THE EFFECTS OF VARIOUS VARIOTHERM PROCESSES AND THEIR MECHANISMS ON INJECTION MOLDING

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Abstract - To eliminate surface defects and improve the quality of molded parts, increasing the mold temperature is one of the solutions. Using high mold temperature can eliminate weld lines, reduce molding pressure, residual stress, clamping force and improve part surface quality. However, with the increasing of mold temperature, the cycle time will also be increased. Hence, people have paid the attention to mold temperature control technologies. Among them, the variotherm molding technologies, including Rapid Heat Cycle Molding (RHCM), Induction Heating Molding (IHM), and Electricity Heating Mold (E-mold), are some effective methods. Although those variotherm technologies have been proposed, how does the external or internal heating source affect the injection molding process and the final product? The true function and the efficiency study of each technology still remain vague. Hence, in this paper, we have systematically conducted various technologies, including Conventional Injection Molding (CIM), RHCM, IHM, and E-mold by using true 3D transient cool technology. Through the inside mechanism investigation from time to time, the functions and the heating-cooling efficiency for each technology can be visualized. Finally, experimental study and verification of IHM is also performed.

Introduction

In recent years, people applied high mold temperature to eliminate weld lines, reduce molding pressure, residual stress, clamping force and improve part surface quality. However, with the increasing of mold temperature, the cycle time will also be increased. Hence, people have paid the attention to mold temperature control technologies. Among them, the variotherm molding technologies, including Rapid Heat Cycle Molding (RHCM), Induction Heating Molding (IHM), and Electricity Heating Mold (E-mold), are some effective methods described briefly as following (Chen 2004, Chen 2006, Chiou 2007, and Chiou 2009).

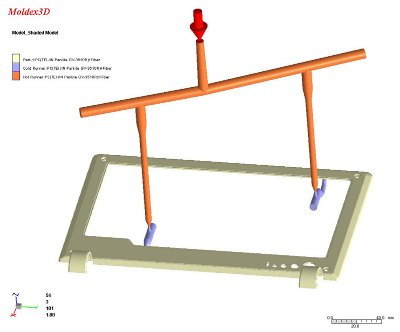
RHCM process generally is applied hot steam to raise the mold temperature during filling phase, and rapidly cool the mold at the beginning of packing. In each cycle, the mold temperature is changed from high to low back and forth. The disadvantages of RHCM process are full moldbase heating, long cycle time, special heating/cooling channel design, complex switchover control and vapor heating equipment. Moreover, IHM process is electromagnetic field inducing eddy current which generates heat within worked piece. IHM designs induction coil for cavity shape, and the coil's current and the distance to mold surface determine the heating rate. The advantages of IHM process are localization heating, i.e. it is not necessary to redesign mold, but the disadvantage is non-homogeneous heating in large areas may occur possibly. Furthermore, the application of E-mold process is to heat the moldbase electrically up to extremely high temperature. Its advantage is uniform high temperature distribution, but the disadvantages are high energy wasted, lower heating rate, and mold design collected. Although various variotherm technologies have been proposed, how does the external or internal heating source affect the injection molding process and the final product? The true function and the efficiency study of each technology still remain vague.

Hence, in this paper, we have systematically conducted various technologies, including Conventional Injection Molding (CIM), RHCM, IHM, and E-mold by using Moldex3D 3D Transient Cool technology. Through the inside mechanism investigation from time to time, the functions and the heating-cooling efficiency for each technology can be visualized. Finally, experimental study and verification of IHM is also performed.

