

## Numerical Study on the Flow Length in an Injection Molding Process with an External Air-Heating Step

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### ABSTRACT

In this study, an external gas-assisted mold temperature control combined with water cooling was applied to achieve rapid mold-surface temperature control for observing the melt flow length in the thin-wall injection molding process. Variable part-thickness values of 0.2 mm, 0.4 mm, and 0.6 mm were used. Through a simulation and experiment, the injection molding process was achieved by using ABS and stamp insert temperatures ranging from 30 to 150 °C. In the simulation, when the stamp temperature was raised from 90 to 150 °C with part thickness of 0.2 mm, 0.4 mm, and 0.6 mm, the melt flow length increased by approximately 25.0%, 19.6%, and 12.8%, respectively. When the stamp temperature was higher than the glass-transition temperature of ABS, the improvement in the melt flow length was clearer, especially in the thinner part. In the experiment, the positive effect of stamp temperature was demonstrated; however, the improvement in the melt flow length was slightly different compared with the simulation owing to the heat transfer between the hot stamp and the environment.

**Keywords** – injection molding, flow-length-to-thickness ratio, heat-transfer coefficient, external air heating

### I. INTRODUCTION

In the field of dynamic mold-temperature control for injection molding, external air heating is one of the fastest methods for heating the mold surface. Consequently, this method has received significant attention from researchers. In the field of plastic manufacturing, as products are becoming thinner and smaller, it is becoming difficult to manufacture such controls using conventional injection molding (CIM) because in thin parts, heat is rapidly transferred from a melt to a mold wall. Increasing the mold temperature, melt temperature, or packing pressure increases the cycle time. Thin-wall parts are defined in two ways: 1) a part with a thickness below 1 mm across an area greater than 50 cm<sup>2</sup> [1, 2] and 2) a flow-length-to-thickness (L/t) ratio greater than 100:1 or 150:1 [3, 4]. To fill a cavity in an extremely short time before the skin layer forms in thin-wall parts, injection-machine manufacturers have developed machines for high-speed injection; this process is called high-speed injection molding (HSIM) [5, 6]. The purpose of performing HSIM is to fill a cavity within an extremely short time. Therefore, a high injection pressure, a stable controller, and rigid steel are necessary for an injection machine and a mold. However, HSIM has some disadvantages in terms of cost because both the injection molding machine and mold are expensive.

Another method for improving an injection-molded part involves the application of a high injection pressure and mold temperature during

injection for minimizing part thickness. However, it is difficult to maintain a high mold temperature during the filling process while lowering the mold temperature to below the deflection temperature during the post-filling process without greatly increasing the cycle time and energy consumption. To solve this problem, a variety of dynamic mold-temperature controls (DMTC) have been explored in recent years. Their purpose is to eliminate the frozen layer and ideally produce a hot mold during the filling stage and a cold mold for cooling. The most inexpensive way to achieve a high mold temperature is to use cooling water at temperatures as high as 90 or 100 °C [8].

Another heating method is local mold heating using an electric heater [9]; it is sometimes used to assist high mold temperature control. However, this method incurs additional design and tool costs. Furthermore, electrical heating is usually used as auxiliary heating and is limited to mold-temperature increases of the order of roughly several tens of degrees Celsius.

Meanwhile, mold surface heating techniques such as induction heating, high-frequency proximity heating, and gas-assisted mold temperature control (GMTC) can provide sufficient heating rates without significant increases in the cycle time. Recently, we conducted a systematic study on mold surface heating and mold surface localization heating of the processing characteristics. In this study, an external gas-assisted mold temperature control (Ex-GMTC) combined with water cooling was applied to achieve rapid mold-

surface temperature control for observing the melt flow length in the thin-wall injection molding process.

## II. SIMULATION AND EXPERIMENTAL METHOD

GMTC is a new technique in the field of mold-temperature control. It can rapidly heat and cool the cavity surface during the injection molding process. In general, the purpose of mold-temperature control is to increase the mold surface temperature to the target temperature before the filling of melt and to cool the melt to the ejection temperature. In this research, the Ex-GMTC system comprised a GMTC controller, hot-gas generator system (including an air compressor, an air drier, a digital volumetric-flow controller, and a high-efficiency gas heater), and water-mold temperature controller, as shown in Fig. 1.

