

Effects of Heat Treatment on the Thermal Properties of A356 Aluminum Alloys in Different Casting Processes

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Abstract: The thermal diffusivity and specific heat capacity of continuous casting (SC) and high-pressure diecasting (HPDC) aluminum alloys before and after T4 and T6 heat treatments were measured at room temperature, and their thermal conductivity was calculated. The effects of heat treatments on the thermal properties of A356 alloys in different casting processes were investigated, and the mechanism of the effects was also discussed. Before heat treatment, the SC alloys had higher thermal conductivity than that of the HPDC alloys. Moreover, heat treatment after forming had a remarkable influence on the thermal properties of the SC and HPDC alloys. T4 treatment had positive effects on the thermal conductivity of the SC and HPDC A356 alloys, and the T6 heat-treatment SC and HPDC alloys had higher thermal conductivity than that of the T4 treatment alloys.

Keywords: Thermal properties, A356 alloys, Heat treatment, Casting process

1 Introduction

Aluminum alloys have been used for the production of high thermal or electrical conductor. Due to the excellent strength, low density and high thermal conductivity, the alloying aluminum has been applied in the industry of 3C products and electronic package^[1-2]. It has been reported that the thermal conductivity of pure aluminum is 237 W · (m · K)⁻¹, which is the fourth highest thermal conductivity among metals next to that of pure Cu, pure Au and pure Ag. Hence, aluminum alloys have attracted immense attention as potential heat sink materials. However, alloying elements, such as Si, Mg and Cu, which strengthen the mechanical properties of Al alloys, significantly reduce the thermal conductivity. For instance, the thermal conductivity of Die-casting ADC12 alloy at room temperature is 92~96 W (m K)⁻¹, not even 1/2 that of pure Al. To solve the problem, a series of studies focused on the effects of heat treatments and forming processes on the thermal properties of aluminum alloys.

This work aimed to study the effects of heat treatment on the thermal properties of A356 alloys in different casting processes at room temperature. The thermal conductivity of A356 at different states was calculated. The grain size was analyzed by the electron back scattered diffraction (EBSD)

technique, and Electron Probe Micro-Analysis (EPMA) results were used to calculate the atomic fraction of solute Si element in the α -Al matrix, which was aimed at revealing the mechanism of the effects of the heat treatment and casting process on the thermal conductivity of A356.

2 Experimental procedure

The material for the present study was commercial A356 aluminum alloy. The samples of A356 were prepared by continuous casting (SC) and high-pressure die casting (HPDC). The chemical compositions of the samples were measured using Electron Probe Micro-Analysis (EPMA). The samples were machined in the shape of round disks with the size of $\Phi 12.7\text{mm} \times 3\text{mm}$ after T4 or T6 heat treatment. X-Ray Diffraction (XRD) analysis was carried out under $\text{CuK}\alpha$ radiation with an incidence beam angle of 2°. Jade 6.0 software was used to identify phases, refine the crystal structure and then calculate the lattice strains by the function of size & strain plot.

The thermal diffusivity and specific heat capacity of the samples were measured at room temperature using the flash method in an argon atmosphere with a NETZSCH LFA 457 Analyzer. Three points were detected for each sample and the average value was obtained. The thermal conductivity was calculated using the following relation:

$$\lambda = \alpha \cdot \rho \cdot C_p \quad (1)$$

where λ is thermal conductivity (W (m K)⁻¹), α is thermal diffusivity (mm² · s⁻¹), ρ is the density of alloy (g · mm⁻³) and C_p is the specific heat capacity (J · (g · k)⁻¹) at constant pressure.

3 Result and discussion

Fig. 1(a) shows the specific heat capacity of SC and HPDC A356 alloys in different states at 25°C. T4 and T6 treatment reduced the heat capacity of the SC and HPDC A356 alloys. The thermal diffusivity of SC and HPDC A356 alloys in different states at 25 °C is shown in Fig. 1(b). The thermal diffusivity of SC and HPDC A356 alloys increased after T4 treatment and rose slightly after T6 treatment. The thermal diffusivity of alloys after T6 treatment was higher than that of as-prepared samples. Fig. 1(c) displays the thermal conductivity of A356 alloys at different states. SC A356 alloys had higher thermal conductivity than the HPDC

alloys. Moreover, the changes in the thermal conductivity of SC and HPDC A356 alloys after heat treatments presented the same trends as mentioned in the thermal diffusivity.

