INTEGRATED TRUE 3D SIMULATION OF RAPID HEAT CYCLE MOLDING PROCESS

Yan-Chen Chiou, Ya-Yuen Chou, Hsien-Sen Chiu,,Chau-Kai Yu and Chia-Hsiang Hsu
CoreTech System Co., Ltd., Hsinchu, Taiwan

Abstract

In the Rapid Heat Cycle Molding (RHCM) Process, the mold temperature is rapidly changed in each cycle to improve part quality and reduce cycle time. In this paper, an integrated fully transient true 3D approach is proposed by considering the interplay between filling/pack and cooling stages to study and further optimize the RHCM process. The agreement between simulation and experiment demonstrates the capability of the proposed numerical model.

Introduction

In order to improve the quality characteristic of molded parts such as welding lines, sink mark, and exposed fibers, increase the mold temperature is the conventional solution. Furthermore, parts like ultra-thin parts, stress free parts, and micro parts, are also in need of raising mold temperature during the injection process. However, with the increase of mold temperature, the cycle time will also increase. Thus, the Rapid Heat Cycle Molding (RHCM) process is introduced to improve the part quality in a reasonable cycle time. The so-called RHCM process is to raise the mold temperature during filling phase, and rapidly cool the mold at the beginning of packing. Thus the welding lines of molded parts could form in high temperature, and the fact that the cooling process starts at a low temperature could shorten the required cycle time. Due to its excellent balance in product performance and production cost, RHCM has gained a lot of attention in plastic injection molding industry recently.

In the RHCM process, the mold temperature is rapidly changed in each cycle. Thus, the conventional cycle-averaged approach is no longer applicable to predict the rapidly change of mold temperature in RHCM process. In previous study, a true 3D and transient thermal response heating and cooling analysis model has been proposed [1]. In this research, an integrated fully transient true 3D approach is proposed by considering the interplay between filling/pack and cooling stages. Moreover, a further application of RHCM process is discussed and the use of RHCM process in micro-injection molding is taken into consideration.

Theory

Energy Conservation

During the molding cooling process, a three-dimensional, cyclic, transient heat conduction problem with convective boundary conditions on the cooling channel and mold base surfaces is involved. The overall heat transfer phenomena is governed by a three-dimensional Poisson equation,

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

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 mold base and plastic part with modification on thermal properties.

Initial Condition

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

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

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 work, the effect of thermal radiation is ignored. The conditions defined over the boundary surfaces and interfaces of the mold are specified as,

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

Where n is the normal direction of mold boundary.
On the exterior surfaces of the mold base Γ_m:

$$h = h_{air}, T_0 = T_{air} \quad for\ \vec{r} \in \Gamma_m \tag{4a}$$

On the cooling channel surfaces Γ_c:

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

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 work, 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

To implement the integrated fully transient true 3D approach in RHCM process, a molded part with micro-probes is adopted as the CAE simulation model. Figure 1 shows the geometry of the molded part, and there are micro-probes on each one of the cavity surfaces respectively. Cooling channels and moldbase constructions are also included in this model. Figure 2 shows the layout of cooling channel and mold-base construction. In order to demonstrate the advantage of RHCM process in such micro-injection molding, the cycle-average approach is used to simulate the conventional molding process, whereas the fully transient true 3D approach is used to simulate the RHCM process. The settings of process condition for filling and packing analyses are listed in table 1. Table 2 shows the different settings for cooling analysis in conventional molding process and RHCM process respectively. In conventional molding process, the temperature of coolant is a constant. In RHCM process, the cooling channels may carry high temperature steam as heating rods during filling phase and carry low temperature coolant as cooling channels during packing and cooling phases. The simulation results will be discussed in the following descriptions.

Conventional molding process

Figure 3(a) shows the history curve of average temperature at part surface, and figure 3(b) shows the temperature change in one shot. After several shots, the average temperature at part surface tends to be stable and the temperature difference during each cycle is within 4 ℃. Hence, the mold temperature keeps at around 75℃. The pressure distribution and the melt front pattern at the end of filling process are shown as figure 4(a) and 4(b). The slicing cut place of the moldbase temperature distribution is shown as figure 5. From the above three figures, we can see that due to the low temperature at the cavity wall, resin at micro-probes at the far end from the gate start to solidify. Thus the pressure cannot convey to the frozen part, and most tips of the micro-probe are not that sharp and some micro-probes are very short. Because that the mold temperature is not high enough to delay the solidification of resin, the micro features in this molded part cannot be well maintained therefore the replication accuracy is not acceptable.

