TWO-MATERIAL INJECTION MOLDING FILLING SIMULATION AND THERMAL STRESS ANALYSIS

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ABSTRACT

Two-material injection molding provides many advantages to plastic part design and manufacturing. But the more complicated process procedure also brings new problems. To have a control over the part quality, there is a high demand for two-material simulation software. A filling simulation program using finite element method was being developed in the injection molding optimization lab in Umass, Amherst. 21/2-D triangle element with thickness was used to simulate the filling phase of the overmold. The bulk temperature of substrate was mapped as the overmold’s boundary temperature. Simulation results were compared with commercial software.

Bonding strength is of great interest in two-material injection molding. It is affected by many parameters and was difficult to predict. A standard mold set up and peeling test method was suggested when it is necessary to know the actual value. A thermal stress analysis was performed in ANSYS to predict the thermal induced stress in the polymers.

INTRODUCTION

Injection molding is the most important process for manufacturing plastic parts. In most cases, products with complex geometries are made in a single shot without further finishing operations. Typical injection molded parts can be found everywhere in daily life.

Injection molding is processed under many conditions. All this conditions and their combinations have a significant effect on the quality of the product. However, due to the complexity of the interplay between the various processing factors and the non-newtonian properties of polymer, injection molding remained something of an art for many years until finite element method was introduced.

Two-material injection molding is a process in which two different melts are combined to form a composite part inside the cavity, requiring the melts to be injected into the mold one after another. There are many advantages associated with two-material injection molding. It allows parts to be produced cheaply, in a single operation. It could integrate different functions in a single component without assembly work. It is also possible to improve on certain service properties including special requirements placed on functions, “feel” and design, such as a composite part that incorporate rigid and flexible materials.

The process conditions for the overmold use information from the packing stage of the substrate. This asymmetric boundary condition brings many problems. Uneven flow front and pressure distribution will bring unexpected sink mark and warpage etc.

NOMENCLATURE

Two-material Injection Molding, FEA Simulation, Bonding Strength, Thermal Analysis

TWO-MATERIAL INJECTION MOLDING PROCESS

The whole two-material injection molding process could be divided as the following stages:

Stage 1: Filling & Post-filling of Substrate
It can be considered as normal filling and post-filling process, so the analysis could be performed by commercial simulation software.

Stage 2: Core Switchover
During this stage, the core is rotated or the insert is retracted to create a cavity for the overmold. All initial data for current stage are obtained from analysis results of the previous stage.

Stage 3: Filling and Post-filling of Overmold
During this stage, melt polymer fills up the cavity of the overmold and solidified. All initial data for current stage are obtained from analysis results of the previous stage.

The simulation formula for the filling phase was developed and a program was written in Fortran.

SIMULATION PROCESS

The simulation difficulties lay mainly on the non-newtonian nature of the polymer melts and complex heat transfer experienced in injection molding. To simplify the algorithm, some assumptions are made.

The polymer melts are assumed to be incompressible, which means the density is constant, and thermal conductivity is also assumed to be constant. Viscoelastic effects is ignored.

Generally speaking, injection molded parts are thin walled, so mid-plane of the part with thickness was used to represent the actual part. The axes are so arranged that at any point in the cavity the x-y plane coincides with the mid-plane of the part and the z-axis points in the thickness direction, as shown in figure 1.

Employing the above assumptions about material behavior and mold cavity, the equations governing the fluid motion could be simplified as:

Continuity equation

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]  

Momentum equation
Where 

\[ S_z = \int_b^z \frac{z^2}{\eta} dz - \left( \int_b^z \frac{z}{\eta} dz \right)^2 \]

Integrate the left hand side of the continuity equation and substitute equations (9), (10) into it, we get:

\[ \frac{\partial}{\partial x} \left( S_z \frac{\partial p}{\partial x} \right) + \frac{\partial}{\partial y} \left( S_z \frac{\partial p}{\partial y} \right) = 0 \quad (13) \]

So equation (13) combines both the momentum and the continuity equations. It could be further simplified due to symmetry across the thickness in common injection molding process. But to deal with asymmetric boundary conditions in the filling phase of overmold, we will solve it directly.

Due to the dependence of \( S_z \) on viscosity, which in turn depends on both temperature and shear rate, equations must be solved simultaneously. When obtaining numerical solution, equations could be decoupled by using small time steps. At a particular time, temperature is assumed constant and pressure field is calculated by assuming a value of viscosity at that temperature. When the time steps are sufficiently small, this decoupling method provides satisfactory results.

The sequence of the solution process is as follows:

1. Calculate \( S_z \). If this is the start of an analysis, a nominal value of viscosity at the melt temperature is used. Otherwise, shear rate and temperature data from a previous step is used to calculate \( S_z \). Then we solve equation (13) for pressure. After calculating the pressure field, it is possible to determine the velocity using equations (7), (8). Assuming constant temperature, the viscosity is updated using the value of shear rate calculated from velocity. This viscosity value is then used to calculate \( S_z \). Equation (13) is now solved again and the entire process repeated until pressure results converge.

2. When pressure calculation has finished, current value of velocities, shear rate and viscosity are used in equation (5) to calculate the convective and viscous heating terms. Solution of (5) is thus reduced to a conduction problem with convection and viscous treated as source terms. The conduction calculations are performed with finite difference methods and give the temperature field.

