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Simulation of Micro-Injection Molding

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ABSTRACT

Two challenges in micro-injection molding process were the modification of conventional injection molding machine and simulation of the molding process. This paper simulates the micro-injection molding process using a conventional software. Successful simulation was performed for the micro-injection molding of polycarbonate micro-components with sub-millimeter dimensions. The micro-cavities, keeping along with a macro-cavity, were filled completely under non-variothermal process conditions. The percentage weight of the melt flow and average flow length were found proportional to the filling time. A sudden drop of melt temperature and a high concentration of shear stress were observed at the entrances of all micro-cavities. The melt flow velocity inside the micro-cavity was much lower than any other places of the cavity. Air traps were identified in each of the micro-cavities.

INTRODUCTION

Micro-molding, a relatively less expensive technology based on LIGA (Lithography, Electroplating and Molding) principle, was used to fabricate three dimensional (3D) micro-components (1, 2). The implementation of micro-molding technology required mainly the modification of molding machines and the simulation of the process (2-5). In the process the melt and the tool temperature should be as high as the maximum processing temperature of the polymer. There should not be any slit to escape the trapped air and the mold cavity should be evacuated before injecting the melt. This phenomenon was reported as 'variothermal' process (2, 3). Because the process was expensive, simulation was desired but there was no software available for micro-molding. The conventional simulation software estimated the surface effects only for the top and bottom of the component. The influence of mold surface roughness was ignored and the effect of viscosity was not treated fully. In micro-molding, these factors were considerably important because of high surface to volume ratio and very short filling time (5).

SIMULATION SETUP

Simulation of micro-injection molding process for the fabrication of pseudo 3D micro-component was performed using conventional software C-mold version 4.0 (6). Three micro-components, #1, #2, and #3, of different sizes were arranged along the side of a bigger component #4, shown in Figure 1a. To estimate the influence of position and orientation, micro-components were arranged in different ways. All the cavities together were treated as a single component and meshed into triangular finite elements of 0.2 mm in size. Injection pressure of 180 MPa and clamping force of 5000 metric ton were used to inject the polycarbonate melt at 265^0 C through the point type gate at P. The surface area and thickness of the entire component were 126 mm^2 and 1mm respectively. The diameter and width of the smallest micro-part #1 was 545 μm and 122 μm respectively. This smallest micro-part was only 0.25% of the entire component by volume.

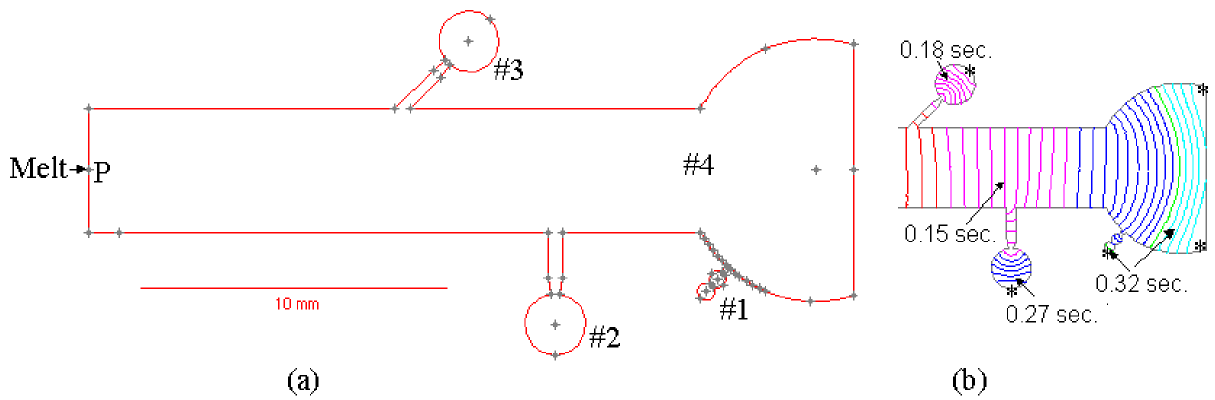

Figure 1. (a) Arrangement of micro-components #1, #2, #3 along with a macro-component, (b) Melt-front advancement (partial view) at different time. The locations of air trap are labeled by "*".

RESULTS AND DISCUSSIONS

The positions of the melt front at different filling times are shown by arrows in Figure 1b. Air traps, labeled by "*" in Figure 1b, are identified in each of the micro-cavities. It indicates that the mold cavity should be evacuated before injecting the melt. Although all the micro-cavities are filled with uniform mass flow rate and flow length, as shown in Figure 2, but the melt pressure, temperature, and speed vary significantly during the filling of micro-cavities. The position and orientation of the micro-cavities affect their filling.

