THERMAL FEATURE OF VARIOTHERM MOLD IN INJECTION MOLDING PROCESSES

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Abstract

With the development of variotherm mold temperature control, people use this technique to fit the special demands in injection molding. Not only the present mold temperature settings, but also the temperature distribution of the previous state will affect mold temperature. Especially when there are multi-layout of mold temperature controls with different heating sources and cooling sources, whole mold temperature properties would be very sensitive. As a consequence, we study mold temperature control system through CAE simulation, and discuss thermal features of different variotherm processes.

Introduction

In the injection process, the design of the cooling system is an important factor. A good cooling system can reduce cycle time and improve the part quality. In the convectional cooling system, suppose the temperature distribution between cooling channels and part stays stable. It is reasonable to use the cycle-average temperature to analysis the molding process. However, when the coolant temperature no longer keeps constant in the variotherm process, the cycle-average approach is not applied suitably any more. As a result, it is important to simulate the temperature distribution of moldbase by the transient analysis. No matter what time to switch coolant settings, the temperature distribution can be observed at any time in the variotherm process.

Rising the mold temperature in the filling stage of injection molding has a lot of advantages: to enhance the fluidity, to improve the product quality [1] and to strengthen the intensity of welding line. However, high mold temperature will increase cooling time to cool down part temperature. In the variotherm process, with the advantage of high mold temperature during filling stage and proper settings, the cooling time will not increase, and then the cycle time will not rise accordingly. There are a lot of kinds of variotherm process, such as rapid heat cycle molding (RHCM) process [2], pulsed cooling process, coolant temperature switch, etc. The mold temperature variation is usually significant in these variotherm processes. It is worth studying how to control temperature to reach the expect result in the variotherm processes.

Theory

Energy Conservation

The overall heat transfer phenomena is governed by a three-dimensional Poisson equation,

$$\rho C_P \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) \qquad (1)$$

where T is the temperature, t is the time, x, y, and z are the Cartesian coordinates, ρ is the density, C_P is the specific heat, k is the thermal conductivity. Equation (1) holds for both moldbase and plastic part with modification on thermal properties.

Initial Condition

The initial mold temperature is assumed to be equal to the input of initial settings. The initial part temperature distribution is obtained from the analysis results at the end of filling and packing stages.

$$T(0,\bar{r}) = \begin{cases} T_c, & for\ \bar{r} \in \Omega_m \\ T_p(\bar{r}), & for\ \bar{r} \in \Omega_p \end{cases} \qquad (2)$$

Boundary Conditions

Heat of the molten plastic part is removed by the coolant flowing through the cooling channel as well as the ambient air surrounding the exterior surfaces of the mold base via a heat convection mechanism. In this study, the effect of thermal radiation is ignored. The conditions defined over the boundary surfaces and interfaces of the mold are specified as,

$$for\ \ t \ge 0, \quad -k_m \frac{\partial T}{\partial n} = h(T - T_o) \qquad (3)$$

Where n is the normal direction of mold boundary.

On the exterior surfaces of the mold base Γ_m:

$$h = h_{air}, T_0 = T_{air} \quad for\ \bar{r} \in \Gamma_m \qquad (4a)$$

On the cooling channel surface Γ_c:

$$h = h_c, T_0 = T_c \quad for\ \vec{r} \in \Gamma_c \qquad (4b)$$

The heat transfer coefficients h_c and h_{air} are obtained from the empirical equations cited in the standard text of transport phenomena.

Numerical Discretization Method

In this study, a numerical solver based on Finite Volume Method (FVM) is developed to solve the governing equations. The solver has been successfully applied in injection molding filling simulation [2]. Numerical experiments confirm the reliability and efficiency of the solver. Currently the proposed solver can handle tetra, hexa, prism, pyramid, and mixing elements. Prism layer element can also be used for analysis to improve thermal boundary resolution while without extensive refining of mesh. This is valuable in mold cooling analysis that may involve millions of elements.

Results and Discussions

In the variotherm process, the cooling channels may carry high temperature steam as heating rods for filling phase and carry low temperature coolant as cooling channels for packing and cooling phases. Figure 1 shows the geometry of the molded part and cooling channels in the model for this study. The dimension of moldbase is 17.5 cm x 21.2 cm x 8.9 cm. The part thickness is 1mm. Figure 2 shows sensor locations in the moldbase.

