A Novel Type of Mg-Zn-Cu Alloys with High Thermal Conductivity

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Abstract: In this work, we investigate microstructure and thermal conductivity of Mg-3Zn-xCu alloys (x=1, 2, 3, wt. %). Firstly, Mg-3Zn-Cu alloys are composed of α-Mg matrix and MgZnCu phase. Secondly, with Cu content increase, the grain size of α-Mg matrix is refining and the volume fraction of MgZnCu phase is increase. Finally, the Cu addition gradually improves thermal conductivity of Mg-3Zn-Cu alloys. The Mg-3Zn-3Cu alloy shows the best thermal conductivity of 138.5 W/(m·K), which are due to reduction of casting defects, formation of continuous MgZnCu network structure, and the introduction of a large number of free electrons. This work proves that the development of Mg-Zn-Cu based magnesium alloys can provide theoretical basis for applications in the engineering field.

Keywords: Mg-Zn-Cu alloy, MgZnCu phase, Thermal conductivity, Mirostructure organization.

1 Introduction

Mg alloys as the lightest structural metal, whichhas a wide range of applications [1-2]. However, with the number of high-power devices is continuously increasing, and the heat generated needs to be dissipated. How to further enhance thermal conductivity of Mg alloy has become a hot topic in research [3-4].The thermalconductivityofpure Mgis 156 W/(m·K). Butthe thermal conductivity of traditional castMg alloys can hardly exceed 100 W/(m·K). Wu et al. [5] has developed a Mg-5Zn-5Cu alloy with a high thermal conductivity of 136.5 W/(m·K). Therefore, it is reasonable to believe that Mg Zn Cu is a new type of high thermal conductivity alloy. In this work, in order to clarify the microstructural changes and thermal conductivity mechanism of Mg-Zn-Cu alloys, three Mg-3Zn-xCu (x=1, 2, 3, wt. %) casting alloys are designed. The results indicate that the thermal conductivity of Mg-3Zn alloy increases with the increase of Cu content. The result provided a theoretical basis for the development of new high thermal conductivity Mg alloys

2 Experimental procedure

The original ingots with nominal composition of Mg-3Zn-Cu (wt. %) were fabricated in an electric-resistant furnace under argon atmosphere by melting high purity Mg, Zn and Cu at 740 ℃ for 30 min. Then, the melts were cast into a preheated mold at 180 ℃ when the temperature was decreased to 720 ℃. Finally, the cast alloys with a diameter of 40 mm and a height of 180 mm were obtained and their measured chemical compositions were examined by inductively coupled plasma analyzer, in Table 1.

Table 1. actual compositions of Mg-3Zn-Cu sample

Alloy	Mg	Zn	Cu
Mg-3Zn-1Cu	Bal.	3.02	0.98
Mg-3Zn-2Cu	Bal.	2.98	2.03
Mg-3Zn-3Cu	Bal.	3.01	3.02

The thermal diffusivity (α) and the specific heat(Cρ) of the sample was measured by LFA-500 laser thermal conductivity instrument at 25℃. The sample with a diameter of 12.7 mm and a height of 3 mm to ensure the one-dimensional heat transfer state. The density (ρ) was determined by the Archimedes method. The thermal conductivity (λ) was calculated by the following Eq. (1):

$$\lambda=\alpha\rho C\rho\#(1)$$

where λ indicates the thermal conductivity, α is thermal diffusivity, ρ is the density, and Cρ is the specific heat capacity.

3 Result and discussion

Figures. 1(a)-1(c) are the OM images showing microstructure characteristic of these as-cast Mg-3Zn-Cu alloys with different Cu content.Meanwhile, their average grain size of α-Mg phase is measured by the linear intercept methodand related results are listed in Figs. 1(g)-1(i). It can be found that the grain size of α-Mg phases in the Mg-3Zn-1Cu, Mg-3Zn-2Cu, and Mg-3Zn-3Cu alloys are measuredtobe 73.24±12.33 μm, 69.74±10.82 μm, and 63.23±9.12 μm, respectively. In addition, it can be found that the as-cast Mg-3Zn-Cu alloys are mainly consisted of α-Mg matrix, and MgZnCu phase in Figs. 1(d)-1(f). the MgZnCu phases distributed along grain boundaries exhibit a discontinuous network shape in the Mg-3Zn-1Cu alloy. At the same time, a semi-continuous network shape in the Mg-3Zn-2Cu alloy and a continuous network shape Mg-3Zn-3Cu alloys, respectively.

