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Short communication

Effect of microalloying with boron on the microstructure and mechanical properties of Mg–Zn–Y–Mn alloy

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ABSTRACT

The addition of boron to long-periodic stacking ordered (LPSO) phase-strengthened Mg–Zn–Y system alloys has been studied for the first time. The as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy containing 0.003 wt% B with abundant LPSO phase and refined grains exhibited optimal mechanical performance with ultimate tensile strength and elongation of 252.5 MPa and 11.0%, respectively.

1. Introduction

Magnesium alloys are the lightest structural materials with high prospects of application, because of their high specific strength, specific stiffness, and good castability [1]. In the last decade, magnesium alloys with long-periodic stacking ordered (LPSO) structures, exhibiting unique microstructures and excellent mechanical properties, have been developed in the ternary Mg–Zn–Y systems and received progressive interest. It has been reported that there are three types of ternary phases in the Mg–Zn–Y alloy system: icosahedral quasi-crystal structure Mg_3Zn_6Y (I-phase), cubic structure $Mg_3Zn_3Y_2$ (W-phase), and 18 R LPSO structure $Mg_{12}YZn$ (X-phase). Recently, a series of Mg–Y–Zn alloys with an atomic Y/Zn ratio of 2:1 have attracted considerable attention because of the presence of large LPSO structures that exhibit excellent mechanical properties [2,3]. In general, X-phase is easier to be formed when the Y content is higher than Zn content. Thus, a major issue that limits the commercial application of the rare earth metal-containing Mg alloys is their high cost.

It has been recognized that the addition of B was extremely beneficial to the mechanical behavior of many metallic materials. This is achieved by: (1) preferential nanoscale segregation at the grain boundaries [4,5] and/or (2) phase modification including precipitation regulation in the matrix [6,7]. The careful addition of B to magnesium alloy is expected to incur similar dopant-related beneficial effects. However, to date, there have been only few studies conducted on B-containing LPSO strengthening Mg alloys. In particular, data on the effect of B on the formation of LPSO phases were reported barely. In this study, different amounts (0.000, 0.002, 0.003, 0.004 and 0.01 wt%) of B in the form of Mg–B master alloy are added to $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy and the effects of B on the microstructure and mechanical properties are studied and results reported.

2. Experimental procedures

The five-group Mg–Zn–Y–Mn–B alloys were melted by using high-purity Mg, Zn, Y, Mn, and Mg-10 wt% B master alloy in an electric resistance furnace under the protective atmosphere of Ar gas at 1023 K. Then, they were cast into a preheated mold at 993 K. Phase constitution analyses were performed with Y-2000 X-ray diffraction (XRD) using monochromatic Cu-Kα radiation. The microstructures and compositions of different phases of the alloys were investigated by scanning electron microscopy (SEM, TESCAN-MIRA3) equipped to energy-dispersive spectroscopy (EDS) and transmission electron microscopy (TEM, JEOL 2010). Thin foils for TEM observation were prepared by cutting the bulk sample into slices, grinding to the thickness of about 50 μm, and ion milling

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finally. Tensile specimens with a gage dimension of 60 × 12 × 2.5 mm were synthesized by a DNS100 electronic universal material test machine with a crosshead speed of 0.2 mm/min at ambient temperature. The nanomechanical properties, including hardness and elastic modulus, were measured by Nano Indenter G200 as the average of 10 values. The grain size and phase fraction were measured and determined by linear intercept method and image analysis technique, respectively.

3. Results and discussion

3.1. Microstructure analysis

Fig. 1a shows the microstructure of as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy containing 0.003 wt% B. It can be indicated that the alloy consisted of α-Mg matrix, block second phases, and fishbone-like eutectic structure. The EDS results (Fig. 1b and c), bright-field (BF) TEM image and the corresponding selected area electron diffraction (SAED) pattern (Fig. 2), and the XRD patterns (Fig. 3) reveal that the second-phase is 18R-LPSO phase ($Mg_{12}YZn$) and the eutectic structure is W-phase ($Mg_3Zn_3Y_2$).

Fig. 4a–e shows the optical micrographs of the as-cast experimental alloys. The grains were observed more finer and globular when the amount of boron was increased from 0% to 0.003%. However, the grains showed a tendency to be coarser with dendritic features with more B addition. As 0.003 wt% B was added, homogeneous spherical grains with an average grain size of 22 μm were observed (Fig. 4c). Therefore, it can be concluded that element B has significant impact on grain refinement of the Mg–Zn–Y–Mn alloys. Previous investigations have reported that the addition of B significantly refined the grain size of AZ91 alloy, which is attributed to the presence of AlB_2 particles. These particles act as potential nucleants for Mg grains [8]. MgB_2 phase in the Mg-10 wt% B master alloy possesses an AlB2-type hexagonal structure (space group P6/mmm) with alternating boron honeycomb planes and magnesium triangular planes [9]. Therefore, the MgB_2 phase acts as potential nucleants in Mg grains. Accordingly, the addition of B can obviously suppress grain growth and refine grains.