3. With temperature field known, viscosity value is updated. Knowing the flow rate into each control volume, it is possible to predict which of these will fill in the next time step. The flow front is advanced accordingly.

Steps 1, 2 and 3 are repeated until whole mold cavity is filled.

Finite element methods are used for the pressure calculation, while temperature calculations use finite difference methods. Advancement of the flow front uses a control-volume approach.

**A SIMPLE GEOMETRY TEST CASE**

In our simple geometry test case, a rectangular substrate with different thickness is analyzed. Lower half part of the substrate are twice as thick as the upper part. After the post-filling stage, the lower part has a much higher temperature. The overmold is a rectangular part with the same outline and uniform thickness. When melt is injected into the overmold cavity, it flows faster in the lower part. The pressure and melt
front advancement results from CMOLD simulation and 2M-filling simulation code are compared in figure 2 and 3.

Filling of the elastomer is simulated by 2M-filling code with the inner surface have a higher initial temperature because of the contact with the hot handle. Asymmetric flow happens in the thickness direction and can’t be distinguished since the thickness is so small. While pressure value result from 2M-filling (figure 4(a)) is greatly reduced in comparison with result from CMOLD (figure 4(b)), which uses uniform mold wall temperature. The difference is caused by the enhanced flow at higher temperature.

AN ACTUAL TEST CASE

An actual two-material injection molding product is being analyzed—a Gillette® razor. It is made up of handle (substrate) and elastomer (overmold). The elastomer is a three-sided partial cover for the handle. A set of mid-plane models is created. To ensure both geometry models can be correctly assembled in the consecutive analysis, a uniform coordinate system is used.

The handle is made by amorphous thermoplastics. It is rigid and offers a high level of strength to sustain force without suffering any major deformation. The elastomer is made by thermoplastic elastomer to provide a soft grip. Material properties are listed in table 1.

<table>
<thead>
<tr>
<th>Table 1  Material properties for the substrate and overmold</th>
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<tbody>
<tr>
<td>Substrate</td>
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<td>-----------</td>
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<tr>
<td>Material name</td>
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<tr>
<td>Material Type</td>
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<tr>
<td>Melt density (g/cm³)</td>
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<tr>
<td>Solid density (g/cm³)</td>
</tr>
<tr>
<td>Thermal conductivity(W/M. °C) At 240°C</td>
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<tr>
<td>Specific Heat (J/Kg. °C) At 240°C</td>
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<tr>
<td>Melt temperature(°C)</td>
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<tr>
<td>Ejection Temperature(°C)</td>
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<tr>
<td>Thermal expansion</td>
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<td>Young modulus(Mpa)</td>
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BONDING STRENGTH

When a number of plastic parts are joined together by means of injection molding, the aim is generally to achieve an integral, adhering bond between the plastic combinations when exposed to mechanical stressing and the action of certain media. This requires an adhesive bond to be created between the components. The development of adhesive forces is based primarily on intermolecular interactions. The injection molding process of the overmold is comparable with the use of a hot melt adhesive, which is applied to the substrate in melting state and gains strength upon solidification and crystallization. In evaluating the bonding strength, melt properties, wetting while in the melt, resolidification are all important factors. Injection conditions also affect the bond formation as a function of time and place as the flow and cooling conditions vary at different distances from the gate.

The building of a bondage between different polymers are affected by too many factors and are almost impossible to simulate. When the bonding strength is of concern, experiments should be done to gain more information.
For two-material injection molding, a standard set up is designed. A set of mold could be made especially for this purpose. A bipolymer sample made up of a 2mm thick substrate and a 1mm thick overmold will be produced and the bonding strength was gained using a peeling test [4]. Different process conditions and different combinations of polymers could be tested in a design of experiments (DOE) to study their effects.

An excessively high shrinkage differential or differences in thermal expansion that are due to the part geometry can lead not only to warpage but also to a failure of the material bond at certain points. So a thermal induced stress analysis was performed in ANSYS.

**THERMAL INDUCED STRESS ANALYSIS**

A thermal induced stress analysis was performed in ANSYS. Two transient thermal analysis was done first to simulate the cooling of the substrate and the overmold. The latter use the result from the former as initial condition (shown in figure 5). There is a 2 second time lag between the two procedures. It is time to eject the part when temperature of the center node drops below ejection temperature. Then the temperatures are applied as load for a stress analysis.

In the above simulation, filling was ignored. Thermal analysis began when polymer was completely filled at melt temperature.

To save computer time, half geometry was used. At the symmetric plane, heat flux was set to zero and displacement in x direction was constrained. Element type plane55 was used in the thermal analysis, which is automatically switched to plane42 in the structural analysis. Corresponding material properties are shown in table 1. Multi-linear properties are assigned to thermal conductivity and specific heat to simulate the actual process.

The simulation results (shown in figure 6) revealed that the maximum stress induced by the injection molding process is 8000psi, which is bigger than the polymer’s tensile stress at yield-5700psi.

**CONCLUSION**

Two-material injection molding gains more popularity nowadays which made its simulation in advance a necessity.

**REFERENCES**

[2] Interfaces, adhesion, and processing in polymer systems: symposium