Numerical Verification of Feasibility of Small Amount of solid phase dispersion die casting method by CONTROLLING Molten Metal Temperature

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Abstract: One method of improving the quality of the die casting process is the semi-solid die casting method using semi-solid slurry. The Partial Solid Die Casting (PSDC) method was developed to address the issue of the semi-solid die casting method, which is an increase in cost due to the increased slurry production process. By reducing the temperature of the molten metal, the proportion of solid fraction in the sleeve immediately before injection is controlled to 0.05 or below, which disperses α-Al crystal nuclei and suppresses the growth of coarse porosity in thick-walled parts, thereby achieving high quality. Furthermore, a significant reduction in the manufacturing stage energy is achieved. The distribution of the solid fraction in the sleeve was precisely verified by numerical analysis of the ladle and the full model of the injection mechanism. This analysis was conducted to determine whether molten metal with the prescribed solid fraction could be produced stably under the manufacturing conditions of the PSDC method.

Keywords: semi-solid die-casting; solid fraction; aluminum; eutectic alloy

1 Introduction

One method of improving the quality of the die casting process is the semi-solid die casting method using semi-molten slurry. One disadvantage of the semi-solid die casting method is the increased cost associated with the production of the slurry. Additionally, the method is not easily applicable to JIS ADC12, a eutectic alloy with a narrow solidification range. To address these issues, Itamura et al. reported the development of a semi-solid die casting method using a hypoeutectic alloy, JIS AC4CH, by controlling the temperature in the sleeve [1]. Furthermore, Koide et al. recently reported the practical application of a semi-solid manufacturing method using slurry of JIS ADC12 alloy [2].

In contrast to these developments, the Partial Solid Die Casting (PSDC) method proposed in this study aims to suppress the coarse growth of porosity in the thick wall of the product at the completion of filling by generating and dispersing a small amount of crystal nuclei in the sleeve through molten metal temperature control. For the mass production of PSDC, it is essential to accurately predict the sleeve temperature at the time of ladle feeding in order to control the solid fraction in the sleeve by the molten metal temperature. In order to validate the PSDC method, the temperature distribution of the sleeve was obtained based on a mold temperature cycle calculation that considers the operating position of the plunger tip when filling the sleeve, and the flow and solidification calculations were verified by coupling the molten metal temperature calculation during ladle feeding with the flow and solidification calculations.

2 Overview of PSDC Method and Experimental Methods

Overview of PSDC Method

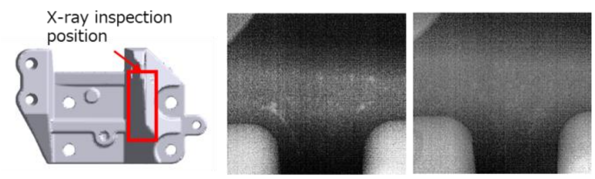
The PSDC method controls the solid fraction in the sleeve by lowering the molten metal temperature. In ADC12, which is a eutectic alloy, there is concern about the formation of cold flakes on the inner wall of the sleeve. In contrast to a solid fraction of 0.1, which increases the possibility of cold flakes, the PSDC method sets the solid fraction at about 0.05. The reduction in the molten metal temperature confers an advantage upon the injection mechanism. The decreased occurrence of galling between the sleeve and injection tip is anticipated to result in the stable operation of the injection mechanism. Furthermore, the cycle time is shortened by a reduction in the quantity of molten metal and an acceleration of the solidification of the stamped part. The lower molten metal temperature reduces the amount of heat input to the mold, but the shorter cycle time allows the mold temperature to be set at a higher level. This prevented the occurrence of flow marks in the product section.

Experimental Conditions and Results

Table 1 shows the experimental conditions used to confirm the effectiveness of the PSDC method. Tests were conducted to compare the PSDC method (PSDC) with the conventional condition of holding the molten metal temperature high (general DC). Casting experiments were conducted using a casting machine with a clamping force of 350 tons and a mold for a product mass of 850 g and a minimum wall thickness of 5 mm. JIS ADC12 alloy was used as the material. Figure 2 shows a comparison of X-ray transmission images under each experimental condition. Porosity was observed in the general DC, but not in the PSDC.

