MAGNESIUM ALLOYS WITH ERBIUM

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One of the most promising methods of improving the strength of magnesium alloys is the use of rare-earth metals (REM) as alloying additions [1-3]. A detailed study of magnesium alloys with four REM of the lanthanum series was made – lanthanum, cerium, praseodymium, and neodymium, and also gadolinium. Alloys of magnesium with other REM have been investigated only from the viewpoint of rare-earth metals [4]. It was shown in [5] that the addition of erbium (up to 25%) increases the strength of magnesium at room and elevated temperatures. In contrast to other alloys of magnesium with REM, the ductility of this alloy remains at a fairly high level.

We investigated the structure of magnesium-rich alloys with erbium.

The original materials were 99.95% pure magnesium (MG95) and two grades of erbium – 99.83% and 99.68% pure, respectively. Erbium contained the following impurities (no more than): 0.1-0.2% REM (Dy, Ho, Tm, Yb, Y), 0.01-0.02% Fe, 0.01-0.03% Ca, 0.03-0.05% Cu, and 0.02% Ta or Mo.

Thermal analysis was conducted with the NTR-70 instrument with photorecording of cooling curves. The cooling rate was ~2 deg/min. The alloys were prepared for thermal analysis directly in the furnace of the instrument. Erbium was added in pure form and in the form of a master alloy containing ~50% Er. We used a corundum crucible, corundum dome, and Chromel–Alumel thermocouples. Melting was conducted under flux consisting of 50% KCl and 50% LiCl.

Thermal analysis and examination of the microstructure of the ingots showed that alloys of magnesium with erbium are characterized by a broad range of solid solutions based on magnesium. The eutectic transformation was observed at 584 ±2°C. The typical microstructure of the ingot with eutectic is shown in Fig. 1a. The phase in equilibrium with the magnesium solid solution has a gray color. From the data in [6] it can be assumed that it is $Mg_{24}Er_5$.

Alloys for determining the solubility of erbium in magnesium in the solid state were melted under the same conditions as in the thermal analysis, but to obtain denser ingots we used flux VI2 [38-46% $MgCl_2$, 32-40% KCl, 5-8% $BaCl_2$, 1.5% MgO, ≤ 8% ($NaCl + CaCl_2$)]. The ingots were hot extruded to bars 6.5 mm in diameter with 90% reduction. The temperature of the ingot before extrusion was 410-430°, the temperature of the container 380-400°. The composition of the alloys was determined by chemical analysis. Samples were quenched after annealing at 615° for 2 h, 580° for 3.5 h, 540° for 4 h, 500° for 5 h, 400° for 8 h, 300° for 24 h, and 200° for 200 h. Annealing at 400, 300, and 200° was preceded by annealing at 500, 400, and 300°, respectively.

Alloys quenched from temperatures below the eutectic had a single-phase α or biphase $\alpha + Mg_{24}Er_5$ structure (Fig. 1b). After quenching from 615° the erbium-rich alloys showed signs of melting, indicating that quenching was conducted from the biphase region $L + \alpha$. The results of examining the microstructure of samples used for determining the solubility and the data from thermal analysis are shown in Fig. 2. Liquidus and solidus lines and the boundary of the magnesium solid solution were constructed on the basis of these data. After annealing at 200° the precipitates of erbium-rich phase are very dispersed and their presence in small quantities is impossible to determine with any degree of reliability by metallographic analysis.

The x-ray analysis was conducted with the URS-50I diffractometer, with use of $K_\alpha Cu$ radiation.

We determined the change in the interplanar distance (213) in relation to composition. The results of the measurements for single-phase and biphase are shown in Fig. 3. With solution of erbium the interplanar distance increases, since the atomic diameter of erbium (3.48 Å) is larger than that of magnesium (3.21 Å) [7]. The results of determining the solubility of erbium in solid magnesium at 500, 400, and 300° from the change

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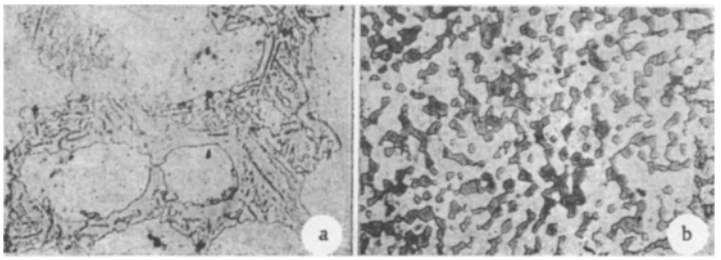

Fig. 1. Microstructure of Mg–Er alloys. a) Mg+42.5% Er, as-cast (200×); b) Mg+36.3% Er, annealed at 500° for 5 h (400×).

