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Creep resistance of a cast Mg-3Er-0.2Mn alloy

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ABSTRACT

In this paper, the microstructure and creep properties of a cast Mg-3Er-0.2Mn alloy was investigated. The results showed that the cast alloy under both as-cast and solution treated conditions is mainly composed of α-(Mg) matrix and $Mg_{24}Er_5$ phase particles. The value of activation energy Q (240~244KJ/mol), for creep deformation of the solution treated alloy, was calculated in the temperature range of 190~210 ^{o}C, and in the stress range of 50~60 MPa, respectively, which can explain that the creep mode involved cross slip of dislocations from basal to prismatic planes in the hexagonal structure or climb. Copyright © 2011 VBRI press.

Keywords: Microstructure; creep properties; erbium; magnesium alloy.

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Introduction

Recently, magnesium alloys have become one of good promising light alloys used widely in aerospace and automobile industries, which are increasing progressively thanks not only to their low densities but also to their excellent properties such as electro-magnetic shielding, damping, and recycling [**1-3**]. The as-cast microstructure of Mg-RE alloys mainly consists of α-(Mg) grains surrounded by Mg-RE phase precipitates, which is of stabilization at high temperature and is a favorable factor to creep resistance. The solubility of RE elements in magnesium at room temperature is very limited because of the bigger atom radius of RE element than that of other metals. Mg alloys containing yttrium and/or RE has the good combination of room and high temperature mechanical properties. Adding RE is an important approach for attaining high temperature creep resistance Mg alloys above 120 ^{o}C. The effects of RE are solution-hardening and precipitation-hardening, especially the latter, resulting in excellent mechanical properties even at high temperatures. These RE elements improve the creep resistance by the formation of RE precipitates. The effect of Mn on the Mg-RE or Mg-Zn-RE system was studied by Weiss et al [**4-6**]. Their findings indicated that the addition of Mn can change the creep resistance by reducing the size and increasing the amount of the precipitates. As-cast and solution treated magnesium alloys have the good values to produce some low costing magnesium products. However, few studies on the creep properties about this kind of alloys were found so far.

The objective of this paper was to investigate the creep resistance of as-cast and solution treated Mg-3Er-0.2Mn alloy, and further explain the creep mechanism of this alloy, which can provide a good way to develop a novel creep resistance magnesium alloy.

Experimental

The alloy was prepared in an electric resistance furnace of 5.0 kg capacity at 730 ^{o}C under a protective atmosphere of dry CO_2 and SF_6 gas mixture, and then cast into a permanent molds. Erbium (Er) addition was made in the form of Er-enriched alloy (Mg-26 wt.%Er). The alloy was solution treated at 520 ^{o}C for 6 h. The chemical composition of the alloy is as followed (wt. %): Er 3.2 %, Mn 0.21 % and balanced Mg.

Samples for optical microscopy (OP) were polish in the conventional way and etched with 6% HNO_3 solution. The gauge section of creep specimen is *d*10 mm × 50 mm. Creep tests were conducted on a MTS810 type creep machine with a electrical resistance heating chamber under a stress range of 50~60 MPa and at a temperature range of 190 ~210 ^{o}C. The specimens required 3 min to equilibrate at the tested temperature prior to initiation of a given stress. The temperature variation during the tensile tests was no more than ±1 °C.

Results and discussion

The microstructures of the as-cast, solution treated and creep deformation specimen are presented in **Fig. 1**. From **Fig. 1(a)** we can see that the cast alloy under both as-cast and solution treated condition is mainly composed of α-(Mg) matrix and some precipitate particles. The phase particles in the as-cast alloy are distributed along the dendrite boundaries, however, the particles in solution treated alloy are distributed in the coarse grains, and it changed smaller than that of as-cast condition, which can be seen in **Fig. 1 (b)**. From the X-Ray spectrum analytical result (**Fig. 2**) we can find that the phase particles should be the $Mg_{24}Er_5$ phase. Few recrystallization grains were found in creep deformation specimen, and the size of recrystallization grains were about 10~30 μm in **Fig. 1(c)**.

