Visualization of Cascade Injection Molding in Hot-runner System

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Abstract. There are many unsolved molding phenomena in the hot-runner mold system, which are caused by complicated flow channels installed with actuated valve-pins inside the high temperature manifold. In the injection molding of large or long-sized products, melts are made to flow continuously by sequentially switching gate-opening one by one from upstream to the area contacting the flow front. Valve gates are appropriately controlled to open/close by the so called "cascade control system", to prevent weld-lines, decrease flow pressure loss, etc. However compared to the single gate system, more complicated flow behaviors are expected to occur when the valve gate near the flow front is opened at the times of open gates. We attempted to visualize the melt behaviors inside hot-runner mold with a cascade control of two sets of valve gates (upstream VG1 and downstream VG2) . Through this visualization experiment, the following results were confirmed. (1) In the case of the direct gate system, where multi-gates are located inside the mold cavity, the flow front velocity was observed to rapidly rise up to 5 or 6 times in a moment after a small amount of back flow, due to low pressure loss at the flow front area just after switching the gate open from VG1 to VG2. (2) In the case of sub-runner systems, where multi-gates are located in the tub area outside the cavity, the later VG1 is switched to VG2, the higher the velocity peak of the melts flowing into the cavity from VG2. All these drastic velocity changes may influence upon surface transcription conditions, leading to surface defects on molded samples.

Keywords: Visualization, Injection molding, Hot-runner system, Cascade injection molding, Melt behavior
PACS: 81.20.Hy, 83.50.Uv

1. INTRODUCTION

There are many unsolved molding phenomena in the hot-runner mold system. In the injection molding of large or long-sized products, melts are made to flow continuously by sequentially switching gate-opening from upstream to the downstream area contacting the flow front. Valve gates are appropriately controlled to open/close by the so called "cascade control system", to prevent weld-lines, decrease flow pressure loss, etc. However, compared to the single gate system, more complicated flow behaviors are expected to occur when the valve gate near the flow front is opened. In this study, we attempted to visualize the melt behaviors especially near opened valve gates using two sets of valve gates for precisely understanding what phenomena occur.

2. VISUALIZATION HOT-RUNNER MOLD AND EXPERIMENTAL METHOD

Using a high-speed video camera, we visualized the resin flow phenomenon in the cavity based on a newly-developed prismatic glass inserted mold specifically designed for hot-runner molds [1]. Fig. 1 shows the fundamental structure of the visualization mold where we installed a prismatic quartz glass at the movable side of the mold to visualize resin flow from the opposite side of the valve gate. At the stationary side of the mold, we installed a hot runner system (VV3-Z03, side-fed system, made by Seiki Corporation) with a φ4mm diameter valve gate at two opposing positions (VG1 and VG2) at a distance of 150mm. At the movable side, we prepared two types of cavities to conduct different setups of the valve gate system; (1) Direct gate system, where multi-gates are located inside a 300mm×130mm×2mm rectangular mold cavity and (2) Sub-runner system, where multi-gates are located in the tub area outside a 13mm wide strip cavity, as shown in Fig.2. The valve gate was opened switching from the lower VG1 to the upper VG2 in all the cases.

We visualized melt behaviors especially focusing around the VG2 area. First, VG1 was opened, then injected melts (transparent) from VG1 were made to approach and bypass VG2 at the timing when VG2 was opened to observe the behavior of melts (white) from VG2. This process was visualized as follows: the whole manifold channel was filled with white melts beforehand, then transparent melts were injected from the nozzle into the manifold channels at the time VG 2 was closed, and VG1 was opened to replace the white melts on the side of the VG1 channel with transparent ones.

