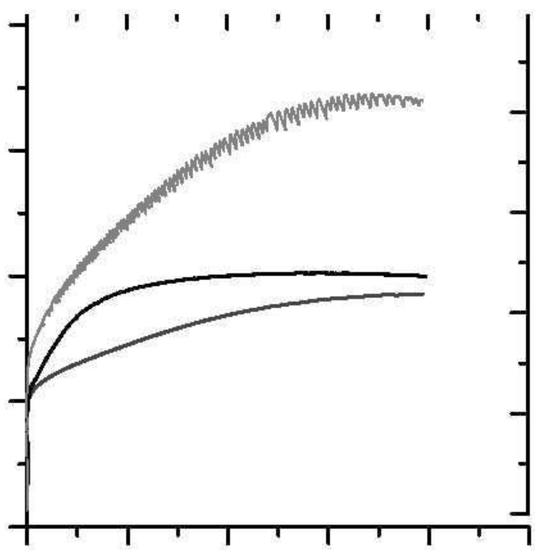

Figure 6. The flow behavior of the alloys studied, at 180°C. The crosses identify the strength values plotted in Figure 7.

4. Discussion

The remarkably athermal behaviour of the Mg-Gd alloy, indicated both by the extended linear hardening regime [1,14] at both temperatures in Figures 2-4 and the small decrease in strength in Figure 7, constitutes strong evidence of the presence of SRO which remains stable at the higher temperature. The Mg-Zn alloy partly reproduces the behaviour of the Mg-Gd, with a shorter linear hardening stage and a larger drop in strength at the higher temperature. This behaviour is consistent with a lower intensity of SRO, which makes it less thermally stable in comparison with the Mg-Gd. The Mg-Al alloy, as expected from its virtual absence of SRO, although it still exhibits a linear hardening at the higher temperature, the hardening rate is much lower and it suffers a substantial drop in strength despite its larger alloy content.

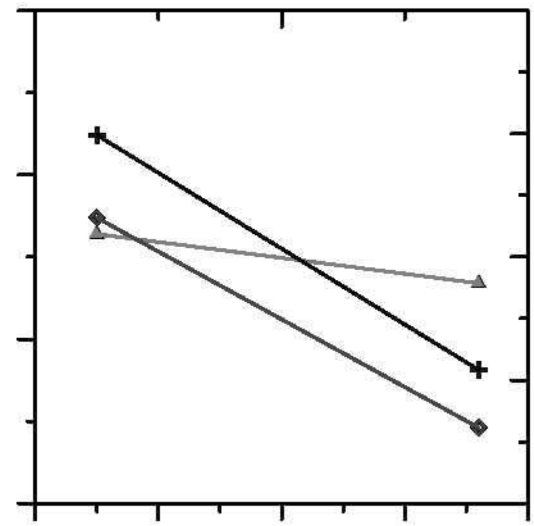

Figure 7. The strength of the alloys studied, at 25 and 180°C, at a strain of 5% (the crosses in Figures 3 and 4).

4. Conclusions

Mg-0.8at.%Gd, Mg-2.2at.%Zn and Mg-2.5at.%Al solid solutions were tested at RT and 180°C.
The solute contents were kept deliberately low to prevent precipitation hardening at the higher testing temperature.
The Mg-Gd lost very little strength at the higher temperature. The loss of strength was larger for the Mg-Zn and substantial for the Mg-Al.
The extent of the athermal behaviour is consistent with the relative strength of short range order in each of the alloys, largest in the Mg-Gd and lowest in the Mg-Al.

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