EFFECTS OF MELT ROTATION ON WARPAGE PHENOMENA IN INJECTION MOLDING

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Abstract

Shear induced imbalanced filling in a geometrically balanced runner system is always a difficult problem to handle in injection molding. Moreover, the shear-induced temperature variation across the cross section also affects the warpage result. Previous research proposed that the melt rotation apparatus could control the warpage phenomena of parts. In this paper, we have proposed a new methodology to analyze this injection process. The comparison between the simulation and experiments can demonstrate and verify the warpage phenomena. The results show that the proposed methodology is a highly valuable tool to understand the melt rotation effects.

Introduction

The filling imbalance in geometrically balanced runner system of multi-cavities is always difficult to handle in injection molding. This phenomenon is always complicated by integration of the runner layout, runner geometry size, material, and process conditions. Previous researchers revealed that the flow imbalance problem is related to the three-dimensional thermal history and shear rate distribution of melt flow in the runner, and accordingly proposed a novel apparatus [1][2] to overturn the melt to avoid this problem. Further, these melt variations may be the root causes of warpage in many plastic parts. The packing stage also influences the deformation behavior. Both of packing time and packing pressure are the key features for the volume shrinkage and part deformation. The complicated interactions between the molding process and mold design make it difficult to understand by experience.

In this paper, we have proposed a new methodology to analyze this injection process. Firstly, a flexible meshing methodology comprising different element topologies is proposed to provide high-resolution mesh for the runner system and cavity. Further, to demonstrate and verify our idea, the comparison between simulation and experiments has been performed, including filling pattern and part deformation. From the numerical experiments, we have proven that the proposed methodology is a highly valuable tool to help understanding and further optimizing the melt flipping apparatus.

New Methodology and Simulation Approach

FVM Technology for 3D analysis

We have adopted the newly developed FVM technology to provide real three-dimensional substantial analyses. This technology is capable of analyzing real conditions such as inertia effect, non-isothermal flow, and so on. Besides, it excels in speedy and accurate calculating abilities. This makes the analysis results approach reality and thus economizes working hours; moreover, it supports mesh analyses for over a million elements!

The polymer melt is assumed to behave as Generalized Newtonian Fluid (GNF). Hence the non-isothermal 3D flow motion can be mathematically described by the followings:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u} - \boldsymbol{\sigma}) = \rho \mathbf{g} \tag{2}$$

$$\boldsymbol{\sigma} = -p\mathbf{I} + \eta\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right) \tag{3}$$

$$\rho C_P\left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \nabla(\mathbf{k}\nabla T) + \eta\dot{\gamma}^2 \tag{4}$$

where **u** is the velocity vector, T is the temperature, t is the time, p is the pressure, σ is the total stress tensor, ρ is the density, η is the viscosity, is k the thermal conductivity, C_p is the specific heat, and $\dot{\gamma}$ is the shear rate. In this work, the Modified-Cross model with Arrhenius temperature dependence is employed to describe the viscosity of polymer melt:

$$\eta(T, \dot{\gamma}) = \frac{\eta_o(T)}{1 + \left(\eta_o \dot{\gamma} / \tau^*\right)^{1-n}} \tag{5}$$

with

$$\eta_o(T) = BExp\left(\frac{T_b}{T}\right) \tag{6}$$

where n is the power law index, η_o is the zero shear viscosity, and τ^* is the parameter that describes the transition region between zero shear rate and the power law region of the viscosity curve. A volume fraction function f is introduced to track the evolution of the melt front. Here, f=0 is defined as the air phase, f=1 as the polymer melt phase, and then the melt front is located within cells with 0<f<1. The advancement of f over time is governed by the following transport equation:

$$\frac{\partial f}{\partial t} + \nabla \cdot (\mathbf{u} f) = 0 \qquad (7)$$

The flow rate or injection pressure is prescribed at mold inlet. No slip is assumed at mold wall. Note that only inlet boundary condition is necessary for the hyperbolic transport equation of volume fraction function. [3-5]

Hybrid mesh for true 3D Injection Molding Simulation

In general, to obtain a reasonable simulation result for the pre-processing, one needs to tune up the resolution of meshing for numerical simulation. However, it's hard to achieve by the traditional method. In traditional way, one has to create the geometry model in CAD software, and then generate the surface/solid mesh based on a given characteristic mesh size. By doing this way, it is very difficult to control the quality and quantity of mesh and elements. It will further increase the computation loading and thus provide the incorrect results.

