Gas-Assisted Mold Temperature Control for Double-Sided Heating and Micro-Structures Molding

Jen-An Chang^{*1, 2, 3}/Shia-Chung Chen^{*1, 2, 3}/Sung-Wei Huang^{*1, 2}
Hsin-Shu Peng^{*4}/Huang-Jie Lin^{*1, 2}

In this study, a gas-assisted heating system for mold surface temperature control was established. Two gap size control modes (A and B) of the gas channel and the heating results of both cavity and core sides were investigated. The results show that the mold temperature difference on the gas inlet of core and cavity surface can be reduced from 39.8°C to 1.4°C under 5 mm gap size with B mode. A case study of micro-molding for double sides 0.4 mm thin wall plate with micro-dot arrays shows that replication accuracies reach higher than 90% when molding at a mold temperature of 150°C. This is an improvement of 25.3% over injection molding at the regular mold temperature of 90°C.

Key words : Gas-assisted heating/Heating efficiency/Micro-feature/Replication accuracy

1. Introduction

Injection molding of plastics for micro-molding and micro-featured products has shown greater commercial potential. In the micro-molding process, the major factors that affect the replication accuracy of molded micro-features are mold temperature and packing pressure. However, packing pressure is not enough to achieve high replication accuracy, particularly for features with micron/sub-micron dimensions or high aspect ratio, because the polymer melt solidifies when filling micro-featured cavities. It is difficult to force the polymer to completely fill the geometry once the melt is partially cooled.

In principle, when the mold temperature is higher than the glass transition temperature (T_g) and the melt can be maintained in a molten state during the filling process, the melt can fill micro-featured cavities completely at an appropriate molding pressure. However, with the traditional method of mold temperature control, this will significantly increase the cycle time of the injection molding process. Therefore, a variotherm approach¹⁾ was proposed in which mold temperature is kept high

only during the melt filling process and then lowered to the ejection temperature in the packing and cooling phase. Such a dynamic mold temperature approach may solve replication accuracy issues without significant increases in cycle time. Maintaining a high mold temperature during the filling process and lowering the mold temperature to below the deflection temperature during the cooling process without increasing the cycle time and energy consumption is not easy. In a conventional molding process, direct heating and cooling of the entire mold is not an economic option due to the large heat mass of the mold. A variety of methods for dynamic mold surface temperature control have been reported²⁾. Chen *et al.*³⁾ developed the induction heating method combined with coolant cooling for mold temperature control. The heating and cooling rates were both found to be significant and efficient for industrial applications. Induction mold surface heating can eliminate part surface defects such as weld lines and fiber floating marks.

In the present study, a gas-assisted heating system was established to heat the mold surface dynamically. In this method, the heating rate is high due to the use of less energy to increase surface temperature. The cooling time can be reduced compared to the other methods, such as heaters heating, steam heating, and hot water heating. This method allows for the selection of the heating area, option for local surface heating, multiple cavity shapes, and both sides of the cavity. In addition, this technique can be applied to the stamp insert mold design⁸⁾.

The concept of gas heating method has been proposed by Kazmer *et al.*^{4), 5)}, an innovative mold design (consist-

^{*1} Department of Mechanical Engineering, Chung Yuan Christian University
200, Chung Pei Rd., Chung-Li, Taiwan, 32023, R.O.C.
shiachun@cycu.edu.tw

^{*2} R&D Center for Mold and Molding Tech., Chung Yuan Christian University

^{*3} R&D Center for Membrane Tech., Chung Yuan Christian University

^{*4} Dept. of Digital Media Design and Management, Far East University

Received Nov. 30, 2011

ing of a thin layer with low thermal conductivity on mold base) and preheating process (using compressed hot air) to control the temperature. Although the simulation of rapid mold surface temperature control using gas-assisted heating systems shows that it can improve the quality of injection molded parts, the effects of heating conditions, gas channel shape, and mold design on the heating efficiency and temperature distribution uniformity have yet to be systematically investigated.

