

Manufacturing Technology for Hollow Structure Large Aluminum Parts Production by High Pressure Die Casting (HPDC)

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ABSTRACT

When using aluminum for vehicle body parts to reduce weight, the high pressure die casting (HPDC) is widely applied due to its adaptability to thin-wall products, near-net-shape castability, and short casting cycle time. Since a hollow construction is advantageous to increase stiffness of body parts, there has been a need of development of techniques for casting of hollow parts by HPDC. So far, hollow casting by HPDC has been realized for small parts using sand cores. When applying that method to large parts, however, it is necessary to increase filling speed. When the filling speed is increased, the core tends to break. In this project, we have developed a method to estimate changes of pressure distribution when filling molten metal by the casting simulation in order to analyze damages to the core. Through the analysis, we discovered occurrence of impulsive pressure waves. Furthermore, the impulsive changes of molten metal pressure have been confirmed through the precise measurement of molten metal pressure. On the basis of the aforementioned findings, we have established a method to prevent core damage by controlling impulsive pressure waves by modifying the flow path. With the newly-developed method applied, the filling speed is increased by 1.5 times more than that of the conventional casting method for small parts, thus realizing casting of large hollow parts by HPDC.

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INTRODUCTION

In the development of a motor vehicle, efforts are made to improve fuel economy by reducing vehicle body weight by use of high tensile steel sheet, substitution of steel with aluminum or CFRP, etc. When substituting the material from steel to aluminum, parts are often produced by casting for reduction of number of parts and/or simplification of production process.

In the aluminum casting, taking advantages of the melting point lower than alloy steel, the high pressure die casting (HPDC) by injection molding has been developed. The HPDC is such a casting method using an injection machine in that the molten aluminum is filled into the die cavity at a high speed, and a high pressure is maintained until the casting solidifies. Accordingly, the HPDC allows near-net-shape casting while maintaining precise shape that can be used as it is. Moreover, when compared to the gravity die casting (GDC) or the low pressure die casting (LPDC), in which molten aluminum is filled at a low speed, the HPDC allows casting of thin-wall parts and reduction of casting cycle time. However, there are three issues when applying HPDC to large parts such as those of wheels and suspensions.

For one, it is the containment of gas in the cast product due to filling of molten metal at a high speed into the cavity. In other words, the porosity tends to occur due to the inclusion of gas, causing lowering of product elongation. The second issue is that when welding cast parts, the contained gas acts like a blow hole, making the welding difficult. As a means to solve the first and second issues, such a method is employed in that the containment of gas is reduced by high vacuum evacuation of the cavity [1] [2].

The third issue is damages to the sand core due to filling of molten aluminum at a high speed and a high pressure, which makes the hollow casting difficult. To reduce weight while increasing stiffness of a structural part, a closed-loop cross-section is more preferable than an open-loop cross section. Accordingly, some types of large hollow parts are produced by welding together a number of parts molded by a high vacuum HPDC [3].

However, there was such an issue in the said method that the parts production process became lengthy due to the need of welding. Recently, in the hollow molding of water jacket in an engine part such as the cylinder block, some examples of producing such parts by HPDC are seen due to the development of strong sand core [4].

Nevertheless, there is no case of practical application of HPDC to such a large part as the structural component of frame body, requiring a technical solution to allow application to such parts.

The authors have been developing a casting method that allows hollow molding of high-quality, weld-able parts. The newly-developed method uses phenol-resin-coated sand cores that are easily available throughout the world and widely applied to GDC and LPDC. In the production process developed earlier for small parts, the hollow molding was enabled by lowering the filling speed of molten metal to such an extent that did not cause damages to the core. Later on, when trying to extend its application to large parts, the filling speed had to be increased due to an increase of cavity volume. To satisfy the said requirement, the core damage had to be eliminated. We have therefore decided to clarify how the core is damaged when the molten aluminum is filled.

This paper describes the issues of prevention of damages to the core used in production of large body parts by HPDC along with the simulation of molten metal pressure in the initial filling period.

OVERVIEW OF DEVELOPMENT PROCESS

Small Part Casting Process and Issues in Application to Large Part

In the development of new casting method for extensive applications of HPDC to various parts, improvements have been proposed by adding special equipment or device to the conventional method, which can be considered attributable to the difficulty of determining optimum casting conditions on the basis of adequate analysis of the filling process because the filling period of molten metal into the die is as short as 20-100 ms.

