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Martensite in die-cast magnesium alloy?

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Abstract

In this paper, the microstructures of a thin-wall die-cast commercial magnesium (Mg) alloy, aged at 200 °C for various times, were investigated using transmission electron microscopy. A martensite-like phase was observed. The crystal lattice parameters of this phase are $a = 0.30948$ nm, $c = 0.50498$ nm, and axial ratio $c/a = 1.6314$. Orientation relationship of the martensite-like phase and the parent has been determined as $(0\,0\,0\,1)_{product} \| (1\,0\,\bar{1}\,0)_{parent}$, and $[0\,0\,0\,1]_{product} \| [1\,0\,\bar{1}\,0]_{parent}$ or $[2\,\bar{1}\,\bar{1}\,0]_{product} \| [2\,\bar{1}\,\bar{1}\,3]_{parent}$. The driving force of the possible martensitic transformation (MT) might came from the residual microstructure stresses left during die-cast process.

Keywords: Magnesium alloy; Martensite; Die-cast

1. Introduction

Martensitic transformation (MT) is diffusionless shear transformation and involves no change in composition. The MT occurred in steels is of the greatest technological importance, where it can confer an outstanding combination of strength and toughness. Many materials other than steel, for example, nonferrous, pure metals, ceramics, minerals, inorganic compounds, solidified gases and polymers, are now known to exhibit the same type of solid-state phase transformation, and in many of these cases the mechanism of the transformation has been completely worked out [1].

Magnesium (Mg) is an important alkaline-earth metal element, to which considerable attention have been paid in solid-state physics field due to its special high-pressure behavior [2–5]. At the same time, its low density and high specific strength also make it find many applications in engineering in form of various alloys [6]. Pure Mg has the hexagonal-close-packed (hcp) structure at ambient condition. However, an energy-dispersive X-ray diffraction experiment conducted by Olijnky and Holzapfel [7] showed that Mg undergoes phase transformation to body-centered cubic (bcc) structure around 50 GPa at room temperature. The result agrees with theoretical predictions made earlier on the basis of first-principle calculation performed at zero absolute temperature [3,4,8], and then extended to finite temperatures [9]. More recently, Jona and Marcus [10] also obtained the same result as stated above by the full-potential, linearized, augmented-plane-wave method. At the same time, another phase transformation from hcp to double layer hexagonal-close-packed (dhcp) in Mg was found by Errandonea et al. [11] in the pressure–temperature range above 9.6 GPa and up to 1527 K, although no hcp → bcc transformation has been observed. In the latest experiment conducted by our group, a martensitic phenomenon was observed in thin-wall die-cast Mg alloy underwent an ageing process at mild conditions. In this shorter communication, an initial result will be reported including phase morphologies, microstructures and chemical compositions.

2. Experimental

Samples studied were cut from a practical component, which was made of AZ91D Mg alloy and fabricated in a hot-chamber die-cast machine (Toshiba, 150 t). The sample thickness is 0.8 mm. The chemical composition of the sample is shown in Table 1. After aged at 200 °C for 10 min, 30 min and 2 h, respectively, the samples were milled mechanically and punched into 3 mm discs. Finally, a Gatan precision ion polishing system 691 was used to thin the specimens under conditions of 3.0 kV and incident angle of 5°. TEM and HRTEM analysis were conducted, respectively, in H-800 and JEOL-2010 transmission electron

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Table 1
Chemical composition of the AZ91D Mg alloy studied (mass%)

Element	Al	Mn	Zn	Cu	Ni	Fe	Si	Be	Mg
Chemical composition (mass%)	8.6	0.18	0.86	0.0007	0.0007	0.0012	0.015	0.0002	Bal.

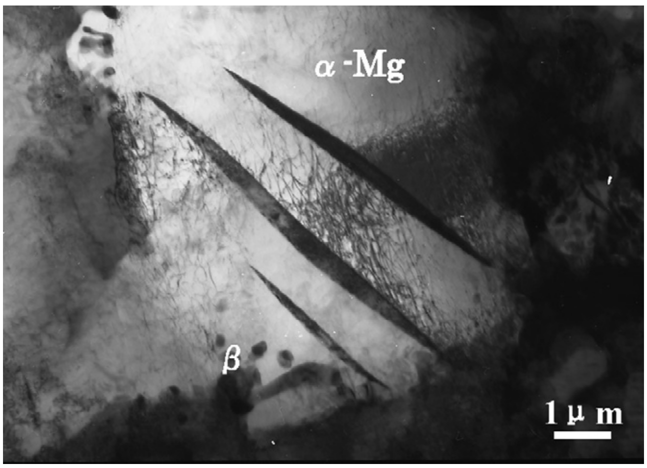

Fig. 1. Microstructures of the Mg alloy studied, which shows the primary, eutectics, β phases, and the needle-like phases.

microscope. Stress analysis and examinations were performed with XRD-7000 X-ray diffractometer.