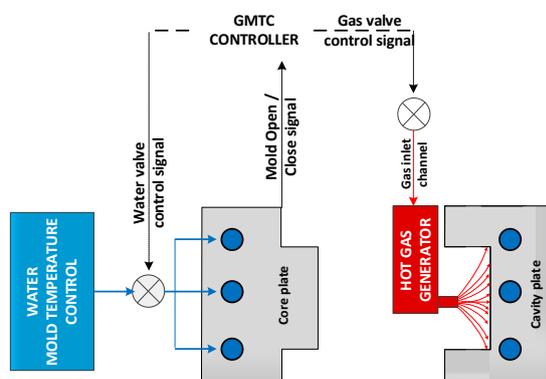


Figure 1. The Ex-GMTC system

The hot-gas generator consists of an air compressor, an air dryer, a gas valve for volumetric-flow control, and a high-efficiency gas heater. The function of the high-power hot-gas generator system is to support a heat source that provides a flow of hot air of up to 500 °C at an inlet gas pressure of up to 7 MPa. For the coolant system, a mold-temperature control was used for providing water at a defined temperature to cool the mold after the filling process and to warm the mold to the initial temperature at the beginning of the process. The valve system was used to control the water for cooling channels and the air for the heating stage. To both control and observe the temperature at the cavity surface, three temperature sensors were used to obtain the real-time mold temperature and to provide feedback to the GMTC controller.

In this study, hot gas is used as a heating source to increase the cavity surface temperature of the injection mold. For the heating operation, first, by opening the mold, two mold plates are moved to the opening position (Fig. 2, Step 1). Second, the hot-gas drier is moved to the heating position, as shown in Fig. 2, Step 2. Then, air is heated when it

flows through the gas drier, and the outside of the gas drier provides hot air, which directly contacts the cavity surface. This hot gas heats the cavity surface to the target temperature (Fig. 2, Step 2). Third, when the cavity surface is heated to the target temperature, the mold completely closes in preparation for the melt-filling process (Fig. 2, Step 3).

In this paper, the gas drier, which has a size of 240 mm × 100 mm × 40 mm, is shown in Fig. 3. A gas channel with a width of 5 mm and depth of 10 mm is cut inside the gas drier. The heating area of the mold cavity is inserted using a stamp with a size of 175 mm × 12 mm. The mold, the stamp insert, and the temperature-measurement points are shown in Fig. 4. In both the simulation and experiment, the position of all systems during the heating stage is shown in Fig. 5. For observing the heating effect of Ex-GMTC on the melt-flow length, three part-thickness values (0.2, 0.4, and 0.6 mm) of ABS are used. In addition, a numerical study is conducted for all the cases. The simulation is performed using the Moldex software. In both the simulation and experiment, before the melt is filled into the cavity, the stamp insert is heated by the Ex-GMTC system to target temperatures of 30, 60, 90, 120, and 150 °C. The injection molding process is controlled with the same value for all the cases in the experiment and simulation. The details of the parameters used are shown in Table 1.

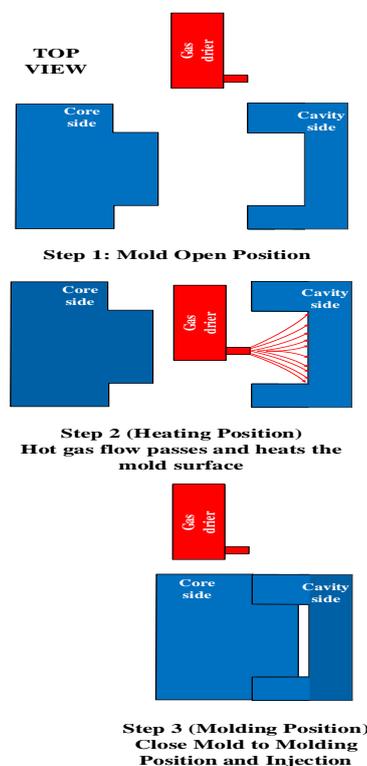
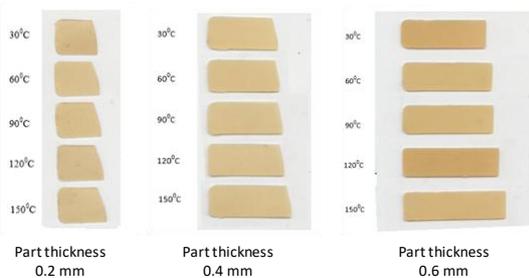


Figure 2. Mold position in the heating stage of the GMTC process.

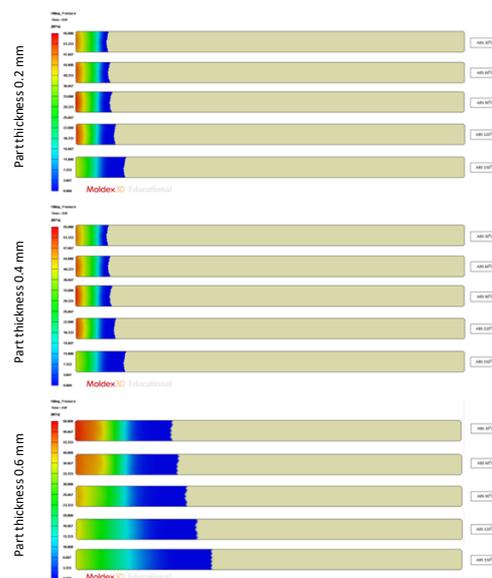


Initial temperature of the stamp insert	30 °C
Density of the stamp insert	2702 kg/m <sup>3</sup>
Specific heat of the stamp insert	903 J/kg*K
Heat-transfer coefficient of the stamp insert	237 W/m*K
Heat-convection coefficient between the mold and air	2340 W/m*K
Simulation type	Transient
Time of heating	0 s → 30 s (step 5 s)

