Low Cost High Performance HPDC AM60 Based Alloys for Super-Sized Integrated Automotive Components

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Abstract: Magnesium alloy super-sized integrated high pressure die casting for automotive structural components has a bright application prospect and attracted much attention. Low cost and high-performance die cast magnesium alloys for super-sized integrated components application are in great need. In this work, microalloying element Mn, Ce and La with an adding content less than 0.2 wt.% were introduced into the commercial AM60 die cast alloys. The ultimate tensile strength, yield strength, elongation of 288.0±1.7 MPa, 158.0±1.0 MPa, and 22.0±3.0 % were achieved in AM60-0.2La alloy. Besides, AM60-0.2La alloy exhibited the best corrosion resistance (0.29 mm/y) and fluidity among the investigated four alloys. The excellent mechanical properties and corrosion resistance are mainly attributed to grain refinement strengthening, low porosity and low content of large shrinkage pores. The current findings offer valuable guidance for the alloy design for magnesium alloy super-sized integrated high pressure die casting application.

Keywords: Magnesium alloys, High pressure die casing, Microstructure, Mechanical properties.

1 Introduction

In this study, small quantities of the alloying elements Mn, Ce, and La were added into the widely used commercial HPDC AM60 alloy. The HPDC alloys, namely AM60, AM61, AM60-0.2Ce, and AM60-0.2La, were subjected to investigate the impact of Mn, Ce, and La on the microstructure, defects, fluidity, mechanical properties, and corrosion resistance of the AM60 alloy. Additionally, it aims to formulate magnesium alloys exhibiting superior comprehensive properties.

2 Experimental procedure

The four AM60 based alloy castings were firstly melted in an electric resistance furnace at 720°C, and then HPDC in a 650 T die caster. The direct die casted tensile specimens with a gauge length of 60 mm and a diameter of 6.4 mm were employed. For corrosion testing, samples measuring 20 mm × 20 mm × 3 mm were cut and immersed for 7 days at room temperature in 3.5 wt.%NaCl solution.

3 Result and discussion

Result

Fig. 1 illustrates the properties of HPDC AM60 based alloys. Fig. 1 (a1) and (a2), depicts the mechanical properties of the AM60 base alloys. The yield strength (YS) of AM60 alloy measures 152 ± 1.0 MPa, the ultimate tensile strength (UTS) is 280.3 ± 1.5 MPa, and elongation (EL) is 19.9 ± 0.8%, respectively. while the addition of 0.2 wt.% La enhances UTS, YS, and EL, yielding optimal mechanical properties. Among commercial and new experimental HPDC magnesium alloys, the developed alloys display the highest UTS, YS, and EL, as shown in Fig. 1 (a2).

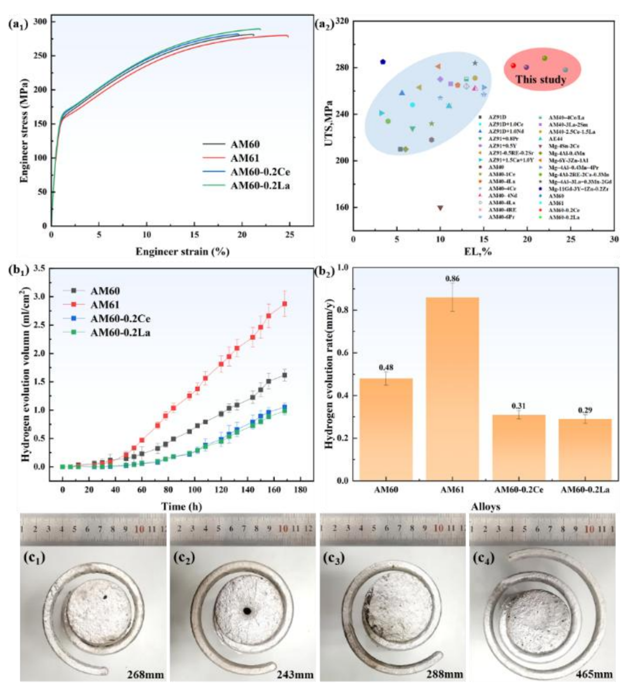

Fig.1. (a) Mechanical properties: (a$_1$) Tensile stress-strain curve and corresponding mechanical property values of AM based alloys. (a$_2$) YS, UTS and EL of various die-casting Mg alloys.
(b)Corrosion property: (b$_1$) hydrogen evolution volume-time curves; (b$_2$) corrosion rate bar chart.
(c)Macro-view photographs of fluidity test sample of AM based alloys: (c$_1$) AM60; (c$_2$) AM61; (c$_3$) AM60-0.2Ce; (c$_4$) AM60-0.2La.

