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Phase structure of ZK60-1Er magnesium alloy compressed at 450 ˚C

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Abstract: The phase structure of ZK60-1Er magnesium alloy thermally compressed at the temperature of 450 ˚C and the strain rate of 1×10^{-4} s^{-1} was determined by transmission electron microscopy (TEM) and high-resolution electron microscopy (HREM). The results show that this magnesium alloy contains many new *W* phases ($Mg_3Zn_3Er_2$, FCC structure) in the matrix. Those new *W* phases have two morphologies, either irregularly rectangular or rod morphology. Lattice constants of the two new *W* phases are slightly higher than those of *W* Phase ($Mg_3Zn_3Y_2$) containing rare earth element of yttrium.
Key words: ZK60; Er; *W* phase; magnesium alloy; phase structure

1 Introduction

ZK60 is a kind of conventional wrought magnesium alloy, in which the mainly alloying element is zinc (Zn) [1−3]. Magnesium-zinc based alloy has excellent hardening response in the magnesium-based alloy system [4−5]. Unfortunately, the application of ZK60 alloy is extremely limited by its bad casting characteristics[6−7]. Recently, improvement of this performance can be introduced by the addition of the rare earth (RE) element of erbium (Er) which can shorten the solidification distance of metal liquid[8−9]. In the meanwhile, many small rare earth phases containing *W* phase, *I* phase and *Z* phase in Mg-Zn-Y and Mg-Zn-Y-Zr alloys deformed at elevated temperatures (250−420 ℃) were reported to improve the mechanical properties of these alloys, especially at high temperature[10−15]. However, few studies on phase structure of the Mg-Zn-Er-Zr system alloy have been carried out. In this work, our main objective is to analyze and determine the phase structure of ZK60-1Er magnesium alloy thermally compressed at high temperature of 450 ˚C and very slow strain rate of 1×10^{-4} s^{-1}.

2 Experimental

Chemical composition (mass fraction, %) of ZK60-1Er alloy used in the present study was as follows: Zn 5.82, Zr 0.51, Er 1.10, Cu 0.03, Ni 0.005, Si 0.01, Fe 0.01, Be 0.001 and Mg balance. The alloy was melted in a mild steel crucible. The ingot was homogenized at 673 K for 18 h. The cylindrical specimen for hot compression was machined to be 8 mm in diameter and 15 mm in length. Before the hot compression test, the specimen was heated to the test temperature for 5 min. Hot compression test was carried out on a Gleeble 1500D hot simulation machine. Compression test was conducted at the temperature of 450 ˚C and the strain rate of 1×10^{-4} s^{-1}. After hot compression, the specimen was water quenched. The TEM specimens, disks with 3 mm in diameter, were punched from the foils mechanically machined and taken from hot compressed specimen for subsequent jet electro-polishing. Thin foil specimens for TEM and HREM were polished in a 15% (volume fraction) nitric acid and 85% methyl alcohol solution at −30 ˚C under a voltage of 20 V. After polishing, the black opaque layer on the surface of the specimen was

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removed by dipping for 1−2 s in 20% nitric acid and 80% ethanol solution. TEM and HREM observation and analysis were made with a TecNai F30 microscope operated at a voltage of 200 kV and 400 kV, respectively, with a double-tilt stage.

3 Results and discussion

Fig.1(a) shows that there exists irregularly rectangular phases along grain boundaries in the alloy matrix. The molar ratio of Mg, Zn and Er element of the phase is approximately equal to 3:3:2 according to the analytical result of energy dispersive spectrum (EDS, Fig.1(b)), and the chemical formula of this phase should be expressed as $Mg_3Zn_3Er_2$.

Fig.2 shows a series of selected area diffraction (SAD) patterns of the $Mg_3Zn_3Er_2$ phase through large-angle tilting of the TEM stage. The crystal structure

