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Study on Melt Flow Length in Injection Molding Process with Induction Coil Heating for Mold Temperature Control

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Abstract-In this study, an induction heating coil mold temperature control (IHC-MTC) combined with water cooling was applied to achieve rapid mold surface temperature control for observing the melt flow length with the thin wall injection molding process. The part thickness was varied with the value of 0.2 mm, 0.4 mm, 0.6 mm. By simulation and experiment, the injection molding process was achieved by ABS material and the stamp insert temperature varied from 30 °C to 180 °C. By simulation, when the stamp temperature raised from 90 °C to 150 °C, with the part thickness of 0.2 mm, 0.4 mm, 0.6 mm, the melt flow length was greatly increased. When the stamp temperature is higher than the glass transition temperature of ABS, the improvement of melt flow length was clearer, especially with the thinner part. By experiment, the positive effect of stamp temperature is also appeared, however, the improvement of melt flow length in experiment has a little different with the simulation due to the heat transfer between the hot stamp to the environment.

Keywords- *Injection Molding, Flow Length to Thickness Ratio, Induction Heating, Mold Temperature Control*

I. INTRODUCTION

In the field of dynamic mold temperature control for injection molding, the heating coil is one of the fasted methods for heating the mold surface. This method had got more attention from researcher. In the field of plastic manufacturing, as products become thinner and smaller, it is difficult to manufacture them using conventional injection molding (CIM), because heat transfers rapidly from the melt to mold wall due to part's thinness. Increasing the mold temperature, melt temperature, or packing pressure, it increases the cycle time. There are two definitions of "thin-wall" parts: a part with a thickness below 1 mm across an area greater than 50 cm2 [1, 2]; and a flow length to thickness (L/t) ratio greater than 100:1 or 150:1 [3, 4]. To fill the cavity in an extremely short time before the formation of the skin layer in thin-wall parts, injection machine manufacturers have developed machines for high-speed injection, and this process was called high-speed injection molding (HSIM) [5, 6]. The object of HSIM is to fill the cavity in an extremely short time. Hence, a higher injection pressure, a stable controller, and rigid steel for the injection machine and mold are necessary. However, the HSIM has some disadvantage as the expensive injection molding machine, as well as the mold price.

In another way, for improving the injection molding part, it requires higher mold temperatures during injection for minimizing part thickness and injection pressure. However, to maintain high mold temperature during the filling process, while lowering the mold temperature to below the deflection temperature during the post-filling process, without great increases in cycle time and energy consumption, is not easy. 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 ideally producing a hot mold during the filling stage and a cold mold for cooling. The most inexpensive way to achieve high mold temperature is to use cooling water at temperatures as high as 90˚C or 100˚C [8].

Another heating method is local mold heating using electric heater [9] is sometimes used to assist high mold temperature control. However, this requires additional design and tool costs. Further, electrical heating is usually used as an auxiliary heating and is limited to increases in mold temperature of roughly several tens of degrees centigrade.

Meanwhile, the mold surface heating, such as induction heating, high-frequency proximity heating, gas-assisted mold temperature control (GMTC) can provide sufficient heating rates without significant increases in cycle time. In reason years, we provide a systematic study on mold surface heating and mold surface localization heating of the processing characteristics. In this study, an induction heating coil mold temperature control (IHCMTC) combined with water cooling was applied to achieve rapid mold surface temperature control for observing the melt flow length with the thin wall injection molding process.

II. SIMULATION AND EXPERIMENTAL METHOD

Induction heating coil mold temperature control (IHCMTC) is a new technical in the field of mold temperature control, which can heat and cool the cavity surface rapidly during the injection molding process. In general, the goals of mold temperature control are increase the mold surface to the target temperature before the filling of melt and cool the melt to ejection temperature. In this research, the IHCMTC system consists of a machine induction heating (MIH), Copper coil, 2 block copper and water mold temperature controller as shown in Fig. 1.

Figure 1. IHCMTC system

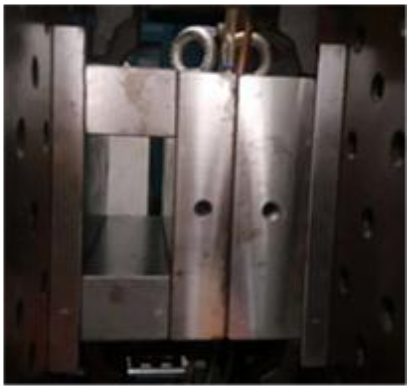
An induction heating will be used to provide high frequency alternating current for the coil to induce the induced magnetic field on the surface heat. During heating, water will be used as a cooling solution for the machine and coils. This device can provide power up to a maximum of 150 A with a maximum power of 45 kW. For the coolant system, a mold temperature control was used to provide the 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 this experience. The valve system was used to control the water for cooling channels. 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 IHCMTC controller.

In this paper, induced current will be 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 will move to the opening position (Fig. 2 – Step 1). Second, the MIH will be turned on and the induction current on the cavity surface. This induced current will heat the cavity surface to the target temperature (Fig. 2 – step 2). Third, when the cavity surface is heated to the target temperature, the mold will completely close in preparation for the filling process of melt (Fig. 2 – step 3).

