Research on Gas Pore Prediction Method Based on Sand Core Characteristic Time

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Abstract

In the production of castings, gas pores are a prevalent defect, particularly in components where air-tightness is crucial, such as cylinder blocks and heads. These defects primarily arise from the intrusion of gases into the casting during the combustion of resin in the sand core. Due to the complexity of the sand core's gas evolution and venting process, predicting gas pores using numerical simulation poses significant computational and time challenges. This paper introduces a rapid prediction method for gas pores based on the characteristic time of the sand core. By setting the heat transfer boundaries, initial conditions, and termination criteria for computation, the thermal conductivity of the sand core is adjusted. The termination computation time is used as the characteristic time of the sand core. This time is then compared with a critical characteristic time to predict the distribution of gas pores. As the analysis of more sand cores is incorporated, the precision of the critical characteristic time improves, leading to more accurate predictions of gas pores in castings.

Keywords: Gas pore; Numerical simulation; Iron casting; Sand core; Resin

1. Introduction

Gas pores are common and typical defects in cast iron and aluminum alloy castings, with entrapped gas pores being a major type of pore defect. In complex castings such as engine blocks and cylinder heads, numerous intricately shaped sand cores are employed. During the filling and solidification of molten metal, the sand cores are subjected to heating, causing the organic binder within them to decompose or burn at high temperatures, generating gas [1], [2]. If the gas cannot be expelled from the core and instead infiltrates the molten metal, it results in entrapped gas pores [3]. The factors influencing the occurrence of entrapped gas pores are numerous, making it challenging to eliminate. This issue significantly impacts product quality, sometimes leading to the rejection of castings or the discovery of pore defects after machining. The complex formation mechanism of entrapped gas pores makes it difficult to predict using numerical simulation methods accurately [4], [5], [6].

This paper adopts a strategy for identifying hazardous sand cores and their critical points. Based on the principles of similarity in heat transfer within the sand core and the transport of gas within it, a virtual heat transfer method for sand cores is employed. The paper proposes a characteristic time indicator for predicting the occurrence of casting porosity induced by sand cores. This indicator is used to assess the critical points and severity of risks associated with sand cores, enabling the determination of whether casting porosity will be induced and predicting the location of gas pore formation. The characteristic time values are stored in a database for validation against actual test results. Furthermore, these values serve as a reference for predicting porosity in new sand cores.

2. Methods

2.1. *Heat transfer analysis and modified thermal property parameters*

Gases produced from the high-temperature decomposition of binders are expelled through exhaust channels. However, due to the intricate geometries of sand cores and variations in the distances from different points to the core head, some points, especially those farthest from the core head, may pose challenges in gas evacuation. This difficulty increases the probability of porosity formation. The term "distance" here is not spatial but pertains to the movement of gas within the sand core, exhibiting a certain similarity principle with heat transfer within the sand core. To identify the point farthest from the sand core, i.e., the most challenging gas evacuation point, a virtual heat transfer method is employed. The numerical simulation for virtual heat transfer focuses solely on the specific sand core in question, with other sand cores, moldings, and castings excluded from the simulation. These excluded components are, however, crucial for automatically determining the core head. This determination is achieved by identifying areas where the sand core does not contact the casting, signifying the presence of the core head.

Heat transfer analysis is the foundation of the resin burning, gas release and flow, the melt solidification, and the formation of gas pores. The heat transfer inside the casting, mold, and sand core during the casting process is expressed by the Fourier equation,

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) + q \quad (1)$$

where ρ is the density, c is the specific heat capacity, T is the temperature, t is the time, k is the thermal conductivity, and q is the latent heat term as the melt solidifies.

The nominal thermal conductivity of the sand core is adjusted based on the permeability of the sand core, and the adjustment formula is as follows:

$$\lambda_1 = \frac{K}{100}\lambda_0 \quad (2)$$

where λ_0 is the real thermal conductivity of the sand core (W/(m·K)), λ_1 is the nominal thermal conductivity of the sand core (W/(m·K)), K is the permeability of the sand core.

The nominal specific heat of the sand core is adjusted based on the gas generation of the sand core, and the adjustment formula is as follows:

$$c_1 = \frac{G}{20}c_0 \quad (3)$$

where c_0 is the real specific heat of the sand core (J/(kg·K)), c_1 is the nominal specific heat of the sand core (J/(kg·K)), G is the gas generation of the sand core.

2.2. *Determination of dangerous gas penetration points in sand cores*

During the simulation process, six distinct boundary interfaces are evident, as depicted in Fig. 1: metal-sand core, metal-air, metal-sand mold, sand core-sand mold, sand mold-air, and sand core-air. The aforementioned coating is applied to both the surface of the sand core and within the sand mold cavity. Consequently, the interfaces involving metal-sand core, metal-sand mold, and sand mold-sand core are influenced by the presence of this coating. Its inclusion results in heightened thermal and penetration resistance at these boundaries. Moreover, owing to the coating's exceptionally low gas permeability, certain segments exhibit zero gas permeability at room temperature, signifying an incapacity to permit gas passage.