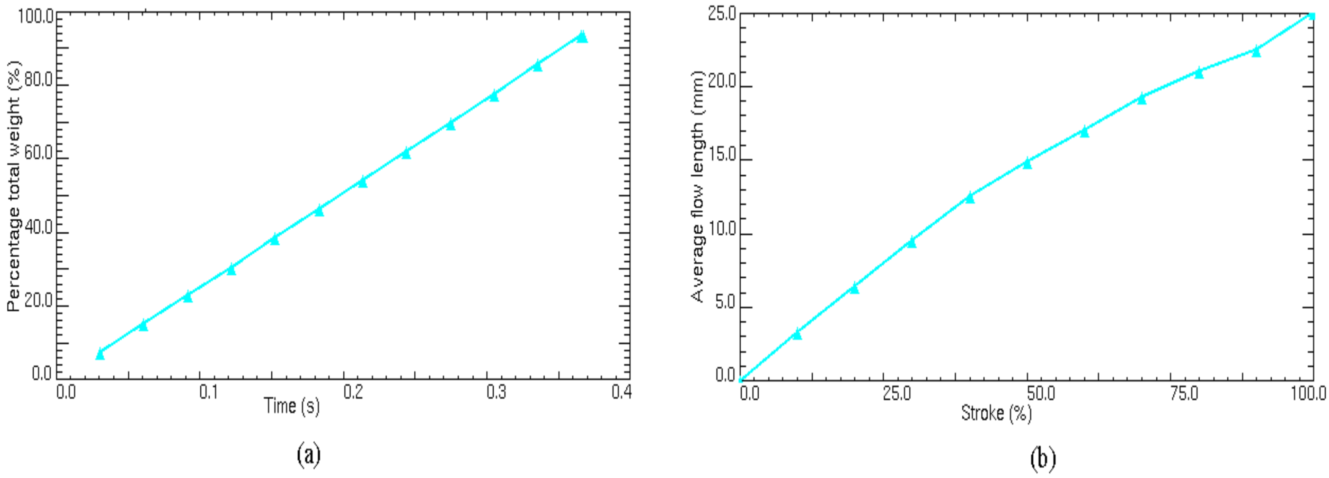

Figure 2. (a) Plot of weight percentage of melt flow vs. filling time, (b) Plot of average flow length vs. percentage of stroke.

Referring to Figure 1b, the cavity #3 is more inclined to the flow direction and the melt-front advances into the cavities #3 and #4 almost at the same filling time and pressure of 0.18 second and 16 MPa respectively. The cavity #1 is almost opposite, and the cavity #2 is perpendicular to the flow direction. These two cavities remain behind and fill afterward at the time of 0.28 and 0.32 second respectively. Where as the filling time of the identical points on the macro-component are about 0.18 and 0.25 second respectively. Figure 3a shows the filling pressure distribution. As the melt moves ahead the melt pressure energy decreases and falls into very low pressure of about 1.0 MPa at the entrances of the micro-cavities. As a result the injection pressure increases gradually up to 30 MPa. Referring to the variation of clamping force in Figure 3b, this pressure increases slowly at the beginning of the filling and rapidly during filling the micro-cavities. Figure 4a shows the temperature distribution at the end of the filling. The initial melt temperature 266^0C drops into 244^0, 255^0 and 252^0 at the entrances of the micro-cavities #1, #2 and #3 respectively during filling. At the end of the filling the temperature of these three micro-cavities raises to about 256^0 C but the temperature of the bigger part remains at about 264^0 C. When a small amount of melt enters into the micro-cavity, it solidifies very quickly because of low mold temperature (24^0C). This variation of temperature in the component causes high concentration of shear stress at the entrances of all the micro-cavities, shown in Figure 4b. This problem clearly indicates the necessity of variothermal process. The 0.95 MPa shear stress, observed during the filling of micro-cavities, is reduced to 0.67 MPa after filling. In other areas, the average shear stress is 0.42 MPa because of less temperature variation.

