THE INVESTIGATION OF WARPAGE BEHAVIOR BY CONSIDERING THE PROCESS-INDUCED PROPERTY VARIATION IN SEQUENTIAL OVERMOLDING

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Abstract

The crucial factors in multi-component molding (MCM) processes were difficult to identify with the conventional trial-and-error method due to its complicated nature and physical mechanism. Regarding the temperate conduction effect between two shots, we adopt directly a true 3D simulation tool to investigate. The part temperature distribution of the first shot is taken into consideration and affects the mold filling pattern of the second shot. Besides, the mechanical property of the first shot will also influence the warpage and shrinkage behavior of the second shot and the final product. Simulations can provide good guidelines to help people understand the mechanism and make the proper design to fabricate modern MCM products.

Introduction

In the modern plastic molded product fabrication, multi-component molding (MCM) is widely applied in various industries and is an efficient technology to the assembly of discrete parts. It is a process that uses two or more molds to produce a multi-material component. The first material, the first shot, is injected into the first mold by standard single material molding technique, and then moved to the next mold where the next material, the second shot, can be injected to combine with it,. Due to the complicated nature and physical mechanism of the Multi-Component Molding (MCM) processes, conventional trial-and-error method usually can not catch the crucial factors effectively.

In the filling and packing phases of MCM, the second shot is usually injected before the first shot is sufficiently cooled down to reach uniform temperature distribution. The uneven temperature may influence the filling pattern and shrinkage of the second shot, which furthermore affects the warpage behavior of the second shot and the final MCM product. Except for the temperature, the mechanical properties of the material chosen for the first shot may sway the warpage behavior of the second shot as well. The anisotropy of fiber-filled material will lead to more complicated warpage behaviors.

In this study, a true 3D simulation tool is adopted to investigate the effects the first shot on the second shot. It can be used as good design verifications to help people understand the mechanism and make the proper design tweak to fabricate modern MCM products.

Analysis Approach

The main processes of injection molding simulation are Filling, Packing, Cooling and Ejection. The part usually shrinks and warps after ejection. For the cooling process, the heat transfer phenomenon is governed by the 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, and k is the thermal conductivity. A fully-transient temperature solver of Eq. (1) was developed to simulate the cooling process.

When considering the thermal interaction of different materials in a sequential molding process, the temperature distribution of the first shot is set as the initial condition of the part insert of the second shot. And then in the second shot, the temperature variation can be calculated by employing the fully-transient temperature solver. The changes of the moldbase temperature affect the pressure and temperature in the filling and packing stages, and furthermore affect the volumetric shrinkage in the second shot.

The warpage analysis assumes the mechanical properties of plastics follow linear elasticity. The deformation can be solved by the equilibrium equation:

$$\nabla \cdot \sigma = 0 \qquad (2)$$

$$\sigma = \mathbf{C}(\varepsilon - \varepsilon_0) \qquad (3)$$

$$\varepsilon = \frac{1}{2}\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right) \qquad (4)$$

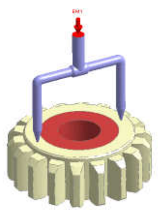
Where σ is the stress, **C** is a 4^{th} tensor related to the material mechanical properties, ε is the strain tensor, ε_0

is the initial strain caused by the PVT relationship, and **u** is the displacement.

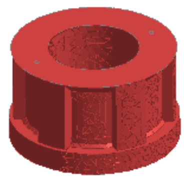
Based on the above description, the temperature distribution of the first shot had affected the volumetric shrinkage of the second shot, so the results of warpage will vary accordingly. In addition, the mechanical properties are important factor for warpage. If the material of the first shot is fiber-reinforced, its fiber orientation should be considered into analyzing the warpage of the second shot.

Results and Discussion

The test case is a MCM gear shown in Fig.1 (a), while the part-insert of this gear, so called the first shot, shown in Fig.1 (b) and Fig.1(c). The coolant systems of the first and second shots are shown in Fig.2 (a) and Fig.2 (b). The material of the first shot is PEI with fiber, while the material of the second shot is ABS. To obtain the properties and results, the XZ planes through the center of this gear are presented in Fig. 3.



(a)



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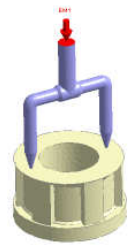
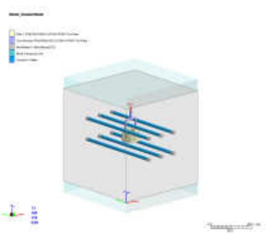
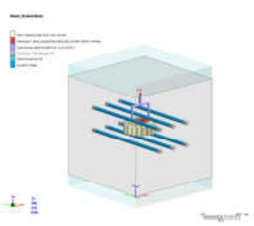


(c)

Figure 1. (a) The model of a MCM gear (Second shot). (b) The model of the part-insert in second shot. (c) The model of the first shot.