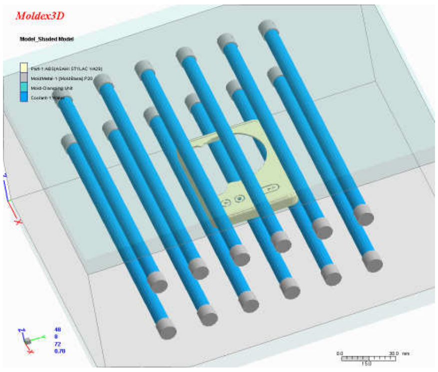


Fig. 1 Geometry of molded part and cooling channels

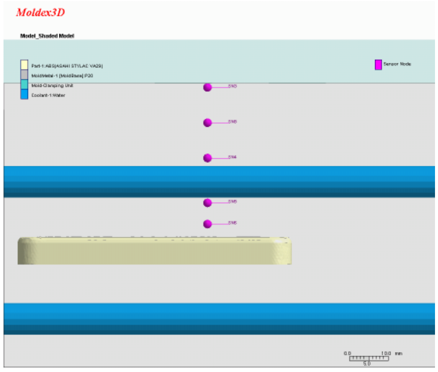


Fig. 2 The location of sensors in the moldbase

In this study, a time control variotherm molding process is adopted to compare with a temperature control variotherm process. In the time control variotherm molding process, the timings of switching coolant temperature had been decided before molding. The process condition settings for the time control variotherm molding process are listed in Table 1. In the temperature control variotherm process, the temperature criteria of process are listed in Table 2. And coolant temperature of heating is set as 120℃ to increase the heating speed. This analysis result will provide an optimized time results for time control variotherm molding process. Simulation results will be discussed in the following descriptions.

Table 1 Process settings for the time control variotherm molding process

Melt Temperature	225℃
Ejection Temperature	110℃
Coolant temperature (Heating stage during filling)	100℃
Coolant temperature (Cooling stage during packing and cooling)	25℃

Table 2 Temperature criteria of the temperature control variotherm process

Heating stage criteria (Coolant temperature 120℃)	Part Surface temperature greater than 100℃
Cooling stage criteria (Coolant temperature 25℃)	Part temperature smaller ejection temperature 110℃

The time control variotherm process

Table 3 shows the timings of switching coolant temperature. Figure 3 shows the average moldbase temperature of variotherm process in cycles. Figure 4 (a) shows the mold temperature distribution in the heating stage, and Figure 4(b) shows the mold temperature distribution in the cooling stage.

In order to heat up the mold to the initial temperature, the preheating time is an issue for variotherm molding process. The proper preheating time will save energy and sure the success of first shot. By tracing the mold temperature history rising from room temperature, heating time can be observed from the history diagram (Figure 5).

Table 3 The coolant switch time for the time control variotherm molding process

Preheating time	124 sec
Cooling time	5 sec
Heating time	30 sec

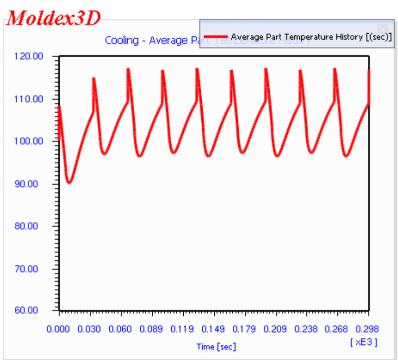
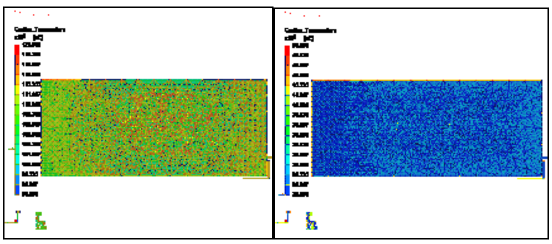


Fig. 3 The average moldbase temperature variotherm process with cycles



(a) (b)

Fig. 4 Moldbase temperature distribution in conventional molding process in period of (a) Heating stage (b) Cooling stage

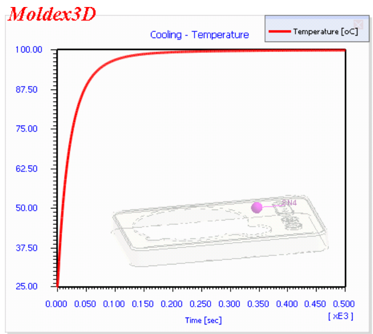


Fig. 5 The average moldbase temperature variotherm process from room temperature to initial heating temperature

The temperature control variotherm process

One of challenges in the variotherm process is to decide the time of heating and cooling. It is hard to make sure that the mold temperature has reached the required temperature. Since the melt only contacts the cavity and the other areas in the moldbase do not influence part directly, the heating time can be decreased by only considering the surface temperature of part.

