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Study on the Deformation Behavior of Mg-3.6%Er Magnesium Alloy

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Abstract: The deformation behaviour of a casting Mg-3.6% Er magnesium alloy after T6 treatment was studied in tensile tests from room temperature to 450 ℃ under different strain rates ranging from 1.0×10^{-4} to 6.0×10^{-3} s^{-1}. Obtained local plateau in the temperature dependence of the ultimate strength (σ_b) and yield strength ($\sigma_{0.2}$) under constant strain rate indicated the presence of dynamic strain ageing (DSA). Serrated flow was observed at the temperature of 200, 250, and 300 ℃. The observed negative strain rate sensitivity suggested that the serrated flow behavior arose from DSA. The temperature and strain rate dependence of the critical strain for the onset of serrated flow was analyzed using a phenomenological DSA equation, and the apparent activation energy Q for the serrated flow was obtained by calculation.

Key words: Mg-3.6% Er alloy; deformation behavior; serrated flow; dynamic strain aging; rare earths
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It is well-known that rare earth (RE) can purify melt and improve the mechanical properties of magnesium especially at elevated temperatures. High performance Mg-RE alloys have several applications in aerospace and automotive industry[1~3]. Despite being used for decades, scientific understanding of the flow behavior of Mg-RE alloys is incomplete. Serrated flow has been observed and investigated in Mg-Nd or Mg-Y-Nd system alloys, for example, Gärtnerová V et al[4] observed serrated flow in Mg-0.7% Nd magnesium alloy under T6 condition at the temperatures of 200 ~ 300 ℃. Zhu S M and Nie J F[5] also found serrated flow in WE54 magnesium alloy after T6 treatment at the temperature range of 150 ~ 225 ℃. But these studies are limited only in Mg-Nd and Mg-Y-Nd alloys, and further researches with regard to the serrated flow of other magnesium alloys containing rare earth elements should be carried out. The serrated flow in Mg-3.6% Er alloy at elevated temperatures was reported and the results obtained were analyzed and explained.

1 Experimental

Magnesium of commercial purity with 3.6% Er ingot (Φ 50 mm × 100 mm) was used in this study. The ingot was subjected to T6 treatment, that is, the solution was treated at 500 ℃ for 8 h, then quenched into warm water of 65 ℃ with subsequent ageing treatment at 200 ℃ for 8 h. Flat tensile specimens with gauge dimensions of 2 mm × 6 mm × 15 mm were machined from ingots, the tensile direction of specimens was parallel to the axes of ingots, and all tensile specimens were machined from the 1/2 radius locations of ingots. The tensile specimens were tested

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using a screw-driven INSTRON testing machine equipped with a heating chamber. The tests were performed at a temperature interval from 25 to 450 ℃ under different strain rates ranging from 1.0×10^{-4} to 6.0×10^{-3} s^{-1}. For tests at elevated temperatures, specimens were heated up to the selected temperatures within 15 min and maintained at that temperature for 5 min before testing. The temperature was controlled within ±1 ℃. Tensile test data were collected by a computer data-acquisition system, from which tensile properties such as yield strength ($\sigma_{0.2}$), ultimate tensile strength (σ_b), and critical strain (ε_c) for serrated flow were determined. Two specimens were used for some test conditions to ensure the reproducibility of data. Microstructures were observed using an optical microscope (OM, LEICA DMR) and a transmission electron microscope (TEM, TECNAI G2).

2 Results and Discussion

Fig. 1 (a) shows the microstructure of undeformed samples after T6 treatment. The microstructure is composed of α-Mg solid solution of Er in Mg matrix and some particles in the solid solution. The structure of these particles are determined by the selected area electron diffraction (SAD) pattern of TEM, which belongs to α-Mn crystal type having body-centered cubic (B.C.C.) structure (Fig. 1 (b)), and its lattice constant is equal to 11.23 nm by calculation. These particles are in $Mg_{24}Er_5$ phase according to Mg-Er binary phase diagram[6] and the SAD analysis result. No precipitated phase was found in the alloy after T6 treatment.

