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Investigation of two-phase Mg-Gd-Ni alloys with highly stable long period stacking ordered phases

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ABSTRACT

The effects of the Ni addition on the microstructures of Mg-2Gd-xNi (at.%, x = 0, 0.25, 0.5 and 1) alloys were systematically investigated. A series of two-phase Mg-Gd-Ni alloys consisting of long period stacking ordered (LPSO) phase and α-Mg were obtained. The LPSO phase presented block-like shape and was distributed between α-Mg dendrite arms. Its volume fraction was found to be proportional to the Ni content, ranging from 0 to ~40% with the Ni content increasing from 0 to 1 at.%. After a heat treatment at 500 °C for 100 h, the LPSO phase experienced a structure transformation from 18R to 14H but was hardly dissolved into the α-Mg matrix, which evidenced a high thermal stability. The mechanism for the effects of the Ni addition on the formation of the LPSO phase was discussed.

1. Introduction

Magnesium alloys containing long period stacking ordered (LPSO) structure have attracted intensive attentions due to their excellent mechanical properties [1]. Up to now, many LPSO-containing alloys have been developed in the Mg-RE-X alloy systems (RE: rare earth element, such as Gd, Tb, Dy, Ho, Er, Tm or Y; X: mostly transition metals such as Co, Ni, Cu and Zn or the post-transition metal Al) [2–13]. Based on density functional theory (DFT) calculations, Saal and Wolverton [14] predicted stable LPSO structures in a number of Mg-RE-X alloy systems, but most of the systems remained uninvestigated. Most studies on LPSO have been devoted to the Mg-RE-Zn alloys. The knowledge about the other Mg-RE-X (X = Co, Ni, Cu, Al) alloy systems is still limited.

Liu et al. [15] reported that partial substitution of Ni for Zn could improve both the strength and ductility of extruded Mg–Y–Zn alloys reinforced by the LPSO phase and that a complete replacement of Zn by Ni could enhance the thermal stability of the LPSO phase. Recently, Wang et al. [16] suggested that the Ni addition could promote the formation of the LPSO phase and improve the mechanical properties of as-cast Mg-Gd-Zn alloys. This made the development of LPSO-forming Mg-RE-Ni alloys of great interest. Xu et al. [17] studied the Mg-Gd-Ni phase equilibria, evidencing the formation of the 18R-type LPSO phase, while Wang et al. [16] reported a 14H-type LPSO phase in an Mg-Gd-Ni alloy. The determination of the LPSO structure(s) and a better understanding about its formation and stability in the Mg-Gd-Ni system are necessary. Moreover, it has been reported that an LPSO/Mg two-phase structure can improve mechanical properties via the fiber reinforcing mechanism [18]. The present work is to systematically investigate the effects of the Ni addition on the formation of LPSO phase as well as the microstructures of Mg-Gd-Ni alloys.

2. Experimental procedures

Mg, Gd and Ni with purity better than 99.9 wt.% were used as starting materials. The alloys with nominal compositions of Mg-2Gd-xNi (x = 0, 0.25, 0.5, and 1, at. %) were melted in a graphite crucible with a high-frequency induction furnace and then cooled down to the room temperature under an argon atmosphere. Each alloy was heat treated at 500 °C for 20 h (and additionally 100 h for the Mg-2Gd-1Ni alloy) and then quenched into water at room temperature. X-ray diffraction (XRD) was performed for phase identification. The microstructures of the as-cast and heat-treated alloys were investigated using optical microscopy and scanning

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electron microscopy (SEM). The alloys were investigated with X-ray energy-dispersive spectrometry (EDX) and transmission electron microscopy (TEM) for a further phase identification. The phase stabilities and transitions were studied with differential thermal analysis (DTA) at a heating rate of 10 K/min. The hardness of constituent phases in the alloy was measured by a Vickers micro-hardness tester using a load of 50 g and holding time of 10 s.

3. Results and discussions

3.1. As-cast microstructure

The optical microstructures and corresponding XRD patterns of as-cast Mg-2Gd-xNi (x = 0, 0.25, 0.5 and 1, at. %) alloys are shown in Fig. 1 and Fig. 2, respectively. All the alloys consist of dendrites of α-Mg and second phases distributed between the dendrite arms. The volume fraction of second phases increased rapidly with increasing the Ni addition. The skeleton-like second phase in the Ni-free binary Mg-2Gd alloy was determined with XRD to be $GdMg_5$. With the addition of Ni, the morphology and specially the nature of second phases changed significantly. A block-like phase emerged, showing the unique morphology of the bulk LPSO phase [2–13].

