International Journal of Research in Advent Technology, Vol.5, No.6, June 2017
E-ISSN: 2321-9637
Available online at www.ijrat.org

Modeling and Simulation of Rapid Heating and Cooling of Mold by FEA

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Abstract- Conventional injection mold (CIM) consists of core and cavity and straight cooling channels machined in a die. According to requirement of high gloss surface appearance, reduced warpage and sink mark a Rapid heating cooling mold (RHCM) is employed in molding. Various methods of heating and cooling the mold are employed in RHCM according to the dynamic temperature control required. In this work, RHCM consisting of electric cartridge heater with annular gap is designed for a mold. The aim of this study is to incorporate a Rapid heating and cooling method and for a 3 Dimensional Computer peripheral mouse part which is liable to get molding defect like sink mark, warpage and weld lines. Also the transient thermal analysis in ANSYS Workbench is performed to analyze the thermal response of rapid heating and cooling of mold on mold heating efficiency. For simulating the injection molding process and to avoid the injection molding defect occurring in molded component Autodesk Mold flow Insight software is used. Based on the results obtained from the simulation in Moldflow Insight software the design changes are incorporated in a final mold. Results of transient thermal analysis in Ansys Workbench 14.5 shows that Rapid heating arrangement with electric cartridge heater is a feasible method to heat the mold cavity to required temperature maintaining temperature uniformity of cavity surface so that the problems of shrinkage and warpage is reduced in the injection molded part.

Index Terms- Rapid heating/cooling mold, Injection molding defects, Thermal analysis of mold, Reducing injection molding defects, Rapid heating and cooling methods of mold, Conforming cooling channels in mold.

1. INTRODUCTION

Rapid heat cycle molding (RHCM) is a molding process that the mold cavity is rapidly heated to a high temperature before plastic melt injection, and then cooled quickly once the cavity is completely filled. Heating/cooling efficiency and temperature uniformity of the RHCM system are two key technical parameters to ensure a high productivity and high quality products. Currently, there are many RHCM mold temperature control systems which have been developed [1]. The cost efficiency of the process is dependent on the time spent in the molding cycle.

Correspondingly, the cooling phase is the most significant step amongst the three; it determines the rate at which the parts are produced. As in most modern industries, time and costs are strongly linked. The longer is the time to produce parts the more are the costs. A reduction in the time spent on cooling the part before it is ejected would drastically increase the production rate, hence reduce costs. The mold surface temperature is critical in the plastic injection molding process. With a high mold surface temperature, the surface quality of the part will be better, although the cooling time will increase and, accordingly, the cycle time will rise as well. The decreasing of the mold surface temperature will reduce the cooling time, but there is no benefit for the surface quality of the part [11].

2. RHCM INJECTION MOLDING

In RHCM process, the cavity surface temperature firstly heated to a preset high level, usually higher than The glass transition temperature or melt temperature of the plastic resin, before melt injection. During the following filling process, the cavity surface temperature is maintained at the high level to facilitate polymer melt filling the cavity. After the filling process is finished, the mold is cooled as rapidly as possible to lower cavity surface temperature and solidify the shaped polymer melt in mold cavity until the plastic part is rigid enough for ejection [5].

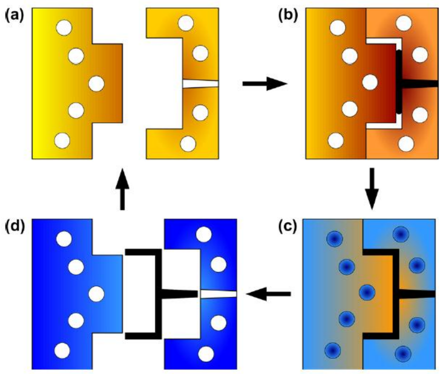

Fig. 1. Schematic diagram of RHCM process [5]

3. MODELING OF RHCM

For designing the mold and analyzing thermal response of the mold upper body of the computer peripheral mouse is selected. This part contains the curved body surface. Thermal analysis of the curved surface was often a problem and design of heating/cooling channel is difficult for complex curved shape parts. Therefore, the upper part body of computer peripheral mouse has been chosen to design a rapid heating mold and perform its thermal analysis.

