

Development of High Temperature Die-Cast Magnesium Alloys for Small IC Engine Application

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Abstract: An innovative and superior coarsening/creep resistant Al-based ternary short-range order (SRO, 0–2 nm)/cluster (2–10 nm) at critically high temperature and stress of 300 °C/50 MPa was proposed and verified in Mg, and a highly heat-resistant die-cast Mg alloy was thus successfully developed with the super low steady-state creep rate ($1.35 \times 10^{-10} \text{ s}^{-1}$) and long creep life (>600 h) under the critical condition of 300 °C/50 MPa. This work changes the common belief of the detrimental effect of Al on the high temperature creep of Mg alloys over the past few decades, and it provides key evidence for the long-term and massive existence of SRO/clusters in Mg alloys under critically high temperatures and stresses. It greatly increases the working temperature of die-cast Mg alloys from 120–200 °C to 300–350 °C. The developed alloy has been transferred into manufacturing high temperature (300–350 °C) Mg components used in small internal combustion (IC) engines.

Keywords: Magnesium alloys; Die casting; High temperature; Engine application

1 Introduction

Magnesium (Mg) alloys are excellent candidate materials for lightweight structures in the automobile, aerospace, rail and other industries when compared to steel and aluminum (Al) alloys [1,2]. Over the past few decades, one of the beneficial applications of magnesium alloys is the manufacturing of powertrain components, operating at the elevated temperatures of 150–200 °C [1,2]. Recently, this advancement has focused on the die-castable components in small IC engines, used in machinery such as powered tools, drones and unmanned aerial vehicles, with a working temperature capable of reaching 200–350 °C, and where the creep resistance is a major challenge [1,2].

In the past, for Mg alloys, Al was considered beneficial for castability, but it was found to be detrimental for creep resistance at elevated temperatures [1,3]. One effective approach to improve elevated creep resistance is to develop Al-free die-cast Mg-RE alloys. However, the RE content in die-cast Mg-RE alloys was usually lower than 4 wt.% as a

high RE resulted in brittleness, and this restricted the die-cast Mg-RE alloys from working at higher temperatures, that is above 200 °C [1,2,4].

In this work, an innovative and superior coarsening/creep resistant Al-based ternary short-range order (SRO, 0–2 nm)/cluster (2–10 nm) at critically high temperature and stress of 300 °C/50 MPa was proposed and verified in Mg, and a highly heat-resistant die-cast Mg alloy was developed with the proper addition of Al. The developed alloy has been transferred into manufacturing high temperature (300–350 °C) Mg components used in small IC engines.

2 Experimental procedure

Cylindrical creep samples designed with ISO 204:2018 were prepared by high pressure die casting (HPDC) on a 4500 kN cold chamber machine; the gauge size of the creep samples were $\Phi 6.35 \times 20$ mm, respectively [1]. The developed die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy was melted in a steel liner and held at 720 °C, under the mixed protection gas of N₂ (6 L/min) and SF₆ (0.025 L/min). The die and pour temperatures were controlled at 225 °C and 715 °C during HPDC [2].

Tensile creep tests were conducted on a lever-type Instron machine following ISO 204:2018, and the temperature of during creep was controlled by thermocouples with an accuracy of ± 1 °C [1]. Transmission electron microscopy (TEM) analysis was carried out on a Thermofisher Titan Themis 60-300 microscope operated at 300 kV.

3 Result and discussion

High temperature creep properties

Fig. 1 shows the representative tensile creep curve of the die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy tested under the critical temperature of 300 °C and the applied stress of 50 MPa. The alloy went into the tertiary state after creep for a considerable long time of 460 h and still did not reach the fracture point after 620 h, and the alloy had a super low steady state creep rate of $1.35 \times 10^{-10} \text{ s}^{-1}$.

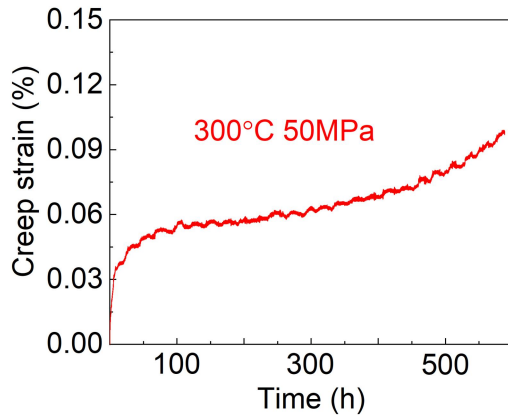


Fig 1. Tensile creep curve of the die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy tested under the critical temperature of 300 °C and the applied stress of 50 MPa.

Microstructure of SRO and cluster

Fig. 2 presents the TEM image showing the Al-based ternary heat-resistant SRO and cluster in the Mg matrix of the die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy, and the SRO and clusters were still smaller than 10 nm after creep at 300 °C/50MPa for 400 h.

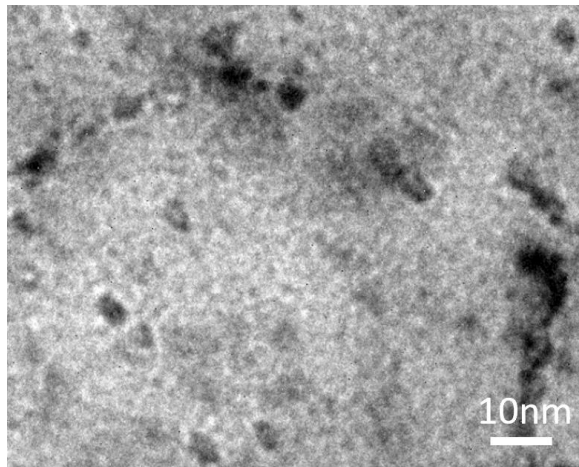


Fig 2. TEM morphology of the Al-based heat-resistant SRO and cluster in the Mg matrix of the die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy after creep at 300 °C/50MPa for 400 h.

Application in small IC engine

The developed die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy has been transferred into manufacturing high temperature (300-350°C) Mg pistons used in small IC engines, as shown in Fig. 3.



Fig 3. Application of the die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy for the manufacturing of the piston used in small IC engines.

4 Conclusion

- (1) An innovative and superior coarsening/creep resistant Al-based ternary SRO(0–2nm)/cluster(2–10nm) at critically high temperature and stress of 300°C/50MPa was proposed and verified in Mg.
- (2) A highly heat-resistant die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy was developed with the super low steady-state creep rate ($1.35 \times 10^{-10} \text{s}^{-1}$) and long creep life (>600h) under the critical condition of 300°C/50MPa.
- (3) The developed die-cast Mg_{3.5}RE_{1.5}GdMnAl alloy was transferred into manufacturing high temperature (300-350°C) Mg components used in small internal IC engines.

Acknowledgments

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