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Compression creep at 240°C of extruded magnesium alloys containing Gadolinium

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Abstract. For uses at high temperatures, magnesium alloys containing rare earths have proven to be very suitable. High proportions of melting precipitates contribute to strengthening, even at temperatures above 200°C. If these alloys are extruded, their creep resistance rises even further due to the resulting fine-grained structure. In this paper, magnesium alloys with 10% Gd and additional small amounts of La and Nd are compared with WE43 for compression creep at temperatures of 240°C and stresses between 80 and 150 MPa. The minimum creep rates are determined and the stress exponent evaluated in accordance with the Norton equation. By calculating the threshold stress, the true stress exponents are determined.

Introduction

For aluminum-free magnesium alloys, rare earth elements are used when good creep resistance is required at high temperatures. Gadolinium is a rare earth element that has been studied less often than cerium, neodymium, or yttrium [1-4]. In addition to the cast alloys predominantly used, in the future, wrought products will also be included in our focus of interest. In this paper, alloys containing 10 wt.-% gadolinium and additionally small amounts of lanthanum and neodymium are analyzed for their high-temperature creep resistance. The composition of the alloys is given in Table 1. For the purposes of comparison, the commercial creep resistant alloy WE43 was selected.

Table 1: Alloying elements of the investigated alloys [wt.-%]

Material	Gd	Nd	La	Y	Ce
1 (WE43)		1		4	2
2	10	1			
3	10	1	1		
4	10		2		
5	10		1		
6	10				

Experiment

For the production of the alloys, pure magnesium was melted at 700°C and the required amount of alloying elements was added. The alloying elements were stirred for 20 minutes into solution and the melt was poured into cylindrical molds. Cylinders with lengths of 300 mm and diameters of 105 mm were extruded at 420°C to a final diameter of 17.5 mm at the "Forschungszentrum Strangpressen" (FZS) in Berlin. A cylinder for creep tests with a diameter of 6 mm and a length of 15 mm was machined from each extruded profile. The position of the axis of rotation of the samples and the profiles were identical. Compression creep test were carried out with an ATS Lever Arm System at constant stress and temperature.

Results and Discussion

Compression creep tests were performed at 240°C and stresses of 80, 100, 120 and 150 MPa. As an example, the creep curves from tests at 100 MPa are shown in Fig. 1. Fig. 2 plots the first derivative of the creep deformation with respect to time. All the investigated materials show only a very short initial creep stage. After passing the minimum, the creep rate increases nearly constantly. The WE43 shows the lowest minimum creep rate. All alloys containing gadolinium are close together at the beginning of the test and differ only at later stages.

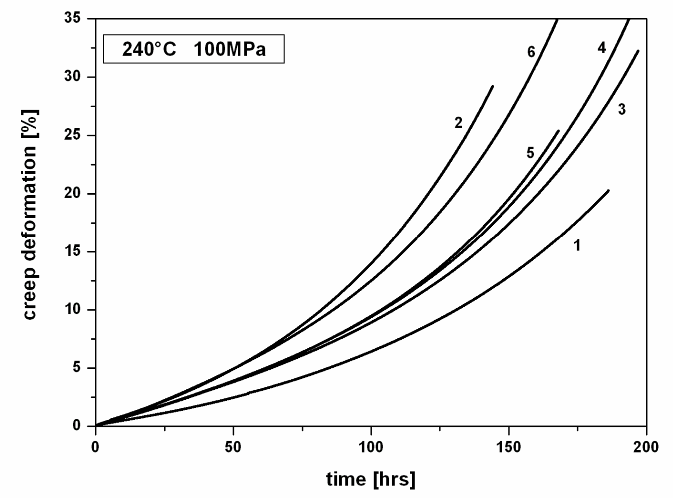

Fig. 1: Creep curves from tests performed at 240°C and 100 MPa.

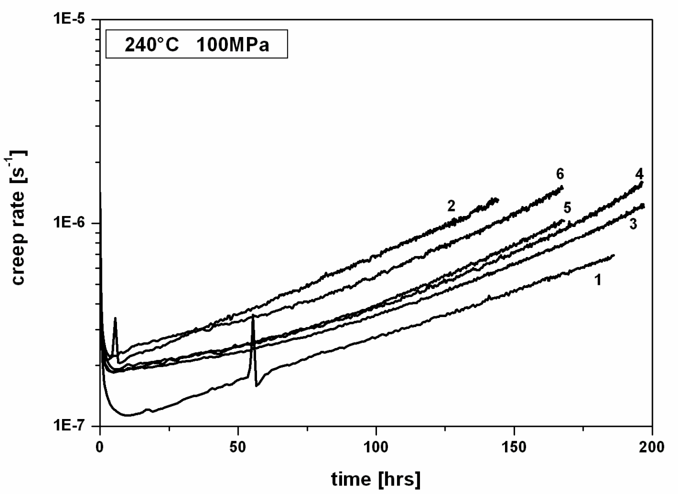

Fig. 2: First derivation of creep deformation as a function of time from tests performed at 240°C and 100 MPa.

