Insights into the Effects of Sm on Microstructure Evolution Mechanism and Mechanical Properties of Mg-8Gd-2Y-1Zn-0.5Zr Cast Alloy at High Temperature

Jianfei Xiao[1,2], Yuyang Gao[1,2,*], Jiangfeng Song[1,2,*], Yuling Xu[3], Jianxin Zhou[1,2], Xiaojun Luo[1,2], Xin Guo[1,2], Jing Wang[1,2], Bin Jiang[1,2], Fusheng Pan[1,2]

1. National Engineering Research Center for Magnesium Alloys, College of Materials Science and Engineering, Chongqing University, Chongqing, 400044, China
2. National Key Laboratory of Advanced Casting Technologies, Chongqing University, Chongqing, 400044, China
3. Baomarc (Hefei) Technology Co., Ltd., Hefei, 238000, China
* gaoyuyang@cqu.edu.cn (Yuyang Gao); * jiangfeng.song@cqu.edu.cn (Jiangfeng Song)

Abstract: In this study, the effects of 1% Samarium (Sm) on the microstructure and room and high temperature mechanical properties of Mg-8Gd-2Y-1Zn-0.5Zr alloy are discussed and analyzed. The addition of Sm increases the volume fraction of lamellar and blocky long-period stacking ordered (LPSO) phases and promotes the precipitation of lamellar β' and β phases. The high yield strength and ultimate tensile strength of Mg-8Gd-2Y-1Sm-1Zn-0.5Zr alloy at room and high temperatures are mainly attributed to the strengthening effects of LPSO, β, and β' phases. The LPSO, β, and β' phases effectively hinder the movement of dislocations and inhabit the migration of grain boundaries. The Mg-8Gd-2Y-1Sm-1Zn-0.5Zr alloy shows superior yield strength (203.3 MPa) and ultimate tensile strength (258.9 MPa) at 350 ℃, which are respectively 67.2 MPa and 23.8 MPa higher than those of Mg-8Gd-2Y-1Zn-0.5Zr alloy (136.1 MPa and 235.1 MPa).

Keywords: Mg-Gd-Y-Zn-Zr, Sm addition, high-temperature mechanical properties, strengthening mechanism

1 Introduction

In the aerospace field, the use of Mg alloys in key military equipment such as airplanes, spaceships and satellites can enhance the maneuverability of aircraft by reducing weight [1]. In some aerospace components, Mg alloys need to work at high temperatures above 300 ℃, such as rocket cabins, aircraft engine casings, and helicopter gearbox housings [2]. However, the commercial Mg-Al-Zn and Mg-Al-Mn series alloys tend to rapidly lose their strength when exposed to temperatures above 125 ℃ [3].

With the incorporation of rare earth (RE) [4], Mg alloys can simultaneously achieve solid solution strengthening and precipitation strengthening, and subsequently exhibit favorable high-temperature mechanical properties. Among RE-containing Mg alloys, the Mg-Gd-Y-Zn-Zr series alloys have gained widespread attention for the high strength and excellent creep resistance [2-4]. It is reported that Mg-10Gd-3Y-1Zn-0.5Zr alloy exhibits excellent yield strength (199 MPa) at 250 ℃, which is 25% higher than the commercial WE54 alloy [1, 5]. However, its yield strength rapidly decreases to 142 MPa at 300℃. Additionally, the studies on the deformation mechanisms and microstructural evolution of Mg alloys at high temperatures are mainly focused on the range of 150 ℃ to 250 ℃. When the temperature is further increased to 350 ℃, the strength of the alloys decreased significantly. The microstructure evolution, deformation mechanism and strengthening mechanism of Mg alloys during tensile deformation above 300 ℃ need to be further studied.

In this study, the effects of Sm on the microstructure and mechanical properties of Mg-8Gd-2Y-1Zn-0.5Zr at room and high temperatures (ranging from room temperature to 350 °C) are discussed. The fracture modes and strengthening mechanisms of the cast alloys at high temperatures are systematically discussed and analyzed. This investigation intends to provide some guidance for the design and preparation of high-strength heat-resistant cast Mg-RE alloys.

2 Experimental procedure

Actual chemical compositions of Mg-8Gd-2Y-1Zn-0.5Zr (VW82) and Mg-8Gd-2Y-1Sm-1Zn-0.5Zr (VW82-1Sm) alloys were tested by the inductively coupled plasma (ICP-OES) and the results were listed in Table 1. The samples for tensile testing were cut from the bottom part of the ingot (as shown in Fig. 1a). The samples for phase analysis and characterization were shown in Fig. 1b. The heat treatment process parameters are 510 ℃×12 h+225 ℃×9 h.