Recent research investigates the heating efficiency of hot gas which was first evaluated by flowing it in a circular tube. The heat transfer coefficient of the hot gas was then identified by matching the measured temperature profile with simulations⁶⁾. A gas-assisted mold temperature control (GMTC) combined with water-cooling was established having gas gap sizes to achieve rapid mold surface temperature control for injection molding⁷⁾. Additionally, the effects of mold design (including a thermal insulation layer provided by coating with ZrO_2) and various gas channel shape design (including fan and tube shaped gas channels) on the heating efficiency and temperature distribution uniformity were also investigated⁸⁾. In this study, a gas-assisted mold temperature control combined with water-cooling, with gap sizes (4 mm, 5 mm, and 6 mm) as the control method. Two gap control types are utilized to achieve the double sided mold surface temperature distribution uniformity. Evaluation of the feasibility of gas-assisted heating for mold surface temperature control during the injection process to improve the replication accuracy of the thin wall (0.4 mm) plate and to obtain a high surface heating uniformity are provided.

2. Experimental Work

In this research, hot air will be used as a heating source to increase the cavity surface temperature of the injection mold. The hot air will flow through the cavity volume by an inlet and outlet channel as shown in Fig. 1. The diameter of channel is 7.0 mm. In general, the application of gas-assisted mold surface heating in injection molding will be achieved using the three steps shown in Fig. 1. In order to verify the heating uniformity on both sides of the cavity, two gap size control modes (A and B) of the gas channel were investigated.

Various sizes (3 mm, 4 mm and 5 mm) of gas channels were designed to verify the uniformity of the mold surface temperature. The high power hot gas generator system provides the heat source, which provides a flow of hot air up to 500° C with a flow rate up to 500 liters/minute. In this research, the fixed time for heating the cavity surface from the initial temperature to the target temperature is 20 s.

For observation of the effect of GMTC on a real molding case, the mold surface of a simple rectangle test

specimen (80 mm × 60 mm × 0.4 mm) is pre-heated across a heating area of 80 mm × 60 mm. The molded part will be compared with a part formed by conventional injection molding, which has no GMTC. The injection mold with the stamp inserted (80 mm × 60 mm × 1 mm) into the center of the mold is utilized. Fig. 2 shows the location of two sensors. In this experiment, two sensors were built onto the stamp surface to collect temperature data from the cavity surface. One sensor is near the gas inlet (T1)

Fig. 1 Mold position in the GMTC steps and modes A and B of the gas gap control designs

Fig. 2 The dimensions of mold plate and measured position

the other is near the gas outlet (T 2) . To study the effect of GMTC on the improvement of double sided micro-structure replication with thin wall parts, PC plastic is used as the molding resin which has a glass transition temperature of about 145℃. The geometry of the molded width was measured by 3 D laser microscope at measure point P and the associated replication accuracies under various mold temperatures have been compared.

3. Results And Discussion

Comparisons of heating temperature, heating uniformity, and mold surface temperature distributions under different gas gap size design modes are illustrated in Fig. 3 and 4. Fig. 3 shows that when the gas gap design is A mode, the heating result on the core and cavity side will be unbalanced more easily. This result can be explained by the decrease of gas channel diameter at the transition between inlet channel and the cavity. This variation will allow the hot gas to easily have contact with the cavity side. Therefore, the heating of the cavity side is much stronger than the core side. In this design, the temperature difference between the core and cavity side at T 1 is

Fig. 3 Comparison of temperature uniformity with A mode gap design

Fig. 4 Comparison of temperature uniformity with B mode gap design

higher than 40℃. Fig. 4 shows the temperature of point T 1 and T 2 with the side of cavity plate and core plate with the mode B. This result shows that the temperature on both the core and cavity side is less than 1.5℃. In this case, the hot gas has fluently flown from the inlet gate to the outlet gate. This is the reason for the temperature uniformity on not only both sides of point T 1, but also the temperature between T 1 and T 2. This is shown especially on the gap size design with 5 mm.

