Microstructure and mechanical properties of as-cast Mg–Nd–Zn–Y–Zr alloys

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Abstract. Mg-2.4Nd-0.2Zn-0.5Zr-xY (x=0, 0.6, 1.2, 1.8wt.%) alloys were fabricated by a casting method, the microstructure and mechanical properties of as-cast alloys were investigated. The results demonstrate that the A, B, C and D alloys are composed mainly of α-Mg and Mg12Nd phases. Phases containing Y were not formed, because trace amounts of Y element was completely dissolved into Mg matrix. The addition of Y was found to improve the mechanical properties of the alloys. The Mg-2.4Nd-0.2Zn-0.4Zr-1.8Y alloy exhibits the optimal mechanical properties in the as-cast condition, the maximum value of ultimate tensile strength, yield strength and elongation to failure were 192MPa, 168MPa and 6.5%, respectively.

1. Introduction
Due to the high specific strength and low density, Mg-Nd alloys are attractive for aerospace, navigation and automobile [1-3]. Compared with aluminum alloys, the strength of Mg-Nd alloys severely restricts the extension of their applications. At present, a considerable amount of works have been focused on the Mg-Nd alloys to improve the mechanical properties. It is well known that the addition of abundant rare earth elements or other elements results in superior mechanical properties at room temperatures [4-7]. Y is one of the cheaper alloy elements than Nd, with maximum solubility in solid Mg of 12.5 wt. % at eutectic temperature 566°C [8]. It is well known that Y can enhance the yield strength and elevated temperature strength by precipitation hardening and solid solution strengthening. However, the addition of high content Y results in increases in the cost. The previous studies focused mainly on the effect of high content Y on the microstructure and mechanical properties of Mg–Nd alloys. The effects of trace amounts of Y on microstructure and mechanical properties of Mg-Nd alloy have been are not investigated. Therefore, the purpose of the present study is to investigate the microstructure and mechanical properties of Mg-2.4Nd-0.2Zn-0.5Zr-xY(x=0, 0.6, 1.2, 1.8wt.%) alloys.
2. Experimental

Pure Mg (99.9 wt.%), and Zn(99.9 wt.%), Mg–25 wt.%Y, Mg–30 wt.%Nd and Mg–25 wt.%Zr master alloys were prepared to make the Mg-2.4Nd-0.2Zn-0.5Zr-xY (x=0, 0.6, 1.2, 1.8wt.%, named by A, B, C and D alloys). The investigated alloys were melted in an electric resistance furnace using a mild steel crucible under a protective atmosphere of CO₂ and SF₆ with a ratio of 99:1. After temperature was reaching to 720℃, the molten alloy was stirred for 3-5min and holding for 20 min. Then, the melt was poured into cylindrical steel mold. The microstructural morphology was observed using optical microscope (OM), scanning electron microscope (SEM). Tensile samples with a gauge size of 50 mm length, 6 mm width and 2 mm thickness were machined by an electric spark wire-cutting machine.

3. Results and discussion

3.1 Microstructures

The OM images of the as-cast A, B, C and D alloys are shown in Fig. 1. It was obvious that the alloys are mainly composed of equiaxed dendrites and partially interdendritic eutectics. The average grain sizes of the cast alloys A, B, C and D are about 40～50μm, which does not decrease with increasing Y content. With increasing Y content, the volume fraction of intermetallic phases increases slightly. Moreover, a few petal-like compounds in the interior of the grains were observed obviously in Fig. 1(a)- (d), which reported to be Zr-rich phases in Zr-containing Mg alloys [8], but not characterized in the present study.

