Research article

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A benchmark experiment of the mold filling of a cast iron plate by lost foam casting

Abstract

In lost foam casting (LFC), the presence of an expanded polystyrene (EPS) inside the mold leads to new features for the filling of the melt. The burning of the EPS pattern has great effect on its filling. To provide benchmark experiments for the modeling and numerical simulation of the mold filling process for LFC, a vertical plate with a window was selected. The window was designed in variation of sizes and distances to the borders so as to investigate the melt filling of a series of narrow paths in LFC. The designed EPS pattern were made and the corresponding molds were prepared and melt cast iron was poured. The measurement system of liquid metal filling based on modified contact time method (METM) was used. The filling of measured points was illustrated by an array of light-emitting diodes (LED) arranged resembling the shape of the casting, with the lightening of each diode representing the filling time instant of the measurement point. The filling times of all the points were obtained by the image analysis of recorded movie. The filling profiles and filling velocity during filling process were obtained. The filling results provide support for numerical simulation of LFC.

Keywords: lost foam casting (LFC), mold filling, modified contact time method, LED display, plate casting, cast iron

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Abbreviations: FMC, full mold casting; METM, metal filling based on modified contact time method; EPS, expanded polystyrene; LED, light-emitting diodes

Introduction

The filling process of the mold, the first step of casting process, is of determining effect on the quality of castings. The mold filling process is always a research topic.[1–4] Lost foam casting (LFC), also called full mold casting (FMC), owns a series of advantages such as dimensional accuracy, excellent surface finish, no parting lines, less pollution and etc. The foam pattern left inside the mold is replaced by the melt by burning or degradation during filling. However, its degradation at the metal front has a significant effect on mold filling, causing casting defects, such as pin holes, entrainment and misrun. Thus, the mold filling in LFC is significantly different from the filling of empty mold in traditional casting process. Lee[5] studied the effect of different gating systems and metallostatic heads on the melt filling process by using a clear silica glass window and a high-speed video camera. Shivkumar et al.[6] investigated the thermal degradation of the foam pattern, gaseous products and a partially depolymerized viscous residue by using a similar method. Sun et al.[7] & Ohnaka et al.[8] directly observed the mold filling behaviors during lost foam casting by X-ray method. Numerical simulation is also a widely used method for the investigation of the filling process of lost foam casting. Mirbagheri et al.[9] established an algorithm to calculate the gas pressure of evaporated foam during mold filling. The effect of backpressure on the filling behavior was modeled with an experimental function by adding three-dimension VOF functions. Some researches managed to measure the filling time of certain points. Jong[10] proposed the contact time method, in which a set of wires locate at the measurement points and one wire at the runner as a public end form a series of open circuits to detect the melt flow and record the switch-on time of each circuit. Abdelrahman et al.[11] developed a kind of capacitive sensor, which is comprised of two electrodes whose capacitive coupling changes as the metal replaces the foam pattern. Wu et al.[12] used both photography and the contact time methods studied the filling process of a lost foam casting of magnesium alloy. However, the measurement points are restricted by the channels of the acquisition card. Kang et al.[13] proposed a modified method based on pairs of electrodes (Modified Contact Time Method, MCTM) and carried out the benchmark test of the filling process of a cast iron plate during lost foam casting. Mold filling with the variation of a series of factors such as metastatic pressure, coating thickness and EPS pattern density were established. In this paper, the MCTM method was used to study the filling of narrow paths for lost foam castings so as to provide benchmark experimental results for numerical simulation.

Experiment design for a vertical plate

To investigate the filling of lost foam casting, a type of 100mm×200mm×20mm plate was selected as the casting specimen. The plate was cast vertically with side filling ingate system. The ingate was located at the middle of the left side of the plate, so the filling of the bottom half and the top half of the plate can be investigated. The basic section size of the sprue and ingate were 30mm×20mm and 20mm×20mm, respectively, the sprue height was 200mm. The middle of the plates were designed with different window size to create difficult filling zones and investigate their filling mode (speed and direction) and possible defects caused by filling, so, the bottom and right narrow path widths were set into options: 20mm (Shape C), 10mm (Shape D), 5mm (Shape E,F,G), respectively, as shown in Figure 1. To check the effect of entrapped air, the top right corner of the thin frame was cut off to form a non-through end, as shown in Shape G in Figure 1.