The heating effects shown in Fig. 3 and Fig. 4, provides information about how mode A has is better while the results can be best explained by the turbulent property of the gas flow. Mode A will become more turbulent than mode B when the gas flows through the transition area between the inlet channel and the cavity. This influence is clearly shown at the inlet area, denoted by T 1.

Applications require the filling of microstructure to be uniform which directly corresponds to the temperature distribution. Due to this requirement, mode B was used to improve the replication accuracy for a molded 0.4 mm thin wall plate with micro-structures on both sides. The micro-dots in the stamp have dimensions of approximately 20 μm in depth and 180~300 μm in width. The measurement of dots structure is shown in Fig. 5.

An initial mold temperature of 90℃ and a target mold temperature of 150℃ are adequate for the filling of PC melt into micro dots. To evaluate the replication accuracy of the molding results, the dimensions of micro-dots depth at position P has been examined by 3 D laser microscope. The measured micro-dot profile on both core and cavity sides is illustrated in Fig. 5, while the corresponding replication accuracies are shown in Fig. 6. Based on this comparison, when the cavity surface is pre-heated to 150℃, the PC melt has filled 92.8% and 91.7% for the cavity and core side, respectively for the micro-dot and micro-structure.

By observation of the results presented, the gas heating method can heat both the cavity and core side of the mold, while the micro-structure of two sides has nearly the same high accuracy. This is a great advancement of the gas heating method, which can be observed when compared to the current methods used in the injection molding community such as induction and infrared heating.

4. Conclusions

In this study, a gas-assisted mold surface heating method to achieve double sided rapid mold surface heating was established. The gas gap design effect of GMTC and the uniformity of mold temperature for thin wall plate molding have been evaluated. Through experimental work, the temperature difference on core and cavity sides can be reduced significantly.

Fig.5 Molding results for different mold surface temperatures (90°C and 150°C) on core and cavity side (measurement point P)

(a) Molded plate (b) Micro structure dimension (c) Micro structure measurement

Fig.6 Molding replication increases with increased mold temperature by GMTC

For the thin wall plates with a micro-structure, the replication accuracy of regular injection molding using PC resin at a typical mold temperature of 90°C was only about 67.5% and 67.4% for the core and cavity side, respectively. With the assistance of hot air heating, the average replication accuracies can be improved to 92.8% and 91.7% at mold temperatures of 150°C on the core and cavity side. This offers a significant gain in efficiency compared with the conventional mold temperature control methods.

Acknowledgment

This research was financially supported from the Ministry of Economic Affairs, the National Science Council, the Ministry of Education, and R&D Center for Membrane Technology of Taiwan, ROC.

References

- 1) Michaeli, W. and Gartner, R. : *SPE-ANTEC Tech. Papers* (2004)
- 2) Tao, D., Chen, S. C. and Kim, B. H. : *Adv. Polym. Technol.*, **27**, 233 (2008)
- 3) Chen, S. C., Jong, W. R. and Chang, J. A. : *J. Appl. Polym. Sci.*, **101**, 1174 (2006)
- 4) Hatch, D., Kazmer, D. and Fan, B. : *SPE ANTEC Tech. Papers*, **47**, 428 (2001)
- 5) Ambady, P. and Kazmer, D. : *SPE ANTEC Tech. Papers*, **47**, 530 (2011)
- 6) Chen, S. C., Chang, J. A., Hsu, W. Y. and Huang, S. W. : *Microelectron. Eng.*, **88**, 1594 (2011)
- 7) Chen, S. C., Minh, P. S., and Chang, J. A. : *Int. Commun. Heat Mass Transf.*, **38**, 304 (2011)
- 8) Chen, S. C., Chien, R. D., Lin, S. H., Lin, M. C. and Chang, J. A. : *Int. Commun. Heat Mass Transf.*, **36**, 806 (2009)