O-146

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Optimization of Gating System Design for High Pressure Die Casting to Reduce Air Entrapment Defects

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This study aimed to optimize a gating system design for high pressure die casting (HPDC) to minimize air entrapment defects using mold filling simulation. The optimized gating system design and another conventional design were applied to actual metal molds, and casting experiments using an HPDC machine with each of the gating system designs were conducted. Eventually, the results showed that the optimized gating system design can excellently decrease air entrapment defects in products.

Keywords: *HPDC, CFD, optimum design, sprue, runner.*

1. Introduction

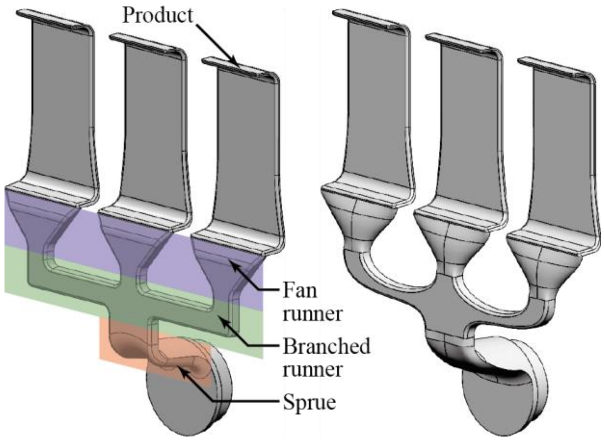
High pressure die casting (HPDC) has a number of advantages and has been used to manufacture automobile parts and many other industrial products. However, in HPDC, when molten metal is plunged into a metal mold, the molten metal can entrap a large amount of air and this generates serious gas porosity defects in products. Since these air entrapments into molten metal can be occurred also in the sprue and runners, the gating systems should be designed to minimize such air entrapments [1, 2].

In the present study, we performed an optimum gating system design for HPDC to reduce air entrapment defects. The optimized design was applied as a metal mold, and its effectiveness was demonstrated through casting experiments using an actual HPDC machine.

2. Optimization of gating system design

2.1 Problem definition

Figure 1 shows the shapes of the products and gating system designs used in the paper. The shape of a product part is a thin plate 3 mm thick, which was designed to prevent air entrapment in itself. The internal structure of the mold has three cavities of product and the shape of the runner is divided into the three directions. The gating system design shown in Fig. 1 (a) is called as the standard shape, which is used to be compared with the optimum shape that is to be derived later.



(a) Standard Shape (b) Optimized Shape

Fig. 1 Shapes of product and gating system design.

In the optimization, to simplify the design problems and reduce the computational time, we divided the gating system into three types of parts: the sprue, the branched runner and the fan runner, which were also designed separately. Each of the parts were evaluated using mold filling simulations based on computational fluid dynamics (CFD).

For evaluation, we defined three objective functions J_1, J_2 and J_3. J_1 was for evaluating air entrapment occurred in each part of the gating system. Thus J_1 was defined as the amount of remaining air in the cavity at the time when the fluid flow became almost a steady state. J_2 and J_3 were for evaluating the uniformity of the fluid arrival and the fluid velocity vectors at the outlet, respectively, which were for considering the continuity of flow when connecting the sprue and runners each other.

Finally, the optimization problem was defined as a multi-objective problem to minimize these objective functions J_1, J_2 and J_3. The problem was solved by using the nonparametric shape optimization algorithm based on a genetic algorithm that we had proposed [3].

2.2 Optimization result

Figure 1 (b) shows the shape derived in the optimization. The optimized gating system design had a round shape as a whole, and this can be expected to efficiently decrease air entrapment defects.

For confirmation, we conducted mold filling analyses in the region of the gating system design and product. As a result, the optimized shape was verified to have a high reduction effect on air entrapment in the product parts on the left and right sides except for the center part, because of the shape of the branched runner in particular.

3. Casting Experiments

3.1 Method

In the experiments, a cold-chamber type HPDC machine with the mold clamping force of 135 t was used. A metal sleeve with the inner radius of 60 mm and the length of 220 mm and metal molds with the standard and optimized gating system design were also used. As casting conditions, the four conditions A, B, C and D listed in Table 1 were selected and used. Here, $t_{pouring}$ is the time required for pouring with the ladle, t_{stl} is the time from the completion of pouring to the start of injection (i.e. shot-time-lag), and $v_{injection}$ is the injection velocity of the plunger. We acquired ten castings as samples for each mold shape and each casting condition. Thus a total of 80 castings were sampled in the experiments.

Table 1 Parameters of Conditions A, B, C and D for pouring and injection.

Condition	$t_{pouring}$ [s]	t_{stl} [s]	$v_{injection}$ [cm/s]
A	2.4	1.0	20
B	2.9	1.1	32
C	2.9	2.0	32
D	2.9	1.6	20

Each of the acquired castings was separated into the product parts and the others at the gates, and these product parts were heat treated to expand the air inside. Then the density ρ of each product part was measured based on Archimedes' principle. Moreover, the volume of internal air per the weight of each product, which is called the specific air volume, was calculated as the following equation:

$$v = \frac{1}{\rho} - \frac{1}{\rho_m}, \qquad (1)$$

where ρ_m is the density of the aluminum alloy, which is 2.74 g/cm^3 in this paper. We finally used this specific air volume v as the evaluation value for the experiments.

3.2 Results

Figure 2 shows the mean values of specific air volume of the product parts on the left and right sides, which had a smaller amount of air entrapment when using the optimized shape in the mold filling analyses. The result shows that the castings molded using the optimized shape had averagely a high density, small amount of air entrapment and thus good quality in each of the casting conditions.

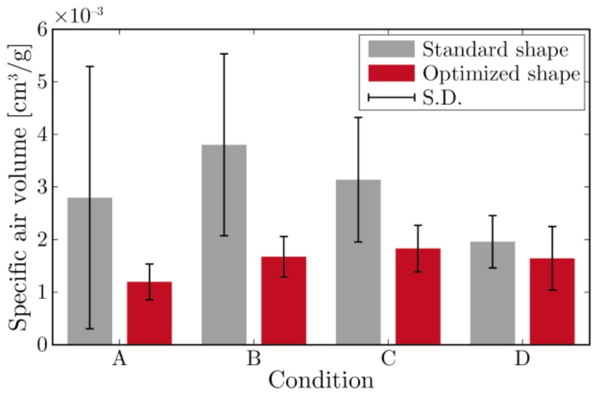


Fig. 2 Mean values of specific air volume of product parts for each condition and gating design system.

4. Conclusions

We optimized a gating system design including a sprue and runners for HPDC in order to decrease air entrapment defects. The performance of the optimized design was evaluated through experiments using an actual HPDC machine. The results showed that the optimized design decrease air entrapment defects in products compared to a conventional design.

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