A typical kind of gray cast iron HT250 (chemical composition: C3.16～3.30wt%, Si : 1.79～1.93wt%, Mn:0.89～1.04wt%, S : 0.094～0.125 wt%, P : 0.120～0.170 wt%) was selected for experiment. Furan resin self-set sand was applied for molding. The foam pattern and gating system were made of polystyrene pieces which were cut by hot wire and then glued together. The foam material with density 16 kg/ m^3 was used. Only natural ventilation was adopted, i.e, there was no ventilation holes. Water-based bauxite was used as coating, 1.5mm thick.

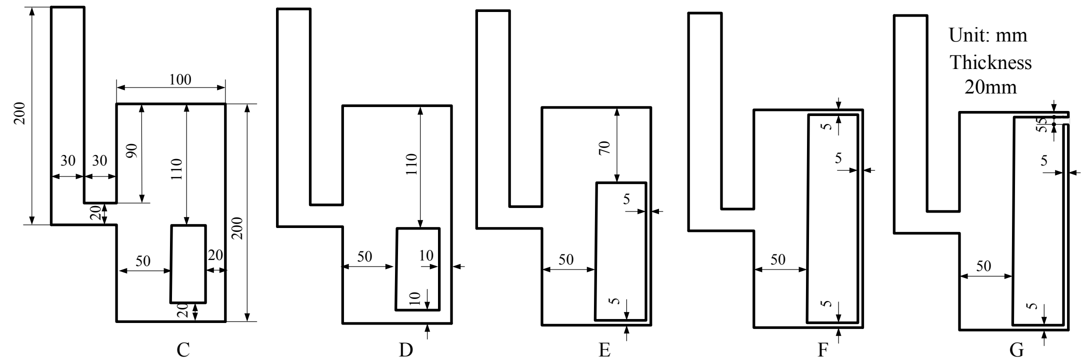

Figure 1 Geometry of casting specimens.

Measurement system of mold filling

The MCTM method was applied to observe the iron melt flow. A public end was located at the sprue bottom and a number of ends at the interested positions in the mold cavity. They were buried during molding process. The public end and each end at an interested point formed an open circuit with a battery power supply. As the melt flew through the sprue, the public end was immersed in the melt. And as the metal reached a measurement point in the mold cavity, the circuit formed by this point and the public end was connected, which sent out an electrical current signal. The LED light connected to the circuit turned on meanwhile. All LEDs were arranged on a board to resemble the shape of the plate according to their relative positions in the mold cavity. Thus, the illumination of the LEDs can vividly show the filling process. A camera with 60 pictures per second was used to record the LED illumination process, and then the time of the turning on of each LED was acquired by photographic analysis of the recorded movie. Therefore, the mold filling process was obtained. The schematic diagram of this method is shown in Figure 2. The measurement wire ends were arranged in lines and rows with equal distance of 10mm on the pattern during the molding process. Two thermal couples were placed at P1 and P2.

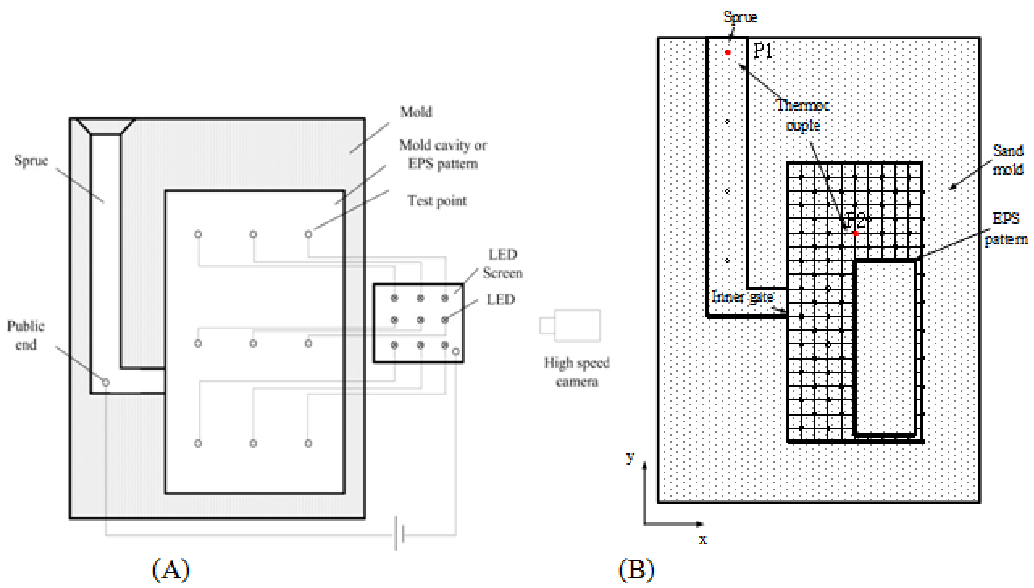

Figure 2 Schematic of the filling process measurement (A) Location of flow measurement points and thermal couples for the vertical plate (B).

