On the Characterization of Microstructure of High-Pressure Die-Cast Alloys with High Thermal Conductivity

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Abstract: The high-pressure die-cast Al-1.5Fe alloy was prepared to achieve high thermal conductivity. The microstructure was characterized using various techniques. Die-cast Al-1.5Fe alloy was hypoeutectic and its microstructure mainly consisted of externally solidified crystals primary α-Al (ESCs-α) formed in the shot sleeve, primary α-Al formed in the die cavity (α) and (α-Al+$Al_{13}Fe_4$) eutectics. The microstructure distribution of die-cast Al-1.5Fe alloy was heterogeneous. ESCs-α was enriched in the center of the bar samples because of the melt force and the equivalent diameter of ESCs-α in the center was larger than that in the surface. Moreover, a eutectic-rich band with numerous $Al_{13}Fe_4$ phases was found in the middle of the sample. $Al_{13}Fe_4$ eutectic phases in the eutectic band were more continuous than those in other regions. The volume fraction of porosity increased from surface to center. Due to the low Fe concentration and the large number of aluminum substrates, the die-cast Al-1.5Fe alloy achieved a high thermal conductivity of over 190 W m^{-1} K^{-1} and a high elongation of over 10%.

Keywords: high-pressure die-cast, Al-Fe alloy, microstructure, thermal conductivity

1 Introduction

High pressure die casting is widely used to produce aluminum castings for heat dissipation components in the fields of electrical vehicles, communications and consumer electronics because of its near-net-shape forming characteristics[1,2]. Nowadays, with the development of electronic and renewable energy, the heat generation of components increases rapidly. Traditional Al-Si die-cast alloys with limited thermal conductivity fail to meet the demand of high thermal conductivity. Recently, because of the low solute concentration of element Fe in Al matrix and the necessity of element Fe for the die solder resistance [3], Al-Fe alloy was developed to obtain higher thermal conductivity. Numerous studies have investigated the microstructural characteristics and the effect of elements on microstructure and thermal conductivity of Al-Fe gravity-cast alloys [4]. However, the study on microstructure and thermal conductivity of die-cast Al-Fe alloys is still lacking. In this work, a high-pressure die-cast Al-1.5Fe alloy was prepared, and its microstructure distribution and thermal conductivity of the die-cast Al-1.5Fe alloy were discussed.

2 Experimental procedure

The Al-1.5Fe die-cast sample was produced using a TOYO 350V5 die casting machine. A φ 6.4 mm*10 mm sample was cut from the standard tensile bar, and the sample was used for optical microscope (OM), scanning electron microscope (SEM) equipped with energy dispersive spectrometer (EDS), and electron probe X-ray microanalysis (EPMA). To study the three-dimension morphology and distribution of eutectic $Al_{13}Fe_4$ phases and pores, a φ 1 mm*6.4 mm sample was prepared for the characterization in BL13HB beamline at Shanghai Synchrotron Radiation Facility (SSRF).

3 Result and discussion

1. Al13Fe4 phase in the Al-Fe die-cast alloy

According to the Al-Fe binary phase diagram, the eutectic point is nearly 1.75 wt.%Fe. To obtain the high thermal conductivity and castability, the chemical composition should be hypoeutectic, near the eutectic point. Then, the Fe content is chosen to be 1.5 wt.%. Figs. 1a-a_2 show the eutectics in Al-1.5Fe alloy, which are fully composed of element Fe and Al. It indicates the eutectic consists of α-Al and $Al_{13}Fe_4$ phases. In Fig. 1b, the alloy primarily contains large-size ESCs-α and lamellar eutectics. Few needle-like primary $Al_{13}Fe_4$ phases are also found in Figs. 1c and d.

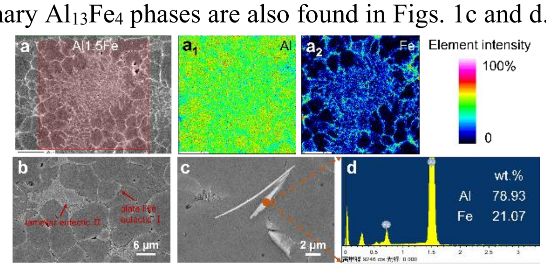

Figure 1 (a-a2) EPMA results of eutectics in Al-1.5Fe die-cast alloy. (b-d) Morphology of eutectics and the primary phase with the corresponding EDS result.

