

# AN INVESTIGATION ON THE TEMPERATURE BEHAVIOR IN MOLD EMBEDDED WITH HEATER

*Shia-Chung Chen<sup>1</sup>, I-Chao Wang<sup>1</sup>, Yan-Chen Chiou<sup>2</sup>, Ya-Yuen Chou<sup>2</sup> and Wen-Hsien Yang<sup>2</sup>*

*1. Mechanical Engineering Dept., Chung Yuan University, Taiwan*

*2. CoreTech System Co., Ltd., Hsinchu, Taiwan*

## Abstract

Conventionally, a mold is to be cooled by cooling channels in an injection molding process. However, the demand for the high quality plastics has popularized the varied-thermo control of mold system. An electrical heater system is one of the popular heating methods used in varied-thermo type methods for its low cost and ease of use. To achieve good efficiency, the system layout and the switchover between heating and cooling have to be properly designed and optimized. In this study, a true 3D fully transient approach is proposed to simulate the temperature behavior of mold embedded with heater. Furthermore an experimental apparatus is also set up to measure and verify this transient behavior.

## Introduction

As the advancement of modern industry, the demands for plastic parts of different varieties become more and more multiplex. Mold temperature control technology had also been developed to meet the different cooling requirement of part design. In order to obtain more uniform cooling conditions for complicated molded parts, cooling layout is developed from several parallel cooling channels to a more complicated layout according to the molded part geometry. Moreover, varied-thermo control of mold system is conducted to improve the efficiency of injection molding. Local mold heating with using electric heating rod is one of the convenient devices to control the mold temperature. For lens parts of high aspect ratio, local heating is of great help to assist melt flow and eliminate weld line and/or air trap.

CAE (Computer-Aided Engineering) has been proved to be an efficient engineering tool for part designers and mold engineers to optimize molding cooling system design parameters and verify the design on the computer before mold is build.[1]. Among the current available CAE technologies for mold cooling optimization, the cycle-averaged approach during cooling phase is used most widely. It simplifies the analysis for predicting the mold temperature, and provides approximation results in seconds. However, the cycle-averaged mold temperature assumption is only suitable for stable cooling conditions like cooling channels. For the more complicated dynamic mold temperature control switching between heating and cooling cyclically, the conventional cycle-average

approach may introduce non-neglectful prediction errors due to the significant temperature variation. Therefore, a true 3D fully transient approach becomes necessary in order to simulate such kind heating and cooling system.

Traditionally, the 3D fully transient approach for mold temperature simulation demands for very high-level hardware equipment and quite long computation time, thus such kind analysis was not widely used in decades. Nowadays there is a great improvement in both hardware and software, therefore the 3D fully transient analysis is no longer restricted and is capable of analyzing the mold temperature variation in more realistic case for mold engineers.

In this paper, a plastic lens is taken as an example to implement the true 3D fully transient approach developed in our research. Due to the uneven thickness of this concave plastic lens, the thinner part at the center of the lens may solidify first during the cooling process. This may lead to air-trap problems, which affect the transparency of lens severely. In order to prevent these air-trap problems, a heater is used to raise the temperature in the vicinity of the center area. The increase in mold temperature is expected to be helpful to the filling process. By the use of fully transient analysis, we can understand the temperature change during molding process influenced by the interplay between heaters and cooling channels. The simulation results predicted in our research will be compared with the results calculated by ANSYS. Furthermore, mold surface temperature was measure by infrared radiation thermal imaging (IRTI) system, and the experiment results can be used to validate the simulation results.

## Numerical Modeling

The temperature governing equation of true three-dimensional transient for part and mold base is listed as follows,

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

where T is temperature,  $\rho$  is density,  $C_p$  is thermal

capacity,  $k$  is thermal conductivity,  $q(t)$  is mold heater/heat resources, if no heater  $q(t) = 0$ . Equation (1) holds for both mold base and plastic part with modification on thermal properties.