3.1. *Geometric and material properties of a Computer mouse*

Fig.2. 3 D rendering view of the model

Total volume = 16.9061 cm^3
Part volume = 16.9061 cm^3
Total projected area = 47.8210 cm^3
Material = Acrylonitrile butadiene styrene (ABS).

Table 1. Material properties of ABS [2]

Material properties of ABS	
Density, ρ	1050 kg/m^3
Young's Modulus, *E*	2.519 GPa
Poisson's ratio, υ	0.4
Yield strength, S_Y	65 MPa
Thermal expansion, α	$65{\times}10^{-6} K^{-1}$
Conductivity, *k*	0.135 W/(mK)
Specific heat, *c*	1250J/(kg K)

3.1.1. Extraction of core and cavity in Catia V5

Core and cavity extraction is a primary step in mold designing. There are many software packages which includes core and cavity extraction module. Generating parting surface is a complicated task as geometrical shape of the part gets irregular. Surface modeling capacity of Catia V5R17 is remarkable; hence core and cavity surfaces and parting surfaces are extracted in Catia V5R17 Core and Cavity module.

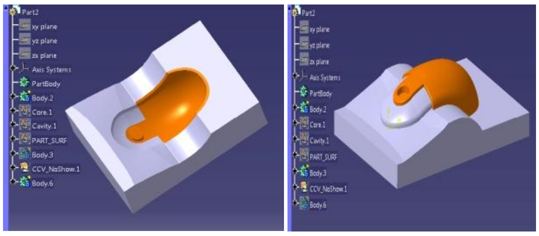

Fig. 3. Core and Cavity Insert with part body

3.1.2. Injection molding simulation in Autodesk Moldflow insight 2014

Model of upper body of computer peripheral mouse is then exported in STL file format for its analysis in Autodesk Moldflow insight 2014. In Autodesk Moldflow Insight, Molding window analysis, Gate location analysis, Fill+Pack+Warp analysis is performed to check the models for various defects of injection molding. These defects are analyzed and checked carefully so that they will not occur in injection molding process. This prior study helps the mold designer to design the mold efficiently.

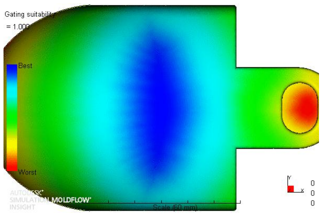

Fig. 4. Gate suitability plot

Recommended gate location(s) are:
Near node = 40184

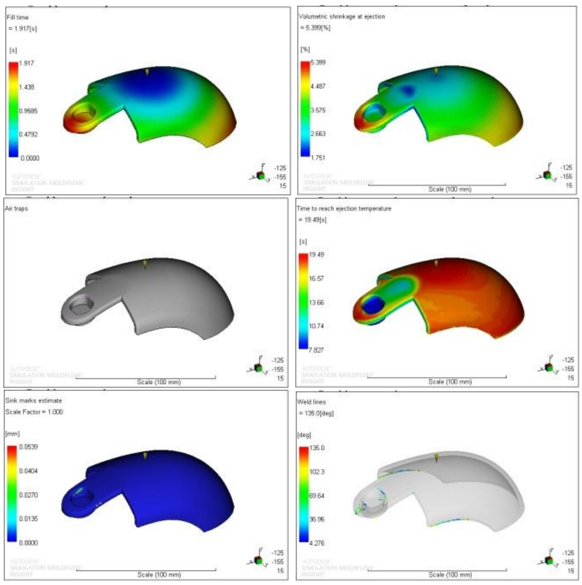

Fig. 5. Results of Fill+Pack+Warp Analysis

Fill+Pack+Warp Analysis is performed to check the part for warpage, sink marks, air traps, weld lines. From the above plots it is found that defects of shrinkage and sink marks, air traps may occur after injection molding. To avoid these defects occurring in final injection molding the injection is mold is designed accordingly.