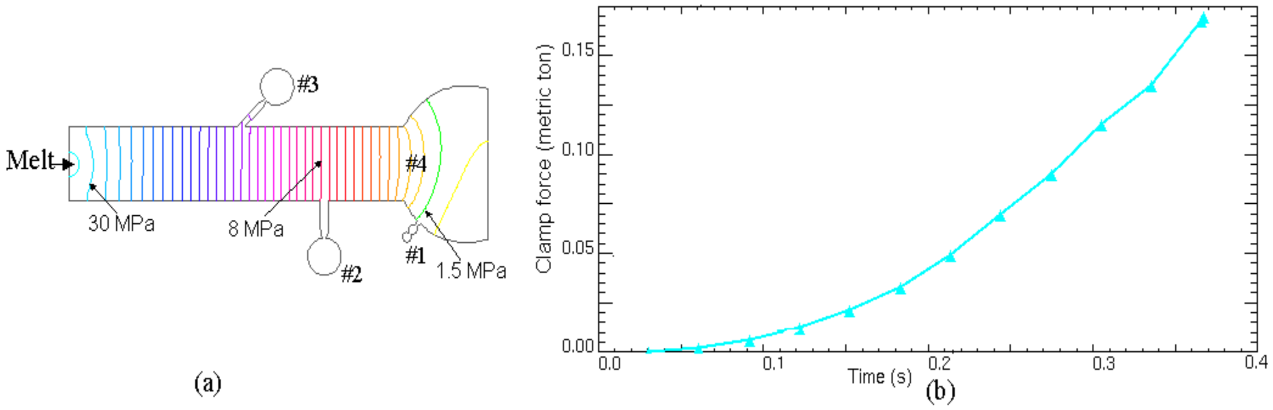

Figure 3. (a) Filling pressure distribution at the end of filling, (b) Plot of clamping force vs. filling time.

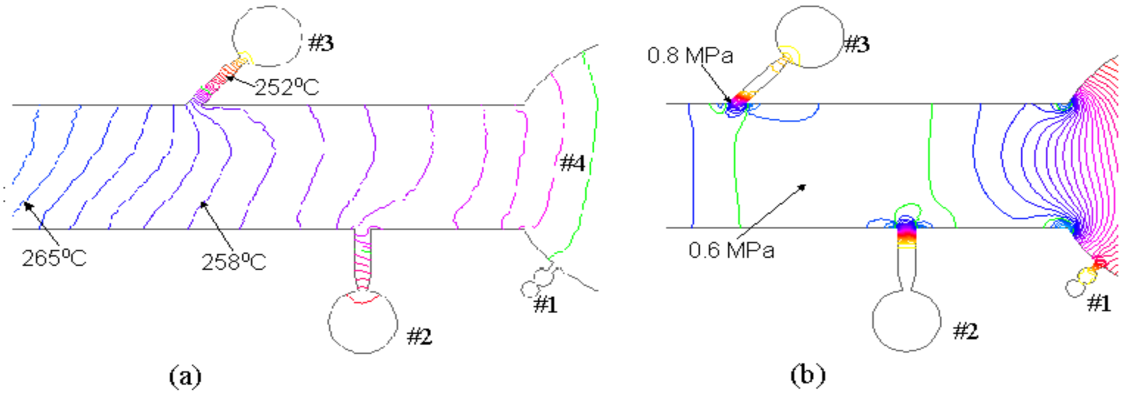

Figure 4. (a) Bulk temperature distribution and (b) Shear stress concentration at the end of filling (partial).

But when the filling is completed, the micro-cavities gain heat from the macro-cavity and hence the disordered molecular and fiber orientation become uniform and reduce the stress concentration. The melt flow speed and velocity inside the micro-cavities are much lower than those at any other places, as shown in Figure 5. Although the maximum melt-front speed is 93.35 cm/s but the speed of 95% and 5% of the melt are only 9.13 and 3.60 cm/s respectively. Figure 5a shows this variation of melt-front speed. The lowest velocity of 0.2863 cm/s, at arrow in Figure 5b, is found at the smallest micro-cavity #1. This happens because of the very small sized gate and sudden cooling of the small amount of melt by the micro-mold cavities themselves. Abrupt changes in the melt-front area, as shown in Figure 6a, are noticed at about 50% and 85% of the stroke. At these two stroke levels, refereeing to Figure 1, the melt-front approaches the cavities #2, #3, and the bigger volume at the end of the cavity #4 respectively. As a result the melt flow tends to be unbalanced, as in Figure 6a, but the ram speed varies accordingly to maintain uniform melt flow as shown in Figure 6b.

