Progress in Cast Magnesium-Matrix Composites with Low Expansion and High Thermal Conductivity

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Abstract: A type of magnesium alloy that urgently needs to be developed is one that has both high thermal conductivity and low thermal expansion, in order to ensure that the thermal physical properties of magnesium alloy components match with other components, and to ensure the dimensional stability of the components. However, in general, the high thermal conductivity and low expansion of magnesium alloys are contradictory, as the fewer alloying elements in magnesium metal, the higher the thermal conductivity (TC), but when magnesium alloys are close to pure magnesium, the thermal expansion coefficient (CTE) is large. The author's research group innovatively designed a Mg-Zn-Cu cast alloy with high TC and good mechanical properties. Due to the Laves structure phase of AB2 type C15 structure, the content of alloy elements in the solid solution is reduced, resulting in a high TC of the alloy, close to pure magnesium. On this basis, in order to further reduce the CTE, ceramic particles with low expansion and high thermal conductivity such as AlN, SiC and BN could be added to prepare cast Mg-matrix composites. The results show that the 10 wt.% AlN /Mg-Zn-Cu composite can reach a room temperature TC of 149.1 W/(m·K), and CTE of around 17.3×10^{-6} K^{-1} at 20 ~ 100℃, which can meet requirements for the thermal physical properties of magnesium alloys in many applications.

Key words: thermal expansion; thermal conductivity; magnesium-matrix composites; Mg-Zn-Cu alloy

1. Introduction

At room temperature, pure Mg has a thermal conductivity of 156 W/(m·K), which is higher than most metals and organic polymer materials, but it is lower than Al (237 W/(m·K)) and Cu, especially when it is alloyed by many elements, such as AZ91 alloy (only 45.1 W/(m·K)) [1].

Less research has been done on the CTE of magnesium alloys. Numerous studies show that the alloying elements are typically low in order to maintain high TC. But low-alloyed Mg alloys have high CTE, usually higher than many metallic materials, such as steels. The average CTE (20-100°C) of pure magnesium is 26×10^{-6} K^{-1}. By combining those components of high TC and low CTE, such as AlN and SiC, with magnesium-based materials, composites with high TC and minimal CTE may be produced. For example, the CTE of AlN is only 4.5×10^{-6} K^{-1} and with high TC of about 320 W/(m·K).

2. Experimental methods

The Mg-xZn-xCu (x=0.5, 1, 3, 5 wt.%) alloys were obtained by melting the raw materials of pure Mg, Zn and Cu in a resistance furnace. The mold used in this study was a cylindrical mold made of steel, the preheating temperature was 200°C, and the ingot size was *Φ*35mm×120mm. Through semi-solid stirring method, AlN particles with an average particle size of 10 μm are introduced to the melt to form AlN/Mg-Zn-Cu composites, with 10 wt.%, 20 wt.%, 30 wt.% respectively, and process can be found in reference [2]. After the synthetic process, the melt is quickly poured into the same preheated steel mold and solidified under a pressure of 50 MPa.

Metallography and SEM methods can be found in reference [3]. A LFA-427 laser thermal conductivity meter was used to measure the TC and the specimen size was Φ12.7 mm×2.5 mm. The CTE of materials was measured using a NETZSCH DIL402 thermal expansion meter at a temperature range of 20-300 ℃.

3. Results and discussions

3.1 Composition design, microstructure and properties of Mg-Zn-Cu alloys with high TC

The Mg-*x*Zn-*x*Cu (*x*=0.5, 1, 3, 5) alloys were designed to study the effects of elemental amount on TC. The as-cast alloys consist of α-Mg (dark parts) and second-phase (white parts) distributed along the grain boundary, as shown in Fig. 1. Combined with the XRD spectrum results, the second phase is identified as CuMgZn ternary phase. The CuMgZn phase precipitates in the form of eutectic in the post process of solidification, and the reason for the grain refinement should be that solute atoms aggregated at the solidification front, resulting in composition overcooling.

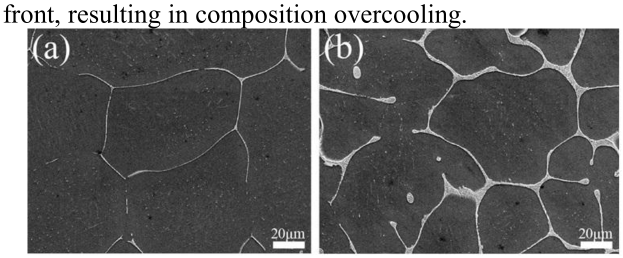

Fig. 1 SEM images of microstructure of Mg-xZn-xCu alloys: (a)x=1; (b)x=3

Fig.2 shows the TC of the alloys. The TC shows a trend of increasing with the increase of temperature. The Mg-0.5Zn-0.5Cu alloy has highest TC at room temperature of 153.0 W/(m·K), and with the increment of Zn and Cu, the Mg-5Zn-5Cu alloy has the lowest thermal conductivity, which is 136.5 W/(m·K). The TC of Mg-1Zn-1Cu is also high of 148.0 W/(m·K). With the increment of the total content of alloying elements, the content of Zn and Cu dissolved in the α-Mg matrix increases greatly, which is the main reason for the change of TC of the alloys.