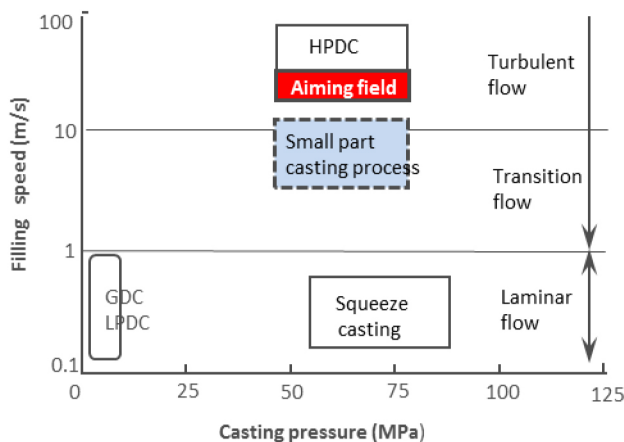


Figure 1. Filling speed and casting pressure of various aluminum casting methods

Due to the recent advancement of aluminum casting simulation including the coupling of filling and solidification, it is now possible to analyze filling process in a quantitative manner. The authors

therefore targeted at resolving of the three issues in HPDC by positive use of simulation without adding special equipment or device. Since it is necessary to clarify how the casting conditions affect each issue when developing a new method, we have decided to review the basic casting conditions. Figure 1 shows filling speed and casting pressure, which are the basic conditions, of various aluminum casting methods [5].

The filling speed of molten metal has been generally considered appropriate when it is in the laminar flow zone (<1 m/s) where the defect-causing gas containment is less likely to occur. The GDC or the LPDC is a typical method using such a zone. As the molten metal is filled at a low speed to eliminate porosity from gas containment, the minimum thickness of product is generally limited at approximately 3.5 mm. Meanwhile in the HPDC in which the molten metal is filled at a speed as high as 30-50 m/s, casting is generally possible for a product as thin as 1.5-2 mm. However, as the molten metal is filled under a turbulent flow condition, issues caused by gas containment occur. To cope with the issue, techniques such as the use of high vacuum have been developed. The squeeze cast, which is aimed at improvement of quality by filling molten metal at a low speed and a high pressure, has been applied to the wheel and suspension parts [6]. However, as the filling is at a low speed, the applications are limited only to products having a minimum thickness of 3.5 mm or more. Further issues in the application of squeeze cast to large structural body parts are the need of solution heat treatment and artificial aging treatment. Especially, the retention of product at a high temperature in the solution heat treatment causes product deformation. Keeping our eyes on the zone indicated in the small part casting process shown in Figure 1, the authors and others have realized practical application of HPDC to hollow products using the sand core [7].

That is the zone where the porosity is less likely because the filling speed is relatively low and the molten metal pressure can be reduced. Nevertheless, there are issues as indicated in the following section when applying to large parts because the filling is at a low speed when compared to the general filling speed of HPDC.

Reduction of Filling Time and Target Filling Speed in Large Part Casting

Due to the extended filling time when casting a large product, the molten metal solidifies before completion of filling, which makes casting difficult. Such a phenomenon is represented by the following equation created by F. C. Bennett [8].

Filling time = (Total heat capacity inside of product)/ (Heat dissipation speed)

The heat dissipation speed Q is represented by the following equation.

$$Q = K \cdot S (T_m - T_d) / (d/2)$$

Where, K : Heat conductivity coefficient of molten metal

S : Cavity surface area

T_m : Molten metal temperature before start of filling

T_d : Die temperature

$d/2$: Length from center of product thickness to cavity surface

When the thickness, molten metal temperature and die temperature are constant, the filling time depends on the heat dissipation speed Q . Accordingly, when the product is large and the cavity surface area S increases, it is necessary to increase filling speed to shorten the filling time. While the cast product in the small part production process weighs 2-3 kg, the product we target at in this project weighs 4-5 kg. From the above equation, approximately 1.7 times faster filling speed is required. Considering that the molten metal is filled at a speed of 10-15 m/s in the small part casting process, we have decided to set a target of this project at a filling speed of 20 m/s or higher.

