Autodesk Moldflow

Moldflow Research & Development

Dr Franco Costa
Senior Research Leader
Research & Development

Research In-house
24 PhD employees in Moldflow development
A Lab with state-of-the-art equipment
  Four modern injection molding machines for test & validation
  Establishing a network of third-party Labs

Academic Research Collaboration
Six Universities with seven PhD students

Industrial Research Partnerships
Over 20 companies and institutions
Outline

- Solver Features in Recent Moldflow Releases
- Solver & Mesh Features under development
- Research Collaborations
RTM and SRIM in 3D

Features

Apply properties of a dry fiber mat where needed.
Anisotropic permeability follows the shape of the product.
Detect areas where resin cannot penetrate.
Includes Vacuum Infusion & Gravity effect.

Results

Degree of Cure, Volumetric shrinkage, Mat orientation, etc.
Improved 3D Fiber Orientation

Position C3, orientation A11

Implementation of a New Model
MRD (Moldflow Rotational Diffusion)

Measured data provided by BASF
BASF PA 30%GF
### Improved 3D Fiber Orientation

Average error of predictions for different releases and constitutive models. Results for the default models are in **bold**

<table>
<thead>
<tr>
<th>AMI release</th>
<th>Constitutive model</th>
<th>BASF</th>
<th>Bradford</th>
<th>Delphi</th>
<th>DSM</th>
<th>EMS</th>
<th>Mechanical Plaque</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cases</td>
<td>1</td>
<td>2</td>
<td>23</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Number of locations for each case</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2017FCS</td>
<td>F-T</td>
<td>0.16</td>
<td>0.20</td>
<td>0.14</td>
<td>0.11</td>
<td>0.23</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>RSC</td>
<td>0.11</td>
<td>0.12</td>
<td>0.11</td>
<td>0.089</td>
<td>0.16</td>
<td>0.14</td>
</tr>
<tr>
<td>2017 R2</td>
<td>F-T</td>
<td>0.091</td>
<td>0.16</td>
<td>0.11</td>
<td>0.079</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>RSC</td>
<td>0.076</td>
<td>0.11</td>
<td>0.10</td>
<td>0.077</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>MRD</td>
<td><strong>0.071</strong></td>
<td><strong>0.11</strong></td>
<td><strong>0.08</strong></td>
<td><strong>0.054</strong></td>
<td><strong>0.12</strong></td>
<td><strong>0.085</strong></td>
</tr>
</tbody>
</table>

**2017 R2 halves the average error of fiber orientation predictions**
3D Residual Stress Prediction

Molded-in residual stress prediction

3D Warp using Residual Stress

Since AMI 2017.3:
- Residual Stress is the default 3D Warp model
- Extended to Thermoset materials
- Mesh Aggregation option enabled
Powder Injection Molding (PIM)

- Mold filling simulation of Metal Injection Molding (MIM) and Ceramic Injection Molding (CIM) materials
- Predict the powder concentration
- Material characterization for PIM is available

Powder concentration
Including Wall Slip for PIM

Failed to predict initial jetting without Wall Slip

With Wall Slip, predicted initial jetting in PIM simulation, which matched reality better

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau_c$</td>
<td>Critical shear stress</td>
<td>0.01 MPa</td>
</tr>
<tr>
<td>m</td>
<td>Slip exponent</td>
<td>1</td>
</tr>
<tr>
<td>a</td>
<td>Constant slip coefficient</td>
<td>1.0e-05</td>
</tr>
<tr>
<td>b</td>
<td>Temperature dependency</td>
<td>0</td>
</tr>
<tr>
<td>c</td>
<td>Pressure dependency</td>
<td>0</td>
</tr>
</tbody>
</table>
Multi-barrel Injection Molding Simulation

Master Barrel with 4 sub-barrel
Delay time 0.25 s and 0.5 s for sub3 and sub 4, respectively
Preconditioning – Reactive Compression Molding

- Use **numerical** simulation to calculate temperature and cure changes during preconditioning stage
- Either use contact conditions to automatically apply temperature boundary conditions or input value specified on elements for the thermal boundary conditions
- Result: Temperature and cure **distribution** at the end of preconditioning stage

Temperature and cure distribution at the end of preconditioning.
- Initial melt temperature: 50 C
- Mold temperature: 175 C
- Delay time: 10 sec
You can now consider cooling rate and pressure effects on Solidification.

\[ T_i(P) = b_5 + b_6 P \]

Polycarbonate: Infino EH-1050; Cheil Industries

Fig. 9. Influence of cooling rate on the specific volume of i-PP at a pressure of 40 MPa. Average cooling rates during crystallization are given in the figure.

van der Beek et. al. Inter. Polymer Processing, 20, 111-120, (2005).
New Features for Recent Releases

Autodesk Moldflow Simulation 2017 R2
1. Wall Slip
2. Resin transfer molding
3. Thermocouple-controlled cooling
4. Heater wattage specification for heater element

Autodesk Moldflow Simulation 2017 R3
5. CAD meshing support for Linux
6. Synergy Support for Delete CAD bodies
7. Synergy Support for Copy of CAD bodies
8. Support the exporting of STEP files
9. Powder injection molding support

Autodesk Moldflow Simulation 2018.0
10. Multi-step large vector deformation support (modelling)
11. Multistage support for normal deformations (modelling)
12. User defined initial strain support for Anisotropic inserts (Warp)
13. Preconditioning analysis for reactive compression molding
14. Injection compression overmolding (3D)
We may make statements regarding planned or future development efforts for our existing or new products and services. These statements are not intended to be a promise or guarantee of future delivery of products, services or features but merely reflect our current plans, which may change. Purchasing decisions should not be made based upon reliance on these statements.