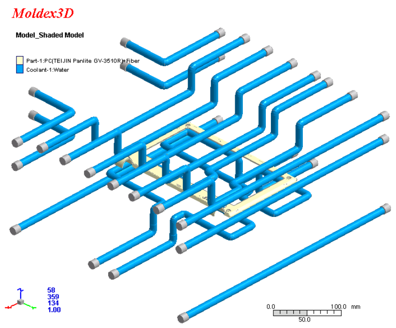
Investigation Procedures

The geometrical model and runner system for CIM are shown in Figure 1. The dimension of this part is 225 mm (length) x 164 mm (width), and the main thickness is 1.5 mm. Moreover, the operation conditions are listed in Table 1. The polycarbonate (PC) produced by Teijin was used. To remove surface defects of injection molded part and improve its quality, the temperature increase on the surface of cavity side up to 150°C at the beginning of filling for RHCM, IHM, and E-mold processes is employed. In order to reach 150°C on the surface of cavity side, 180°C steam (see Figure 2) is set to heat cavity side for 25 seconds in RHCM process. Similarly, apply the induction heater to heat cavity side for 4 seconds in IHM process. Also, use the electricity heater to heat cavity side for 8 seconds in E-mold process.

The time sequence of each cycle for different processes is in Figure 3. In CIM process, the water temperature on both cavity side and core side is 80°C, and the cooling time and cycle time are 10.7 and 19.2 seconds respectively. In RHCM process, the water temperature on the core side is 80°C. The 180°C steam is used to heat cavity side from open mold time to filling time. During packing and cooling phases, water with 55°C is used to cool the cavity side. The cooling time and cycle time are 25 and 58.5 seconds respectively. In IMH process, the water temperatures on the core side and cavity side are 80°C and 60°C. The cooling time and cycle time are 12 and 24.5 seconds respectively. In E-mold process, the water temperatures on the core side and cavity side are 80°C and 60°C. The cooling time and cycle time are 50 and 62.6 seconds respectively.



(a)



(b)

Figure 1 The system construction: (a) the runner system (b) the cooling channel layout.

Table 1 Process Conditions Setting

Filling time	0.5s
Packing time	3s
Melt temperature	285°C
Pack pressure setting	
0~0.5s	160MPa
0.5s~1s	140MPa
1s~1.5s	120MPa
1.5s~3s	80MPa

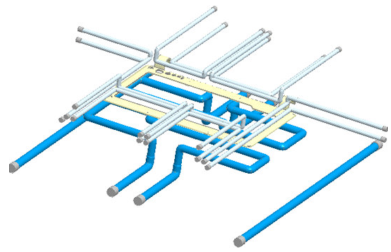


Figure 2 the coolant channel of RHCM

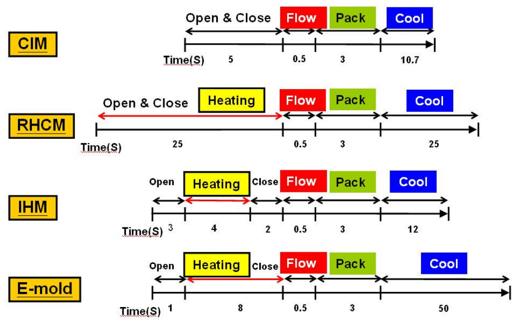
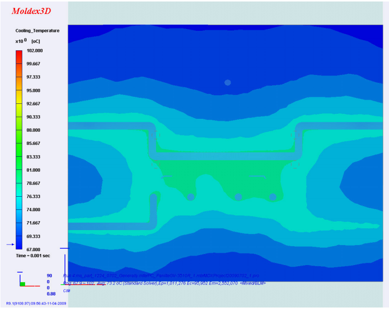


Figure 3 The time sequence of each cycle for different processes.