3.2. *RHCM using Electric cartridge heater in a mold cavity*

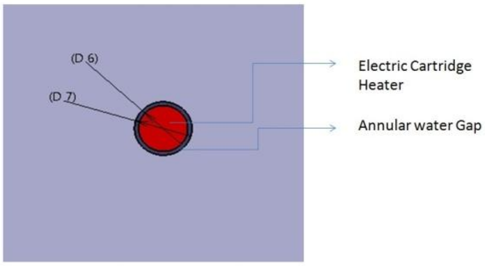

Fig. 6. Cell Model of a mold with electric heater and annular gap

In this work the electric cartridge heaters are mounted in a mounting hole so that an annular gap is formed and water is passed through the annular gap. First the water is passed through the electric heaters and then heaters are switched on so that heat is transferred from cartridge heater to the mold surfaces through this annular gap. The presence of the annular gaps can greatly simplify the installation and removal of the electric heaters. In addition, the annular gap can also be used as the coolant channel to cool the mold. Therefore, external separate cooling channels for conventional electric heating mold are eliminated.

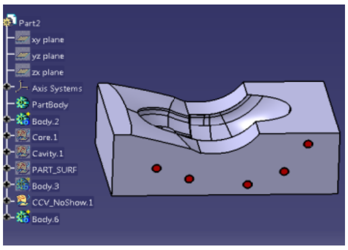

Fig. 7. Mold cavity with electric heater assembly

A layout of heating channel is designed through the results of pre analysis which is performed in Autodesk Moldflow Insight software and accordingly the position, location and number of electric cartridge heaters are selected. The centre of heater is positioned by offsetting the outer edge of geometry 1.5-2 times the diameter of heater. Cavity insert after locating the positions of heater and fixing the heaters is shown in figure above.

4. THERMAL ANALYSIS OF RHCM

As the goal is to find out the temperature uniformity and temperature at cavity surface, therefore the attention is focused on cavity insert only. In Rapid heating of mold only cavity surface is heated as only outer surface is required to have high gloss appearance and high surface finish. Therefore the attention is focused on transient thermal analysis of cavity insert half only. This model is subjected to transient thermal analysis by applying the necessary boundary conditions.

4.1. *Boundary Conditions for transient thermal analysis*

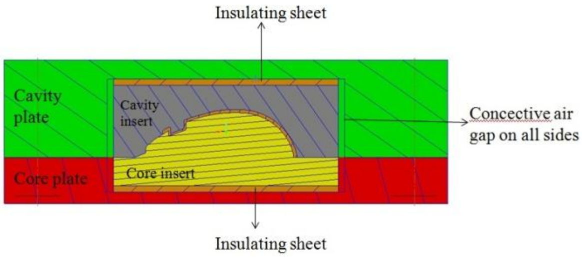

Fig. 8. Core and cavity inserts fixed in a respective plates

As the goal is to find out the temperature uniformity and temperature at cavity surface, therefore the attention is focused on cavity insert only. In Rapid heating of mold only cavity surface is heated as only outer surface is required to have high gloss appearance and high surface finish. Therefore the attention is focused on transient thermal analysis of cavity insert half only.