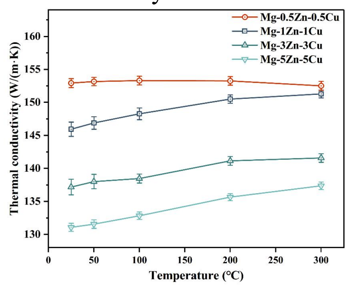

Fig. 2 TC variation of Mg-Zn-Cu alloy with temperature

Fig. 3 shows two presentative CTE of Mg-xZn-xCu alloys. Contrary to TC, the CTE increases with the increase of alloying element content. The average CTE of Mg-0.5Zn-0.5Cu alloy at 20-100℃ is 22.8×10^{-6} K^{-1}, while the CTE of Mg-5Zn-5Cu alloy is 24.7×10^{-6} K^{-1}, which is 8.3% higher. Moreover, the CTEs of all Mg-Zn-Cu alloys are still very high. Therefore, although the designed and developed Mg-Zn-Cu alloy has a high TC, its CTE is also relatively high and does not meet the ideal requirements. Other measures need to be taken for regulation, such as adding a second phase with low CTE to form composites.

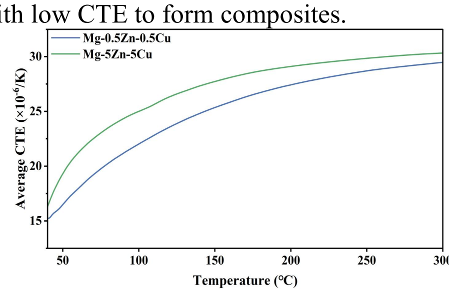

Fig. 3 CTE variation of Mg-Zn-Cu alloy with temperature

3.2 Structure and properties of low expansion and high thermal conductivity AlN/Mg-Zn-Cu composites

Fig.4 is representative microstructure of AlN/Mg-0.5Zn-0.5Cu composites, and the semi-solid stirring technique allows AlN to enter the magnesium matrix and distribute uniformly. The AlN particles are distributed inside the grains and at the grain boundaries, surrounded by the white eutectic structures α-Mg+CuMgZn.

Fig. 5 shows the temperature dependence of TC of AlN/ZC0505(wt.=0, 10%, 20%, 30%) composites. The TC of the composites decline with increasing AlN concentration, and AlN does not have the expected strengthening impact on TC. Adding 10 wt.% AlN decreases the TC at room temperature by 2.5%, from 153.0 W/(m·K) to 149.1 W/(m·K) in this study. But overall, TC of the composites is still very high. Fig. 6 shows the temperature dependence of CTE. The average CTE of 10% AlN/ZC0505 composites is 19.0×10^{-6} K^{-1}, and it is 16.7% smaller than matrix alloy. AlN

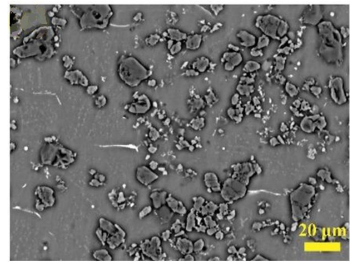

Fig. 4 SEM of 20 wt.% AlN/Mg-0.5Zn-0.5Cu composites

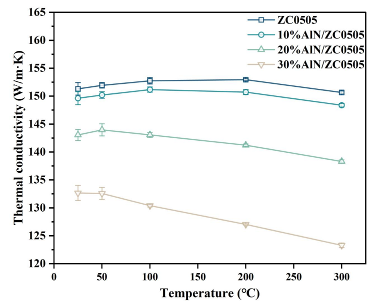

Fig. 5 TC variation of AlN/Mg-0.5Zn-0.5Cu composites

effectively reduces the CTE of the composites due to its low CTE. With the addition of 20 wt.% and 30 wt.% AlN, the CTE of the composites is only 17.3×10^{-6} K^{-1} and 15.6×10^{-6} K^{-1}, which is 24.1% and 31.6% less than that of the matrix alloy respectively.

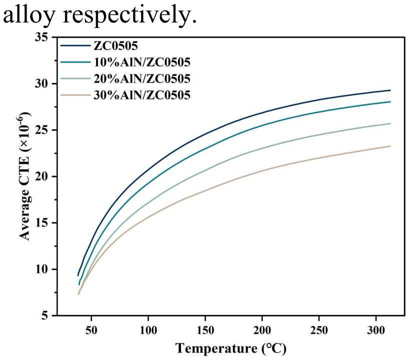

Fig. 6 CTE variation AlN/Mg-Zn-Cu with temperature

4. Conclusions

The TC of newly designed Mg-0.5Zn-0.5Cu alloy is as high as 153.0 W/(m·K). For every 1wt.% increment in element content, the TC decreases by about 1.95W/(m·K). The TC of AlN/ZC0505 composites decreased slightly with the increase of AlN content, TC of 10% AlN/ZC0505 decreased 2.5% from 153.0 W/(m·K) to 149.1 W/(m·K).
The AlN limit effectively the thermal expansion of the composites. The CTE of 20% AlN/ZC0505 is only 17.3×10^{-6} K^{-1}, which is 24.1% lower than that of the matrix alloy.

References

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