Fig. 1(b1) (b2) depicts the corrosion properties. The corrosion rate in the initial 36 hours of immersion is slow. The cumulative hydrogen evolution for AM60, AM61, AM60-0.2Ce, and AM60-0.2La is 1.26 mL/cm², 2.65 mL/cm², 0.78 mL/cm², and 0.76 mL/cm², respectively, with AM60-0.2La showing the lowest hydrogen evolution.

In addition, the fluidity of four alloys were also investigated and the results were shown in Fig. 1(c1-c4). The fluidity of the alloys shows the trend of AM60-0.2La > AM60-0.2Ce > AM60 > AM61.The increase in Mn content slightly decreases the flow length of the AM60 alloy, while the La addition largely improves the flow length.

Discussion

The primary strengthening mechanism of HPDC magnesium alloys is grain refinement strengthening. Grain refinement significantly enhances the strength of alloys, particularly YS. The studied alloys demonstrate satisfactory grain refinement.Furthermore, AM61 alloy exhibits high amount of ESCs and pore defects, significantly deteriorating mechanical properties. Conversely, AM60-0.2Ce and AM60-0.2La alloys manifest reduced defects. HPDC AM60-0.2La alloy exhibits the best mechanical properties among all.

The fluidity hierarchy of alloys was observed as follows: AM60-0.2La > AM60-0.2Ce > AM60 > AM61. Firstly, precipitation of phases like Al_8Mn_5 before α-Mg increases melt viscosity, thus reducing fluidity. Secondly, the diffusion coefficient of elements in Mg melt, following the order of La > Ce > Al >Mn, contributes to higher fluidity due to faster diffusion rates.

For magnesium alloys, impurity content, second phases, and defects are pivotal factors influencing the corrosion behavior. The addition of Mn, La, Ce will decrease the corrosion rate of AM60 alloy in the aspect of impurity content[1-2].Incorporating RE elements Ce and La results in the precipitation of the $Al_{11}RE_3$ phase [3]. The presence of $Al_{11}RE_3$ phase will decrease the micro-galvanic corrosion of magnesium alloy. In the aspect of casting defects, the addition of Mn to AM60 will largely increase its corrosion rate, while the addition of La and Ce will decrease its corrosion rate. Overall, the corrosion resistance of the four alloys follows: AM60-0.2La > AM60-0.2Ce > AM60 > AM61.

4 Conclusion

In this investigation, we developed AM60-0.2La alloys by incorporating trace amounts of the RE element La into commercial AM60 alloys. This addition not only promotes grain refinement but also reduces the porosity. These microstructural adjustments result in superior fluidity, mechanical properties, and corrosion resistance of the AM60-0.2La alloy. Besides, the minor addition of inexpensive La ensures the low cost of AM60-0.2La alloy, which is very promising for super-sized integrated HPDC automotive part application.

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References

[1] G. Wu, C. Wang, M. Sun, W. Ding, Recent developments and applications on high-performance cast magnesium rare-earth alloys, J. Magnesium Alloys 9(1) (2021) 1-20.

[2] T. Chen, Y. Yuan, T.T. Liu, D.J. Li, A.T. Tang, X.H. Chen, R. Schmid-Fetzer, F.S. Pan, Effect of Mn Addition on Melt Purification and Fe Tolerance in Mg Alloys, Jom 73(3) (2021) 892-902.

[3] M.S. Dargusch, S.M. Zhu, J.F. Nie, G.L. Dunlop, Microstructural analysis of the improved creep resistance of a die-cast magnesium–aluminium–rare earth alloy by strontium additions, Scr. Mater. 60(2) (2009) 116-119.