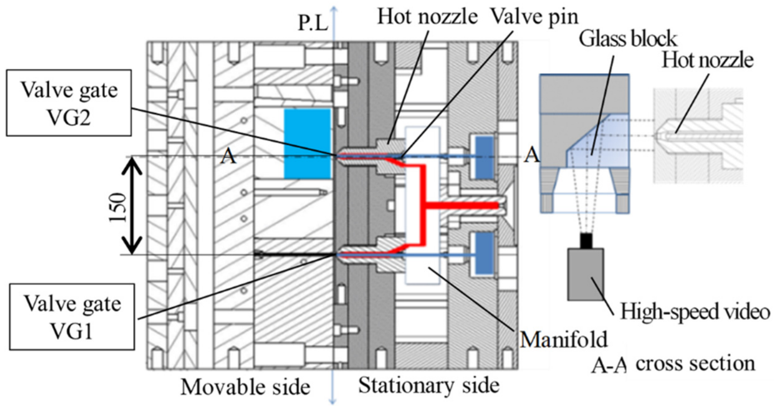

FIGURE 1 Basic structure of the visualization mold

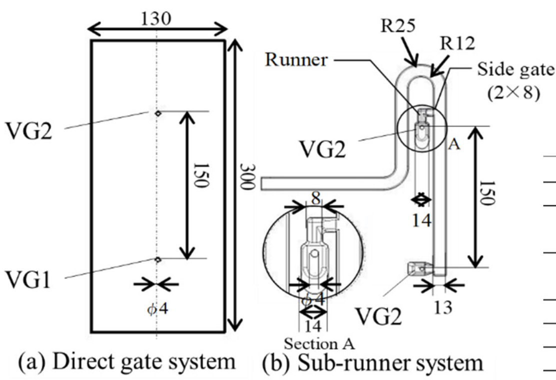

FIGURE 2 Cavity shapes (Unit:mm)

TABLE 1 Experimental materials, instruments and molding conditions

Injection molding machine	FN4000-9HTN(Nissei Plastic Industrial Co., Ltd.)
Hot runner	Side feed system(Seiki Corporation, VV3-Z03)
Resin	PS/679(PS Japan Corporation) PS/679,white-colored
Cylinder temperature [° C] NH/C1/C2/C3/HP	220/ 220 /200 /180 /60
Injection rate [cm^3/s]	10,20,40
Manifold temperature[° C]	220
Mold temperature [° C]	40

3. EXPERIMENTAL RESULTS AND DISCUSSION

Through this visualization experiment, the following results were confirmed.

3. 1 Direct Gate System

Figure 3 exemplifies some observation images of filling behaviors near VG2 under injection rate of 40cm3/s and direct gate system, where t[s] means time elapsed after injection starts. Depending on the observation images, flow patterns of transparent resin (from VG1) and white resin (from VG2) were extracted every 0.05s and 0.01s as shown in Fig.4. Transparent melts were observed to suddenly protrude and flow forward by the white melts rapidly injected from VG2 in Fig.4 (a), while the white melts were also confirmed to flow backward slightly in Fig.4(b).

Change curves with time of the flow front velocities of transparent and white melts are shown in Fig. 5, where the upper flow direction is defined as plus. The flow front velocity of transparent melts flowed almost constantly until the VG2 was opened. In contrast, at the moment when VG2 opened, it slightly decreased instantaneously as shown in Fig.5 “d”, then suddenly rose by 5 or 6 times (around 500mm/s), and gradually returned to a constant velocity. It took about 0.1s to return to the initial constant velocity from the start of sudden increase in velocity. The decreasing phenomenon “d” of flow front velocity is thought to be due to melts being momentarily drawn into the pocket generated by the valve-open operation. As for the flow front velocity of white melts from VG2, it sharply increased up to minus100mm/s to generate a certain backflow as well as the melts' rushing-out behaviors in the upward direction. These phenomena are thought to be mainly due to low pressure loss at the flow front area just after switching gate open from VG1 to VG2.