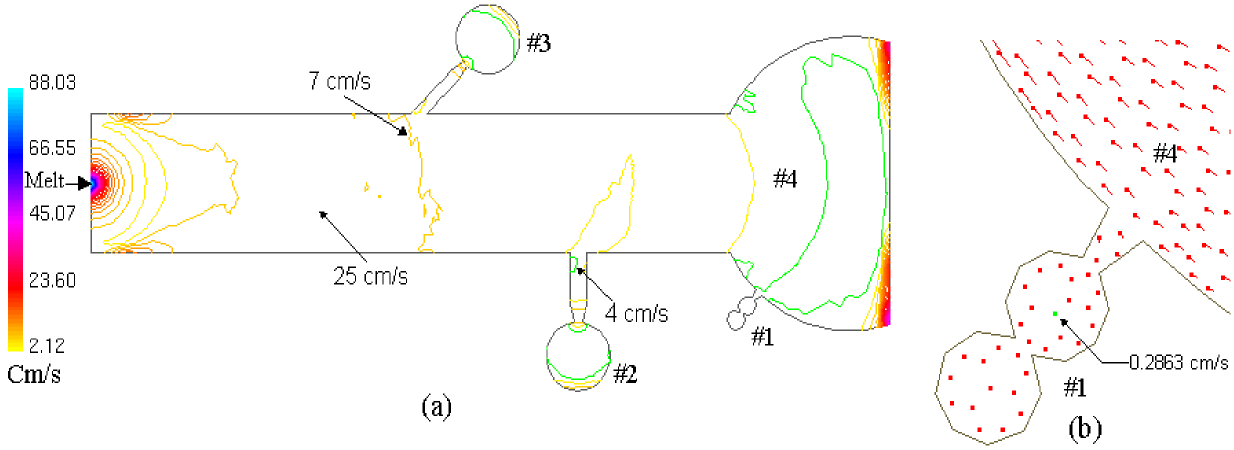

Figure 5. (a) Melt-front speed in different zone. (b) Average melt flow velocity inside the cavity.

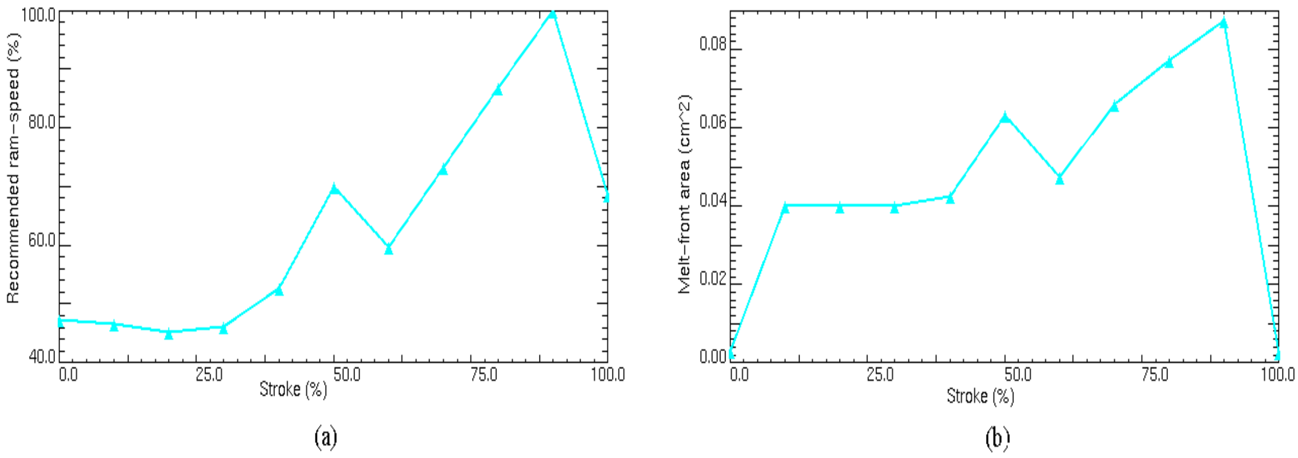

Figure 6. (a) Melt-front area at different percentage of stroke, (b) Recommended ram speed.

SUMMARY

C-mold software was used to simulate the micro-injection molding process. The simulation results should be integrated with variothermal process conditions during real fabrication. An injection molding machine, capable of providing 40-50 MPa injection pressure, and temperature range 300-450^0 C should be used. Micro-cavities should be arranged along the both sides of the macro-cavity to balance the melt flow. The lower inclination angle of the flow direction into the micro-cavity with the main flow stream could provide better results. The simulation showed:

1. All the cavities were filled by the polymer melt and the weight of the entire component was 0.14 gm.
2. The filling and post filling times were 0.36 and 60 seconds respectively.
3. The maximum injection pressure was 30 MPa and the required clamp force was 0.17 metric ton.
4. The maximum and minimum speeds of the melt front were 9.33 and 1.8 cm/s respectively.
5. Air traps were observed in five places.
6. The mass flow rate and flow length were uniform through out the filling process.
7. There was a better filling for the micro-cavity inclined to the flow direction.
8. Abrupt changes of melt-front area were compensated by respective changes in ram speed.
9. Temperature and melt-front speed fall down suddenly at the entrances of the micro-cavities.
10. High concentration of shear stress at the entrance of micro-cavities were identified.

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