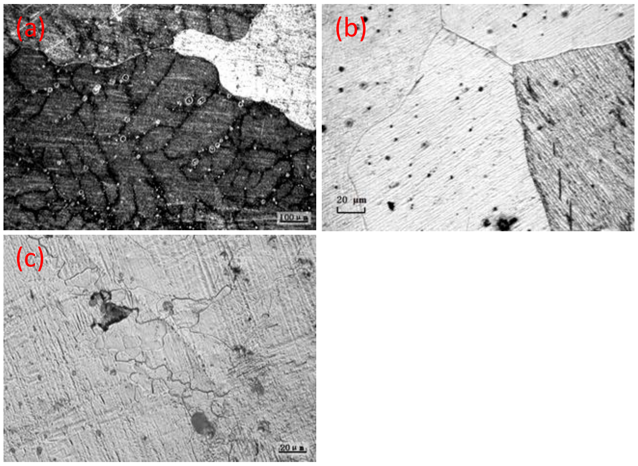

Fig. 1. Microstructures of the as-cast (a), solution treated under 520 oC keeping for 6 h (b), creep deformation at 210 ℃/50 Mpa for 250 h (c) Mg-3Er-0.2Mn alloy.

The creep properties of the solution treated alloy were assessed in the temperature range of 190~210 ^{o}C, and in the stress range of 50-60 MPa. As shown in **Fig. 3**, a typical creep curve of the alloy consists of two stages, primary and secondary creep stage. The steady-state creep rate was calculated using the linear section of the curve as shown in Fig. 3 and termed-secondary creep stage which can be linear-regression analysis, the results of which are presented in **Table 1**.

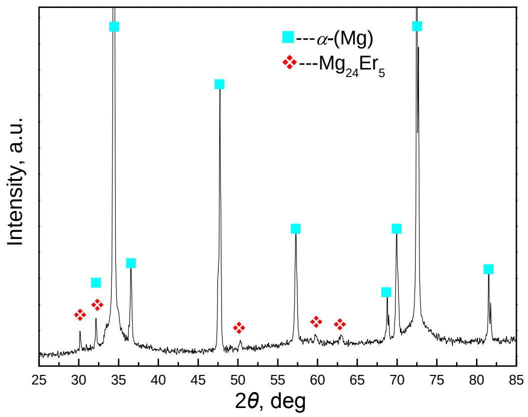

Fig. 2. XRD result of the as-cast Mg-3Er-0.2Mn alloy.

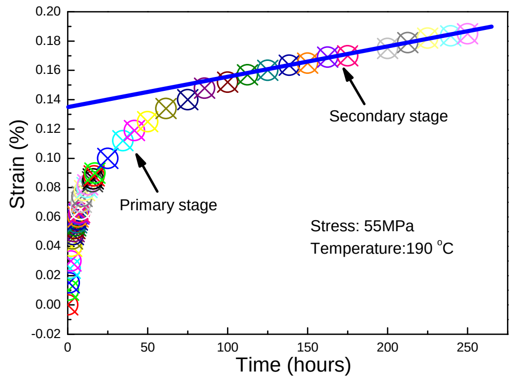

Fig. 3. Typical creep curve of Mg-3Er-0.2Mn alloy at 190 ^{o}C/55 Mpa

Table 1. Variation of the steady creep rate versus temperature and stress.

Temperature	Minimum creep rate, Stress-50 MPa	Minimum creep rate, Stress-55 MPa	Minimum creep rate, Stress-60 MPa
190 ºC	3.60E-10	9.20E-10	3.60E-09
200 ºC	1.50E-09	3.90E-09	1.60E-08
210 ºC	5.00E-09	1.30E-08	4.80E-08