For different mold temperature control technologies,  $q(t)$  is different too. For RHCM technology, i.e. high and low temperature coolant switchover for heating/cooling, also called mold temperature controller, the key points is that to determine the coolant convective heat transfer coefficient by flow numerical simulation or empirical formula calculation whether high temperature coolant or low temperature coolant, then computing the value of  $q(t)$  in eq.1. When heating by electrical heaters and cooling by icy coolant,  $q(t)$  is computed by power or an equivalent constant temperature. When using induction technology heating mold surface and cooling by low temperature coolant, the coupled electromagnetic field and thermal field should be solved (multi-field problems)[2], the results of electromagnetic field are used as input boundary and initial condition to the thermal field to determine  $q(t)$  in eqs.1. Detailed boundary condition and initial condition mathematical described can be seen in ref.[3]

In this paper, 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 [4]. Numerical experiments confirm the reliability and efficiency of the solver.

## Results and discussions

A concave lens cavity model with heater and cooling channels as shown in Fig.1 were utilized for the simulation and experiment. The heater was put in the vicinity of the lens center, and the cooling channels were put around the cavity. Fig.2 is the cut view of the meshed cavity and coolant channel. The lens part is meshed by the hexahedral element, and the coolant channels are meshed via the combination of prismatic element in the axial direction and the tetrahedral element in the juncture region. The mold base is meshed by the tetrahedral element except in the region adjacent to the coolant surface, where only pyramid element can be used.

Fig.3 is the filling pattern for this part without mold heating control. Due to the relatively thin thickness in the center region, the melt flow strongly hesitates there in comparison to the filling in the peripheral areas, leading to an obvious welding line and air trap problem for this part. A local mold heating control is expected to assist melt flow and eliminate weld line and/or air trap. Accordingly, the following discussions will focus on the three-dimensional fully transient simulation of the mold temperature control.

Fully 3D transient analysis of mold temperature field using both commercial software ANSYS and the proposed approach were carried out first for the case without mold heating by the embedded heater. After the simulation of the first cycle, the mold temperature was used as initial condition for the next simulation. Simulation continues until mold temperature reaches cyclic steady state. Within each cycle, mold temperature exhibits transient behavior. One of the simulated mold temperatures in the center slice is compared in Fig. 4, showing good agreement between ANSYS and our results. Because of the heat removal from cavity to moldbase, we can see that the mold temperature around the cavity is much higher than the other region. Fig. 5 is the comparison of the cavity surface temperature for both simulations. The center region has lower temperature than the surrounding region due to its relatively thin thickness, leading to the welding line and air trap observed both in the simulation and experiment. These figures illustrate the validity of the proposed methodology for the transient mold temperature computation without heating control.

Fig. 6 and Fig. 7 are the result comparisons for the case with mold heating by the electric heater. Again, either for the temperature prediction inside the mold base or that on the cavity surface, our results are in reasonable agreement with the results from ANSYS. Moreover, from Fig 7, we can see that the center cavity surface temperature is increased from 81 °C to around 90 °C through the heat from the electric heater. However, the 9 °C surface temperature difference cannot improve the welding line too much in this case from our filling simulation results. More testing by changing different mold temperature controls are still underway at the moment.

The temperature distribution of mold surface was also measured by infrared radiation thermal imaging (IRTI) system [5]. Several interested locations at core side and cavity side were selected as shown in Figure 8, and the mold surface temperature was detected once the mold was open. Temperature variations at these points are used to verify the simulation results, and the result comparisons are listed from table 1 to table 4. The temperature results calculated by ANSYS are also included in these tables. From the comparison through these tables, we can see that both ANSYS and our simulation methodology can predict the surface temperature in core side and cavity side well qualitatively.

## Conclusions

In this paper, a true 3D fully transient numerical approach is present to investigate the temperature behavior in mold embedded with heater. Comparing with

experiment, both the current work and ANSYS can deliver reasonable agreement. Future work is underway to investigate the effect of control parameters of mold heating on the filling patterns of the lens part studied in this paper.

