Polymer Injection Molding Simulation Using ANSYS CFX

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Content

• Background
• Filling/packing/mold cooling/deformation analysis of thermoplastic injection molding
• Flowing, curing and wire sweep analysis of epoxy molding compounds for encapsulation semiconductor
Why General CFD

- Increasing the accuracy of injection molding simulation
  Epoxy Molding of Semiconductors\cite{1} Non-uniform Thickness\cite{2}

- Developing physics model to simulate the complex phenomena of polymer flow

- Customization for new processing technology
Challenge to General CFD

• Convergence Difficulty
  – Viscosity of polymer is much larger than the viscosity of air
  – The flow approaches to stop during packing process when the temperature of polymer becomes lower than transient temperature

• Calculation Time
  – A very fine mesh is necessary near wall to describe the characteristic of polymer viscosity
  – A small time step ($10^{-4}$-$10^{-5}$s) may be needed for convergence
  – The calculation time may be unacceptable (weeks or months/case)
Advantages of ANSYS/CFX

• Stronger convergence and accuracy
  – The free surface analysis of polymer and air with very different viscosities could convergence based on CFX accurate discretization scheme.
  – The solution could be obtained even when the flow almost stop during packing by a coupling multigrid solver.

• Powerful performance in speed and parallel
  – Could use a relative large time step \((10^{-2}-10^{-3}\text{s})\) to get a convergence solution
  – Accessible parallel scalability
  – Acceptable calculation time (1 or 2 days/case)
Filling/packing/mold cooling/deformation analysis of thermoplastic injection molding
Geometry and Mesh

Mold Mesh
Nodes  433,402
Elements  396,855
Mesh for Cavity

Layers of gate thickness 10

Nodes  97,688
Elements 88,620
Layers of cavity thickness  20
Polymer Properties

Viscosity (Cross-Exp)

\[
\mu = \frac{\mu_0(T, p)}{1 + \left(\frac{\mu_0 \times \dot{\gamma}}{\tau^*}\right)^{1-n}}
\]

PVT (Tait)

\[
v(T, p) = v_0(T) \ast (1 - C \ln(1 + \frac{p}{B(T)})) + v_i(T, p)
\]
Melt Front Advancement
3D Flow Effect and Fountain Flow

3D Flow near gate

Fountain Flow at melt front
Pressure during Packing
Center plane of cavity

- $t=1$ [s]
- $t=3$ [s]
- $t=7$ [s]
- $t=15$ [s]
Temperature at Center of Cavity

Graph showing the temperature at the center of a cavity over time, with markers at 15 s, 7 s, 3 s, and 1 s.
Mold Temperature

$t=1 \text{ [s]}$

$t=3 \text{ [s]}$

$t=7 \text{ [s]}$

$t=15 \text{ [s]}$
Pressure & Temperature (From Filling to Packing)

- V/P Switch
- Pressure Release
- Shear Heating
- Gate seal

- \( P_{\text{inlet}} \): inlet
- \( P_{\text{gate}} \): gate
- \( P_1 \): \( \frac{1}{4} \) of cavity length
- \( P_2 \): \( \frac{1}{2} \) of cavity length
- \( P_3 \): \( \frac{3}{4} \) of cavity length

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Deformation

- X direction (wide)
- Y direction (length)
- Z direction (thickness)
- Total deformation
Flowing, curing and wire sweep analysis of epoxy molding compounds for encapsulation semiconductor
Geometry

Inlet

Outlet

Wire Diameter : 0.028

Chip

Frame

20

10

1
**Polymer Properties**

**Viscosity (Herschel-Bulkely)**

\[
\eta(\dot{\gamma}, T) = \tau_y(T) / \dot{\gamma} + K(T)\dot{\gamma}^{(n-1)}
\]

\[
K(T) = K_0 \exp\left\{-C_A(T-T_g)/(C_B+(T-T_g))\right\}
\]

\[
\tau_y(T) = \tau_{y0} \exp(T_y / T)
\]

\[
K_0 = K_{00} \left\{\alpha_{gel} / (\alpha_{gel} - \alpha)\right\}^{(C_1+C_2\alpha)}
\]

**Curing Rate (Kamal)**

\[
\frac{d\alpha}{dt} = (K_1 + K_2\alpha^m)(1-\alpha)^n
\]

\[
K_1 = A_1 \exp(-E_1 / T)
\]

\[
K_2 = A_2 \exp(-E_1 / T)
\]
Melt Front Advancement

$t=0.5 \, [s]$  $t=1.0 \, [s]$  $t=1.5 \, [s]$  

$t=2.0 \, [s]$  $t=2.5 \, [s]$  $t=3.0 \, [s]$
Animation of Melt Front

Time = 0 [s]
Animation of Melt Front Passing Wires
Fluid Force

- $F_z$
- $F_y$

- $F_x$
- $F_y$
- $F_z$

- $F_x$
- $F_y$
- $F_z$

- $F_x$
- $F_y$
- $F_z$
Deformation

Chip Warpage

Wire Sweep

Extend by 4000
Summary

• Filling / Packing / Mold Cooling / Deformation analysis about thermoplastic injection molding were performed using ANSYS CFX. Pressure and temperature variation during whole filling & packing process are predicted.

• Flowing, curing and wire sweep analysis of epoxy molding compounds for encapsulation semiconductors were performed. It shows that molding defects such as voids, wire sweeps, and so on could be predicted.

• ANSYS CFX have been proved to have the ability to perform the integrated simulation of injection molding and reaction injection molding.

• The innovate ideas in polymer process could be developed using ANSYS extensive physical models, efficient solver performance and flexible customization.
References