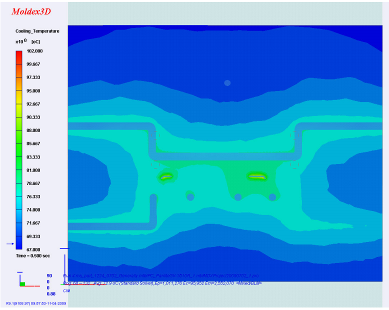
Result and Discussion

Figure 4 shows the temperature distribution of moldbase at the end of filling in CIM process. The high temperature region is located in the center of moldbase with highest temperature of 106°C. Figure 5 shows the temperature distribution of moldbase during filling phase in RHCM. Obviously, the high temperature region is located around steam channel during filling phase. Figure 6 shows the temperature distribution of moldbase in filling phase in IHM process. Since the heating method is via the mold surface using electrical power, the high temperature region is located on the surface of cavity side at the beginning of filling. Also, at the end of filling, the temperature is cooled down. Finally, Figure 7 shows the temperature distribution of moldbase during filling phase in E-mold process. A high temperature region occurs around the heater when using the electrical heating.

Furthermore, the usage benefits of high mold temperature for the quality improvement of injection parts can be verified via the temperature distribution around the weldline location as shown in Figure 8 and Table 2. Apparently, the application of variotherm technologies, including RHCM, IHM, and E-mold, makes the surface temperature raised up at the end of filling. The strength of the weldline is therefore enhanced.

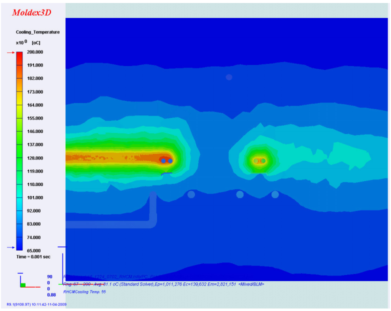


(a) 0.001s

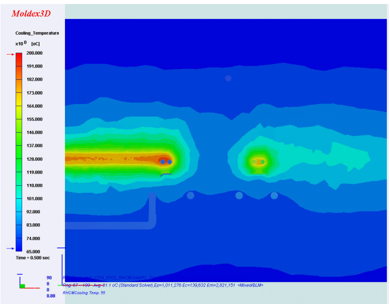


(b) 0.5s (end of filling)

Figure 4 Temperature distribution of moldbase during filling phase in CIM process.

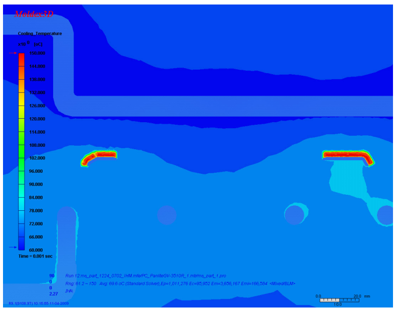


(a) 0.001s

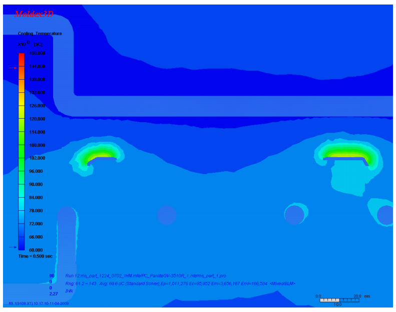


(b) 0.5s (end of filling)

Figure 5. Temperature distribution of moldbase during filling phase in RHCM process

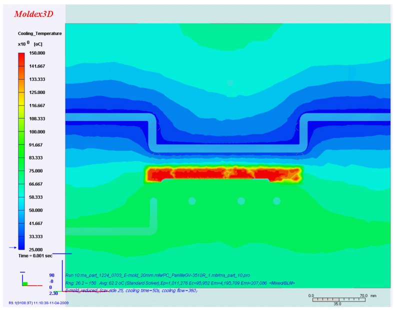


(a) 0.001s

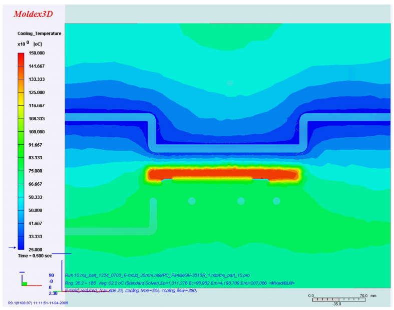


(b) 0.5s (end of filling)

