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## Review

# A study of die design of semi-solid die casting according to gate shape and solid fraction

C.G. Kang[a,*], S.M. Lee[b], B.-M. Kim[c]

[a] School of Mechanical Engineering, National Research Laboratory of Thixo and Rheo Forming, Pusan National University, Pusan 609-735, South Korea
[b] Engineering Research Center for Net Shape and Die Manufacturing, Pusan National University, Pusan 609-735, South Korea
[c] School of Mechanical Engineering, Pusan National University, Pusan 609-735, South Korea

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ABSTRACT

In this paper, the effects of gate shape and solid fraction on filling behavior during semi-solid processing of A356 alloys have been demonstrated by experimental and computer simulation. Effects of solid fractions and gate shapes on material properties have been investigated through experiment and computer simulation. Although the cross-section areas of the gates were identical, the filling behavior of the semi-solid material differed due to differences between the widths and heights of the gates. Furthermore, when the cross-section area of the gate is held constant, the increase in height plays a key role in improving mechanical properties. Because the pressure applied by the plunger transfers easily to the material during injection when the cross-section area of the cavity is large, the mechanical properties improved. Therefore, the optimization of die design and the experimental conditions that enhance material properties are proposed in this paper.


## Contents



* *Corresponding author.*
E-mail address: cgkang@pusan.ac.kr (C.G. Kang).
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## 1. Introduction

The need for energy efficiency, by reducing the weight of automobiles and household appliances, has been increasing. To meet this requirement, the demand for aluminum-based products has been rapidly increasing. Conventional casting and die casting processes for aluminum alloys result in inhomogeneous mechanical properties due to a dentritic microstructure and liquid segregation occurring during solidification and the problems in the die structure caused by heat impact imposed on a die. Thus, studies concerning semi-solid processing have increased to mitigate these problems (Chirmetta and Zanardi, 1996; Young, 1996; Flemings, 1991).

Semi-solid processing offers numerous advantages such as energy efficiency because the processing is operated at low temperature (low power consumption), and improvement in the quality of the materials is achieved by minimizing casting defects like porosity and shrinkage (Chiarmetta, 1996; Chen et al., 1979; Kiuchi and Sugiyama, 1992). The microstructural features of the products have good mechanical properties due to their fine and homogeneous globular microstructure. Because the forming load is reduced, it is possible to reduce power consumption and the size of the equipment. Furthermore, complex-shaped materials, which are hard to form in a solid state, can be easily formed to a near net shape because of their low resistance to deformation. Therefore, this forming technique has mostly been used to form automobile components (Pinsky and Charreyron, 1993).

In the semi-solid die casting process, the solid and liquid phases in the molten metal may separate when filling complex-shaped cavities; thus this separation leads to liquid segregation which deteriorates the product's mechanical properties. It is known that liquid segregation may be caused by variations in both product thickness and filling speed due to the presence of flow obstacles in the mold cavity. When using semi-solid materials, a runner, gate, cavity, and overflow are used to fill the mold cavity. Liquid segregation may be caused by filling speed because rapid changes in the direction of material flow occur when the front of the fluid first contacts the wall of the mold.

Studies concerning the forming processes for products that use pressurized molding methods like semi-solid die casting are interested in controlling the flow of the molten metal filling the mold cavity. Defects such as air entrapment can occur based on the filling pattern of molten metal. Laminar flow in most die casting processes occurs by using injection velocities as low as 0.3–0.5 m/s (Street, 1986; Seo et al., 2006). These low injection velocities increase the time needed to fill the cavity and cause productivity to decrease (Kang, 1998). The constant injection velocities affect rheology behavior when filling a mold and influence the deterioration of material properties. The filling pattern affects rheology behavior because the viscosity varies according to the solid fraction. Semi-solid die casting uses a solid fraction within a range of 50–60% (Kang and Jung, 1999; Jung and Kang, 1999). However, although the material has a constant solid fraction during casting, it does not maintain a constant solid fraction throughout the entire product due to the effects of temperature change. Therefore, studies concerning the behavior of semi-solid materials in terms of solid fractions are needed. Because the gate shape influences filling velocity and behavior, it is a very important factor in designing molds for semi-solid die casting (Itamura et al., 1999; Kang and Jung, 2001).

The semi-solid die casting process, which has attracted the attention of the car component industry, has been recognized as a technique which can overcome the difficulties of forming automobile parts. Studies concerning the rheological characteristics of semi-solid materials have been performed (Ko et al., 1999; Lee et al., 2004; Tims et al., 1996), but the relationship between the effect of the gate shape and the mechanical properties has not been experimentally validated.

Thus, during semi-solid die casting, this study intends to verify how rheological behavior is influenced by variations in the solid fraction of the material and deformations in the gate shape of the die. In addition, an experiment has been designed to verify the simulation results for die design of semi-solid die casting.

Based on the effects of the changes in the solid fraction and gate shape on filling behavior and the mechanical properties of the components fabricated by semi-solid die casting, the method controlling rheological behavior of the semi-solid material and die design methodology for semi-solid die casting has been demonstrated.

## 2. Experimental method

### 2.1. *Forming experiment according to solid fraction*

A356 (SAG Inc.) was used to perform the semi-solid forming tests with solid fractions ranging from 0.3 to 0.6 and filling behavior tests by gate shape. The reheating conditions used to investigate the filling behavior of the semi-solid material were determined based on the results of the present author's previous studies (Jung and Kang, 1999; Kang et al., 2003). Fig. 1(a) shows the specimen used to investigate the effects of the solid fraction and gate shape on filling behavior while injecting the mold. The die structure was designed based on the shape of the test piece in Fig. 1(a). As can be seen, the thickness of the piece decreases from position A–E. Fig. 1(b) shows the dimensions of a fabricated specimen with the thickness gradually decreasing by 2 mm interval from 20 mm at $t_1$ to 4 mm at $t_9$.