The stress-strain curves obtained under a constant strain rate of 1.0×10^{-4} s^{-1} and at various temperatures are shown in Fig. 2 (a). Work hardening was seen in the whole temperature range. Ductility of the alloy is relatively high compared with other Mg-RE alloys[4,5]. Serrated flow was observed at the temperatures of 200, 250, and 300 ℃, and softening of the alloy was observed during deformation at 300 ℃ and higher temperature. Relationships between temperature and yield strength ($\sigma_{0.2}$) or ultimate strength (σ_b) are shown in Fig. 2 (b). It can be seen that the temperature dependence of both $\sigma_{0.2}$ and σ_b is nonmonotonous. In addition, a local plateau of $\sigma_{0.2}$ or σ_b is observed in the temperature interval of 200 ~ 300 ℃, which suggests the presence of dynamic strain ageing (DSA).

Twins were observed in whole temperature

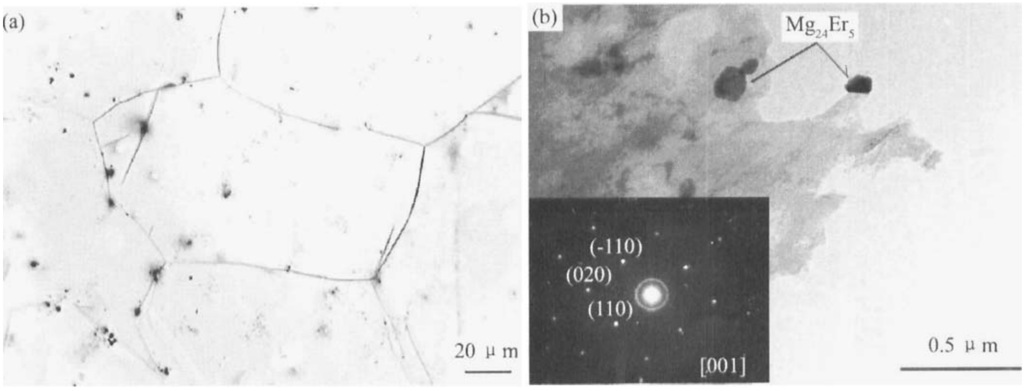

Fig. 1 Metallographic picture of Mg-3.6%Er alloy after T6 treatment (a), and TEM image and SAD pattern of $Mg_{24}Er_5$ phase (b)

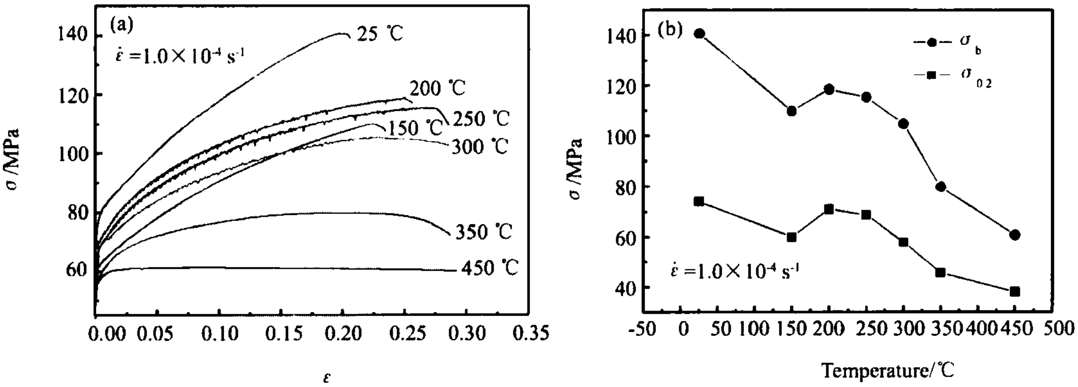

Fig. 2 Stress-strain curves (a) and temperature dependence of σ_b and $\sigma_{0.2}$(b) under constant strain rate of 1×10^{-4} s^{-1}