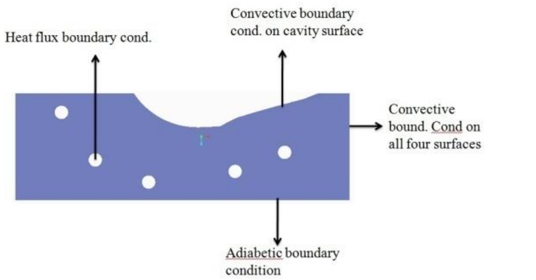

Fig. 9. Cavity insert faces subjected to boundary condition

Boundary conditions

- The initial mold temperature is the same as the ambient temperature = 30°C
- The heat exchange between the mold surface and surrounding environment belongs to air free convection, and the convection heat transfer coefficient is assumed to be 20 W/cm^2°C.
- The heat flux, the value of which equals to the power density of heating rods used, is loaded at the interface of electric heater mounting holes and

mold cavity. Assume the Effect of annular gap is considered to be negligible because it is very small and does interfere with heat transfer.

- Adiabatic heat condition is applied at the bottom surface because these surfaces are insulated with a insulating material sheet.

4.2. *Transient thermal Analysis based on numerical simulation*

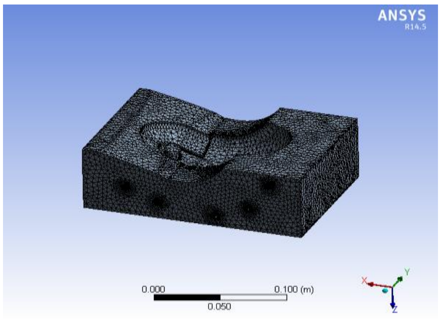

Fig. 10. FEA mesh model of the cavity insert with heating channels

Cavity half is subjected to thermal response analysis in Ansys Workbench 14.5. Thermal analysis for different power densities is performed. Thermal response analysis based on numerical simulation was conducted to investigate the influence different power densities on the temperature attained and temperature uniformity on cavity surface.

Thermal analysis simulation of Cavity half of the injection molds for 80s of time is performed. Four simulations with four heaters of power densities of 25 W/cm², 30W/cm², 35W/cm², 40 W/cm² are performed.

5. RESULT AND DISCUSSION

5.1. *Effect of heaters of different power densities on temperature uniformity*

To check the temperature uniformity of cavity surface three reference points on mold cavity are taken. These points are selected such that they cover the whole mold cavity surface. Temperature distribution and temperature versus time data for these three points are shown in figure below.

Glass transition temperature of ABS is 116.2°C. For rapid heating cavity insert is required to be heated 10°C higher than the glass transition temperature. Hence aim here is to heat the cavity surface to 125°C and that too in a minimum time.