The Company assumes no obligation to update these forward-looking statements to reflect events that occur or circumstances that exist or change after the date on which they were made.
Centerline Extraction for CAD Cooling System

Extracting Center Lines of CAD Cooling System
Faster Conformal (3D) Coolant Flow Solver

Supports Linux, & Parallelization
Use the Autodesk “Flow Design” Voxel CFD Solver

Moldflow 3D Channel mesh
Voxel mesh
Voxel solve
Voxel results

Cross section
Pressure
Velocity

AUTODESK
Underflow Diagnostic Plot

“Underflow severity” as a result

Underflow region

(viewmold.com)
Adaptive Fiber Model Orientation Prediction

Skin Orientation
Believed to be due to fountain flow

Shell Orientation
Strong alignment in flow direction
Alignment controlled by fiber interactions, $C_i$, $ARD b$, $MRD D$.

Core Orientation
Transverse or random orientation dependent on flow near gate
Width Controlled RSC factor $\kappa$
Fiber Concentration

Higher concentration at core while lower concentration at shear region. Fiber concentration, orientation, & breakage affect mechanical properties.

Warp Accuracy: Thickness Shrinkage for Warpage

MF 2×4mm corner mold (MAT5322 PP)

F. van der Veen corner mold (CM1160 PP)

MF 2x4mm Corner Mold with unfilled PP

F. van der Veen Corner PP

- Corner piece test mold
- Local geometry options: R1 or R5
- Gate thicknesses: 1 = 0.6 or 0.8 [mm]
Warp Accuracy - Shrinkage Correction by Machine Learning

- Use Machine Learning to estimate molded shrinkage
- Provide CRIMS correction for non-shrinkage characterized grades
Warp Accuracy - Anisotropic Thermo-Viscoelastic Stress Model

Stress relaxation (viscoelastic)
Long cooling time effect
In-mold shrinkage
Liquid portion at ejection
Solidification sequence effect
Ejection Force

Automatic Detecting based on ejectors movement direction

User check, add or remove surface elements manually

Final contact surface

Von Mises Stress During Ejection
Mold Fatigue

Calculate the mold life and approximated range of cycles.

Thermal Stress
Pressure-induced Stress
Clamping-force-induced Stress
Mold Fatigue
Cooling Network Only Analysis

Features: Minor Loss, Friction formula, Simulate energy equation, & Simulate gravity

New results: K factor, & Friction factor
Overview of Moldflow External Research Collaborations

- Completed Projects
  - Long Carbon Fiber Orientation and Breakage – PNNL

- Ongoing Projects
  - Composites Injection Overmodling – TPRC
  - Microcellular Foaming – Univ of Toronto
  - Fiber Effect on Viscosity – RMIT (Melbourne)
  - Composites Compression Overmolding – HUST
  - Fiber breakage in Barrel – Univ of Bradford
  - SMC Compression Molding – Ford
  - Long Carbon Fiber Orientation and Breakage – GM
  - Yokoi Injection Molding Consortium – Univ of Tokyo
Long Carbon Fiber Thermoplastic: Fiber Length

Prediction of fiber orientation and breakage during injection molding of "long" carbon fiber thermoplastics

Comparison of measured and predicted fiber length distribution
Fiber Breakage in Barrel

Prediction of long fiber breakage during melting in injection barrel

Aim: Initial fiber length distribution for polymer at the sprue tip
Fiber breakage in barrel
Observing Fountain Flow Oscillation (Tiger Stripe)
Flow Imbalance (Race-Track)
Model the change in viscosity due to filler migration, fiber orientation and fiber breakage.
Composite Overmolding

Model non-recoverable deformation and resistance of a continuous fiber composite (pre-preg) being compression overmolded
Bubble effects on fiber orientation

Bubble nucleation or growth and the final foam structure
(Microcellular Plastics Manufacturing Lab, Univ. Toronto)
Injection Overmolding on Continuous Fibers Composites

Interfaces AniForm draping solution to Moldflow Warp analysis of the combined structure.

Models bond strength
Chopped Carbon Fiber Compression

US DOE funding to develop ICME for carbon fiber draped and compression molded parts (Automotive)

Autodesk Moldflow was invited to provide process modeling of Compression molding, Fiber Orientation, & Local fiber volume fraction
Flow instability mechanism understood.
Potential collaboration to study appearance factors (aimed at Automotive parts)
Academic Research Collaborations

University of Bradford (UK)
Long Fiber Orientations, & Fiber breakage in barrel

Tokyo University
Fiber breakage visualization, & Race track visualization

RMIT University (Australia)
Effect of fiber and filler migration to change viscosity, & Thermal stresses in SLM 3D Printed parts

Huazhong University of Science and Tech
Compression Overmolding of Continuous Fiber Composites

University of Toronto
Microcellular bubble formation

University of Wyoming
Progressive failure of composites
Industry Research Partnerships

Long Carbon Fiber Thermoplastics (Injection Molded)
- Pacific Northwest National Labs, & GM

Chopped Carbon Fiber Thermoset (Compression Molded)
- Ford, Dow, Northwestern University

Microcellular
- Trexel, University of Toronto, & Ford

Thermoplastic Composite Overmolding
- TPRC (The Netherlands), Boeing, Fokker, Johnson Controls, Victrex