Figure 6 Temperature distribution of moldbase during filling phase in IHM process



(a) 0.001s



(b) 0.5s (end of filling)

Figure 7 the temperature distribution of moldbase during filling phase in E-mold process

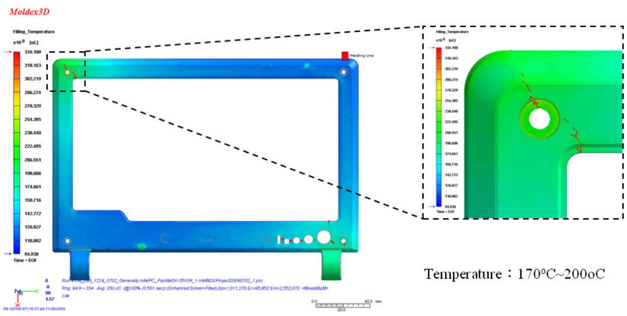


Figure 8 Temperature distribution around the weldline location at the end of filling for CIM.

Table 2 Temperature distribution around the weldline location for various technologies

	Weldline temperature
CIM	170°C ~200°C
RHCM	190°C ~220°C
IHM	205°C ~235°C
E-mold	210°C ~240°C

Moreover, we also considered the temperature history after cooling phase. Figure 9 shows the temperature distribution inside the mold at the end of cooling for various processes. In CIM and IHM processes, it needs only 12 seconds to cool down to 90°C. However, in RHCM and E-mold processes, it needs more than 25 seconds to cool down to 90 oC. In IHM process, it could reach 90°C just similar to that of CIM. Of course, the cooling period depends on how much heating source we have introduced.

Regarding the quality issue, warpage behavior is of vital importance. Figure 10 shows the Z-displacement. It is clear that when the thermal system is changed, the warpage behavior is changed accordingly. However, since the introduced heating amount and source is not optimized, the warpage trend doesn't seem to improve much either Z-displacement or total displacement.

Furthermore, to verify the simulation, one of variotherm technologies based on IHM is performed. To catch the temperature variation along the injection history from cycle to cycle, the sensors are set and located as shown in Figure 11. The basic construction and operation conditions are described in Table 1 and Figure 3. Figure 12 shows the temperature history curve sensed from three sensors numerically. The temperature is heating up to 230^{o}C and cooling down back and forth from cycle to cycle. Also, Figure 13 displays the comparison between the numerical simulation and experimental results for temperature history curve at sensor S1. Clearly, the trend is in a reasonable agreement. Finally, the warpage behavior is also evaluated both numerically and experimentally. Figure 14 demonstrates the locations and numbers of each measure node for displacement measurement. Figure 15 shows the Z-displacement behavior from the front view for both experimental and simulation results. The trend is matched well. Table 3 shows the amount of Z-displacement. Obviously, both numerical simulation and experimental result are in a good agreement.