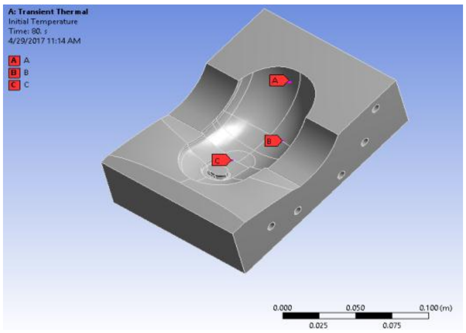

Fig. 11. Position of three different reference points on cavity surface

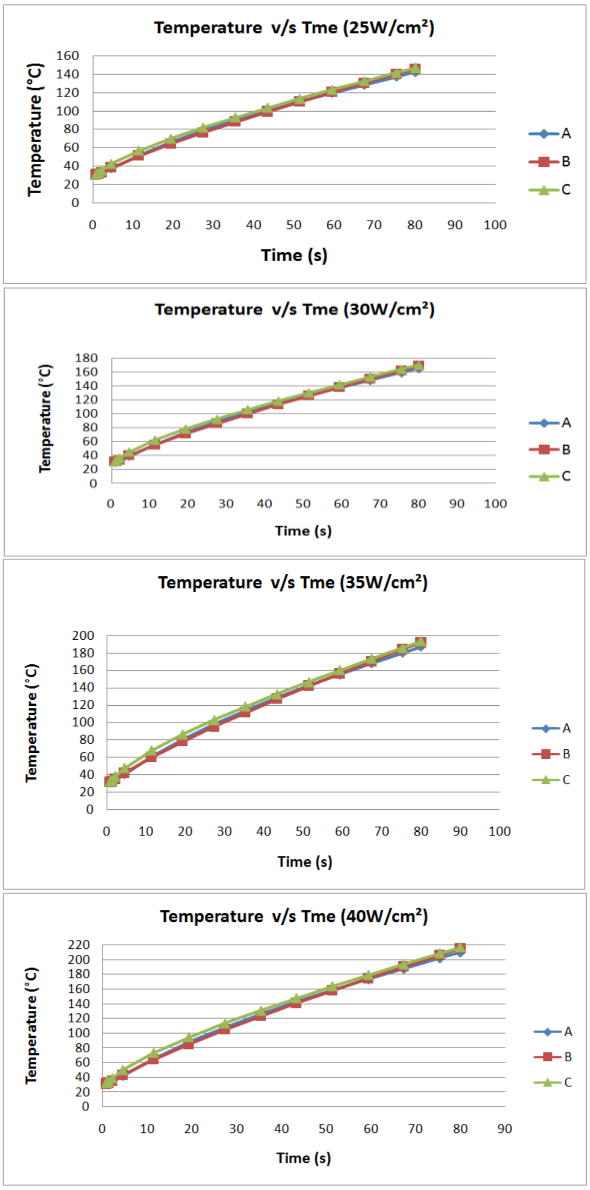

Fig. 12. Temperature response curves for three reference points with power density 25 W/cm², 30W/cm², 35W/cm², 40 W/cm² respectively.

As shown in Fig. 12, are the temperature response curves of the cavity surface corresponding four heaters of power densities of 25 W/cm², 30W/cm², 35W/cm² and 40 W/cm².

From all the graphs, temperature versus time curves for all three points overlaps very closely. Hence it can be said that cavity surface is heated uniformly with different power densities. Heating speed is increases as the heater power density increases and heating time decreases as the heater power density increases.

Table. 2 Temperature attained for three reference points

	Point A	Point B	Point C
Power density			
25W/cm²	142.3°C	145.53°C	146.54°C
30W/cm²	164.75°C	168.63°C	169.84°C
35 W/cm²	187.21°C	191.74°C	193.15°C
40 W/cm²	209.67°C	214.84°C	216.46°C

5.2. *Heating time for uniform temperature distribution*

Heating process of a mold is simulated is Ansys Workbench 14.5. Temperature versus time plot is observed for uniform temperature distribution of cavity surface. It is found that for different power densities, the uniform temperature is observed at different heating times. Temperature versus time counter plot of the cavity surface for different power densities is shown below.