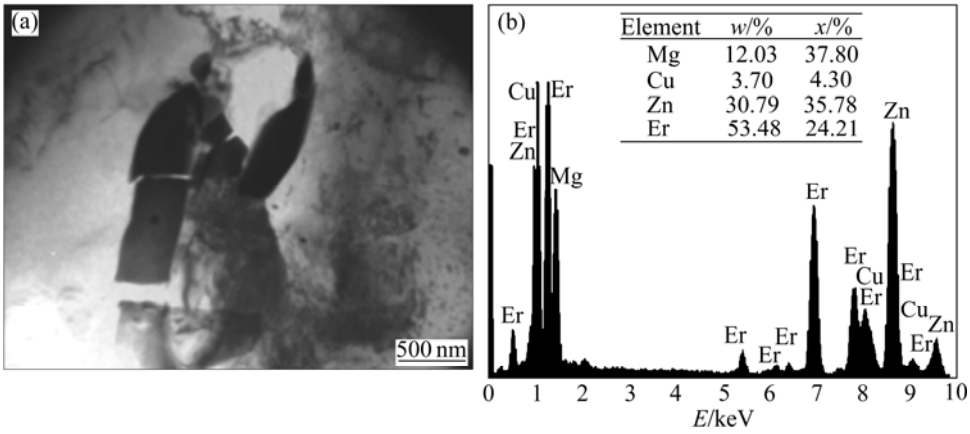

Fig.1 TEM image (a) and its EDS result (b) of irregularly rectangular phase

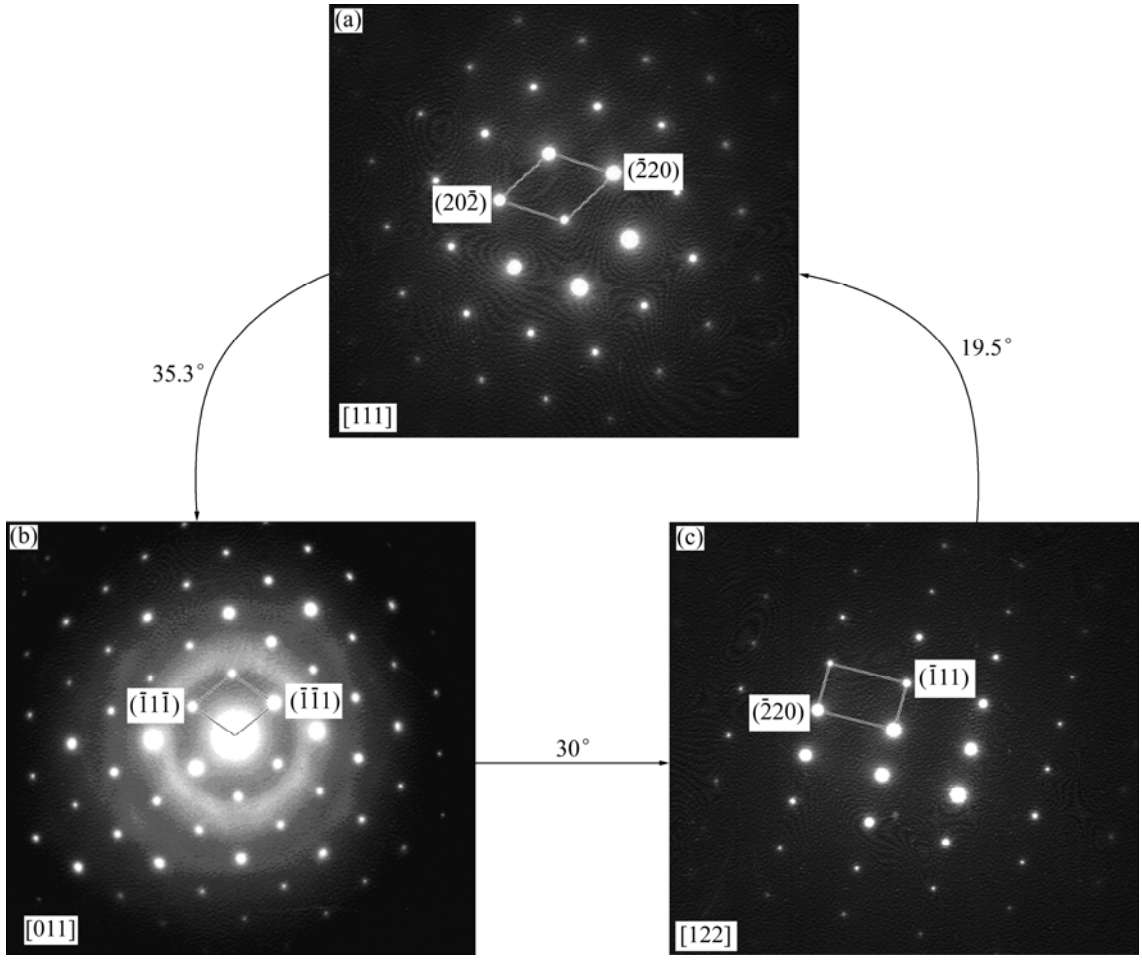

Fig.2 Three SAD patterns of irregularly rectangular phase: (a) [111] axis zone; (b) [011] axis zone; (c) [112] axis zone

