Study on the Microstructure and Hardness of Mg-4Al-4RE-0.3Mn Alloy in High Vacuum Die Casting under Aging

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Abstract: This article studies the microstructures and properties of Mg-4Al-4RE-0.3Mn (wt.%) (AE44-2) magnesium alloy before and after aging. The alloy is prepared by high vacuum die casting (HVDC). The aging treatment on HVDC-AE44-2 is performed at 100 ° C (0h, 4h, 8h, 12h, 16h, 20h, 24h, and 28h) and 150 ° C (0h, 4h, 8h, 12h, 16h, 20h, 24h, and 28h), respectively. The results show that there is precipitation of the Al-Mn phase in the HVDC-AE44-2 alloy after aging. The Al-Mn phase can effectively hinder the slip of dislocations and make the alloy achieve the hardness peak after aging at 150 ° C for 16 hours. The hardness peak is 66.2HV.

Keywords: Magnesium alloy; Die casting; Microstructure; Hardness

1 Introduction

Magnesium alloy is the lightest structural metal material, widely used in the automotive industry, aerospace, and electronic communication due to its high specific strength and stiffness, good electrical and thermal conductivity, electromagnetic shielding, damping, and shock absorption [1, 2]. Compared with other processing technologies, high-pressure die casting injects molten metal into the mold rapidly, resulting in castings with smooth surfaces and near-net shape, which effectively saves time and reduces costs.

However, liquid melt splashes backward during the die-casting process, creating a highly turbulent flow that entraps a large amount of air. The trapped gas shrinks and deforms, remaining on the surface or inside the castings, resulting in more micropores in the die castings. Currently, many scholars have conducted research on the aging treatment of magnesium alloys [3]. However, research on die-cast magnesium alloys mainly focuses on Mg-Al-RE alloys without high vacuum. Mg-Al-RE alloys without high vacuum cannot be aged due to the presence of pores trapped inside or on the surface of the casting, making it difficult to further improve the alloy properties. There is little research on the aging treatment of Mg-Al-RE alloy by high vacuum die casting (HVDC).

This paper investigates the effects of aging temperature and time on the microstructures and properties of the HVDC-AE44-2 alloy. The Al-Mn precipitates are characterized to study the change in the hardness of HVDC-AE44-2 alloy.

2 Experimental procedure

The alloy used in this work is Mg-4Al-4RE-0.3Mn (mixed rare earth (RE) element of La and Ce) provided by Haimagnete Co., Ltd. (Shaanxi Province, China). The die-casting parts are prepared using the precision horizontal cold chamber die-casting machine DM300 under high vacuum and high pressure.

3 Result and discussion

Microstructure

Fig. 1 shows the metallographic microstructures under different heat treatment conditions. Under aging treatment (T5), the grain size of the HVDC-AE44-2 alloy remains basically unchanged before and after aging. The alloy is mainly composed of α-Mg matrix and second phases, where α-Mg is surrounded by the second phases. A large number of the second phases are distributed at the grain boundaries and a small number of fine particles are distributed inside the grains. Compared to the die-cast state, HVDC-AE44-2 showed a significant increase in Al-Mn precipitates within the crystal and at grain boundaries after 16 hours of aging at 100 ° C and 150 ° C.

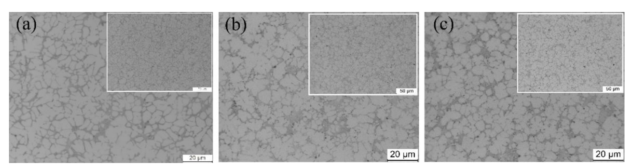

Fig. 1. Metallographic image of HVDC-AE44-2 alloy. (a) as cast, (b) at 100 ° C × 16h, (c) at 150 ° C × 16h.

From the phase diagram in Fig. 2, the precipitated phase Al-Mn is a high-temperature stable phase. When the aged HVDC-AE44-2 alloy undergoes deformation at 150 ° C, the Al-Mn phase still exists. This phase can effectively hinder the slip of dislocations and improve the strength of the HVDC-AE44-2 alloy.

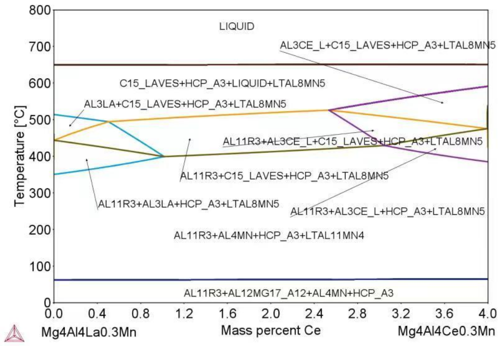

Fig. 2. Phase diagram of HVDC-AE44-2 alloy.

Hardness

Fig. 3 shows the age-hardening curve of HVDC-AE44-2 alloy. The specimens are subjected to medium temperature aging at 100 °C and 150 °C. With the increase of aging time, the hardness of the specimens shows a trend of first increasing and then decreasing at both 100 °C and 150 °C and the hardness reached the peak at 16 hours of aging. The hardness after 16 hours of aging at 150 °C is 66.2 HV, and the hardness after 16 hours of aging at 100 °C is 65.4 HV. The hardness after 16 hours of aging at 150 °C is higher than that after 16 hours of aging at 100 °C. When the hardness peak is reached, the hardness value shows a rapid decrease, manifested as over-aging.

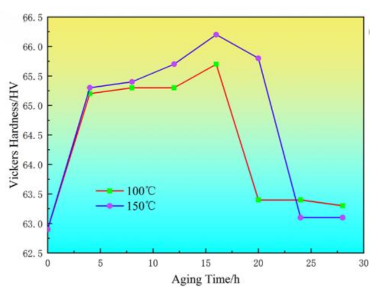

Fig. 3. Age hardening curve of HVDC-AE44-2 alloy.

4 Conclusion

In the aged HVDC-AE44-2 alloy, the precipitation of high-temperature stable Al-Mn phase can effectively prevent dislocation slip, resulting in a trend of first increasing and then decreasing hardness of the aged alloy. The hardness after 16 hours of aging at 150 °C is 66.2 HV, which is the hardness peak.

Acknowledgments

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References

[1] D. Zhang, J. Zhang, Y. Zhang, D. Zhang, T. Xu, B. Li, Y. Zhao, J. Meng, Superior high-temperature strength in a low RE containing Mg extrusion alloy with nano-spaced stacking faults, Materials Science and Engineering: A 854 (2022) 143791.
[2] J. Xie, J. Zhang, Z. You, S. Liu, K. Guan, R. Wu, J. Wang, J. Feng, Towards developing Mg alloys with simultaneously improved strength and corrosion resistance via RE alloying, Journal of Magnesium and Alloys 9(1) (2021) 41-56.
[3] Q. Yang, K. Guan, B. Li, S. Lv, F. Meng, W. Sun, Y. Zhang, X. Liu, J. Meng, Microstructural characterizations on Mn-containing intermetallic phases in a high-pressure die-casting Mg–4Al–4RE–0.3Mn alloy, Materials Characterization 132 (2017) 381-387.