The stress dependence of the minimum creep rate $\dot{\varepsilon}_s$ at a constant temperature is usually given by

$$\dot{\varepsilon}_s = \frac{ADGb}{kT}\left(\frac{\sigma}{G}\right)^n, \tag{1}$$

where A is a dimensionless, material-dependent constant, D is the diffusion coefficient (=D_0 exp(-Q_C/RT)), G the shear modulus, b the Burgers vector, k the Boltzmann constant, σ the applied stress, and n the stress exponent. Plotting all the minimum creep rates according to Eq. 1 the stress exponent n can be determined as the slope of the resulting linear fit, as shown in Fig. 3. The values of n are given in Table 2. A threshold stress σ_0 was introduced, being the stress below where no creep deformation takes place at a given temperature. Li and Langdon [5] presented a method to calculate the threshold stress. An extrapolation of log $\dot{\varepsilon}_s$ against log σ plots to a value of 10^{-10} s^{-1} gives σ_0, because this is meant to be the lowest measurable deformation. Usually this threshold stress decreases with increasing temperature [6, 7]. Replacing σ in Eq. 1 by an effective or true stress σ_{true} in a way that $\sigma_{true} = (\sigma - \sigma_0)$ leads to

$$\dot{\varepsilon}_s = \frac{ADGb}{kT}\left(\frac{\sigma-\sigma_0}{G}\right)^{n_t}. \quad (2)$$

The dependence of the minimum creep rate from the true stress gives the true stress exponent n_t. This plot is shown in Fig. 4 and the resulting values of n_t are given in Table 2. The values are a little higher than 3, which is the theoretical value for dislocation glide as the rate-controlling process during creep deformation.

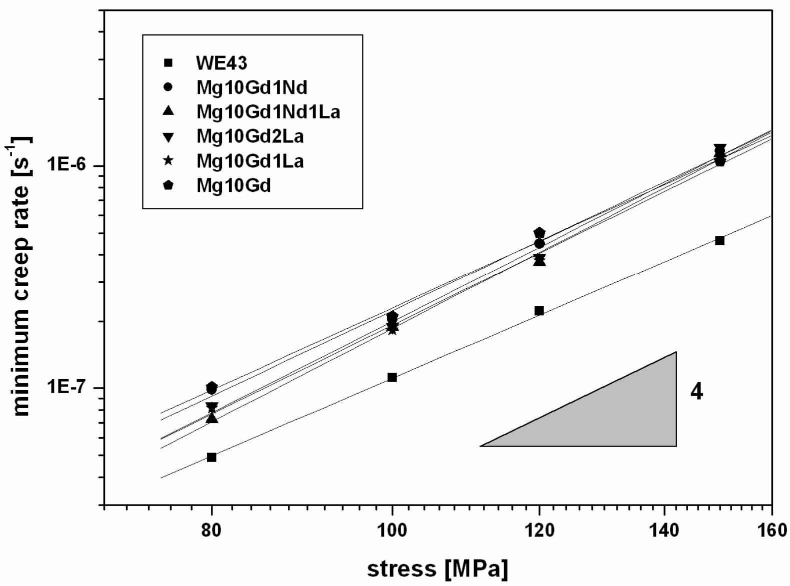

Fig. 3: Double logarithmic plot of minimum creep rates against applied stress of tests performed at 240°C.

Table 2: Stress exponent n, calculated threshold stress σ_0 and true stress exponent n_t of tests performed at 240°C.

Material	Stress exponent n	Threshold stress σ_0	True stress exponent n_t
1 (WE43)	3.6	14.2	3.1
2	4.0	14.3	3.4
3	4.3	17.6	3.6
4	4.2	16.6	3.6
5	4.1	15.9	3.5
6	3.8	13.1	3.4

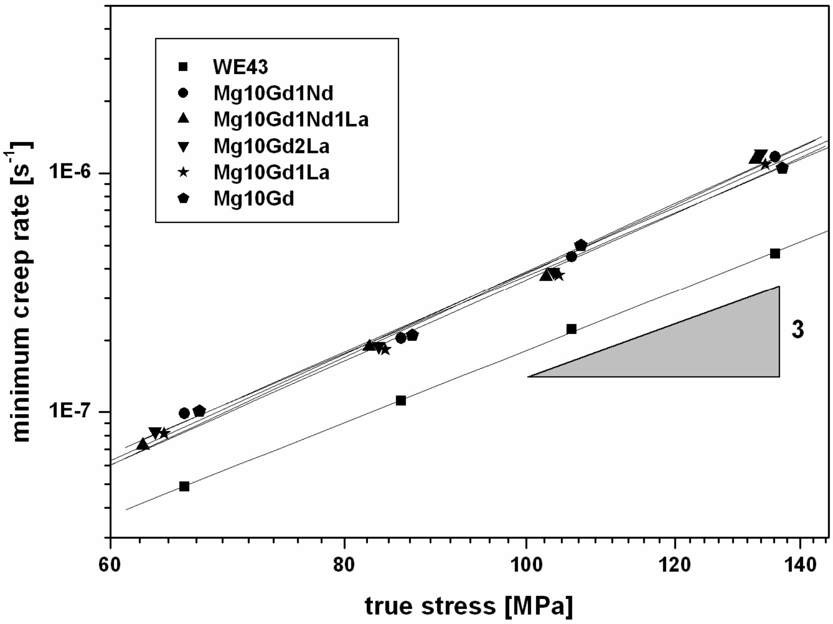

Fig.4: Double logarithmic plot of minimum creep rates against true stress of tests performed at 240°C.

Summary

Compression creep tests were performed on magnesium alloys containing gadolinium with small amounts of lanthanum and neodymium. Tests were conducted at 240°C and stresses between 80 and 150 MPa. For comparison, tests were done with WE43 samples, too. This material shows the best creep resistance at later stages. From the materials containing gadolinium, samples with an addition of 2 wt.-% lanthanum and/or neodymium performed better, compared with the samples without any additional rare earths. Applying the concept of threshold stress, it was found that for all materials σ_0 is in the range 13-17 MPa, which leads to true stress exponents of about 3.5. This is a good indication that the dislocation glide is the rate-controlling deformation process during creep.

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