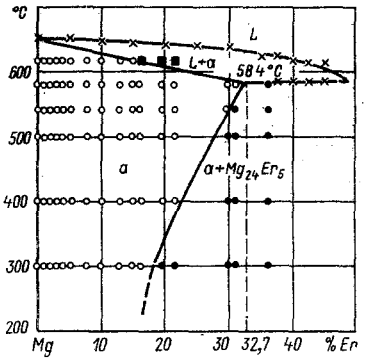

Fig. 2

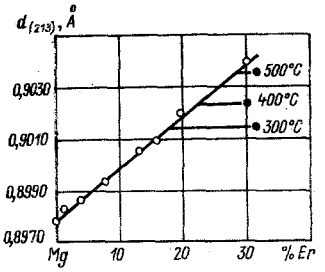

Fig. 3

Fig. 2. Phase diagram of the Mg–Er system on the basis of data from thermal (X) and metallographic (○, ●, ■) analysis.

Fig. 3. Variation of the interplanar distance (213) of the crystal lattice of the magnesium solid solution with composition. ○) Single phase alloys; ●) biphase alloys annealed at different temperatures (given on the curves).

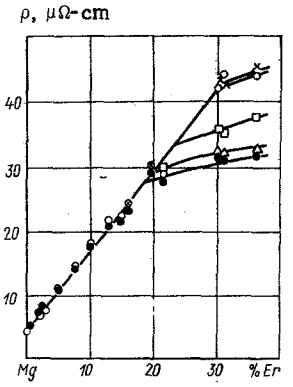

Fig. 4. Specific electrical resistivity of Mg–Er alloys in relation to composition. ○) Annealing at 540°; X) 500°; □) 400°; Δ) 300°; ●) 200°.

in the interplanar distance match the results from microstructural analysis. At 200° the interplanar distance (213) of the saturated solid solution coincides with the interplanar distance at 300° within the limits of the error in the measurements.

The solubility of erbium in the solid state determined by x-ray and metallographic analysis is given below.

Temperature, °C	Er, wt.%, in solid solution
584	32.7 (6.56)
540	30.5 (5.99)
500	28.3 (5.42)
400	23.0 (4.15)
300	18.5 (3.17)

Note. 1) The erbium concentration in atomic percent is given in parentheses. 2) The solubility of erbium at eutectic temperature (584°) was determined by extrapolation.

Figure 4 shows the results of measuring the specific electrical resistivity of alloys quenched after annealing. It should be noted that the electrical resistivity increases considerably in the range of solid solutions. The inflection on the curves corresponds to the change from the single-phase to the biphase region. The values of the solubility of erbium in solid magnesium determined from the inflection on the resistivity curves are somewhat higher than the values determined by metallographic and x-ray analysis but are in satisfactory agreement with them. The lower resistivity of erbium-rich alloys after annealing at 200° in comparison with annealing at 300° indicates a reduction of the solubility of erbium in magnesium when the temperature is lowered from 300 to 200°, which cannot be established by metallographic or x-ray analysis. The mechanical properties of hot extruded bars of the Mg–Er alloy were given in [5].

Magnesium alloys with >10% Er have high strength characteristics at 250° – σ_b = 22-24.5 kgf/mm^2 and $\sigma_{0.2}$ = 15.5-17.5 kgf/mm^2 – and therefore can be considered as the basis for the development of magnesium alloys intended for high-temperature applications. The high solubility of erbium in solid magnesium is responsible for the high ductility of the alloys at room temperature (δ = 9-12%). For this reason, the danger of brittle fracture increases negligibly even with the addition of large quantities of erbium.

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