THE ROLE OF MATERIAL DATA IN THE SIMULATION OF INJECTION MOLDED PARTS

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Nature of the Problem

• Material
  • Non-linear, dependent on time, rate, temperature, moisture

• Process Simulation
  • Transient non-linear, non-isothermal compressible flow simulation
  • Non-isothermal visco-elastic effects
  • Cooling rate & shear-dependent crystallization (semi-crystalline polymers)
  • Fiber orientation (fiber-filled plastics)

• Performance Simulation (Structural Analysis)
  • Non-linear elasticity
  • Deviatoric and volumetric plastic strain
  • Properties change over product operational temperature & environmental exposure
  • Rate-dependent behavior (impact, creep/stress relaxation)
General Solution Outline

• Correctly understand your materials and application
• Properties needed are solver dependent
• Obtain correct representative data for your materials
  • Material supplier
  • From a qualified database
  • Test lab (internal or external)
• Make a good material model
• Check for simulation accuracy (Validation)
• Store data for consistent use
  • All users
  • All solvers
What is Representative Data

- Actual material used in your product
- Represents real-life situation
  - Temperature
  - Rate-dependent
  - Product environment
  - Processing method

strengthening the materials core of manufacturing enterprises
Required Testing for Injection-molding Analysis

- Mold Filling
- Packing
  - Post-Mold Shrinkage
  - Warpage
Measurement of Viscosity

- Capillary rheometer is used
- Material is extruded through a restriction of known geometry (extremely high precision dies)
- Temperature and flow rate are controlled
- Pressure drop across the restriction is used to determine viscosity as a function of shear rate and temperature
Problematic Materials

- Moisture sensitive materials
  - Improperly dried materials cause reduction in viscosity
  - Over-dried materials cause a rise in viscosity
  - PET, PA, PC, PBT etc.
- Highly fiber-filled materials
  - Need to account for fiber breakage during processing
  - Perform rheology with molded parts to get process history
- Thermally unstable materials,
  - 3-4 min. residence time (eg. PAI) too short for capillary rheometer
  - Requires very careful attention to residence times
  - Consider using injection-molding rheometer
Moisture Study of PA 6/6
Wet/Dry Viscosity Comparison

Coefficients (SI units) Dry

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<td>$\tau^*$</td>
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Coefficients (SI units) Wet

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</table>
Mold Filling Pressure
Pressure Profile Near Gate and Away

- Dramatic difference in pressure in mold
- Almost 5 times pressure for only 0.25 % moisture
Required Testing for Structural analysis
Measuring Stress-strain

- Universal Testing M/c
- Extensometry for strain
- Stress-strain data
  - Modulus, Poisson’s ratio
  - Stress v. plastic strain
Material Model

- Tensile and Density Tests
- Elastic
  - $E = 1572$ [MPa]
  - $\nu = 0.29$
- Plastic curve (Right)
- Density
  - $\rho = 7.9 \times 10^{-6}$ [tonne/mm$^3$]
- Measured at QS speeds
Using Validation to Check Simulation Quality

- Instron 8872 universal testing machine (UTM)
- 1 mm/min displacement of nose
- Apply speckle pattern to part to allow use of DIC strain capture
- Two camera DIC to capture 3D strain
Side by Side Comparison of Strains

• Matched the strains in the legend for the DIC image for easy comparison
• The lower strains match closely but the shape of the higher strains on the experiment end up more triangular than the simulation
Comparison Simulation to Experiment

- Strain vs. Displacement
  - Diverges after 2 mm
  - Onset of yield
  - Volumetric strain not accounted for

- Force vs. Displacement
  - Similar response throughout
Fiber-filled Plastics

• Spatial orientation of fibers
  • Properties vary spatially
• Can be approximated
  • Worst case- use cross-flow data
• Fiber-orientation material modeling
  • Perform injection-molding simulation
  • Obtain fiber orientations
  • Calculate local orientation-based properties
  • Send to FEA

Source: e-Xstream
Typical Test Protocol

- Mold long plaques
  - Edge gated: short-end
  - Fully developed flow
  - High fiber orientation
- Cut test specimens
  - 0°, 90°, 45°, ...
- Obtain true stress-strain data
- Calibrate material model
Example- Airbag Housing

Source: e-Xstream
Impact on Failure

With Fiber Orientation

Source: e-Xstream

Isotropic
In closing

- Plastics simulations are affected by
  - Material data
  - Choice of material model
  - Parameter conversion
- Models are not perfect
  - Validation is a useful confidence-building step
- High fidelity simulation is possible with representative material data
Reference

• NAFEMS book
• Determination and Use of Material Properties for Finite Element Analysis
  • By Hubert Lobo and Brian Croop. NAFEMS, 2016. 90 pp.
  • Available from NAFEMS.org

• Advanced topics at http://knowmats.com/