![Fig. 1 Optical microstructures of as-cast A, B, C and D alloys](image)

The XRD traces for the as-cast alloys are shown in Fig. 2. The results demonstrate that the A, B, C and D alloys are composed mainly of α-Mg and Mg₁₂Nd phases. Phases containing Y are not formed, because trace amounts of Y element are completely dissolved into Mg matrix [5].
The microstructures of as-cast alloys are observed under the SEM and EDS analyses, the results are shown in Fig. 3. The particle-like eutectic compounds is formed along the boundaries in the alloy A (Fig. 3a). Based on the XRD pattern and EDS analysis (Fig. 3e), it demonstrates that the particle-like eutectic compounds is Mg12Nd phases. With increase of Y content, the particle-shaped phase gets coarsened. It can be seen clearly that the particle-like and lamella-like phases are located along the boundaries of alloys B, C, D. With increase of Y, The volume fraction and size of eutectic compounds increases slightly. The EDS analysis result indicates that the composition of the lamella-shaped phase is Mg12Nd (Fig. 3e), which some Y dissolves into Mg12Nd phase.

Fig. 4 shows a SEM image together with corresponding elements map distributions for as-cast alloy D. It is obvious that the elements Nd, Zn partition mainly to the Mg12Nd phase which distributes mainly in the grain boundary and the element Y and Zr are distributed in the grain.

3.2. Tensile Properties
The tensile properties of the four alloys in as-cast conditions at room temperatures are shown in Fig. 5. It can be seen that both the ultimate tensile strength (UTS) and yield strength (YS) increase slightly with increase of Y contents in the as-cast conditions. However, the value of elongation increases obviously by 50.9% from alloy A to alloy B, and then reduces gradually from 8.5% (alloy B) to 6.5% (alloy D). Addition of 1.8 wt% Y (alloy D) leads to the highest UTS and YS of 192 MPa and 128 MPa at room temperature condition.

In the as-cast conditions, there are following factors that affect the mechanical properties. On the one hand, it is noted that suitable fine fibrous eutectic area were responsible for the relatively high strength of the as-cast alloys \[9]. In alloy A, minimum eutectic compounds distribute along the grain boundaries as shown in Fig. 1, which is in accordance with the lowest strength and elongation. When the addition of Y increases to 0.6 wt. %, appropriate eutectic compounds are observed, corresponding to better mechanical properties. When the Y addition increases from 0.6 wt. % (alloy B) to 1.8wt. % (alloy D), coarse eutectic compounds are observed along the grain boundaries, resulting in further improvement in UTS and YS while the deteriorated ductility. On the other hand, XRD spectrum (Fig. 2) and EDS analyses (Fig. 3) of eutectic compounds indicate that the eutectic compound is Mg12Nd, Ma12Zn, and Mg12Zr.
which has a body centered tetragonal structure with $a = 1.03$ nm and $c = 0.593$ nm \cite{1}. It is incompatible with the hcp structure of $\alpha$-Mg matrix during deformation, resulting in a decrement of the bonding between the $\text{Mg}_{12}\text{Nd}$ phase and the Mg matrix \cite{4}. Consequently, fractures will be formed at the interface between them which lead to the decrease in the ductility. Moreover, Y is completely dissolved into the Mg matrix, which increases solid solution strengthening \cite{5}.

Fig.3 The SEM and EDS of as-cast alloys (a) and (e) alloy A; (b) alloy B; (c) alloy C; (d) and (f) alloy D.
4. Conclusion

(1) The alloys are composed mainly of \(\alpha\)-Mg and Mg\(_{12}\)Nd phases. Phases containing Y were not formed, because trace amounts of Y element are completely dissolved into Mg matrix.

(2) Y additions can improve the mechanical properties of the Mg-2.4Nd-0.2Zn-0.5Zr alloy. In the as-cast condition, the values of maximum UTS, YS and elongation are 192MPa, 128MPa and 6.5\%, respectively.

Fig. 4 The SEM images with elements map distributions of the as-cast alloy D

Fig. 5 The mechanical properties of as-cast A, B, C and D alloys
The increasing mechanical properties of alloy are mainly attributed to the suitable fine fibrous eutectic area and solid solution strengthening of Y element.

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