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# Microstructure and mechanical properties of Mg–4Al–4Nd–0.5Zn–0.3Mn alloy

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ABSTRACT

Mg–4Al–4Nd–0.5Zn–0.3Mn alloy was prepared by metal mould casting method. Microstructure, aging behavior, mechanical properties and fracture morphology of the alloy were investigated. The results showed that α-Mg, $Al_{11}Nd_3$, $Al_2Nd$ and $Mg_{32}(Al,Zn)_{49}$ phases were the main phases of the as-cast alloy. And the long rod-like $Al_{11}Nd_3$ phase was decomposed to granular $Al_2Nd$ through T6 heat treatment. The tensile strength was also enhanced by T6 treatment. The yield strength was increased by 17% and 21% at RT and 150 °C, respectively. It was mainly because that the precipitates were refined through T6 treatment and this became more benefit to hinder dislocations slipping.

## 1. Introduction

In order to reduce fuel consumption and gas emission of automobiles, lightweight design is becoming a more and more effective solution. Magnesium alloys are attractive due to their low density and high specific strength [1]. AZ and AM alloy systems exhibit superior castability and good strength, ductility and corrosion resistance. Therefore, they have been widely used to manufacture automotive components such as the panel beams, cam covers, steering wheel and so on. However, their applications are limited due to their rapid decrease in mechanical properties at elevated temperature which is related to the poor thermal stability $Mg_{17}Al_{12}$ phase discontinuously precipitated at grain boundaries. Great efforts have been paid to develop new Mg–Al based alloys with good performances at elevated temperature, and the Mg–Al–RE (AE), Mg–Al–Si (AS) and Mg–Al–Ca (AC) alloy systems have been developed [2]. Among these systems, the AE alloy system performs the best comprehensive mechanical properties and gains actual application in automobile industry. Mg–4Al–2RE (AE42) alloy has been successfully used to produce gear box by General Motors' (GM) company due to its outstanding strength at elevated temperature [6,7]. In addition, the creep strength of AE42 at high temperature is much better than that of AZ91D and AS21 alloys [3–5]. However, AE Alloy system contented 4 mass% Nd has been few reported. In the present work, Mg–4Al–4Nd–0.5Zn–0.3Mn alloy is prepared, and the microstructures and tensile properties of the as-cast and heat treated state alloys are investigated.

## 2. Experimental procedures

The Mg–4Al–4Nd–0.5Zn–0.3Mn alloy was prepared in a graphite crucible under protection of an anti-oxidizing flux. Commercially pure Mg, high pure Al and Zn were used. Mn and Nd were added as Al–10 mass% Mn and Mg–20 mass% Nd master alloys. The melt was homogenized at 750 °C for 30 min and then cast into a preheated steel mould of $10 \times 5 \times 1\,cm^3$ at 720 °C. The nominal composition and the detailed composition of the experimental alloys were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) and the results were listed in Table 1. Part of the as-cast ingots were furnace heat-treated at 420 °C for 8 h followed by water quenching, and a subsequent aging treatment of the alloy specimens was performed at 220 °C for different time.

The microstructure was characterized by Olympus GX71 optical microscopy (OM), and Philip-XL30 scanning electron microscopy (SEM) equipped with an energy dispersive spectrometer (EDS). Phase analysis was conducted by X-ray diffraction (XRD) and transmission electron microscopy (TEM). The Vickers hardness (Hv) of alloys was measured on a Vickers microhardness tester (FM-700) with a loading force of 25 g and holding time for 15 s. Tensile test was carried out on the WSM-50KB-type testing machine at room temperature (RT) and 150 °C with initial strain rate of $1.67 \times 10^{-3}\,s^{-1}$. The samples were isothermally held for 10 min to balance the temperature before tensile test at 150 °C. Fracture surface of tensile specimen was observed by SEM.

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**Table 1**
The nominal composition and the detailed composition of the experimental alloy (mass%).

| Elements | Nd | Al | Zn | Mn | Mg |
|---|---|---|---|---|---|
| Nominal | 4 | 4 | 0.5 | 0.3 | Bal. |
| Detailed | 3.43 | 3.41 | 0.54 | 0.27 | Bal. |

## 3. Results and discussion

### 3.1. Microstructures of as-cast alloy

The optical microstructure of the as-cast alloy is shown in Fig. 1(a). It reveals that there are two different morphological precipitates. One is the large number of rod-like phases, the other is the polylateral massive phases. The rod-like phases aggregate together and exhibit cluster shape. The XRD result of the as-cast is shown in Fig. 2. It indicates that the as-cast alloy consist of α-Mg, $Al_{11}Nd_3$, $Al_2Nd$ and $Mg_{32}(Al,Zn)_{49}$. The SEM image of the as-cast alloy is shown in Fig. 3. The phases compositions are analyzed by EDX. The results show that both of the rod-like and polylateral massive phases consist of Al and Nd elements and the corresponding Al/Nd atom ratios are about 78:22 and 64:35, respectively, which are near to 11:3 and 2:1. Combining with the XRD result of the as-cast alloy, they could be confirmed as $Al_{11}Nd_3$ and $Al_2Nd$ phases. The TEM image of the as-cast state alloy is shown in Fig. 4. The select electron diffraction pattern conforms that the polylateral massive precipitate is $Al_2Nd$. Moreover, a spot of short strip phase is found in Fig. 3, it is identified to be $Mg_{32}(Al,Zn)_{49}$ phase.