To avoid this problem, here we proposed a new methodology to handle this pre-processing issue. In this way, users only need to draw lines to represent the runner layout, and set the parameters of the runner geometry. Then, the runner solid mesh can be generated automatically. Indeed, the hybrid mesh is feature of this method; shown in Fig.1 and Fig.2. Through this way, people can flexibly tune up the resolution of element layer and also retain the quality and quantity of elements. It can further enhance the efficiency of the computation and provide more reasonable results.

Boundary layer meshing method is another innovation technology, shown in Fig.3. For injection molding CAE analyses, the element layer count across the part thickness direction is very important. This is because the element layer count determines the resolution of CAE analysis results. The boundary layer meshing method is also a kind of hybrid meshing method, and it provides at least five-element layer count across thickness direction for the whole part. Thus the temperature difference caused by the shear heating phenomena at the cavity boundary can be simulated more accurately. Further, the analysis results of the filling pattern, pressure profile, and so on, can be predicted more accurately as well.

Results and Discussion

The detailed filling imbalance mechanism is provided before [1][2][6], and the imbalanced temperature distribution is also found in this study. To compare with experimental data, we prepared a two-cavity mold; the mold cavity was 25 mm wide x 120 mm long x 1.5 mm thick as seen in Fig. 4. The molded material is Acrylonitrile-Butadiene-Styrene (ABS). Based on the original design, Fig. 5 shows the imbalanced temperature distribution of the part. The hotter melt (or high shear rate region) always exists at the inner side of the runner.

The second sample is based on the original design with a melt rotation apparatus, as shown in Fig. 6. Under the same material and molding condition, we have a balanced temperature distribution in X-Y plane direction, as Fig. 7. Fig.8 is the temperature distribution in X-Z direction, and the temperature at the bottom side is always hotter than the temperature at the top side. On the top-bottom side asymmetry temperature results from the melt rotation apparatus. That is to say, the melt rotation apparatus place the high sheared melt on the bottom side of the part. A region of the part formed from the hotter temperature melt might be expected to shrink more than a region formed from the low temperature melt. The relative shrinkage difference would make a part warpage, as Fig. 9.

The volume shrinkage and warpage are also affected by packing pressure and packing time. Fig. 10 is the graph of packing time versus warpage at a constant packing pressure, published by John Beaumont [6], and Fig. 11 is the simulation result. From the analysis result, it shows that as packing time was increased, warpage was decreased from 1.1 to 0.74. The tendency of the analysis result is the same as that of the experimental data, but the magnitudes are different. This is because the packing pressures of the experimental and simulation are not exactly the same. Besides, the property of the material is another variable of this issue.

Conclusions

In this study, we have proposed a new methodology to analyze the part warpage behavior of a multi-cavity mold. By comparing the simulation and experimental results, this study shows the reason why the warpage changes in the model with melt rotation apparatus. Furthermore, the visualization result can greatly help us to realize how the melt rotation apparatus impacts on the warpage behavior. The melt rotation apparatus affects the thermal history and shear rate distribution, and thus changes the filling pattern, volume shrinkage, and part warpage. Hence, with the assistance of the CAE tool, people can realize and handle these phenomena easily and effectively.

Acknowledgements

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Reference

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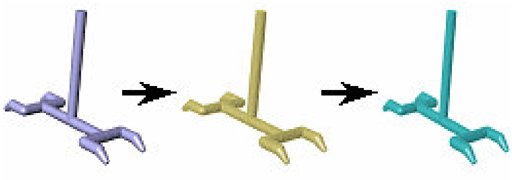
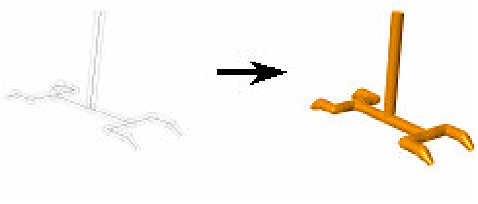
Key Words

