Journal of Materials Processing Technology 222 (2015) 21–26

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

A submerged-gate casting method

Tingli Wang, Shan Yao*, Wei Shen

School of Materials Science and Engineering, Dalian University of Technology, Dalian, China

ARTICLE INFO

Article history:
Received 8 November 2014
Received in revised form 14 February 2015
Accepted 24 February 2015
Available online 5 March 2015

Keywords:
Casting
Submerged-gate
Slice
Filling
Solidification

ABSTRACT

The sprue gate is submerged to a certain distance below the surface of the molten metal in the mold during the filling process. This is a digital casting technology, which is highly integrated with CAD/CAE, process detection and control technology. The 3D models of the casting (corresponding to the mold cavity) and the ladle are cut into slices to obtain the sectional information for the iterative calculation. The relative displacement of the gate is calculated by iteration. The ladle or mold is moved up and down by the elevator to ensure that the gate submerges below the molten metal surface to a specified distance. It can be seen from the numerical simulation and experimental results that this method can avoid the need for a complex filling system, which is convenient for designing, manufacturing and assembling the mold. Additionally, it has advantages of stable filling and full feeding.

1. Introduction

Casting is the most economical technology to produce readily usable components using raw materials. Metal castings are fundamental products for practically all other manufacturing industries (Campbell, 2003). However, in foundry production, due to the complex mold cavities and the complicated filling and solidification processes, it is easy to induce defects such as inclusion, bubble, shrinkage, etc. (Campbell, 2004). The consensus is that stable filling and full feeding are critical for casting quality. It is indeed a headache for engineers to design a filling and feeding system with excellent performance. Additionally, the present pouring process depends much on personal intuition and experience, which usually results in greater production time, higher cost and unstable product quality.

With the developments of computer science and technology, CAD/CAE technology, process detection technology, control engineering technology, quality inspection technology, etc. have been widely used in casting research and production. Pedersen and Tiedje (2005) investigated the solidification of thin walled ductile iron based on the temperature measurement, microstructure examination and numerical simulation. The study revealed that the effect of austenite dendrites was more pronounced in thinner plates than in thicker plates. Pequet et al. (2002) modeled microporosity, macroporosity, and pipe-shrinkage formation during the solidification of alloys by a mushy zone refinement method. The influence of the cooling condition, the metallostatic pressure and the gas concentration were shown by numerical simulation. Sun et al. (2011) analyzed the reasons for some typical defects in truck rear axle composed of ductile iron and optimized the pouring system by CAD (Pro/E software) and CAE (Z-CAST FDM simulation software). The results of the new product showed that it was very helpful to improve the casting quality. Wang et al. (2014) investigated the heat transfer behavior between the casting and the twin-roll using equipment designed according to the characteristics of the top side-pouring twin-roll casting process. It was concluded that the way to improve the contact conditions was always accompanied by increasing the interfacial heat transfer coefficient. Shinde et al. (2013) attempted to optimize the mold yield by selecting the correct combination of box size and number of cavities based on the simulation results of the solidification time and mold temperature. The results were employed to generate a technical database to optimize the mold cavity layouts. Nwaogu et al. (2013) used a 3D optical system to measure the surface roughness of the castings. The results from the 3D surface comparator had more information and higher precision than their 2D counterparts.

The previous study focused on the optimization of the traditional casting processes and detection methods. To some extent, it could minimize casting defects and provide useful references. However, the limitations of the traditional casting method mentioned above still exist. In this paper, a submerged-gate casting method has been proposed. In the present study, the device and process work flow were introduced. The calculation method of the gate displacement curve was investigated, which could be considered a form of process control. The characteristics of the filling process were discussed based on the results of the numerical simulation.

---

* Corresponding author. Tel.: +86 411 84709389; fax: +86 411 84709389.
E-mail address: yaoshan@dlut.edu.cn (S. Yao).

http://dx.doi.org/10.1016/j.jmatprotec.2015.02.034

Finally, an active block of a tire mold was manufactured by the submerged-gate casting method.

2. Method of submerged-gate casting

Submerged-gate casting means the sprue gate submerges a certain distance below the surface of molten metal during the filling process. The device is shown in Fig. 1 and the process flow is represented in Fig. 2. It includes the following steps:

Step 1. Modeling. Design 3D models for the casting (corresponding to the mold cavity) and the ladle respectively with CAD software.

Step 2. Slicing. Cut the 3D model of the casting into slices along the horizontal direction, and then compute and store the thickness, cross-sectional area and volume of each slice. Complete a similar process for the ladle.