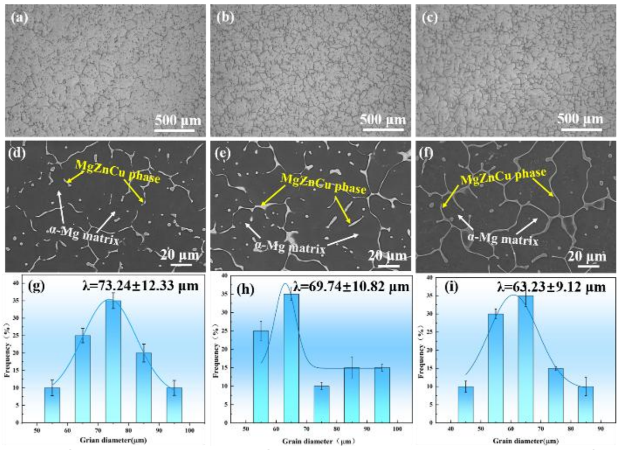

Fig. 1. Optical microscopy (OM) images showing (a) Mg-3Zn-1Cu, (b) Mg-3Zn-2Cu, and (c) Mg-3Zn-3Cu alloys. (e)-(f) Scanning electron microscopy (SEM) images showing secondary phases under different Cu contents: (e) Mg-3Zn-3Cu, (f) Mg-3Zn-2Cu, and (g) Mg-3Zn-3Cu alloys. (g)-(i) correspondingly grain size of α-Mg phases in (a)-(c).

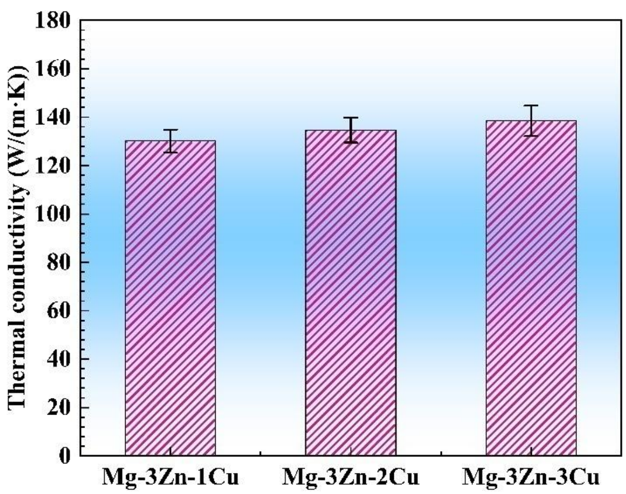

Fig. 2. Thermal conductivity of the as-cast Mg-3Zn-1Cu, Mg-3Zn-2Cu, and Mg-3Zn-3Cu alloys at 25°C temperature, respectively.

Thethermalconductivityofthethreesetsofalloysaremeasuredt obe 130.1 W/(W·K), 134.7 W/(W·K), and 138.5 W/(W·K) in Fig. 2. It can be concluded that the thermal conductivity of Mg-3Zn-Cu alloy increases with the increase of Cu content.The reasons for Cu improving the thermal conductivity of Mg-3Zn-Cu alloys, which could be explained by the following reasons. Firstly, Cu can increase the undercooling of Mg-3Zn-Cu alloy, which can refine grain size of α-Mg and eliminate casting defects. The reduction of casting defects decrease the scattering of electrons and phonons, which improving the thermal conductivity of the alloy. Secondly, with the increase of Cu content, the shape of MgZnCu phase changes from a discontinuous to a continuous. The continuous network shape provides favorable channels for heat conduction. Finally, Cu atoms contain a large number of free electrons, which is beneficial for the thermal conductivity of the Mg-3Zn-Cu alloy.

4 Conclusion

(1)The Cu addition can refine the grain size of α-Mg phase and increase the volume fraction of MgZnCu phase.

(2)The Cu addition can improve the thermal conductivity of Mg-3Zn-Cu alloys. Due to Cu addition can reduce casting defects and Cu contains a large of free electrons, which improve the thermal conductivity of Mg-3Zn-Cu alloys.

(3)The Cu addition forming a continuous network structure, which is beneficial for heat transfer and further improved the thermal conductivity of the Mg-3Zn-Cu alloys.

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