CAE, FEM, FVM, Mesh, Injection Molding

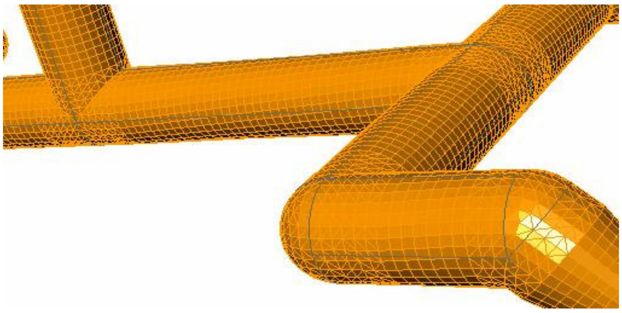


(a) (b) (c)

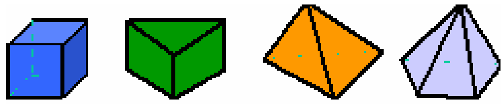
Figure 1. Create mesh flow path (traditional) (a) build geometrical of model (b) create surface mesh (c) generate the solid mesh



(a) (b)



(c)



(d) hexahedron prism tetrahedron pyramid

Figure 2. Create mesh flow path (New) (a) Use line to build geometrical of model (b) Create solid mesh (c) Hybrid solid mesh (d) Different solid element

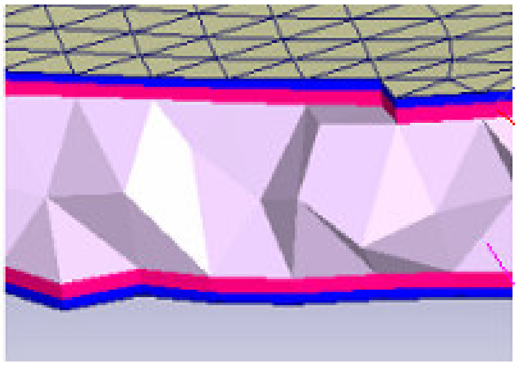


Figure 3. The boundary layer meshing method

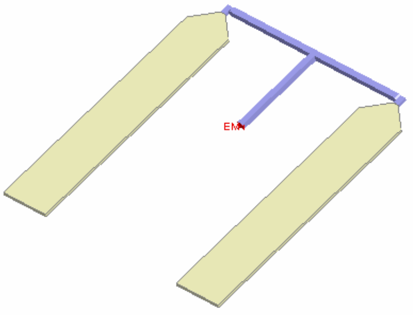


Figure 4. The two cavities sample model (original design).

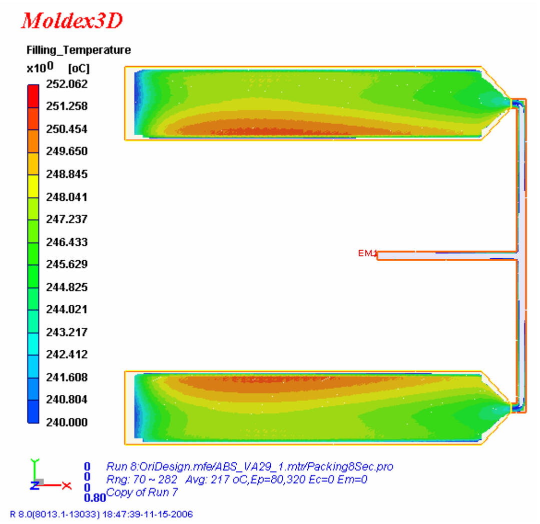


Figure 5. X-Y direction temperature profile (original design)