2. The distribution of microstructure in the Al-Fe die-cast alloy

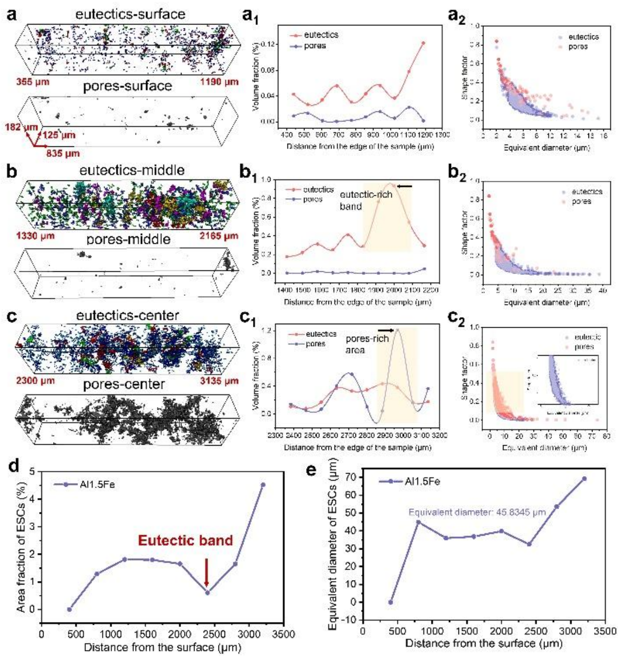

Figure 2 (a-c_2) Distribution of eutectics and pores in Al-1.5Fe die-cast alloy. (d-e) Distribution of ESC-α in Al-1.5Fe die-cast alloy.

Figs. 2a-c show the distribution of eutectics and porosity in the surface, middle and center. Because of the limited resolution of the beamline, the reconstructed results can only show the morphology of eutectic cells instead of the individual lamellar phase. In Fig. 2b, eutectics in the middle are coarser and more continuous. The quantitative result in Fig. $2b_1$ indicates that the volume fraction of eutectics increases sharply to ~1% at the position of 2000 μm. There are more eutectics with larger sizes in the middle from Fig. $2b_2$. Figs. 2c and c_1 reveal that the volume fraction of porosity in the center increases dramatically and the most large-size pore is over 70 μm. In Figs. 2d and e, the area fraction and equivalent diameter of ESCs-α both increase in the center because of the Saffman force produced by the different velocity between ESCs-α particles. Notably, in the range of 2000 to 2500 μm, the area fraction of ESCs-α decreases, marking the eutectic-rich band. Because of the gathering of ESCs-α in the center, the size of eutectic cells here is smaller than that in the middle, although the low cooling rate causes the $Al_{13}Fe_4$ eutectic phase becoming larger in size. Additionally, the enrichment of ESCs-α in the center also causes the remaining liquid with a high Fe concentration in the middle. Thus, the eutectic-rich band is formed in this region.

3. Thermal conductivity of the Al-Fe die-cast alloy

Table 1 shows the properties of the Al-1.5Fe die-cast alloy. The thermal conductivity (TC) is 197.1 W m^{-1} K^{-1}. The elongation (EL), yield strength (YS) and ultimate tensile strength (UTS) are 15.7%, 131.7 MPa and 63.4 MPa, respectively. The die-cast alloy has higher thermal conductivity and elongation as well as lower strength compared to commercial die-cast Al-Si alloys. The TC near 200 W m^{-1} K^{-1} is attributed to the low concentration of Fe in Al from the binary phase diagram (~0.05%) and a large number of Al substrate (only 1 vol.% in the eutectic-rich band), which significantly decreases the negative effect of the impurity (solutes and precipitates) scattering on the electron movement in the alloy.

Table 1. Properties of Al-1.5Fe die-cast alloy

YS (MPa)	UTS (MPa)	EL (%)	TC (W m^{-1} K^{-1})
63.4±1.8	131.7±1.9	15.7±6.7	197.1±1.8

4 Conclusion

(1) The die-cast Al-1.5Fe alloy mainly consisted of ESCs-α, αand (α-Al+$Al_{13}Fe_4$) eutectics.
(2) ESCs-α were enriched in the center of the bar and the equivalent diameter of ESCs-α in the center was larger than that in the surface.
(3) An $Al_{13}Fe_4$ eutectic-rich band was in the middle of the sample. $Al_{13}Fe_4$ eutectic phases in the eutectic band were more continuous than those in other regions.
(4) The volume fraction of porosity increased from surface to center.
(5) Due to the low Fe concentration and large number of aluminum substrates, the die-cast Al-Fe alloy had a high thermal conductivity of over 190 W m^{-1} K^{-1} and a high elongation of over 10%.

Acknowledgments

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