3. Results and discussion

Fig. 1 shows microstructures of the sample aged at 200 °C for 10 min. The microstructures consist of primary α-Mg, eutectics (α-Mg + β-$Mg_{17}Al_{12}$), β phase and needle-like phase (NLP) distributed in the primary. The former two phases formed during die-cast process and the latter two did during ageing. The β phase precipitates were little in quantity because ageing time was short, only 10 min. It is reasonable because the precipitation process of the β phase is diffusion-controlled. In contrast, the NLP formed quickly. Its length grows up to about 8 μm in so short ageing time. It is impossible for the NLPs to form by migration of atoms. Moreover, there are no detectable changes in quantity and size of the NLPs with prolonged ageing times. It indicates that a MT possibly takes place in the Mg alloy under study. Further observation revealed that the NLPs are always distributed in the primary and are parallel to each other. The NLP maximum in length passes exactly pass through the primary, just as shown in Fig. 1.

One can find that the NLP is of lens-shaped by rotating specimen holder (Fig. 2). The morphology of the NLP changes from lath to needle, while rotated by 5° approximately. The diffraction pattern from the interface between two phases, i.e., the parent and the NLP, is shown in Fig. 3.

The chemical composition of the parent and the NLP is shown in Table 2. The composition of the β phase is also listed there. It can be seen, that there is no obvious discrepancy in chemical composition between the parent and the NLP. Some solute Al atoms were left in the two phases, which is slightly higher than

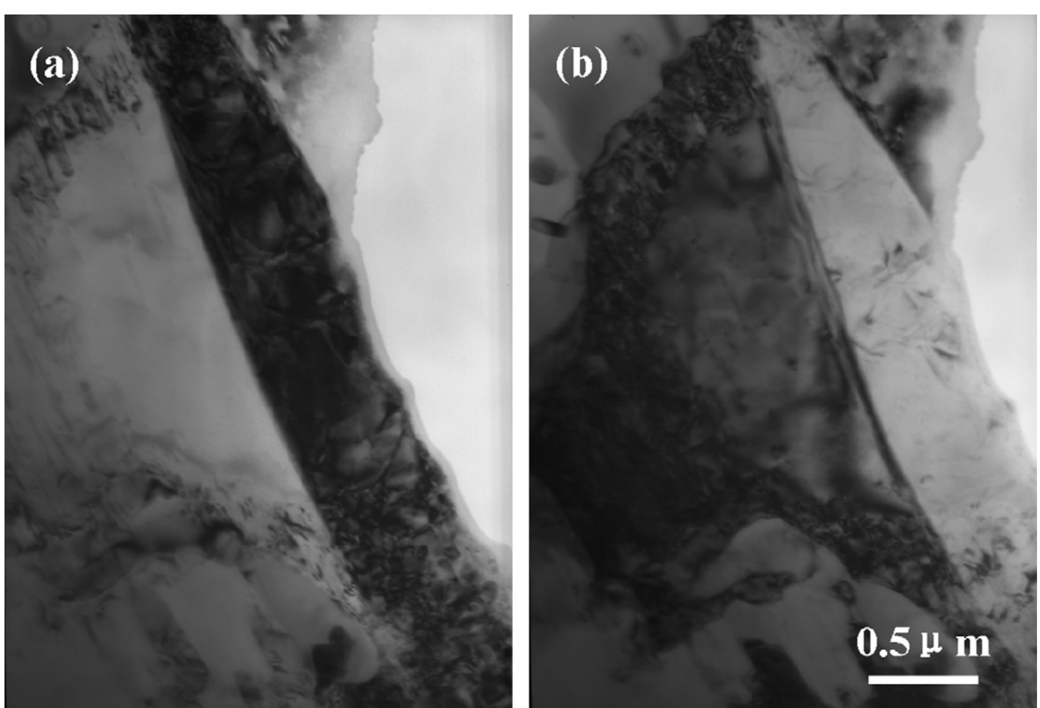

Fig. 2. Morphologies of the needle-like phase.