In the meantime, when the filling speed is increased, the inertia energy increases proportionally to the square of speed. That's why the sand core becomes damaged when the filling speed is increased. Described hereafter is the newly-developed core.

Required Characteristics of Core Including Strength Limit

The core has to be broken easily and taken out of the small opening in the product after completion of molding while maintaining its shape until completion of solidification after filling the molten metal. It is preferable if the broken and taken out core material can be reused. From such viewpoints, the sand is an excellent material for cores. Sand cores are widely used in GDC and LPDC where the filling speed is 1 m/s or lower as shown in [Figure 1](#). However, since there is a limit in the strength of such sand cores, it has been considered that sand cores are hard to apply to the general HPDC in which the molten metal is filled at a high speed under a high pressure. Under the said circumstances, researches have been made for alternative core materials such as the low melting metal, polycarbonate, and salt core. Among those, the salt core is drawing attention due to its strength and easy removal after molding. As the salt core, which is made of melting salt, can be taken out by submerging the product in water and having the core dissolved, the strength of core can be increased. However, considerable limitations apply to the shape of core. Although the salt core is suitable for thin cores such as the water jacket of engine parts, as cracks tend to occur when there is a thick portion in the core, it is not suitable for large cores. In view of the above, we concluded that the sand core was suitable for large frame body parts.

[Figure 2](#) shows the cross section of the core we have recently developed. In the main body of core, the phenol resin is coated on the sand as a binder. The application of a layer of refractory, which is finer than the sand, on the core surface prevents penetration of molten metal to inside of the core when subjected to the casting pressure.

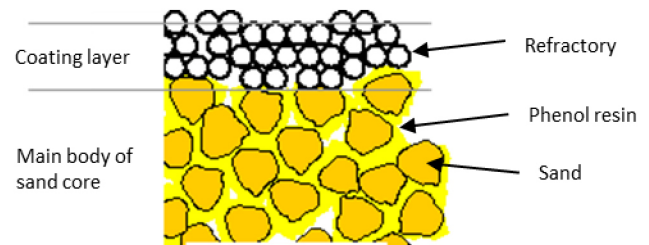


Figure 2. Cross section structure of developed sand core

[Figure 3](#) shows the transverse rupture strength of various cores. The strength of melting salt core in the picture is taken from the data in the reference literature written by Yamada, et. al. [9].

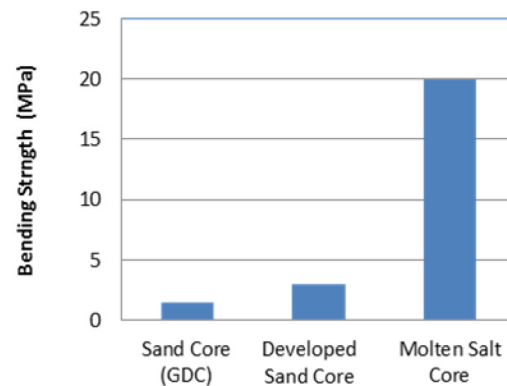


Figure 3. Comparison of transverse rupture strength of various cores

Although the specific gravity of sand is raised in this project and the core is twice stronger than the core used in GDC, the strength is far lower when compared to the melting salt core. The reason is that small cracks occur in the sand core due to the compression when subjected to a high HPDC pressure, and in addition to that, the phenol resin decomposes due to the latent heat of solidification released from the molten metal. As the sand core is destructed to some extent after casting, it is possible to break the sand core to such an extent that allows removal of sand from the de-sanding hole by application of mechanical vibrations from outside of product. Although the transverse rupture strength can be enhanced by increasing the amount of resin on the sand core, when excessive, the core does not break adequately after casting, making de-sanding difficult. Accordingly, we chose to increase the filling speed after doubling the core strength from the conventional level.

At this time, damages to the core actually occurred during the development of large cast parts when the filling speed was increased. To cope with that issue, we analyzed how the core was damaged by the simulation and the measurement of molten metal pressure, and took a countermeasure. Thus enabled is the casting of large parts using the core having the prescribed strength. The details are described hereafter.