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The effect of the gate shape on the microstructural characteristic of the grain size of Al–Si alloy in the semi-solid die casting process

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Abstract

Semi-solid forming is an attractive process for fabricating sound, weight-reduced automotive parts. Therefore, in this work, die systems of varied gate shape, gate width, and gate thickness were designed to investigate the filling characteristics of semi-solid material with a controlled solid fraction. When semi-solid materials with controlled solid fraction of 50% filled inside die cavity, the causes of liquid segregation according to the separation phenomena of solid particles and liquid materials were investigated. The parts were characterized for eutectic segregation, a segregation band, cracks and shrinkage hole on the part surface. It was found that all these defects could be solved by the selection of the optimal casting speed and selection of gate shape when the semi-solid material with a controlled solid fraction completely filled the die cavity. The correlation between liquid segregation and a gate system has been synthetically investigated with experimental results and theoretical results. The hardness in the primary α zone and the eutectics microstructural zone were measured by nano indentation. The relationship between liquid segregation and hardness was also investigated.

Keywords: Semi-solid die casting; Gate shape; Liquid segregation; Solid fraction; Injection speed; Mechanical properties

1. Introduction

The flow phenomenon inside the die cavity is an important problem in the semi-solid die casting process. The soundness of fabricated semi-solid parts depends on factors such as air entrapment and air porosity [1–3]. The general injection speed of conventional squeeze casting ranges from 0.3 to 0.5 m/s because the liquid segregation is neglected. Its speed is constant until the semi-solid metal completely fills the die cavity. The injection can achieve a laminar flow in the squeeze casting process. However, it takes a long time for the material to fill the die cavity. Therefore, the productivity rate decreases in mass production due to the increase of the cycle time. Partially, in the case of semi-solid die casting, the rheological behavior has an influence on the various defects when semi-solid materials are filled into the die cavity under a controlled solid fraction. Furthermore, in the semi-solid die casting, the gate shape in the die structure has an effect on the filling velocity, the filling pattern and the mechanical properties. Therefore, the gate shape is an important factor in semi-solid die casting design [4–6].

Recently, as mentioned above, there have been problems with obtaining the homogenous mechanical properties without defects. The semi-solid process is a manufacturing process specifically designed to solve these problems [7]. Study on the rheological behavior of semi-solid materials has made progress up to now [1,8,9].

However, the data reported through experiments and filling simulations is limited [10–12]. Therefore, in this study, the effect of the gate shape on the rheological behavior of the semi-solid material at a given solid fraction was investigated and the flow pattern was simulated. The filling behavior was also compared with both experimental and theoretical results. The effect of the gate shape on liquid segregation was investigated with regard to proposed die shapes. On the basis of the experimental and theoretical results, die design rules considering flow control that

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have an influence on liquid segregation and mechanical properties in the primary α and eutectics zones were proposed for various gate shapes.

2. Experimental process of semi-solid die casting

To investigate the effect of the gate shape on the filling phenomena and liquid segregation, semi-solid die casting experiments were performed using the designed die with four kinds of die systems. The used Al–Si alloy was fabricated by a continuous casting process with an electromagnetic stirring system [13].

To fabricate sound parts with semi-sold die casting, a reheating process to control the solid fraction is necessary. The reheating experiments were performed using an induction system with the capacity of 50 kW. The heating conditions are given in published papers [14–16].

Fig. 1 shows the four kinds of gate shapes of various dimensions of width and thickness, in the die cavity entrance. Table 1 shows the gate dimensions of width (W), thickness (t), and gate area (A). Gates A, B, and D, as shown in Table 1, vary in thickness with a constant width of 50 mm. Gate C is of the same area as gate B; however, the shape of gate C is different compared with that of gate B, as shown in Fig. 1(b) and (c).

Fig. 2 shows the four different gate shapes. With regard to the investigation of the effect of the gate shape on the filling pattern and liquid segregation, Fig. 3(a) and (b) show the test piece shape with the gate, runner, overflow, and test part dimensions. The part thickness, except for the runner and the gate, changed from a maximum of $t_1 = 20$ mm to a minimum $t_9 = 4$ mm. The thickness of a part decreased according to the filling direction, as shown in Fig. 3(b). The part thickness was that of automotive suspension parts and the part length was $l = 225$ mm, in the investigation of the effect of the gate shape on the phenomena. Parts A–E of Fig. 3(a) show portions with a width of 50 mm. Points (1)–(3) of each position from A to E, as shown in Fig. 3(b), were examined to investigate the microstructure and hardness of the test piece parts.

In the semi-solid die casting process, the injection velocity for the variation of the plunge tip is very important because of the separation of solid and liquid particles inside the die cav-

Table 1
The dimension of various gating systems

Gate	Width, W (mm)	Thickness, t (mm)	Area, A (mm^2)
A	50	5	250
B	50	10	500
C	30	16.7	501
D	50	16.7	835

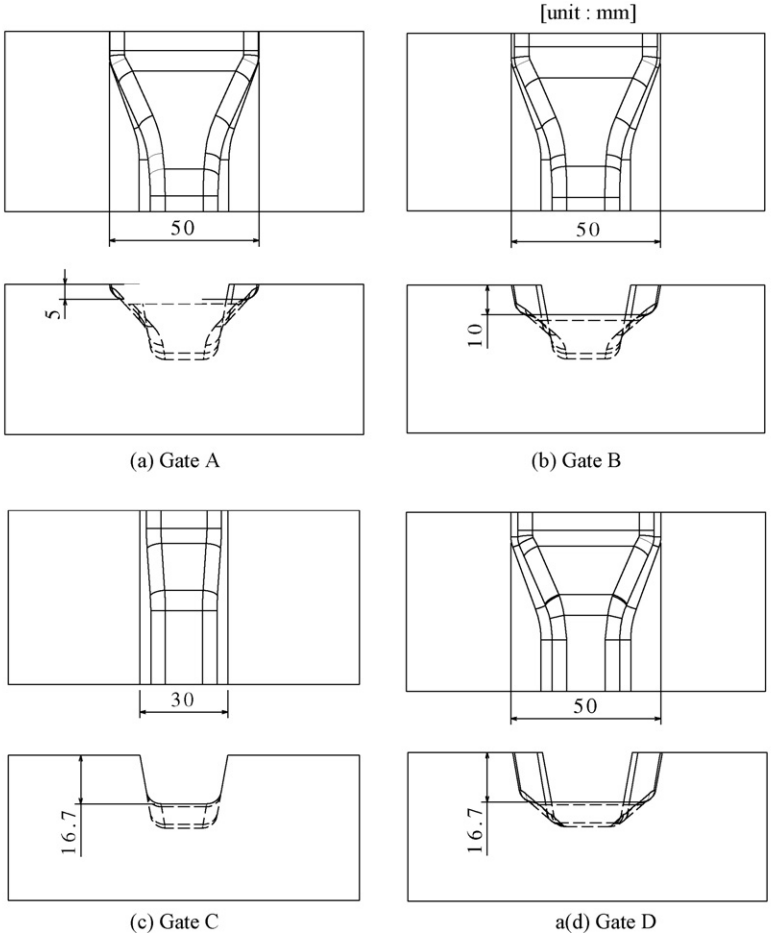

Fig. 1. The dimensions for four kinds of gate shape.