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Experiment

The whole test consists of foam pattern making, molding, melting, pouring, measurement and fettling in order. All patterns in the tests were cut and glued by plate Styrofoam. Then they were painted with coating. The melting was done with an electric induction furnace with capacity 50kg. The temperature measurement system was made up of type K thermocouples inserted the pattern in advance. A temperature recorder with 16 channels data was used to record data from the thermal couples with 0.1s time interval. The tapping temperature of molten metal was 1400°C.

Results and analysis

The mold filling process of shape E is shown in Figure 3. The filling process and the melt front can be seen clearly. As the melt flew out of the inner gate, it filled the mold in a radial shape, then the right thin column was filled by the stream from the bottom. The mold filling contours of the Shapes. E~G are plotted in Figure 4. The starting time was measured from the beginning of pouring. It can be seen that the red arrow indicates the melt flow in the narrow paths. For shapes C and D, the right path was filled by two streams from the bottom and top. They met at the lower right corner, which meant the top flow was faster than the bottom because of the narrow path was lower than the ingate and the downward flow was faster than the flow upward. For Shape C the narrow path was filled only by the bottom flow, the reason is that the window is higher than the ingate, so it took long time for the flow to reach the top of the narrow path. For Shape F, the right narrow path was filled by both streams from the top and bottom; the ratio of length to width of the path is 95, so it was very hard for the flow from the bottom. The upward stream stopped moving forward at the height of 150mm.

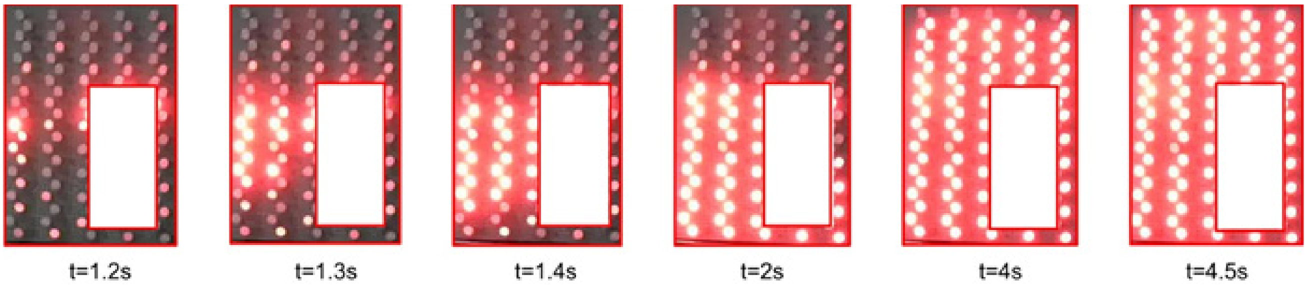

Figure 3 Filling process illustrated by LED pattern of shape E.