Fig. 3 shows the electron image of the as-cast Mg-2Gd-1Ni alloy and evidences a two-phase structure consisting of the primary α-Mg grains and interdendritic secondary phase. A spot EDX measurement gave that the α-Mg grains contained 1.8 at.% Gd but were

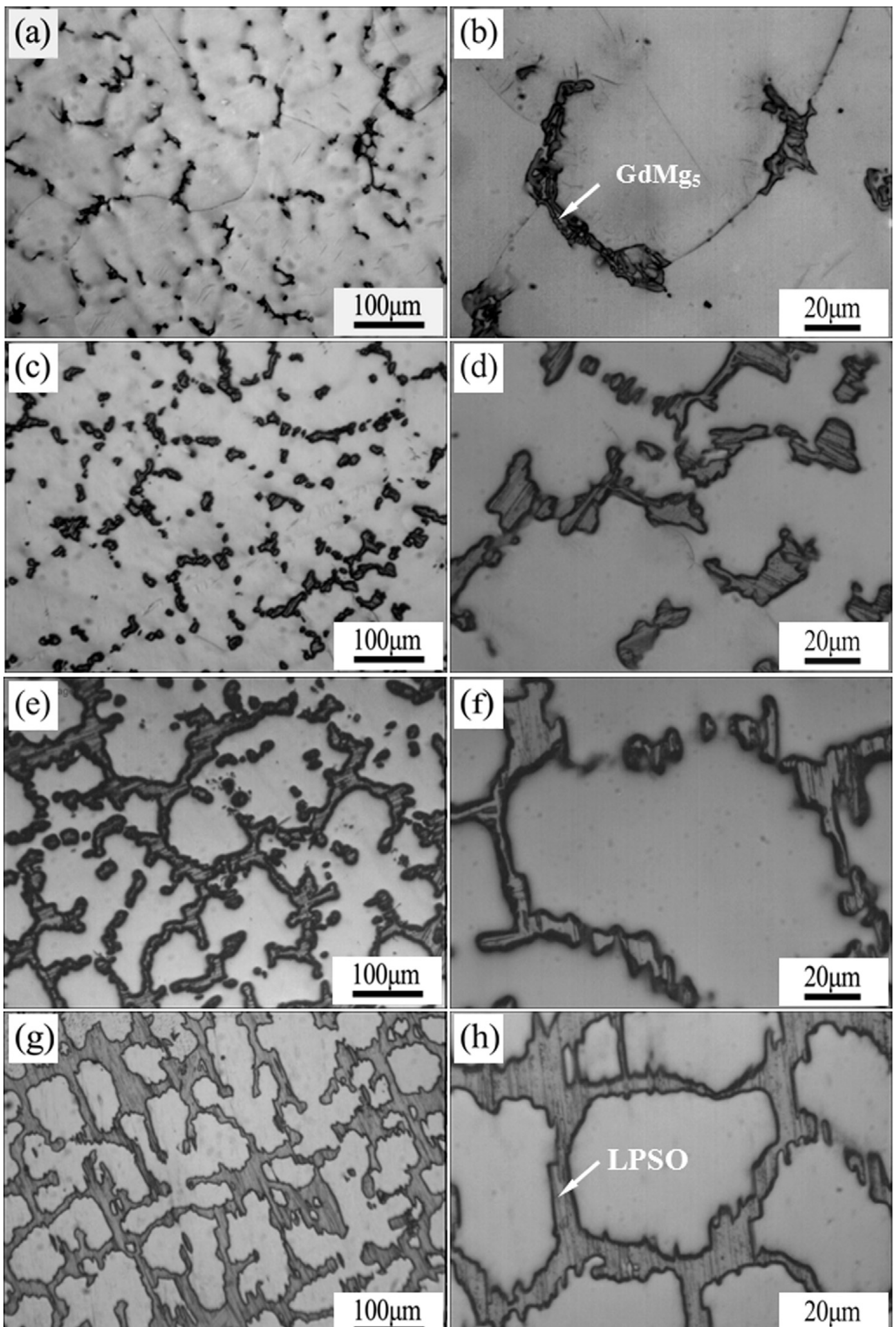

Fig. 1. Optical micrographs of the as-cast Mg-2Gd-xNi alloys: (a and b) x = 0, (c and d) x = 0.25, (e and f) x = 0.5, (g and h) x = 1.