Step 3. Calculating. Obtain the relative displacement of the gate versus time during the filling process (the process control curve) by an iterative calculation.

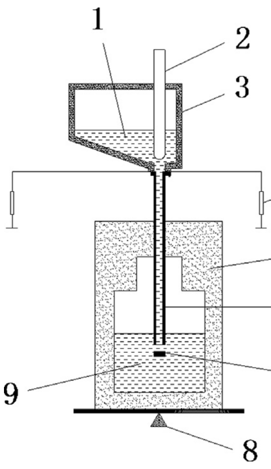

Fig. 1. Schematic diagram of the submerged-gate casting technology. 1, Molten metal in the ladle; 2, stop rod; 3, casting ladle; 4, elevator; 5, mold; 6, sprue; 7, diverter; 8, electronic scale; 9, poured metal.

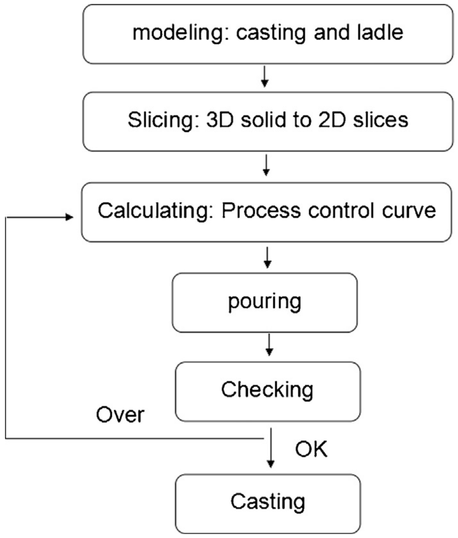

Fig. 2. Process flow of the submerged-gate casting technology.

Step 4. Pouring. Open the stop rod and start to pour. According to the process control curve, the ladle or mold should be moved up and down by the elevator to ensure that the gate submerges below the surface of the molten metal at the specified distance.

Step 5. Checking. Compare the measured value with the calculated value at set intervals. If the error is greater than the set value, then the control curve needs to be revised, and then pouring may continue.

Step 6. Shakeout. After the casting cools to room temperature, shake out and obtain the casting.

The filling system of submerged-gate casting is very simple: it only requires a sprue which can be reused many times. In the foundry process design, the engineers only need to pay attention to the casting itself without consideration of the troublesome filling system.

The submerged-gate casting method is highly integrated with CAD/CAE, process detection and control technology. The features of the casting could be turned into digital information, and the filing process could be automatically controlled by a computer. This could be considered digital casting technology. According to the process control curve, the elevator moves the ladle (or mold) up and down. It avoids manual operation to ensure the quality stability of the casting.

3. Determination of the gate displacement

During the filling process, the surface of the molten metal in the mold is relatively stable (refer to the numerical simulation results in Section 4 and the experimental results in Section 5), meaning that the filling process could be simplified as the liquid level height changes. Therefore, the casting could be produced by a special additive manufacturing process in which successive layers of molten metal are laid down by the sprue gate (Fig. 3). To keep the submerged distance at the specified value, the relative displacement of the gate versus time should be equal to the height change of the liquid level in the mold. Therefore, the relative displacement of the gate versus time could be considered as the control curve of the filing process.

In specific applications, due to the differences in the process parameters, such as the casting shape and size, the ladle shape and size, the internal diameter, the height of the sprue, etc., the value of the control curve would be unique. However, the calculation method is consistent.

The filling process could be described by Bernoulli Equation:

$$H_L + \frac{P_L}{\rho \cdot g} + \frac{v_L^2}{2g} = H_M + \frac{P_M}{\rho \cdot g} + \frac{v_G^2}{2g} + h_w \tag{1}$$

$$h_w = \zeta \cdot \frac{v_G^2}{2g} \tag{2}$$

where H_L, liquid level in the ladle, m; P_L, pressure on the molten metal in the ladle, N/m^2; ρ, density of the molten metal, kg/m^3; g, gravitational acceleration, 9.8 m/s^2; v_L, velocity of the molten metal in ladle, m/s; H_M, liquid level in the mold, m; P_M, pressure on the molten metal in the mold, N/m^2; v_G, velocity of the molten metal at the gate, m/s; h_w, loss, kg · m^2/s^2; ζ, drag coefficient of the sprue.

As in the atmospheric condition $P_L = P_M$, Eq. (1) could be simplified as:

$$H_L + \frac{v_L^2}{2g} = H_M + (1+\zeta) \cdot \frac{v_G^2}{2g} \tag{3}$$

The liquid level difference

$$H_0 = H_L - H_M \tag{4}$$