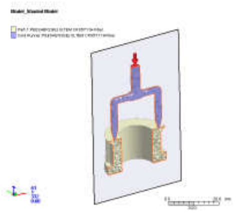


(a)

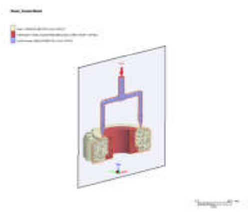


(b)

Figure 2. The full model includes the moldbase, the coolants and the cavity. (a) The first shot. (b) The second shot.



(a)



(b)

Figure 3.Slicing plane to obtain results. (a) The first shot. (b) The second shot.

As for the first shot, the cooling temperature distribution is shown in Fig.4. Its temperature range vary from 87.5℃ to 278.6℃, and the average value is 172.4℃. The results of fiber orientation are shown in Fig.5. Due to the flow direction, the primary direction of fiber orientation toward Y direction is in the center, and that toward Z direction is on the surface.

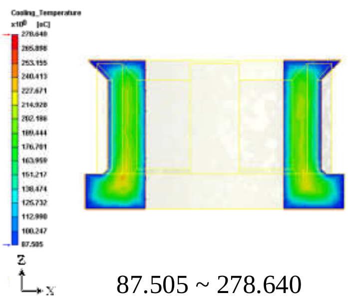
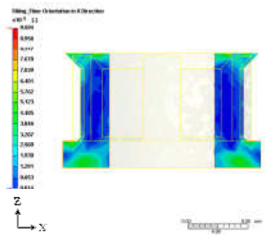
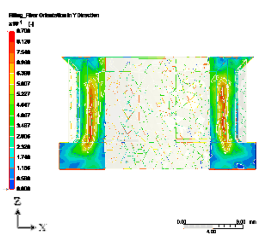


Figure 4. The cooling temperature distribution of the first shot.



(a)



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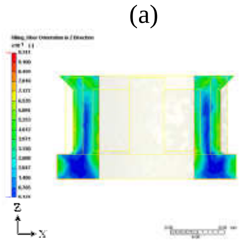


(c)

Figure 5. Fiber orientation of the first shot. (a) In X direction. (b) In Y direction. (c) In Z direction.

In order to observe the influnce of the temperature and fiber orientation from the first shot on the second shot, three settings of the second shot are used in the study. In Table 1, neither temperature distribution nor fiber orientation of the first shot is considered in Run1, the temperature distribution of the first shot is taken only in Run 2, and both of temperature distribution and fiber orientation of the first shot are considered in Run 3. The temperature distribution of three runs are shown in Fig. 6., and the volumetric shrinkages of three runs are shown in Fig. 7. Because the temperature of first shot is considered both in Run2 and Run 3, the results of volumetric shrinkage are the same in Run2 and Run3. Compared Run 1 with Run 2, the temperature of Run 2 that located in the interface between insert and part is higher, so it has larger shrinkage than Run 1.

Table 1. Runs for simulation:

Run	Consider cooling results of the first shot	Consider fiber orientation of the first shot
Run 1	No	No
Run 2	Yes	No
Run 3	Yes	Yes

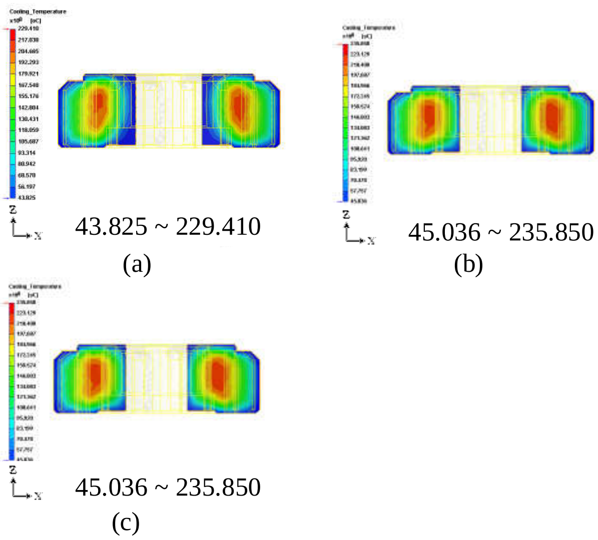


Figure 6. The cooling temperature distribution of the product: (a)Run 1. (b) Run 2. (c) Run 3.