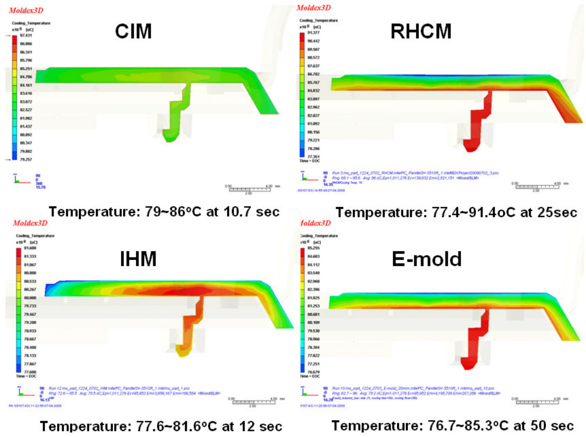


Figure 9 the temperature distribution inside the mold at the end of cooling

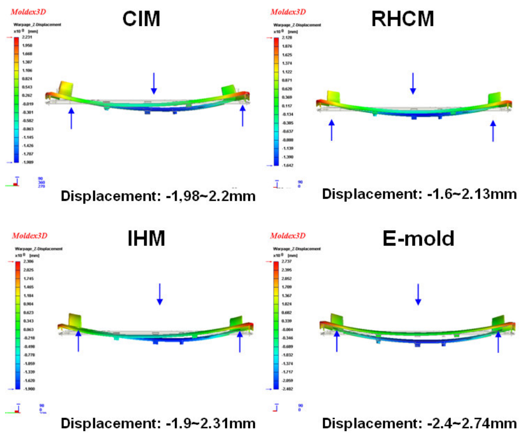


Figure 10 Z-displacement results

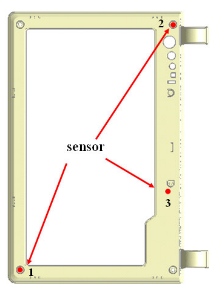


Figure 11. The location of sensors to measure the temperature variation in IHM experiments.

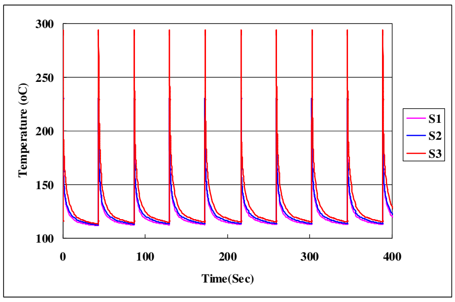


Figure 12 Temperature history curve for three pre-installed sensors.

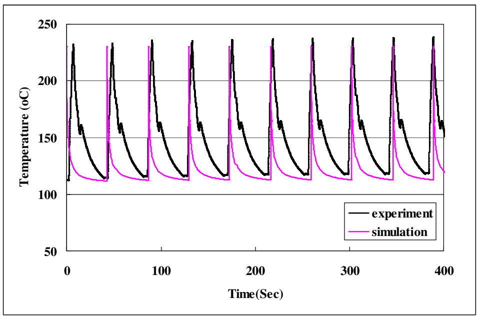


Figure 13. The comparison between the numerical simulation and experimental results for temperature history curve at sensor S1.

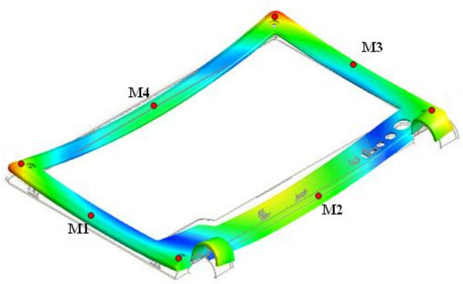
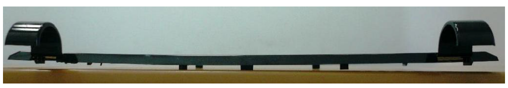


Figure 14. The locations and no. of measure nodes for displacement measurement.


(a)

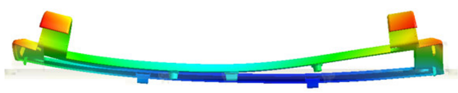

(b)

Figure 15 The displacement measurement based on IHM: (a) experimental result, (b) simulation result.

Table 3 the compare of Z-displacement between experiment and simulation.

Displacement (mm)	M1	M2	M3	M4
Experiment	0.2	1.4	0.2	0.8
Simulation	0.2	1.29	0.17	0.66

Conclusions

In this study, we have systematically studied CIM and various variotherm technologies, including RHCM, IHM, and E-mold, numerically. Through 3D transient behavior investigation inside the moldbase, the dynamic feature of the temperature can be obtained. This technique can help us to realize the thermal history from location to location and also from time to time for various technologies. To verify this technique, the experimental study based on IHM is also performed. Through the temperature history curve and Z-displacement measurement, both numerical and experimental results are in a good agreement.

References

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