The activation energy *Q* was calculated using equation (1) and (2) [**4**], which are as followed:

$$\dot{\varepsilon}_s = A(\frac{\sigma}{G})^n e^{-(\frac{Q}{RT})} \quad \text{---------------} \ (1)$$

$$Q = -R \times \frac{\ln \dot{\varepsilon}_2 - \ln \dot{\varepsilon}_1}{T_2^{-1} - T_1^{-1}} \times 10^{-3} (KJ/mol) \quad \text{-----------} \ (2)$$

where, *A* is the pre-exponential complex constant containing the frequency of vibration of the flow unit, the entropy change, and a factor that depends on the structure of the material, *G* is shear modulus of magnesium G_T = 0.000192-8.6*T*; *Q* is activation energy; *R* is gas constant; and *n* is stress exponent constant. The activation energy was thus calculated from the creep rates at a varying temperature (**Table 1**) to be in the range of 240~244 KJ/mol, which can be seen in **Fig. 4**. The line slopes of linear-regression analysis are equal to the values of *Q*. Previous workers reported lower values (around 130 KJ/mol) when only basal slip was observed, and higher values of activation energy (around 220KJ/mol) were calculated when cross slip took place [**7**]. So, the value of calculated activation energy *Q* for creep indicates that the creep mode involves a cross slip mechanism from basal to prismatic planes in the H.C.P. structure. From **Fig. 1(c)** we can find few crystaiilization grains, which can prove the occurence of some dislocation climb during creep deformation for the alloy, and the creep mechanism can be attributed to dislocation cross slip or climb controlling. As a result, the creep mechanism of the alloy can be ascribed to the combined effects of dislocation cross slip or climb controlled by diffusion and grain boundary slip.

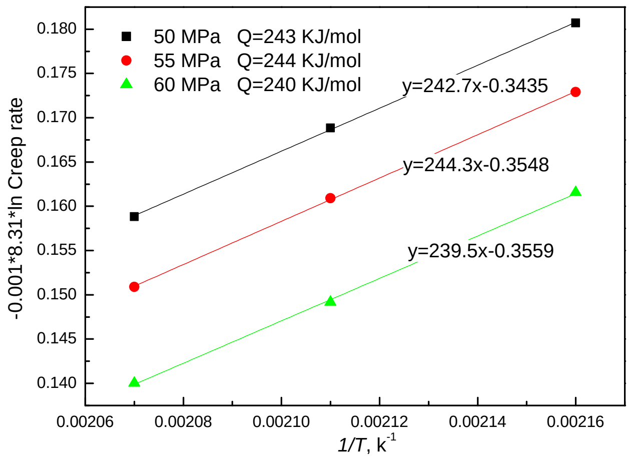

Fig. 4. Activation energy *Q* calculation.

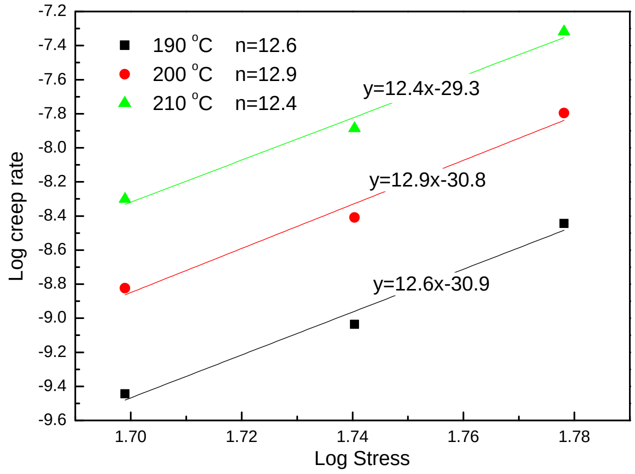

Fig. 5. Stress exponent *n* calculation.

The good adherence and thermal stability between $Mg_{24}Er_5$ phase particals and the alloy matrix may have contributed to the relatively high values of activation energy.

The calculation of the stress exponent for creep deformation was also made. The values of stress exponent *n* calculated was 12.4 ~ 12.9 as expressed in **Fig. 5** by linear-regression analysis.

Conclusion

The Mg-3Er-0.2Mn cast alloy under both as-cast and solution treated conditions is mainly composed of α-(Mg) matrix and $Mg_{24}Er_5$ phase particles; The value of activation energy for creep of the solution treated alloy is between 240KJ/mol and 244 KJ/mol, which can explain that the creep mode involved cross slip of dislocations from basal to prismatic planes in the H.C.P. crystal structure or climb.

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