Through the CAE tool, the temperature of the whole part surface can be monitored. Heating time is decided by that if the minimum mold temperature is high enough. And the cooling time is decided by that if the whole part temperature reaches the ejection temperature. Based on the above two criteria, the optimized history result shows on Figure 6. From the optimized result, the settings of coolant switch timing can be found and shown in Table 4. Figure 7 shows the temperature history which is the simulation result by applying new coolant switch timing. Figure 8 shows the temperature history on sensor which is nearby the part, comparing with temperature history which is nearby coolant layout (Figure 9). The temperature history of coolant layout shows greater variation than that nearby part. Furthermore, from the temperature history which is nearby moldbase surface (Figure 10), the temperature variation is more stable than previous ones. That shows that the heat transfer effect from cooling channels is not significant on regions far from cooling channel layouts.

Table 4 The coolant switch time from optimizing result of the temperature control variotherm process

Preheating time	51 sec
Cooling time	6 sec
Heating time	26 sec

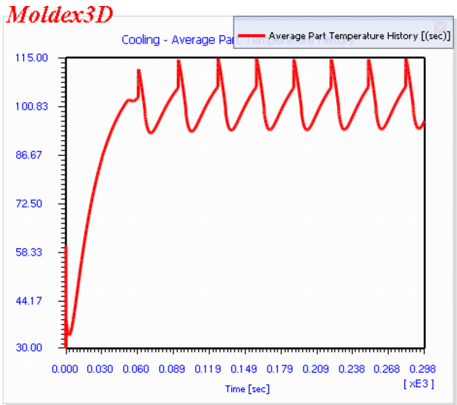


Fig. 6 The optimizing history result which follows the temperature criteria

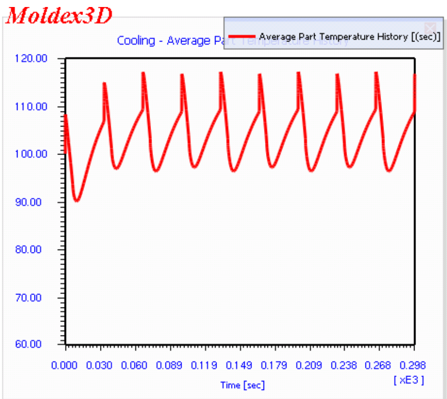


Fig. 7 The history result with optimizing time settings

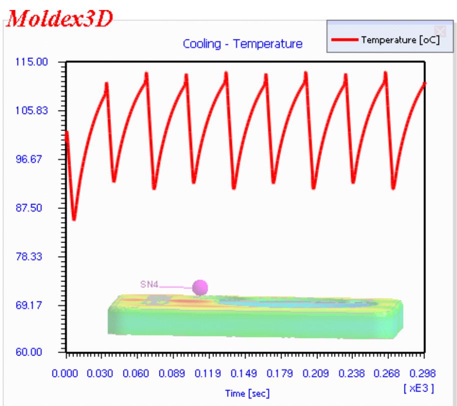


Fig. 8 The temperature history on sensor which is nearby the part

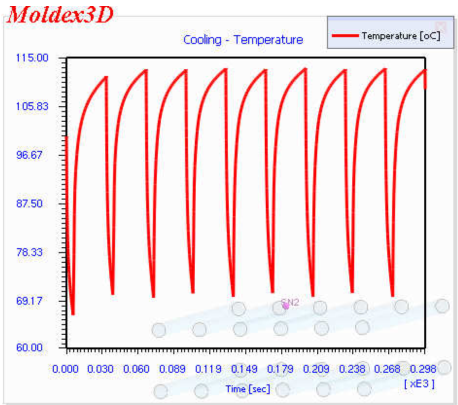


Fig. 9 The temperature history which is nearby coolant layout

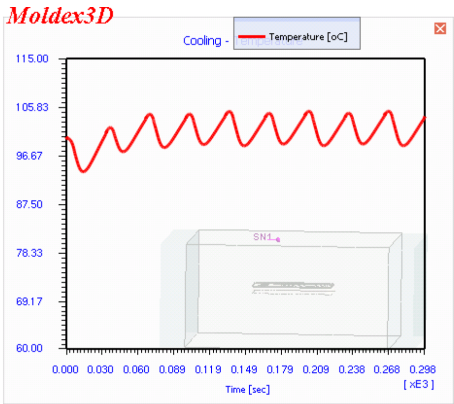


Fig. 10 The temperature history which is nearby moldbase surface

Conclusions

In this research, the mold temperature histories at the sensor locations can be observed. The temperature variations which are at different sensor locations show different thermal characters. By means of a further application of optimizing the time of heating and cooling by monitoring temperature histories in specific areas, the efficiency of variotherm process can be increased without providing too much heat on the unnecessary area. We can see that molding by optimizing variotherm molding process, the cycle time can be decreased. This result also demonstrates the advantage of the simulation tool to handle the properties of variotherm process.

References

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Key Words: 3D, RHCM, Mold Cooling, simulation, fully transient