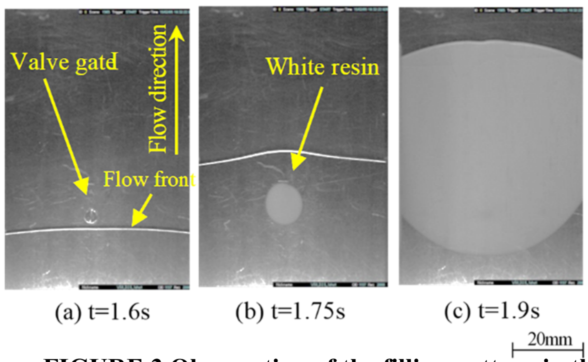

FIGURE 3 Observation of the filling pattern in the cascade injection process of direct gate system

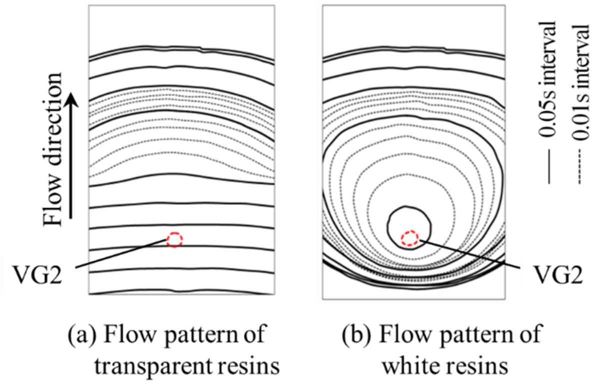

FIGURE 4 Flow patterns in the cascade injection process of direct gate system

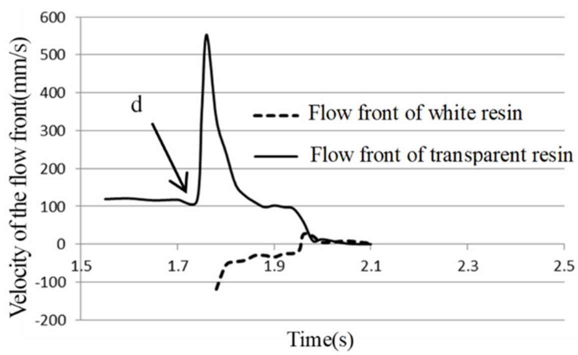

FIGURE 5 Time sequential curves of flow front velocity near VG2

3. 2 Sub-Runner System

Figure 6 shows the observation images of filling behaviors near both VG2 and its downstream cavity area under the injection rate of 20cm3/s and sub-runner system, where t[s] means time elapsed after injection starts. In the same way as the above direct gate system, flow patterns of transparent and white melts were extracted every 0.05s and 0.01s as shown in Fig.7.

From the observation results of flow front traces, the flow front of transparent melts from VG1 advanced constantly until arriving at the side gate. Next, once a split flow into a slug well via the side gate occurred, the flow front velocity inside the long strip cavity (main cavity) decreased stepwise according to the change in the cross-sectional areas of the split flow channel. VG2 is located around the central area of the slug well as shown in Fig.2 (b). While a split flow advanced and approached to VG2 inside a well channel, VG2 was set to open at different timings. Once VG2 was opened and the white melts were rapidly injected from it, they were confirmed to momentarily fill into the unfilled area of the slug well, after which they were subsequently forced to move the residual molten transparent resins backward, and to partially return them to the main cavity, through the slug well channel via the side gate. Here, t1 [s] is defined as the time when the flow front of transparent melts (from VG1) bypasses VG2. By changing the valve open timing from (t1- 0.2), t1 and (t1+0.2), we investigated the influence of valve open timing of VG2 upon the flow front velocity change of transparent melts inside the main strip cavity. The other molding conditions are the same at all different valve open timings.