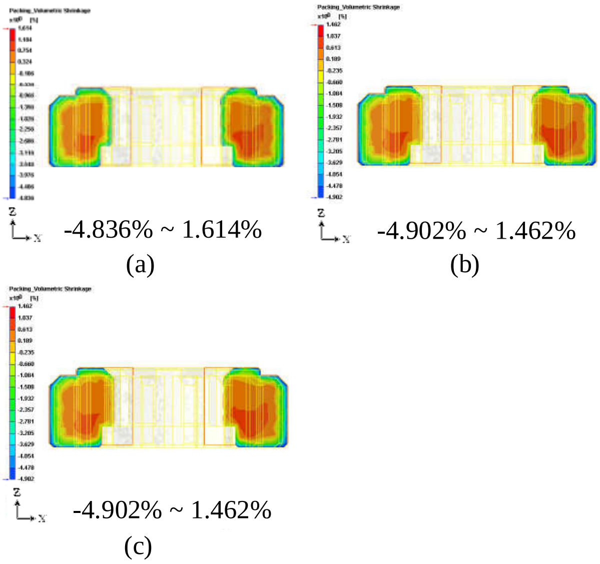
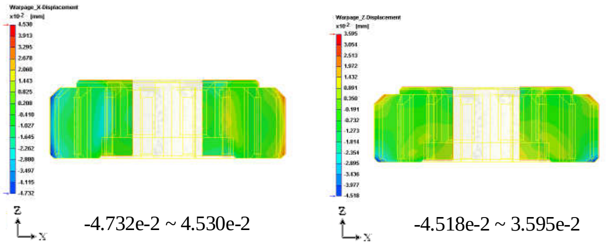


Figure 7. The volumetric shrinkage distribution of the second shot: (a)Run 1. (b) Run 2. (c) Run 3.

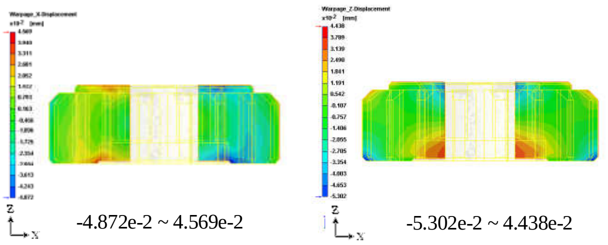
Fig. 8, Fig. 9 and Fig. 10 represents respectively the warpage results of Run 1, Run 2, and Run 3. Fig.11 demonstrates the inner and outer diameters, and Table 2 shows the vaules of inner and outer dimension. To understand how the temperature of the first shot after cooling stage affects the warpage of the second shot, the results of Run 1 and Run 2 are compared. Because of larger displacement induced by higher volumetric shrinkage in Run 2, the diamesion of Run 2 is smaller than that of Run 1. It shows the temperature of the first shot will affect the second shot indeed.

For understanding how the fiber orientation of the first shot affects the warpage of the second shot, the results comparision between Run 2 and Run 3 are discussed here. From the points of view of fiber mechanism, the fiber deformation in transverse-direction is larger than that in the axial direction. Besides, in fig. 5, it showed the main fiber orientation of the first shot is in Y direction during filling stage. Based on the above remarks, the warpage in X and Z directions of Run 3 is larger than that of Run 2. And the product diameter of Run 3 will be smaller than that of Run 2. It proves the fiber orientation of the first shot influences the warpage behavior of the second shot a lot.



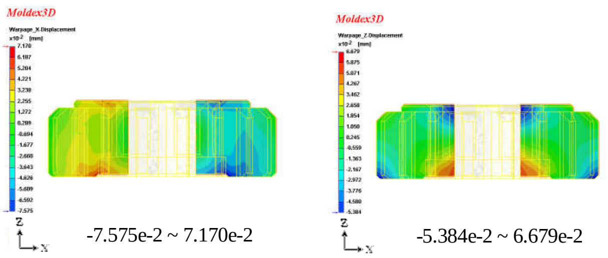
(a) (b)

Figure 8. The warpage results of Run 1: (a)X displacement. (b)Z displacement



(a) (b)

Figure 9. The warpage results of Run 2: (a)X displacement. (b)Z displacement



(a) (b)

Figure 10. The warpage results of Run 3: (a)X displacement. (b) Z displacement.

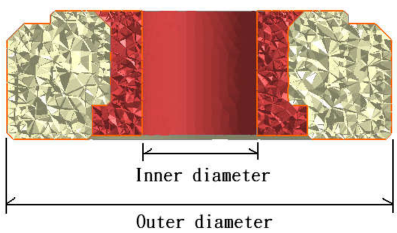


Figure 11. The Inner diameter and outer diameter of the gear.

Table 2. Inner diameter and outer diameter after warpage:

	Inner diameter (mm)	Outer diameter (mm)
Original model	13.98	46.72
Run 1	13.97	46.80
Run 2	13.94	46.76
Run 3	13.90	46.71

Conclusions

In this study, the effects of temperature and fiber orientation from the first shot are obtained by using the true 3D simulation. Through the simulation results, both of the temperature distribution and material mechanical properties of the first shot influences a lot on the warpage behavior of the second shot. In the future, experiments will be performed to verify the simulation for obtaining more accurate prediction for MCM process.

References

1. Chao-Tsai Huang, Ching-Hui Yeh and Shi-Chang Tseng,“Geometrical Effect and Material Selection in Multi-Component Molding (MCM) Development”, *SPE-ANTEC Tech. Papers*, 103493, 2006.
2. Rong-Yeu Chang, Yi-Hui Peng, David C.Hsu and Wen-Hsien Yang,“Three-Dimensional Insert Molding Simulation in Injection Molding”, *SPE-ANTEC Tech. Papers*, 2004.

Key Words: Multi-Component Molding , MCM, Warpage, previous shot.