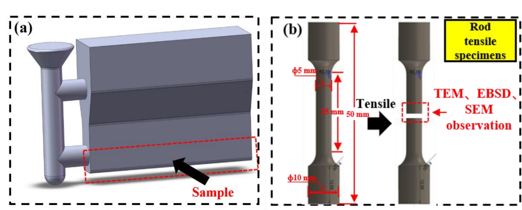

Figure 1. (a) casting mould, (b) tensile sample and observation sample.

Table 1. Composition of Alloy

Alloy	Mg	Gd	Sm	Y	Zn	Zr
VW82	Bal.	8.04	—	1.94	1.09	0.52
VW82-1Sm	Bal.	8.13	1.10	2.25	1.07	0.47

Tensile tests at 25 ℃, 250 ℃, 300 ℃, and 350 ℃ were carried out on a CMT 6305-300 KN testing machine. During the high-temperature tensile test, the tensile specimen was firstly heated to the set temperature and maintained for 30 minutes, and then the test began. The tensile test was carried out at a strain rate of 0.001 m/s. The tensile test was repeated three times to ensure the accuracy and reliability of the data.

3 Result and discussion

1. Mechanical properties and microstructure at aged state

The introduction of Sm results in a reduction in the average grain size of α-Mg from 40.3 μm in VW82 alloy to 35.4 μm in VW82-1Sm alloy. The volume fraction of LPSO phases increases from 12.6% to 21.8%. At room temperature, the YTS (235.3 MPa) and UTS (325.7 MPa) of VW82-1Sm alloy are 62.9 MPa and 43.3 MPa higher than those of VW82 alloy (172.4 MPa and 282.4 MPa), respectively. At room temperature, although the density of the β' phase is not high, the co-precipitation of β' precipitates and γ' precipitates can prevent basal slip more effectively.

2. Mechanical properties and microstructure at high temperature

When the temperature is further increased to 350 °C, the YTS (203.3 MPa) and UTS (258.9 MPa) of VW82-1Sm alloy are 67.2 MPa and 23.8 MPa higher than those of VW82 alloy (136.1 MPa and 235.1 MPa), respectively. The continuous precipitation of strengthening phase β' within the grains at high temperatures, along with the continuous growth and densification of β phase, which can pin the grain boundaries. This enables VW82-1Sm to maintain a high yield strength even as non-basal slip initiation and grain boundary sliding tendency increase with temperature.

4 Conclusion

1. The addition of 1 wt.% Sm effectively refine the grain sizes of the cast alloys. In addition, the introduction of Sm element increases the volume fractions of β', β, β1, and LPSO phases in VW82-1Sm alloy.

2. The introduction of Sm enhances the high temperature strength of VW82-1Sm alloy. The high strength of VW82-1Sm alloy can be attributed to the continuous precipitation of β and β' phases, as well as the increase in volume fraction of LPSO phase.

5 Acknowledgments

This work is financially supported by the National Natural Science Foundation of China (Grant Nos. U2037601, 52271090, 52071036, U21A2048, and 52201106), the National Key Research and Development Program of China (Grant Nos. 2021YFB3701000 and 2022YFB3709300), and the Fundamental Research Funds for the Central Universities (Grant Nos. SKLMT-ZZKT-2022Z01 and SKLMT-ZZKT-2022M12).

References

[1] G. Wu, C. Wang, M. Sun, W. Ding, Recent developments and applications on high-performance cast magnesium rare-earth alloys, J. Magnes. Alloy 9(1) (2021) 1-20.
[2] J. Song, J. She, D. Chen, et al. Latest research advances on magnesium and magnesium alloys worldwide, J. Magnes. Alloy, 8(1) (2020) 1-41.
[3] X. Dong, L. Feng, S. Wang, et al. A new die-cast magnesium alloy for applications at higher elevated temperatures of 200–300 °C, J. Magnes. Alloy, 9(1) (2021) 90-101.
[4] H. Pan, G. Qin, Y. Huang, et al. Development of low-alloyed and rare-earth-free magnesium alloys having ultra-high strength, Acta. Mater, 149 (2018) 350-363.
[5] Z. Chang, Y. Wu, N. Su, et al. Microstructural evolution of Mg-10Gd-3Y-1Zn-0.4Zr (wt%) alloy prepared by strain-induced melt activation process, Mater. Charact, 171 (2021) 110831-110831.