The above results indicate that no Mg–Nd and Mg–Al–Nd phases phase are detected. The possibility to form metallic compound is related to the electronegativity differences between two elements [8,9]. The larger electronegativity differences between two

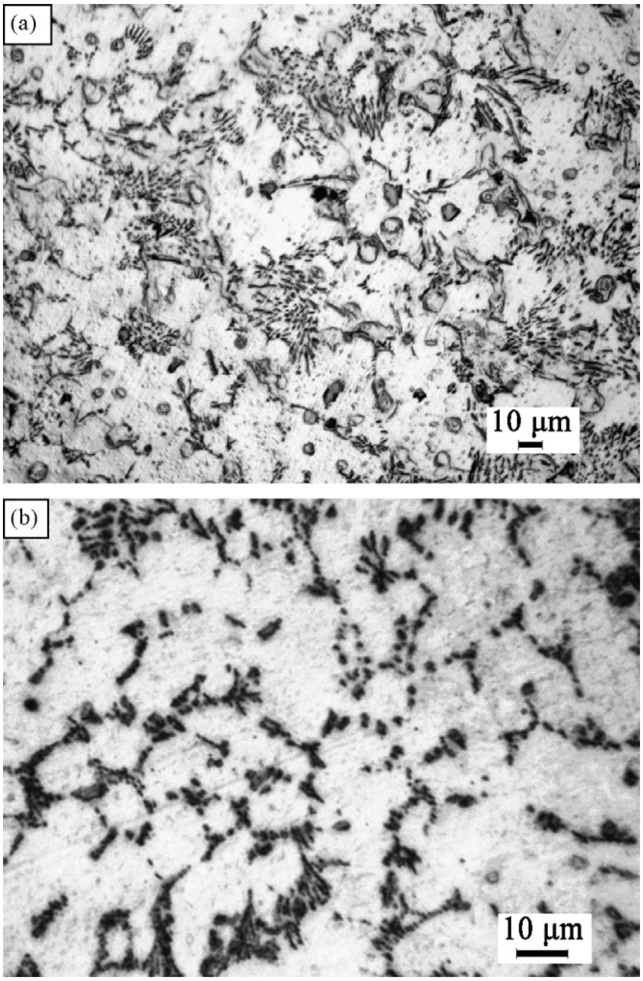

**Fig. 1.** The optical microstructure the alloy (a) as-cast state (b) T6 state.

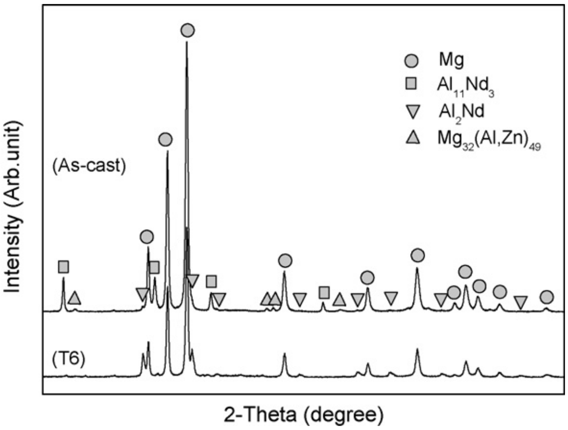

**Fig. 2.** XRD spectrum of the as-cast and the T6 treated alloys.

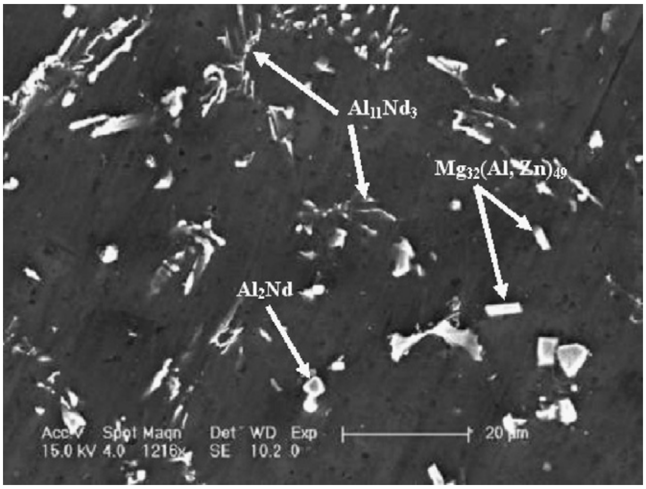

**Fig. 3.** The typical SEM micrograph of the as-cast state alloy.

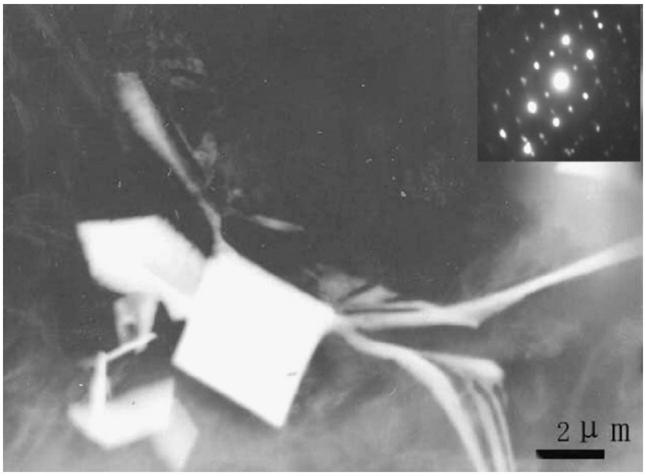

**Fig. 4.** The TEM image of the as-cast state alloy and electron diffraction pattern of polylateral massive precipitate.