### Acknowledgement

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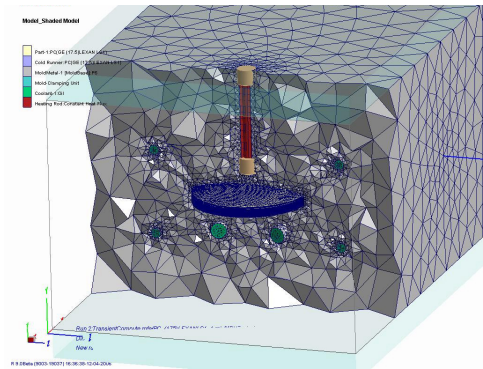


Fig. 2 The FEM mesh used in this work

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### Key Words

3D, fully transient, Mold Cooling, simulation, electrical heater

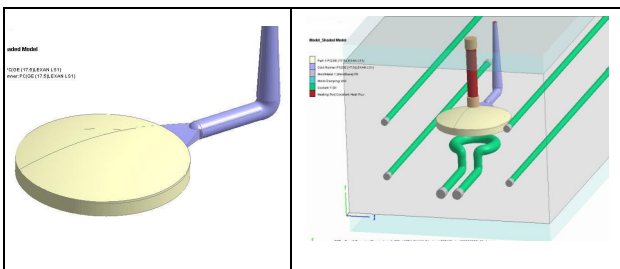


Fig. 1 Geometry and mold layout of the lens part

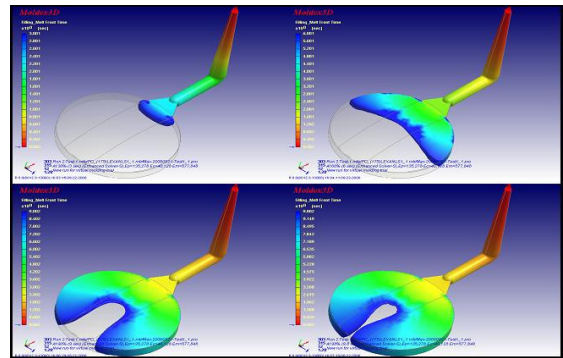
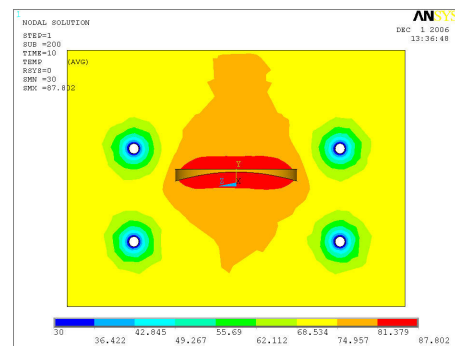
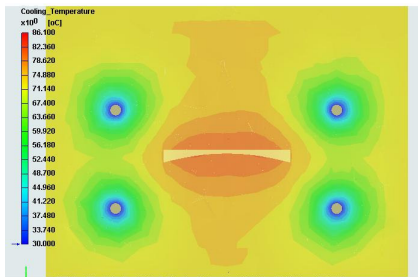


Fig. 3 The filling pattern for the lens part without mold heating control

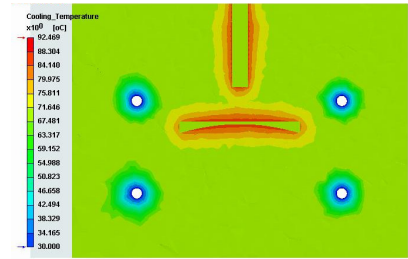


(a)