of this phase was determined by indexation of crystal plane, calculation and self-consistency analysis to be face-centered cubic (FCC) structure. The calculated value of the crystal lattice constant is equal to 0.706 nm.

From the above experimental results, we can see that both the chemical formula and the crystal structure of the irregularly rectangular phase ($Mg_3Zn_3Er_2$) are similar to those of the *W* phase ($Mg_3Zn_3Y_2$) of the Mg-Zn-Y ternary alloys. In the meanwhile, the calculated lattice constant (0.706 nm) of $Mg_3Zn_3Er_2$ phase is slightly larger than, but approximately equal to 0.685 nm of $Mg_3Zn_3Y_2$ (*W* phase)[12]. So, we can denominate the $Mg_3Zn_3Er_2$ phase as new *W* phase, temporarily.

It was also found that there are a lot of or many rod-liked phases in the matrix of this hot compressed alloy (Fig.3(a)). This kind of rod-like phase is another morphology of the new *W* phase, whose chemical formula can likewise be expressed as $Mg_3Zn_3Er_2$ by EDS and HREM analytical result.

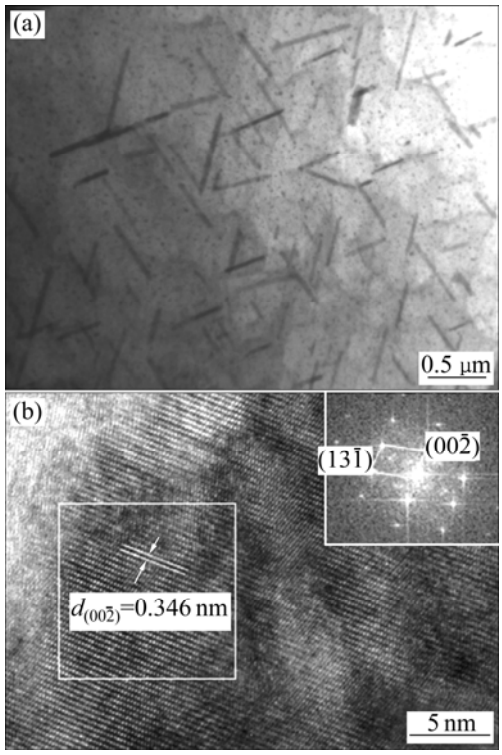

Fig.3 TEM image (a) and HREM image, inverse Fourier transform and interplanar spacing of crystal plane $(00\bar{2})$ of rod-like new *W* phase (b)

Fig.3(b) shows the HREM image, inverse Fourier transform result and its plane indexation of reciprocal lattice of the new *W* phase. We can obtain the values of some different interplanar spacings from Fig.3(b). For example, the value of the interplanar spacing of the low index number plane of $(00\bar{2})$ can be measured, which is equal to 0.346 nm. Consequently, the value (0.692 nm) of the lattice constant of the rod-like new *W* phase can be calculated by cubic crystal system equation:

$$a=\frac{d_{hkl}}{\sqrt{h^2+k^2+l^2}}$$

which is also slightly higher than that (0.685 nm) of the *W* phase ($Mg_3Zn_3Y_2$)[9], possibly resulting from the higher atomic radius of Er than that of Y.

4 Conclusions

1) The phase structure of ZK60-1Er magnesium alloy thermally compressed at the temperature of 450 ˚C and strain rate of 1×10^{-4} s^{-1} contains many new *W* phases ($Mg_3Zn_3Er_2$, FCC structure) besides the alloy matrix.

2) New *W* phases have two morphologies, irregular rectangle and rod-like morphology.

3) The value of the lattice constants of the irregular rectangle and rod-liked new *W* phase are 0.706 nm and 0.692 nm, respectively, larger than that of the *W* phase ($Mg_3Zn_3Y_2$) containing rare element of Y, 0.685 nm.

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