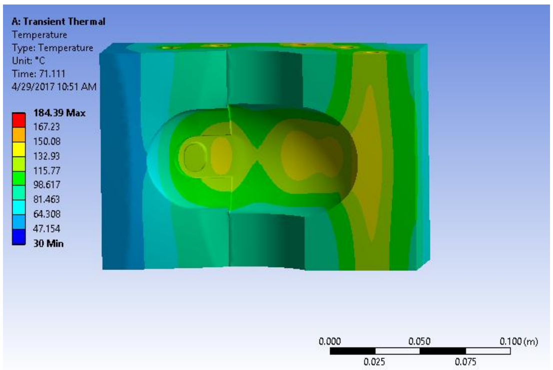

Figure 4.3.14: Temperature uniformity of mold cavity for 25W electric heater

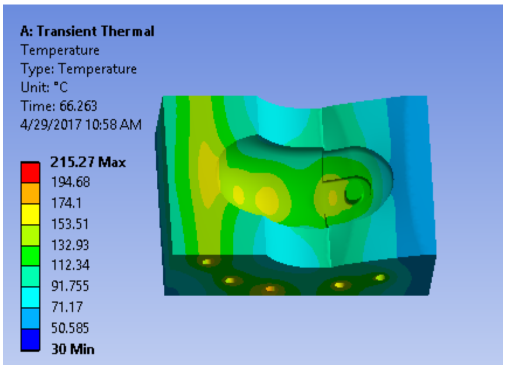

Figure 4.3.15: Temperature uniformity of mold cavity at for 30W electric heater

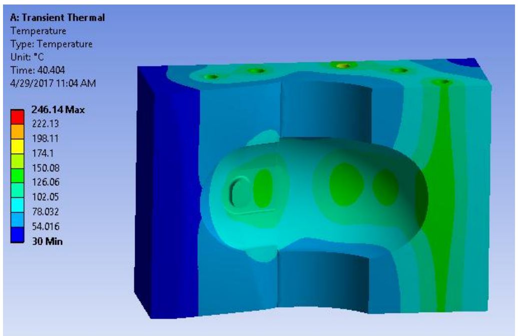

Figure 4.3.16: Temperature uniformity of mold cavity for 35W electric heater

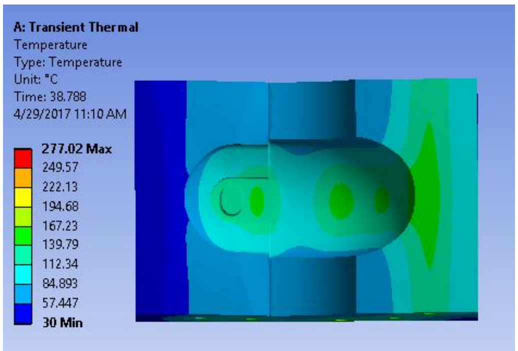

Figure 4.3.17: Temperature uniformity of mold cavity for 40W electric heater

Above temperature contour plots are the plots of simulated heating process of transient thermal analysis for the electric cartridge heater with power density 25 W/cm², 30W/cm², 35W/cm², 40 W/cm² respectively. It can be seen from the temperature plot of the heating process, the different uniform temperature are observed at different times due to variation in used power density of heating for four cases.

Table 4.3.3: Heating time obtained for heaters with different power densities

Power density	25 W/cm²	30 W/cm²	35 W/cm²	40 W/cm²
Heating time	71.11s	66.263s	40.40s	38.78s

From the table it is seen that the uniform temperature of 125°C is observed at time 38.78 s for 40 W/cm². Therefore in order to maintain the molding cycle to a minimum value and to achieve high production rate 40 W/cm² is most feasible.

6. CONCLUSION AND FUTURE SCOPE

(1) Injection molding defects are observed effectively by performing injection molding simulation in Autodesk moldflow insight software. The results of gate location analysis, Molding window analysis, Fill+pack+warp analysis are taken into consideration in designing a mold.

(2) A parting surface of a mold for a computer peripheral mouse is extracted in CATIA V5R17 Core and cavity module. Parting surface is not a planar surface since the mold cavity is complex.

(3) After generation of parting surfaces core and cavity inserts are derived by 3D modeling in CATIA V5R17. This software is capable of generating complex surfaces because of good surfacing capability

(4) A complete mold base is designed in Creo Parametric 2 from a basis structure of mold i.e core and cavity. A Hasco mold manufacturing catalogue proved beneficial for designing a mold base.

(5) Electric cartridge heaters are employed for rapid heating of a mold. Based on the injection molding simulation performed in Autodesk Moldflow Insight software, the result of the analysis are taken into account and based on that result the layout of electric heaters id decided. This layout is found to be efficient in heating the mold uniformly in later stages of analysis.

(6) Transient thermal analysis is performed in Ansys Workbench software for different power densities of electric heaters. All heaters are found to achieve the required temperature of 125°C in 80 s of heating time. All heaters heat the cavity surface uniformly but the heating time differs for different power densities.

(7) Based on the numerical simulation and graphs it is found that the heater with power density can heat the mold in 38s most efficiently than other heaters of different power densities.

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