In this paper, the MIH with the size of 120cm x 60cm x 100cm is shown in Fig. 3. In this research, the heating area of mold cavity will be inserted by a stamp with the size of 100 mm x 20 mm. The mold, the stamp insert and the temperature measurement points are shown in Fig. 4. In both simulation and experiment, the position of all system in the heating stage is shown in Fig. 5. For observing the heating effect of Ex-GMTC on the melt flow length, three part thicknesses (0.2,0.4,0.6 mm) were experimented with the material of ABS. Besides that, the numerical study was also applied for all cases. The simulation was achieved by the Moldex software. In both experiment, before the melt fills into the cavity, the stamp insert was heated by the IHCMTC to the target temperature of 30, 90, 110, 140, 180 °C. The injection molding processes are controlled with the same value for all cases in experiment and simulation. The parameter details are shown in Table 1.

Step 1: Mold open position

Step 2: heating position (machine induction heating will be turn on)



Step 3: close mold to molding position and injection

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

Figure 3. Induction heating machine

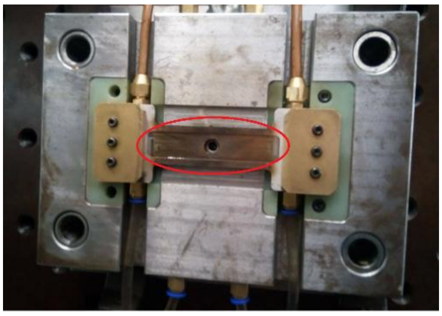


Figure 4. Heating position of Ex-GMTC

III. RESULTS AND DISCUSSIONS

In this paper, the part thickness is in the range of thin wall injection molding, meaning that the heat of polymer could more easily be dissipated by the mold wall. By comparing with the same time for melt flowing, with a lower mold temperature, the freeze layer will defend seriously the melt flowing [1 - 3]. In the contrary, with a higher mold temperature, the freeze layer will be reduced, as a result, the melt flow will be farer [5, 6]. So, in general, according to the effect of freeze layer, the mold temperature will be heat by the induced current, which will reduce the heat transfer from the melt to the mold volume and will let the longer flow length.

In this research, the melt of ABS (Acrylonitrile butadiene styrene) will be filled into cavity with the melt temperature of 225 °C, mold temperature of 30 °C, the injection pressure of 243 MPa, and the heating target of stamp temperature is varied from 30 °C to 180 °C. The ABS material has the glass transition temperature of 105 °C. After the molding process was finished, the melt flow length will be measured by the length of molding part. For observing the influence of stamp temperature on the ability of melt filling, three-part thicknesses will be applied. Each type of case, the molding process will be run with 10 cycles for reaching to the stable stage. Then, in the next 10 processes, the molding part will be collected and their length values will be used for comparing and discussing.

The length of parts under different stamp temperature was shown in Fig. 6 and 7 and Table 2 and 3. According to simulation results, when the stamp temperature is lower than the glass transition temperature of ABS, the melt flow length is not varied clearly. However, when the stamp temperature is higher than the melt, flow length got the advantage, with the thicker part, this change is clearer. When the stamp temperature raised from 90 °C to 180 °C, with the part thickness of 0.2 mm, 0.4 mm, 0.6 mm, the melt flow length was greatly increased. The measurement for flow length shows that with the thinner part, the effect of stamp temperature is more efficiency, which is due to the face that the effect of freeze layer is clearer with the inner wall product.

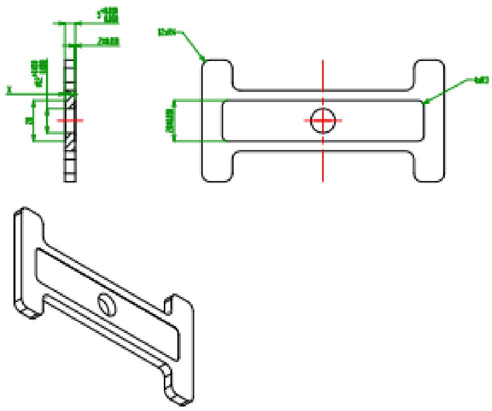


Figure 5. Mold cavity for experiment

TABLE I. SIMULATIONA AND EXPERIMENT PARAMETERS

Injection press	243 MPa
Injection speed	20%
Time cooling	15s → 40s
Plastic temperature	235˚C
Cavity temperature	30˚C → 180˚C
Time for heating	3 s → 9 s (step 2)

By experiment, the positive effect of stamp temperature is also appeared, however, the improvement of melt flow length in experiment has a little different with the simulation. The comparison between simulation and experiment were shown in Fig. 8 to 10. These results show that with the low stamp temperature the simulation and experiment are almost the same. However, with the higher stamp temperature, the simulation value is higher than the experiment, especially with the case of thinner part. This is due to the face that the heat transfer from hot stamp to the environment, which let the stamp temperature drops fast right after the air heating process was stop. This effect was ignored in simulation. So, in experiment, the injection process was achieved with the lower stamp temperature than the simulation, and the result is the worse melt flow length was appeared in experiment.