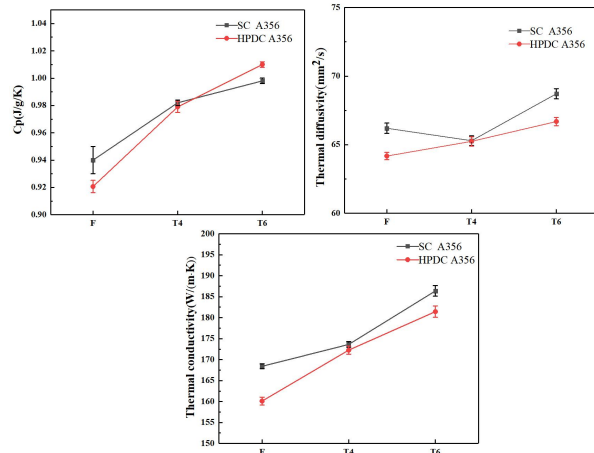


Fig. 1. Specific heat capacity (a), Thermal diffusivity (b) and Thermal conductivity (c) of SC and HPDC A356 alloys in different states at 25°C.

According to Fig. 1(c), thermal conductivity increased after T4 treatment for the SC and HPDC A356 alloys, this outcome was attributed to dissolution of the block-like eutectic silicon phases and the change of morphology of eutectic silicon from block to fine spherical, the secondary phase volume fraction of both the SC and HPDC A356 alloys decreased. Eutectic silicon phases along grain boundaries were largely dissolved during the solution treatment. It has been shown that thermal conductivity is usually related to the symmetry of a crystal lattice and reduced by the scatter of foreigner atoms. For A356 alloys, the atomic radii of Si and Al are 0.117 nm and 0.143 nm, respectively, and the variance in atomic radii could cause massive amounts of lattice distortion in Al-Si solid solution. The lattice strain of both the SC and HPDC A356 alloys increased after T4 treatment, proving that T4 treatment caused lattice distortion.

The lattice distortion caused by a solute alloying element was much more serious than that of a metallic compound. Hence, the lattice distortion caused by the increased solute Al acted as scattering centres, which limited the mean free path of electrons and phonons and reduced the thermal conductivity of the as-SC and as-HPDC A356 alloy. However, the T4 and T6 heat-treatment SC and HPDC alloys presented higher thermal conductivity than that of the without treatment alloys.

During artificial ageing treatment, the Si phases precipitated near the grain boundaries. Compared with T4 alloys, T6 SC and HPDC alloys had a higher volume

fraction of secondary phase and lower solute Al in the α -Al matrix. Moreover, the lattice strain of T6 SC and HPDC alloys was also lower than that of T4 alloys, which accounted for the increase in thermal conductivity of these alloys. Moreover, the thermal conductivity of both T6 and T4 SC and HPDC alloys was obviously higher than that of as-prepared alloys. This is mainly due to the change of the morphology of eutectic silicon.

The thermal conductivity of the SC A356 alloys was higher than that of the HPDC alloys mainly because of the lower solute Si atoms in the Al matrix and larger and more uniform grain size. The results of microscopic observations showed that the eutectic silicon phases in the HPDC A356 alloys were much more dispersed and finer compared with those in the SC A356 alloys. The volume fraction of the secondary phases in the HPDC A356 alloys was higher than that in the SC alloys, the lattice strain of the as-HPDC alloys was lower than that of the as-SC alloys; this outcome meant that less lattice distortion was formed after high-pressure die-casting. Although the grains of the HPDC alloys were finer than those of the SC alloys, which meant that the volume fraction of grain boundary (that could act as the scattering sources blocking the free movement of electrons and decreasing thermal conductivity) was higher. It was believed that the lattice distortion had greater influence on the heat transfer than the grain boundaries, therefore, the HPDC alloys had higher thermal conductivity.

4 conclusion

The thermal conductivity of the SC and HPDC A356 alloys before and after T4 and T6 treatment at room temperature were measured and analyzed. The conclusions are summarized as follows:

- (1) The thermal conductivity of the SC and HPDC alloys increased notably during T4 treatment and T6 treatment.
- (2) The thermal conductivity of the as-SC alloys was higher than that of the as-HPDC alloys.

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References

- [1] R.N. Lumley, I.J. Polmear, H. Groot, J. Ferrier, Thermal characteristics of heat-treated aluminum high-pressure die-castings. *Scripta Mater.* 58, 1006-1009 (2008)
- [2] M.C.S. Jr, A.R. Machado, W.F. Sales, M.A.S. Barrozo, E.O. Ezugwu, Machining of aluminum alloys: a review. *Int. J. Adv. Manuf. Technol.* 86, 1-14 (2016)