Effects of Squeeze Casting and Heat Treatment on Properties of Low-Cost Mg-Si-Zn-Cu Alloy

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Abstract: Magnesium alloys possess several advantages such as low density, high thermal conductivity, and excellent seismic resistance, making them ideal materials for laptop frames. However, current research on thermal conductive magnesium alloys focuses mainly on incorporating costly metal elements such as RE and Sn. This not only increases the production costs but also raises the density of magnesium alloys, hindering the commercialization of thermal conductive magnesium alloys. Therefore, the present study aims to develop an Mg-Si-Zn-Cu alloy that offers desirable mechanical properties and thermal conductivity while considering cost and density control. The impact of squeeze casting and heat treatment on the overall properties of this alloy was investigated. The research findings demonstrate that squeeze casting enhances the mechanical properties of the alloy without compromising its heat dissipation performance. Furthermore, heat treatment improves the thermal conductivity of the alloy effectively, primarily attributed to the spheroidization effect on secondary phases resulting from isothermal heat treatment.

Keywords: magnesium, thermal conductivity, Mg_2Si, heat treatment

1 Introduction

Rare-earth elements have shown significant potential in enhancing mechanical properties of magnesium alloys. These elements are commonly employed as alloying agents in the development of magnesium alloys with superior strength and conductivity [1]. Nevertheless, it is important to acknowledge that rare earth elements are generally associated with high cost, which may pose challenges in the commercialization of magnesium alloys. Additionally, the introduction of rare earth elements elevates density of magnesium alloy, which is not desirable for mobile devices. Mg-Si alloys offer advantages in terms of lower density and reduced cost when compared to rare earth element-containing alloys. Mg_2Si is the main strengthening phase in Mg-Si alloys and is an ideal in-situ strengthening phase in magnesium alloys [2]. Mg_2Si possesses high hardness and high modulus, which contribute to overall improved mechanical properties of magnesium. At the same time, the solid solubility of Si in Mg is very small, which avoids decrease in thermal conductivity of magnesium alloys caused by solid solution atoms.

This study aims to develop a new high-strength and high-thermal conductivity magnesium alloy by incorporating small amounts of Zn and Cu elements into the Mg-Si eutectic alloy. The performance of this new alloy undergoing squeeze casting and gravity casting was explored, followed by utilization of heat treatment to enhance its thermal conductivity.

2 Experimental procedure

The raw materials are industrial pure magnesium(99.95%), pure zinc(99.99%), pure copper(99.95%), and Mg-30Si master alloys. After removing the oxide skin from the surface of pure magnesium, it was placed in a resistance furnace, and 0.1vol.%SF_6+99.9vol.%N_2 mixed gas was inlet to prevent melt combustion. When the temperature of melt was raised to 800℃, the preheated Mg-30Si master alloy was added and melted completely after holding for 2 hours. Then, the melt was cooled to 750℃ and Zn and Cu were added. After 30 min, the melt was cooled to 700℃ for pouring. Before pouring, the melt was stirred to prevent Zn and Cu from sinking. The casting mold was metal mold with preheating temperature of 200℃ and ingot size of D30mm×90mm. The actual composition and of Mg-Si-Zn-Cu alloy was shown in Table 1.

Table 1 Composition of Mg-Si-Zn-Cu alloys

Mg	Si	Zn	Cu
Bal.	1.34	0.62	0.57

3 Result and discussion

3.1 Effects of squeeze casting on Mg-Si-Zn-Cu alloy

Fig. 1 displays the microstructures of the Mg-Si-Zn-Cu alloy under gravity casting and squeeze casting. After gravity casting, the alloy primarily consists of coarse α-Mg and eutectic Mg_2Si, interspersed with minor worm-like eutectic MgCuZn. Following squeeze casting, the size of α-Mg is significantly refined, resulting in the segmentation of large eutectic Mg_2Si blocks into a network-like framework encircling the α-Mg.

Following squeeze casting, the microstructure of the Mg-Si-Zn-Cu alloy exhibits significant refinement, leading to an improvement in its mechanical properties. The room temperature tensile curves of the Mg-Si-Zn-Cu alloy prepared by gravity casting and squeeze casting are shown in Fig. 2. For gravity cast(GC) alloy, the ultimate tensile strength (UTS) is 165 MPa and the elongation (El.) is 6.2%.

