Characterization of Externally Solidified Crystals (ESCs) and Porosity of HPDC AlSi9MnVZr Alloy

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Abstract: An investigation was conducted to characterize externally solidified crystals (ESCs) and porosities in a high-pressure die-cast AlSi9MnVZr alloy using an optical microscope (OM), SEM, and computed tomography (CT). Particularly two sets of HPDC process parameters were designed. The microstructure of HPDC AlSi9MnVZr alloy mainly comprised of primary α-Al, ESCs, Al-Si eutectic and iron-rich phase. ESCs nucleate in the shot sleeve whereas α-Al form in die cavity. In sample produced without fast shot speed and intensification pressure revealed the aggregation of larger-size dendritic ESCs in the casting. Moreover, big gas pores and shrinkage pores along with many small dispersed pores with high porosity fraction were observed. When both slow shot speed and fast shot speed were induced, the diameter and the area fraction of ESCs in casting were significantly reduced. In addition, the value of porosity substantially lowered and obvious reduction in the porosity fraction percent was observed as its value decreased from 1.07 % to 0.1 %.

Keywords: high-pressure die-cast, Al-Si alloy, ESCs, porosity

1 Introduction

High pressure die casting process is extensively used to manufacture aluminum castings due to its ability to produce complex shapes with excellent dimensional accuracy and surface finish [1-2]. However, due to the characteristics of slow shot speed in the shot sleeve, higher speed filling and high intensification pressure in the die cavity result in the formation of ESCs and porosities in die-cast parts, which limits their potential applications [3]. Currently, heat-treated Al-Si alloys are most commonly used alloys, heat treatment consumes energy which leads to the deformation of large die-casting parts and increases the difficulty of subsequent machining and the cost. Therefore a non-heat treated AlSi9MnVZr alloy was developed to obtain highly efficient properties with less energy consumption. Previous studies have reported that several process parameters influence the extent of defects in die-cast parts such as die temperature, melt temperature, low shot speed, fast shot speed, intensification pressure, and casting geometry. However, the study on the influence of process parameters on ESCs and porosities in Al-Si alloys is insufficient. In this study, HPDC AlSi9MnVZr alloy was developed and the influence of two sets of process parameters on the microstructures was studied.

2 Experimental procedure

A TOYO BD-350V5 cold chamber die-casting machine was used to produce AlSi9MnVZr alloy. The samples with dimensions of φ6.4 mm*10 mm were cut from the center of the standard tensile test bar. The samples were ground using 400# to 2000# SiC paper, polished with diamond past, and etched using Murakami reagent (10 g of NaOH, 5 g of $K_3(Fe(CN)_6$, and 60 ml of H_2O). The microstructure was examined using a Zeiss scope A1 optical microscope (OM) and laboratory CT scan (nanotom m CT). The working electric current, voltage, and the voxel in CT were set as 110 μA, 100 kV and 3 μm, respectively.

Table 1. Key parameters of HPDC process

Sample	Slow shot speed	Fast shot speed	Intensification pressure
S-F	0.1	1.04	-
S	0.1	-	-

3 Result and discussion

Fig.1 (a-b) shows the microstructure of AlSi9MnVZr alloy. The microstructure comprises of primary α-Al, ESCs, Al-Si eutectic, pores, iron-rich phase and Zr-rich phase. ESCs nucleate in the shot sleeve whereas α-Al form in die cavity.

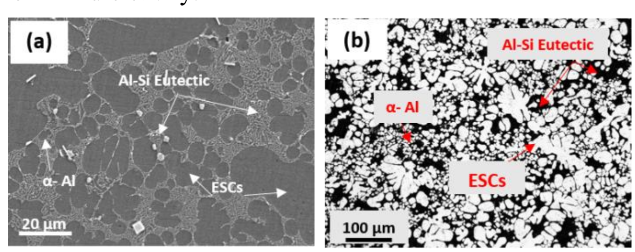

Figure 1 Microstructure of AlSi9MnVZr alloy (a) OM; (b) SEM

Fig.2 shows distribution of ESCs at surface and center of bar samples at two different process parameters. The equivalent diameter and the number of ESCs increased from the surface to the center for both sample.