Table 1 Comparison of conditions for casting experiments

Casting parameter	General DC	PSDC
Molten metal temperature (℃)	640	605
Low injection speed (m/s)	0.15	0.27
High injection speed (m/s)	2.7	3.2
Casting pressure (MPa)	50	65
Thickness of stamp (mm)	45	20
Delay time of injection (s)	1.0	0
Cycle time (s)	53.9	41.0



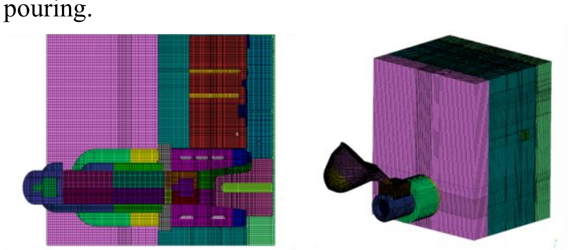
(a) General DC (b) PSDC

Figure 1 Comparison of X-ray transmission images of thick wall

3 Verification by simulation

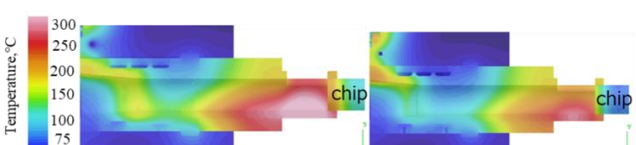
Temperature Distribution Verification of Injection Mechanism Section

The software utilized for the calculations was CAPCAST®. Figure 2 shows the mold model for flow and solidification calculations and the ladle pouring model. Figure 3 shows the temperature distribution in the sleeve cross section just before the molten metal is poured. It is evident that there is a significant temperature gradient in the sleeve from the pouring section to the stamping section just before the pouring.



(a) Solidification, Flow calculation model (b) Ladle molten metal pouring model

Figure 2 Full mold model including ladle and injection section

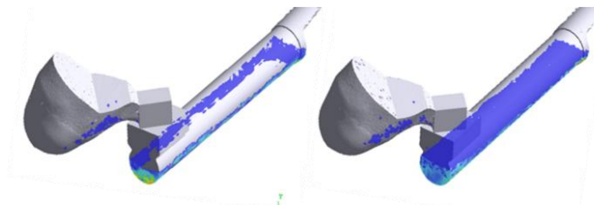


(a) General DC (b) PSDC

Figure 3 Comparison of sleeve cross-sectional temperature distribution during filling

Verification of solid fraction distribution in the sleeve

Figure 4 shows the isosurface distribution of the solid fraction (fs=0.01) of the molten metal in the sleeve immediately after the completion of molten metal injection. In general DC, the solid phase is distributed on the bottom of the sleeve in the form of a skin. In contrast, in PSDC, almost the entire molten metal is covered by a small amount of solid fraction distribution. Figure 5 shows the isosurface volume for each fs as V_{fs}, the total molten metal volume V_{all}, and the isosurface volume ratio R_{atio} = Vfs / V_{all}. The molten metal with a large solid fraction at fs=0.5 is almost gone.



(a) General DC (b) PSDC

Figure 4 Comparison of solid phase ratio isosurface in the sleeve (fs=0.01)

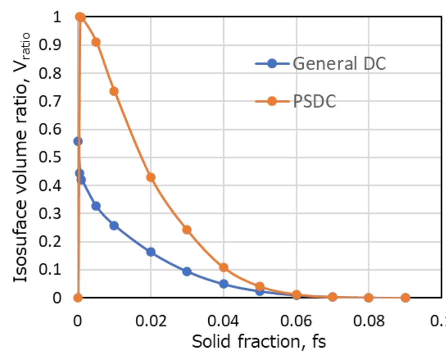


Figure 5 Variation of isosurface solid fraction fs and isosurface volume fraction

4 Conclusion

The solid phase distribution of the molten metal was verified by full model simulation of the PSDC die casting with molten metal temperature control, including the injection and ladle pouring sections.

1) In the PSDC method, a small amount of solid fraction fs=0.0005 is uniformly distributed in the molten metal at the completion of pouring.
2) The decrease in porosity is thought to be due to the small amount of solid phase in the molten metal of the PSDC method, which acts as a crystal nucleus, dispersing the formation of porosity and promoting solidification around the porosity.

References

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