In the experiment, a positive effect of the stamp temperature was observed; however, the improvement in the melt-flow length was slightly than that in the simulation. The comparison between the melt-flow lengths measured in the simulation and experiment at various part thicknesses are shown in Figs. 8–10. These results show that the melt-flow lengths obtained at low stamp temperatures are similar in both the simulation and experiment. However, at high stamp temperatures, the simulation value is higher than the experimental value, especially in the case of the thinner part. This is because the heat transfer from the hot stamp to the environment, which causes rapid decreases in the stamp temperature after the completion of the air-heating process. This effect was ignored in the simulation. Thus, in the experiment, the injection process was achieved with a stamp temperature that was lower than that in simulation; thus, a smaller melt-flow length was obtained in the experiment.



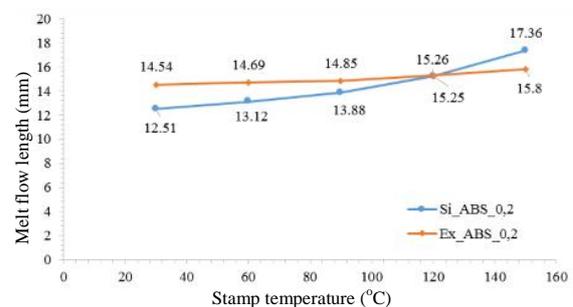
**Figure 6.** Melt-flow lengths measured in the experiment with the stamp temperature varying from 30 to 150 °C.



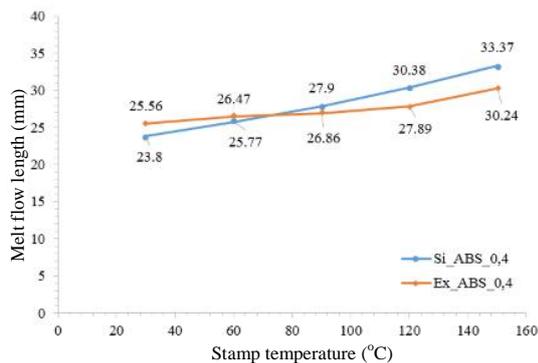
**Figure 7.** Melt-flow lengths measured in the simulation with the stamp temperature varying from 30 to 150 °C

**Table 2.** Simulation and experimental results for melt-flow length under different stamp temperatures

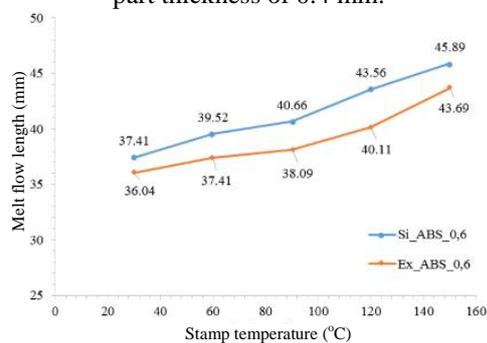
	Stamp temperature (°C)				
	30	60	90	120	150
Si_ABS_0,2	12,51	13,12	13,88	15,25	17,36
Ex_ABS_0,2	14,54	14,69	14,85	15,26	15,8
Si_ABS_0,4	23,8	25	27,9	30,38	33,37
Ex_ABS_0,4	25,56	26,47	26,86	27,89	30,24
Si_ABS_0,6	37,41	39,52	40,66	43,56	45,89
Ex_ABS_0,6	36,04	37,41	38,09	40,11	43,69



**Figure 8.** Comparison of the melt-flow lengths measured in the simulation and experiment with a part thickness of 0.2 mm.



**Figure 9.** Comparison of the melt-flow lengths measured in the simulation and experiment at the part thickness of 0.4 mm.



**Figure 10.** Comparison of melt-flow lengths measured in the simulation and experiment with a part thickness of 0.6 mm.

#### IV. CONCLUSIONS

In this study, via a simulation and experiment, the effect of the stamp temperature on melt-flow length was evaluated using different part thicknesses. In addition, by varying the stamp temperature from 30 to 150 °C, the accuracy of the simulation was verified. Based on the results, the following conclusions were obtained:

- ✓ In the simulation, when the stamp temperature was raised from 90 to 150 °C at part thicknesses of 0.2 mm, 0.4 mm, and 0.6 mm, the melt-flow length increased by approximately 25.0%, 19.6%, and 12.8%, respectively.
- ✓ When the stamp temperature was higher than the glass-transition temperature of ABS, the improvement in the melt-flow length was clearer, especially in the thinner part.
- ✓ In the experiment, the positive effect of the stamp temperature was observed; however, the improvement in the melt-flow length in was slightly little different than that in the simulation.

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