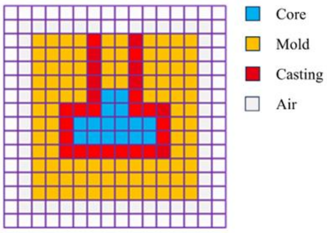

Fig. 1 Boundary setting conditions.

Establishing the boundary conditions for the sand core involves setting the surface temperature of the core head to a constant 1500℃. The remaining exterior surfaces of the sand core are considered adiabatic. The initial temperature of the sand core's elements is set at 25℃. The virtual heat transfer computation is programmed to automatically terminate when the volume of the unheated portion of the sand core reaches 100 mm^3 , as illustrated in Fig. 2. This moment is recorded as the characteristic time of the sand core.

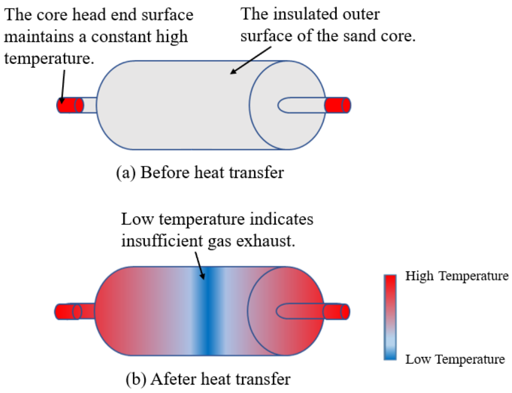

Fig. 2 Virtual heat transfer of sand core identifies the most challenging gas exhaust point.

When the characteristic time of the sand core exceeds the critical time for gas pore initiation, it is determined that the sand core induces gas pores in the casting. Conversely, when the characteristic time of the sand core is less than the critical time for gas pore initiation, it is determined that the sand core does not induce gas pores in the casting. The topmost units in the unheated portion of the sand core are selected, and these units are identified as the critical points for gas pore initiation in the casting. These critical points represent the locations in the sand core most susceptible to inducing gas pores in the casting.

Save the characteristic time of the sand core to the sand core characteristic time database, and adjust the critical characteristic time based on the actual occurrence of gas pores for each sand core.

3. Pore prediction results

3.1. *Parameters*

Predictions of pores were performed on a single cylinder head. The casting consists of the intake manifold, exhaust manifold, upper water jacket, lower water jacket, and chassis core.

Due to the relatively simple geometry of the intake and exhaust manifold cores, only the cores themselves were considered in the determination of dangerous areas during the assessment of the intake and exhaust cores. For virtual heat transfer computations, the thermal property parameters of the cores were set with a density of 1.6×10^3 kg/m³, a nominal specific heat of 1×10^3 J/(kg·K), and a nominal thermal conductivity of 0.5 W/(m·K).

3.2. *Gas pore*

The virtual heat transfer simulation was conducted for the casting and sand cores, and the computation was terminated upon meeting the specified conditions. The characteristic time for the sand cores was determined to be 2.1 s. The critical units of each sand core, as illustrated in Fig. 3, align with the experimental results, where the critical characteristic time for gas pore generation in the sand cores was identified as 1 second. Consequently, the casting exhibits gas pores, and the locations of these pores are depicted in Fig. 4.

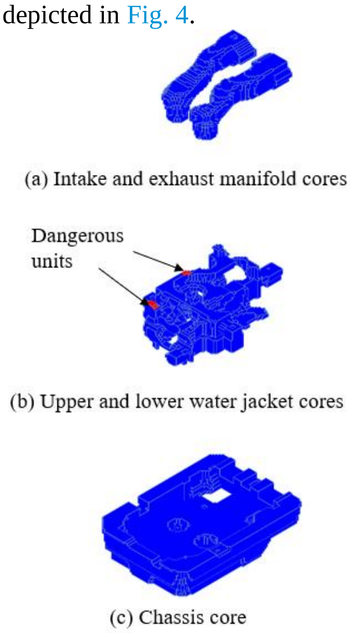

Fig. 3 Dangerous units in each sand Core

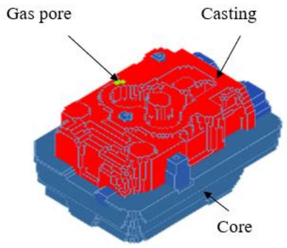

Fig. 4 Casting pore results

Comparison with castings produced in the actual factory workshop reveals a consistent distribution of gas pores, validating the effectiveness of the proposed method.

4. Conclusion

This paper proposes a gas pore prediction method based on the characteristic time of sand cores, enabling the forecasting of pores in castings. It addresses the challenges associated with the complex gas generation and exhaust processes in sand cores, difficulties in predicting them through numerical simulation techniques, and the significant costs and time associated with such simulations. This method provides guidance for practical casting production. As the analysis of sand cores increases, the critical characteristic time becomes more precise, leading to more accurate gas pore predictions.

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