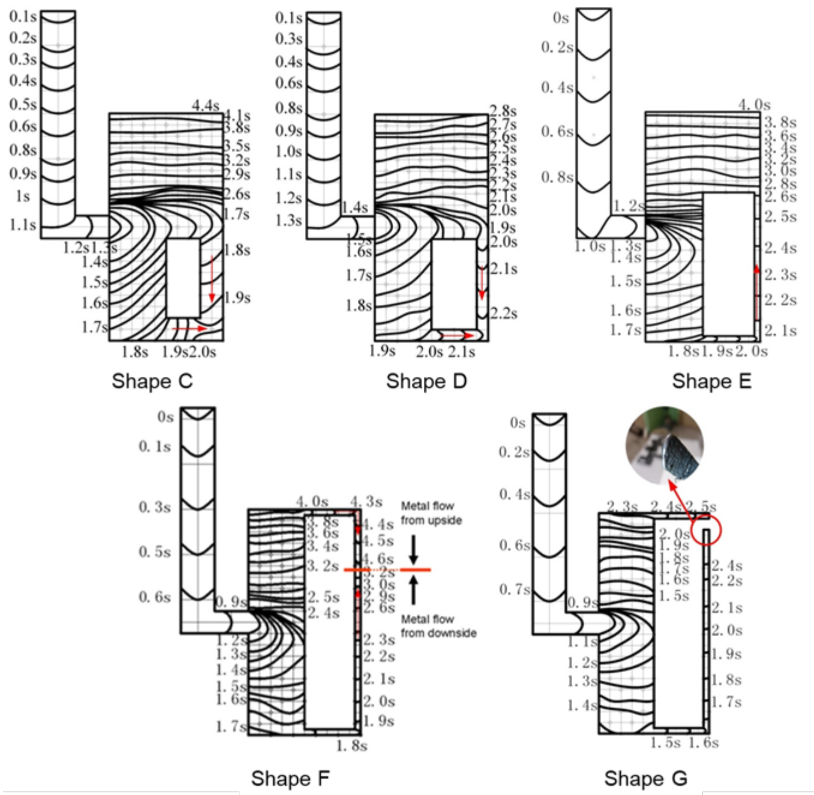

Figure 4 Filling process of the vertical plates with narrow paths.

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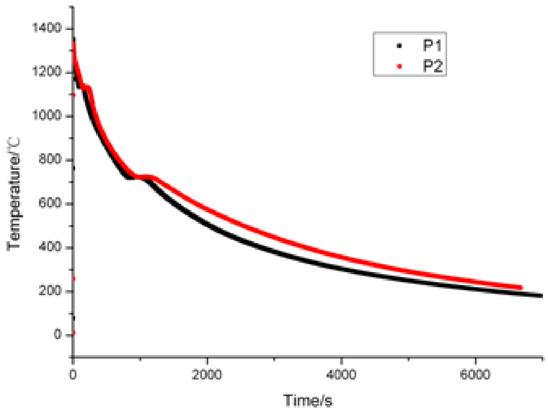
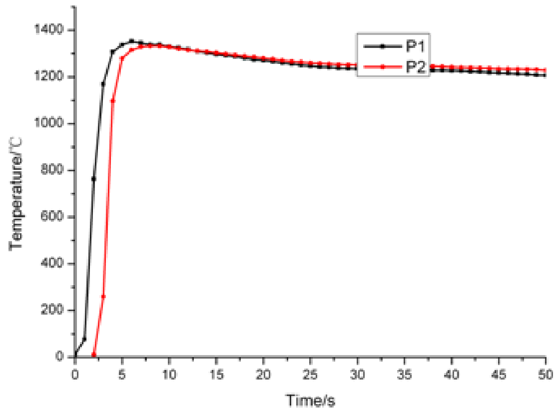
The downward stream from the top met it there 1.4 seconds later. Thus, the front of the upward stream would solidify, it was prone to cause cold shut. For Shape G, the filling of the isolated narrow path wasn't successfully finished, leaving defects –insufficient filling there. That is mainly because that the long narrow path had no outlet and the flume released from the pattern was entrapped at the end. As the flowing up of the melt, the metallostatic head dropped, meanwhile, the narrow but long path made the melt cool faster and decreased its flowability. All of these reasons slowed the melt flow, finally the melt solidified; misrun formed finally. The filling height of bottom flow in Shape G is the same as that in Shape F. The actual castings are shown in Figure 5. It can be seen that Shape G is unsound with misrun at the far end of the thin column, 17mm shorter than the designed shape, which is in agreement with the measured filling contours. Cooling curves in the filling process are shown in Figure 6. The curve of Point 1 is 2.3 seconds earlier than that of Point 2, which complies with their filling sequence.

Shape C Shape D Shape E Shape F Shape G

Figure 5 Shape G Cast specimens.



(A) Whole filling and cooling process



(B) First 50 seconds

Figure 6 Cooling curves of the measured points.

Conclusion

The mold filling process of a vertically placed plate was studied by the method. The results of the movement of the melt front were obtained. The experimental results show that the filling of narrow path is difficult, especially for blind path, it is prone to entrap air and cause misrun. Under this kind condition, ventilation is necessary. The experiment results can serve as a benchmark for the validation of numerical simulation.

Acknowledgements

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Conflicts of interest

The authors declare no conflict of interest.

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