Figure 8 shows the change curves with time of the flow front velocities of transparent melts. For reference, the results obtained under two different conditions are demonstrated; (a) injection from a single gate VG1 (dashed line), and (b) simultaneous injection from double gates VG1 and VG2 (dotted line). The velocity before the opening of VG2 is similar to that in a single gate filling condition (a), whereas it drastically increased right after the opening of VG2 and also approached the velocity level for the double-gate filling condition (b). Moreover, it was clearly confirmed that the later VG2 was opened, the higher was the velocity peak of the transparent melts, flowing into the main strip cavity from VG2 via the side gate. This may be because; (1) The more VG2 open timing was delayed, the higher was the viscosity of melts inside a slug well and gate channel due to cooling effects, (2) It resulted in the increase in the necessary pressure for the melts to flow backward in the slug well, and (3) There generated a drastic increase in pressure difference in between the slug well and the main cavity, which resulted in a sudden velocity increase at the moment the melts flowed backward into the main cavity.

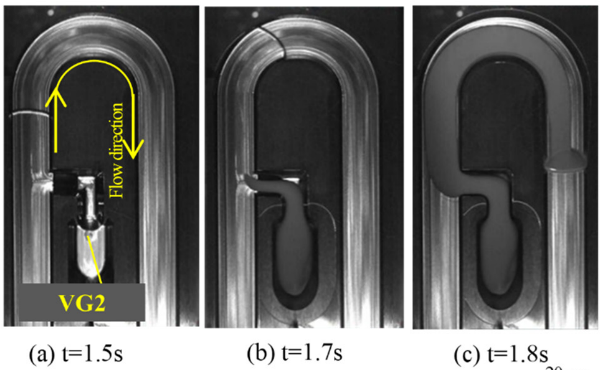

FIGURE 6 Observation of the filling pattern in the cascade injection process of sub-runner

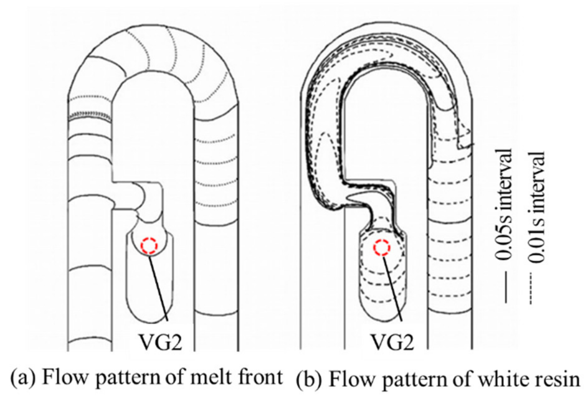

FIGURE 7 Flow patterns of each melt injected from VG1&VG2 in the cascade injection process of sub-runner system

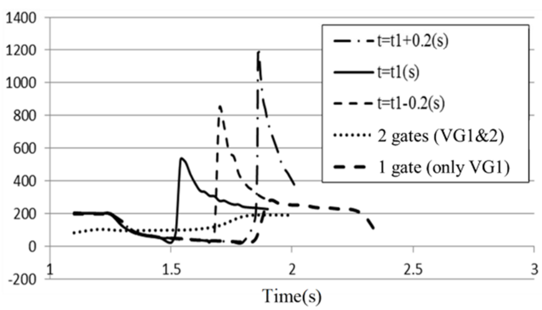

FIGURE 8 Time-sequential curves of flow front velocity of transparent resin under different valve-open timings

4. CONCLUSION

We attempted to visualize the melt behaviors inside hot-runner mold with a cascade control of two sets of valve gates (upstream VG1 and downstream VG2). Through this visualization experiment, the following results were confirmed.

(1) In the case of the direct gate system, where multi-gates are located inside the mold cavity, the flow front velocity was observed to rapidly rise by 5 or 6 times in a moment after a small amount of back flow, due to low pressure loss at the flow front area just after switching gate open from VG1 to VG2.

(2) In the case of sub-runner systems, where multi-gates are located in the tub area outside the cavity, the later VG1 was switched to VG2, the higher was the velocity peak of the melts flowing into the cavity from VG2.

All these drastic velocity changes may influence surface transcription conditions, leading to surface defects on molded samples.

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