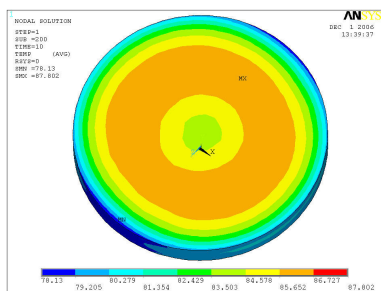
(b)

Fig. 4 Mold temperature comparison without mold heating (a) ANSYS (b) this work

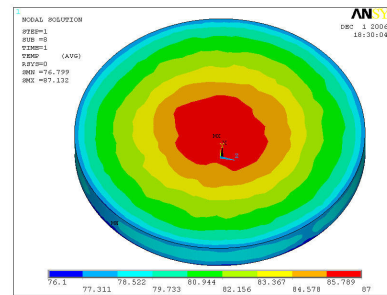


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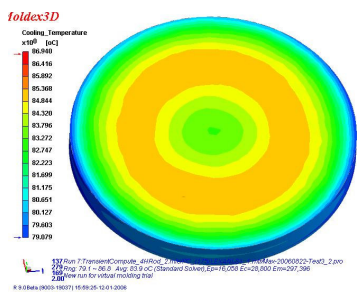
Fig. 6 Mold temperature comparison with mold heating (a) ANSYS (b) this work



(a)

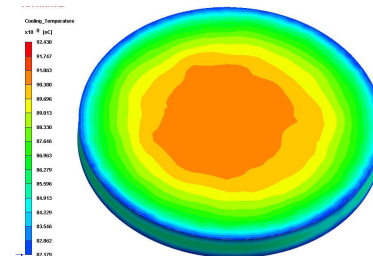


(a)



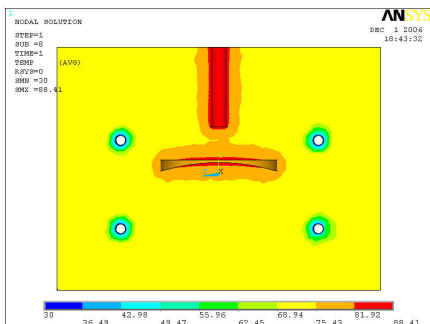
(b)

Fig. 5 Cavity surface temperature comparison without mold heating (a) ANSYS (b) this work



(b)

Fig. 7 Cavity surface temperature comparison with mold heating (a) ANSYS (b) this work



(a)

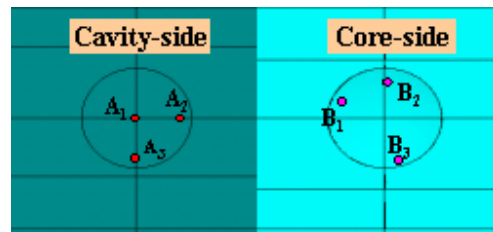


Figure 8. Location of measuring point on the part

Table 1. Temperature on the cavity-side (with heater)

	<b>A1</b>	<b>A2</b>	<b>A3</b>
<b>Exp.</b>	149°C	130°C	133°C
<b>This work</b>	134°C	117°C	114°C
<b>ANSYS</b>	195°C	154°C	142°C

Table 2 Temperature on the cavity-side (without heater)

	<b>A1</b>	<b>A2</b>	<b>A3</b>
<b>Exp.</b>	95°C	94°C	95°C
<b>This work</b>	100°C	101°C	100°C
<b>ANSYS</b>	142°C	141°C	142°C

Table 3 Temperature on the cavity-side (with heater)

	<b>B1</b>	<b>B2</b>	<b>B3</b>
<b>Exp.</b>	125°C	125°C	125°C
<b>This work</b>	105°C	106°C	106°C
<b>ANSYS</b>	144°C	133°C	135°C

Table 4 Temperature on the cavity-side (without heater)

	<b>B1</b>	<b>B2</b>	<b>B3</b>
<b>Exp.</b>	115°C	116°C	115°C
<b>This work</b>	103°C	103°C	103°C
<b>ANSYS</b>	124°C	121°C	118°C