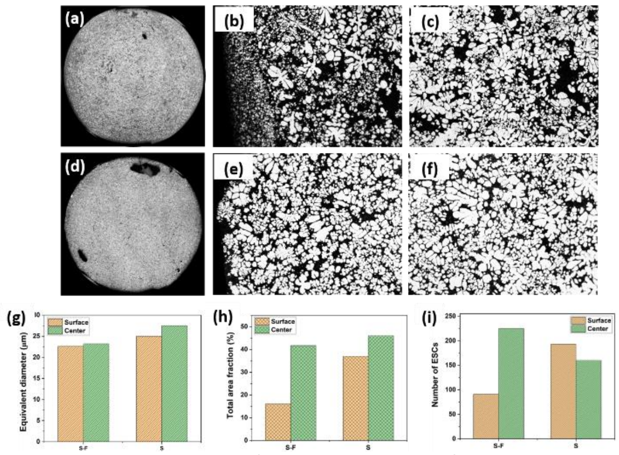

Figure 2 Microstructure of the cross-section of bars sample at different process parameters; (a-c) S-F and (d-f) S. (a,d) overview of the microstructure across the cross-section; (b,e) and (c,d) magnified view of surface and center; (g-i) statistical distribution of ESCs.

In Fig.2 (b-c), from the surface to the center, the size of ESCs was smaller in the bar sample with slow shot speed and fast shot speed (S-F), whereas both the size and the total area fraction of ESCs increased from surface to center in the bar sample without fast shot speed and intensification pressure (S), as shown in Fig.2 (e-f). Fig 2(g-h) shows that the average equivalent diameter increased from 23 μm to 27 μm and the total area fraction increased from 28.8% to 41.5%. During the filling process in HPDC, higher melt flow speed caused a turbulent state, which created considerable thermal shock and convection, resulting in ESC remelting and fragmentation.

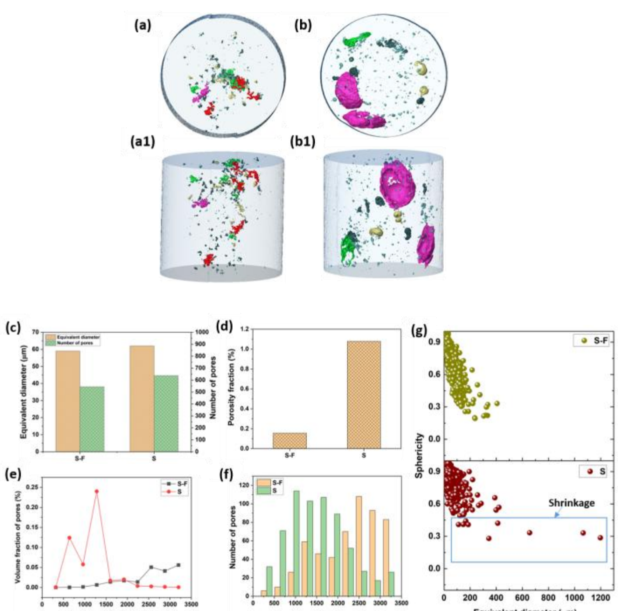

Figure 3 3D morphology of the porosity of bars sample at different process parameters; (a-a1) S-F and (b-b1) S; (c-g) statistical distribution of porosity.

Fig. 3 shows 3D morphology of the porosity of two different process parameters. It is evident from the sample S-F that the fast shot speed could significantly reduce porosity. As shown in Figs.3 (a, a1), the size of pores dramatically decreases in the specimens produced with slow shot speed and fast shot speed. As shown in Figs. 3(b-b1), without fast shot speed and intensification pressure, larger pores are distributed in the bar cross-section accompanied with a lot of dispersed small pores. According to the statistics in Fig. 3(c-d), the average diameter of the pores increased from 59 μm to 62 μm and the porosity fraction percent exhibited an obvious declined trend, and its value decreased from 1.07 % to 0.1 % in S-F sample, compared to S sample. Fig. 3(e-f) shows the volume fraction percent of pores and the number of pores aggregated. The ESCs had continued growth and showed an increase in size in the S bar sample. As a result, additional and larger ESCs would be linked together, creating greater spaces between them. This makes it more challenging to fill the remaining molten material, leading to the formation of more and larger pores.

4 Conclusion

(1) The AlSi9MnVZr alloy comprised of α-Al, ESCs, Al-Si eutectic, iron-rich phase and Zr-rich phase.

(2) The absence of fast shot speed and intensification pressure resulted in larger dendritic ESCs aggregation and the formation of larger pores with high porosity fraction percent.

(3) When slow shot speed and fast shot speed were introduced, the equivalent diameter and area fraction of ESCs decreased. Moreover, the porosity fraction percent exhibited an obvious decline, and its value decreased from 1.07 % to 0.1 %.

Acknowledgments

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