As can be seen from Fig. 4f obtained by quantitative analyses of

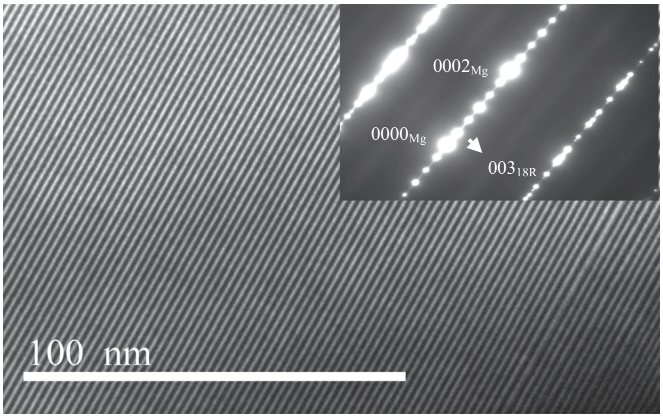


Fig. 2. Bright field (BF) TEM image and the corresponding selected area electron diffraction (SAED) pattern of the second phase in the as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy containing 0.003 wt% B.

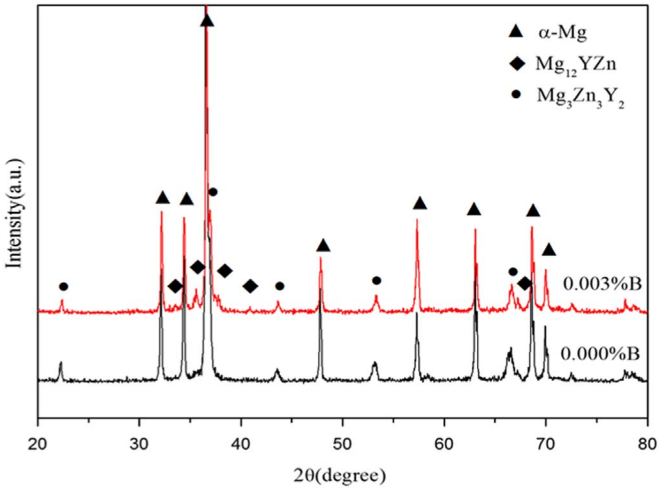
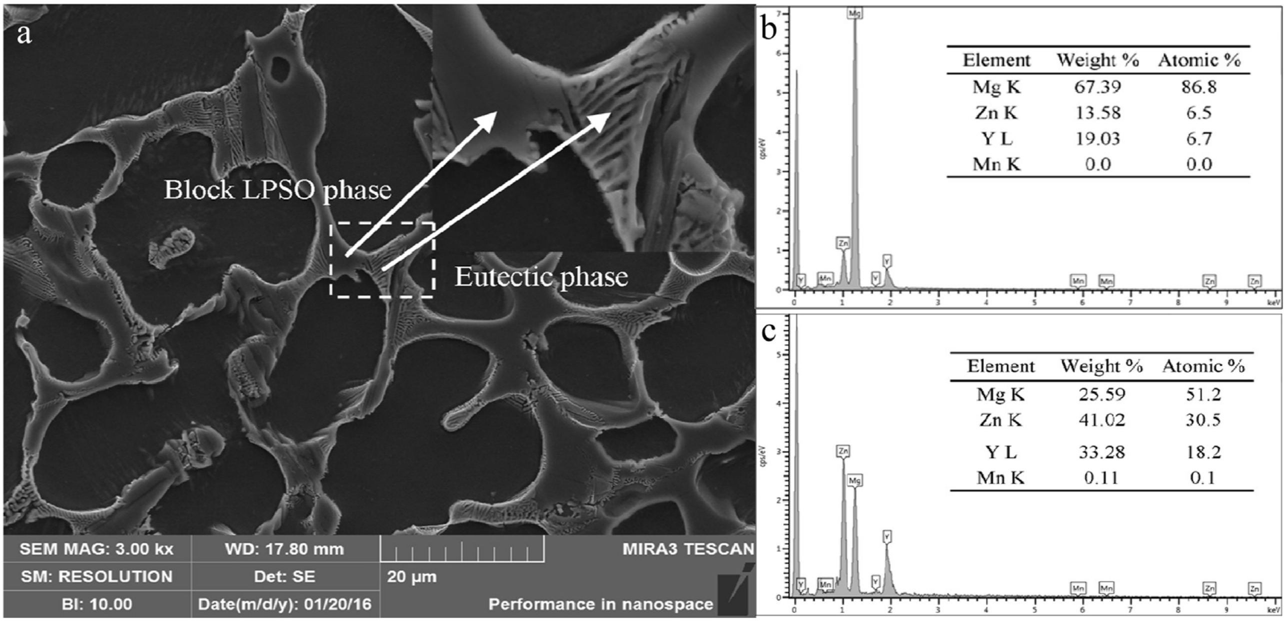


Fig. 3. XRD patterns of the as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloys with different B additions.



b

Element	Weight %	Atomic %
Mg K	67.39	86.8
Zn K	13.58	6.5
Y L	19.03	6.7
Mn K	0.0	0.0

c

Element	Weight %	Atomic %
Mg K	25.59	51.2
Zn K	41.02	30.5
Y L	33.28	18.2
Mn K	0.11	0.1

Fig. 1. (a) SEM image of the as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy containing 0.003 wt% B, EDS spectra of (b) second phase and (c) eutectic structures in as-cast $Mg_{94}Zn_{2.5}Y_{2.5}Mn_1$ alloy containing 0.003 wt% B.