The RHCM process

Figure 6(a) shows the history curve of part temperature in RHCM process, and figure 6(b) shows the temperature change in one shot. We can see that the mold temperature is raised to 120℃ at the beginning of filling, and is cooled as packing process starts. The average temperature of cavity surface versus time of each cycle is significantly different from figure 3(a). The temperature difference of mold temperature is much higher and is around 100℃. The simulation results of pressure distribution and melt front pattern at the end of filling are shown as figure 7(a) and 7(b) respectively. The slicing cut place of the moldbase temperature distribution is shown as figure 8, and 8(a) is temperature distribution during filling phase whereas 8(b) is during packing and cooling phases. These results show that the high mold temperature during filling phase can delay the solidification of resin and keep the resin in a liquid state, thus the pressure can convey to the tips of micro-probe during packing stage and all the micro features can be well maintained. We can see that almost all micro-probes are molded completely, and the tips of micro-probe are sharp. This tells that the replication accuracy is good under the RHCM process.

Conclusions

In this research, an integrated fully transient true 3D approach is proposed by considering the interplay between filling/pack and cooling phases. A further application of RHCM process is discussed and the use of RHCM process in micro-injection molding is taken into consideration. We can see that molding by conventional molding process, replication accuracy is not acceptable since the mold temperature is not high enough. In RHCM process, mold temperature is high enough to delay the solidification of resin and keep the resin in a liquid state, thus the replication accuracy is improved greatly. This result also demonstrates the advantage of RHCM process in the use of micro-injection molding.

Reference

[1]. Chen YuFeng, Yang Venny, Yang WenHsien and Chang Rong-Yeu, "Temperature characteristics of moldbase in RHCM process with 3D Fully

Transient Simulation", 1295, ANTEC 2006

[2]. R. Y. Chang and W. S. Yang, "Numerical Simulation of Mold Filling in Injection Molding Using a Three-dimensional Finite Volume Approach", Int. J. Numer. Meth. Fluids, Vol.37, 125-148(2001)

[3]. J. A. Chang, S. C. Chen and J. C. Cin, "Rapid Mold Temperature Control on Micro Injection Molded Parts with Aspect Ratio Micro-features", 1275, ANTEC 2006

[4]. S. C. Chen, W. R. Jong, Y. J. Chang, J. A. Chang and J. C. Cin, "Rapid Mold Temperature Variation for Assisting the Micro Injection of High Aspect Ratio Micro-feature Parts Using Induction Heating Technology", J. Micromesh. Microeng., 1783-1791, 2006

Key Words

3D, RHCM, Mold Cooling, simulation, fully transient

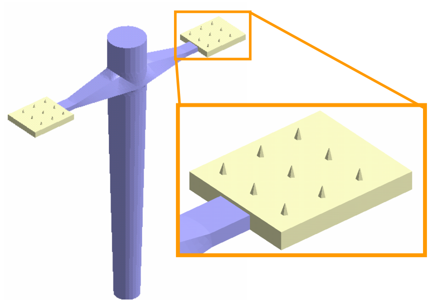


Fig. 1 Geometry of molded part

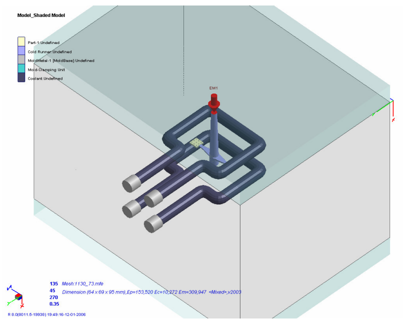
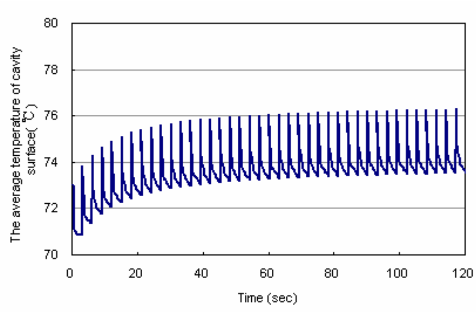
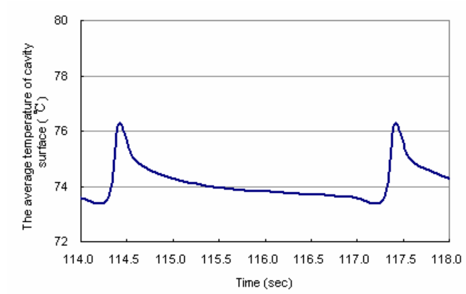