Due to the refined α-Mg segmenting the large eutectic Mg_2Si blocks, the elongation of the squeeze cast(SC) alloy increased to 8.6%. The network-like Mg_2Si framework, compared to large eutectic Mg_2Si blocks, provides a better stress-bearing capability, resulting in an increased UTS of 192 MPa for the SC alloy.

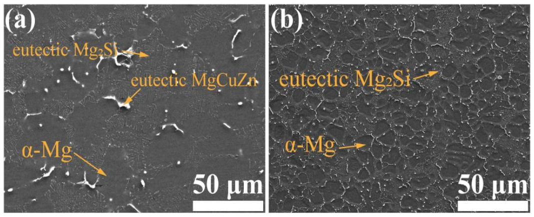

Fig. 1 SEM images of Mg-Si-Zn-Cu alloy under different casting methods: (a) gravity casting; (b) squeeze casting.

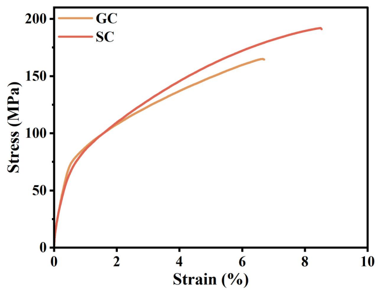

Fig. 2 Room temperature tensile curves of Mg-Si-Zn-Cu alloy prepared by gravity casting and squeeze casting

3.2 Effects of heat treatment on Mg-Si-Zn-Cu alloy

In this study, T1, T4, and T6 heat treatments were applied to the Mg-Si-Zn-Cu alloy to investigate the variations in its thermal conductivity under different conditions. Fig. 3 presents the microstructure of the alloy after the three heat treatments, with Fig. 8(d) focusing on a high-magnification image of the spheroidized Mg_2Si shown in Fig. 8(c). The morphology of Mg_2Si changes significantly with different heat treatments. The T4 and T6 treated samples underwent isothermal heat treatment at 450℃ for 24 hours, resulting in the transformation of Mg_2Si morphology from lamellar to short rod and spherical forms. The T1 treated samples were held at 180 ℃ for 6 hours, maintaining the lamellar morphology of Mg_2Si.

Fig. 4 illustrates the curves of thermal conductivity and thermal diffusivity of the alloy after heat treatment. Compared to the as-cast alloy, the thermal conductivity of the alloy decreases slightly after T1 treatment, but increases after T4 and T6 treatments. T4 heat treatment increases the concentration of solute atoms in α-Mg matrix, but the thermal conductivity exceeds that of as-cast sample. This result indicates that the spheroidization of Mg_2Si enhances the thermal conductivity of the alloy. The above heat treatment experiments confirm that the spheroidization of Mg_2Si leads to an increase in the thermal conductivity of the Mg-Si-Zn-Cu alloy, with the thermal conductivity reaching 142.6 W/(m·K) after T6 treatment.

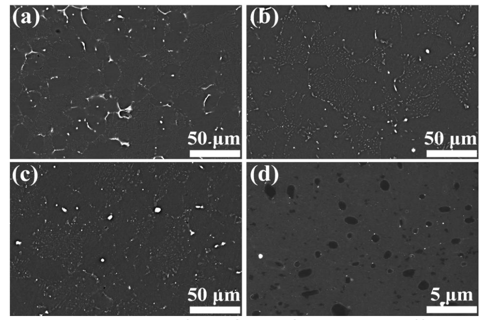

Fig. 3 Microstructure of Mg-Si-Zn-Cu alloy at different heat treatment states: (a)T1 heat treatment; (b) T4 heat treatment; (c)T6 heat treatment; (d) high magnification microstructure after T6 heat treatment

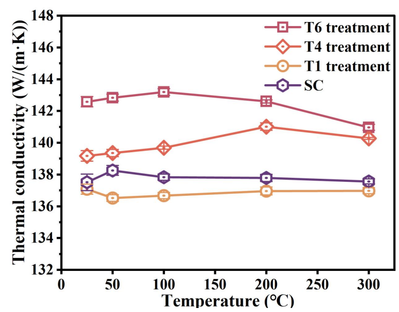

Fig. 4 thermal conductivity cureves of Mg-Si-Zn-Cu alloy after different heat treatments

Conclusion

(1) Squeeze casting refines the primary α-Mg and fragments the eutectic structure, thereby enhancing the strength and elongation of Mg-Si-Zn-Cu.

(2) The isothermal treatment causes the eutectic Mg_2Si to undergo spheroidization, thereby improving the thermal conductivity of Mg-Si-Zn-Cu.

References

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