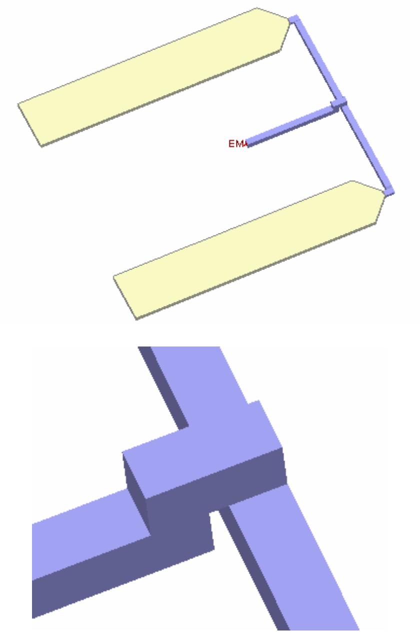


Figure 6. Sample model with melt rotation apparatus

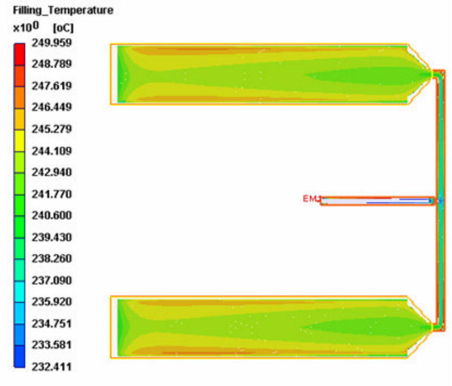


Figure 7. X-Y direction temperature profile (model with melt rotation apparatus)

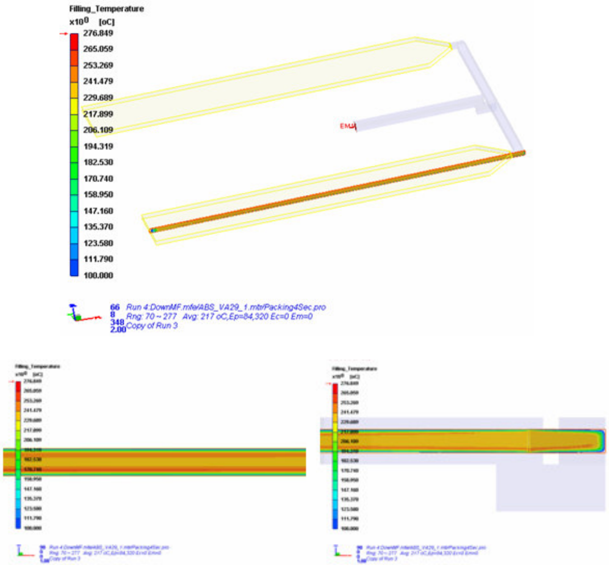


Figure 8. X-Z direction temperature profile (model with melt rotation apparatus)

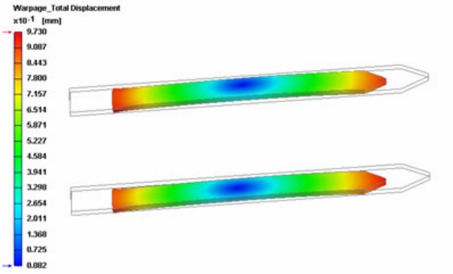


Figure 9. The warpage result of the sample with melt-rotation apparatus

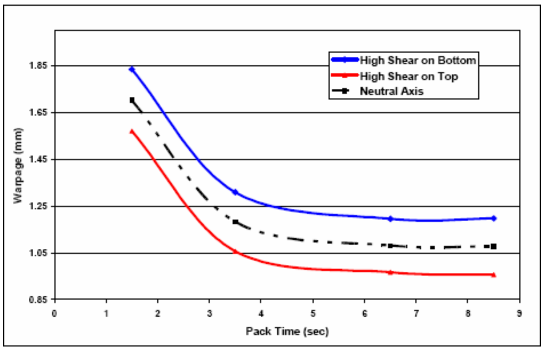


Figure 10. The experimental data of packing time versus warpage at a constant packing pressure [6]

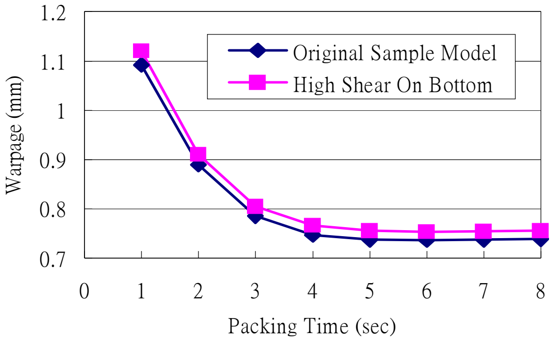


Figure 11. The simulation result of packing time versus warpage at a constant packing pressure