0.2mm 0.4mm 0.6mm

Figure 6. Melt flow length by experiment with stamp temperature varies from 0s to 9s.

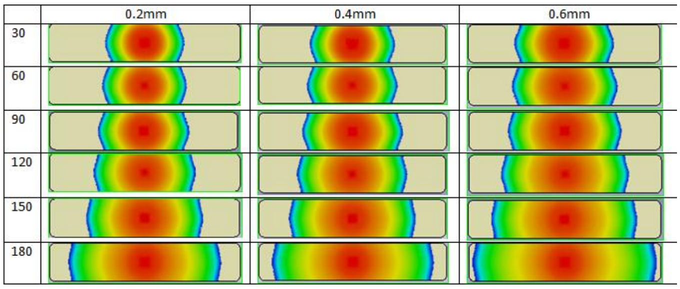


Figure 7. Melt flow length by simulation with stamp temperature varies from 30 °C to 180 °C

TABLE II. SIMULATION RESULT OF MELT FLOW LENGTH UNDER DIFFERENT STAMP TEMPERATURE

	Stamp temperature (°C)					
	30	60	90	120	150	180
Si.ABS0,2	39,39	42,22	46,51	52,95	61,37	79,77
Si.ABS0,4	43,47	46,35	51,36	57,21	66,54	84,9
Si.ABS0,6	49,65	52,62	57,47	64,82	74,65	94,69

TABLE III. EXPERIMENT RESULT OF MELT FLOW LENGTH UNDER DIFFERENT STAMP TEMPERATURE

	Stamp temperature (°C)				
	30	80	110	140	180
Ex.ABS0,2	10,4	13,6	38,4	68,3	80,5
Ex.ABS0,4	14,5	32,8	52,7	75,5	85,6
Ex.ABS0,6	19,6	37,9	59,3	87,1	91,8

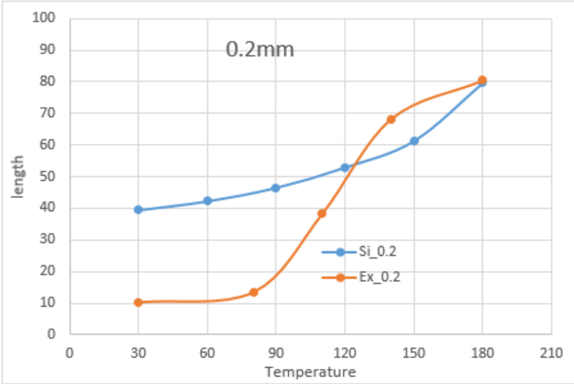


Figure 8. Comparison of melt flow length between simulation and experiment with the part thickness of 0.2 mm.

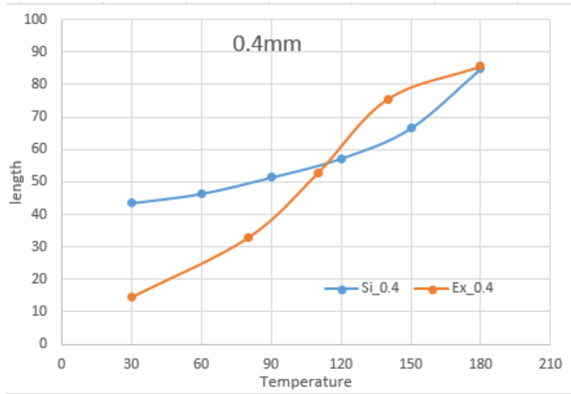


Figure 9. Comparison of melt flow length between simulation and experiment with the part thickness of 0.4 mm.

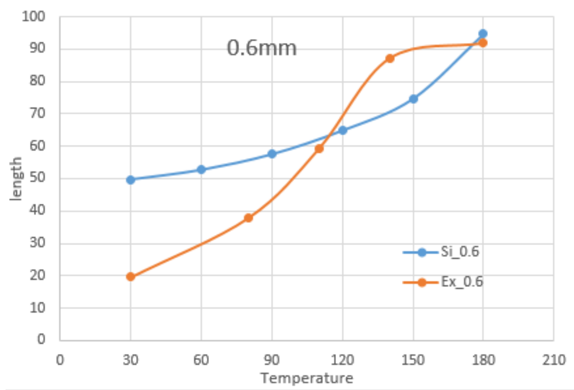


Figure 10. Comparison of melt flow length between simulation and experiment with the part thickness of 0.6 mm.

IV. CONCLUSIONS

In this research, by simulation and experiment, the effect of stamp temperature on the melt flow length was overseen under different part thickness. In addition, by varying the stamp temperature from 30 °C to 180 °C, the accuracy of simulation was verified. Based on the result, these conclusions were obtained:

- In simulation, when the stamp temperature raised from 90 °C to 180 °C, with the part thickness of 0.2 mm, 0.4 mm, 0.6 mm the melt flow length was greatly increased - When the stamp temperature is higher than the glass transition temperature of ABS, the improvement of melt flow length was clearer, especially with the thin part.

- By experiment, the positive effect of stamp temperature is also appeared, however, the improvement of melt flow length in experiment has a little different with the simulation.

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