Fig. 2 The layout of cooling channel and mold-base construction

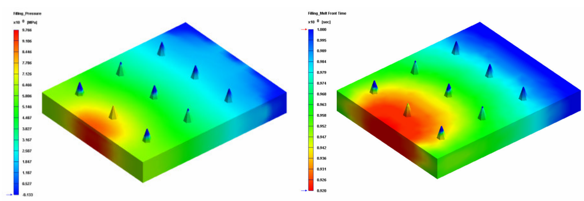


(a)



(b)

Fig. 3 The history curve of average part surface temperature of conventional molding process in period of (a) 0~120 sec (b) 114~118 sec



(a) (b)

Fig. 4 (a) Pressure distribution and (b) Melt front pattern of conventional molding process

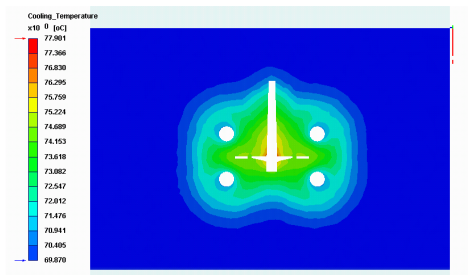
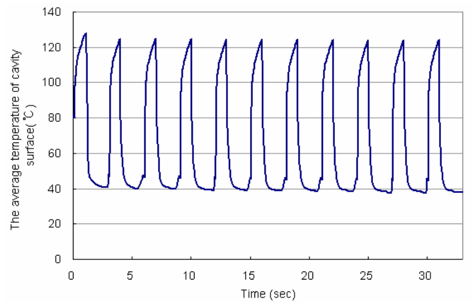
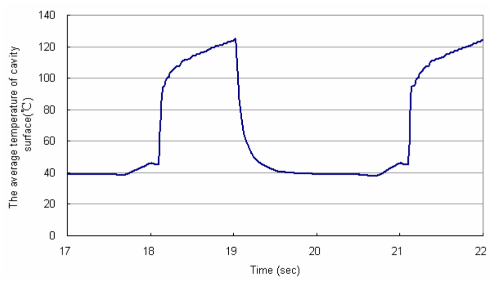


Fig. 5 Moldbase temperature distribution in conventional molding process

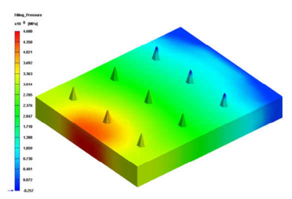


(a)

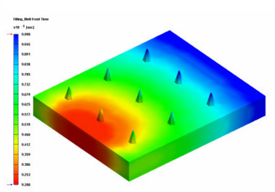


(b)

Fig. 6 The history curve of average part surface temperature of RHCM process in period of (a) 0~30 sec (b) 18~21 sec

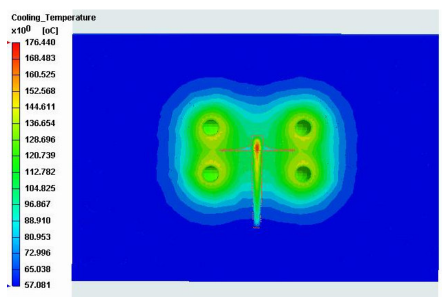


(a)

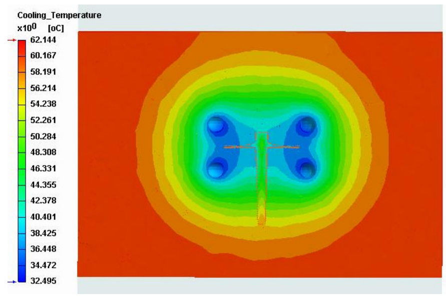


(b)

Fig. 7 (a) Pressure distribution and (b) Melt front pattern of RHCM process



(a)



(b)

Fig. 8 Moldbase temperature distribution in RHCM process during (a) filling phase (b) packing and cooling phases