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 viscoelastic 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

Required Testing for Injection-molding Analysis

- Viscosity
- Specific Heat
- DSC Transition Temperatures
- Thermal Conductivity

} Mold Filling

- PVT

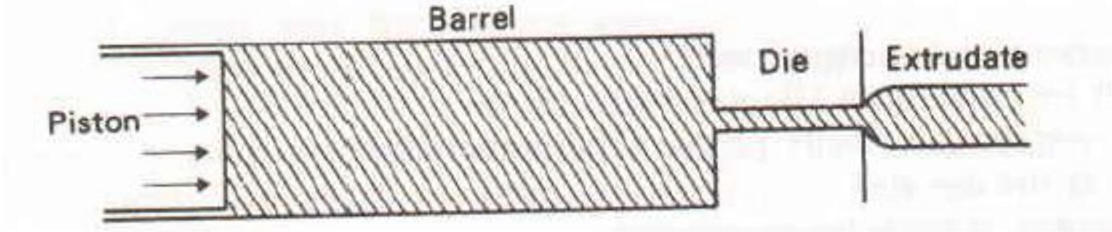
} Packing

- Shrinkage data
  - Mechanical properties
    - *Moldflow, Moldex3D, Simpoe*
  - CRIMS
    - *Moldflow*
  - Viscoelastic Properties
    - *Sigmasoft*

} 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

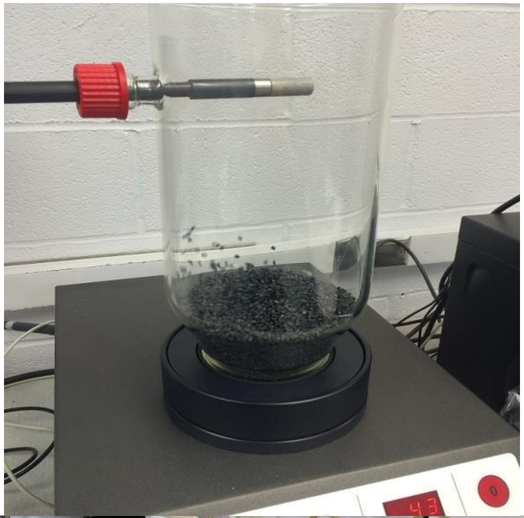


Problematic Materials

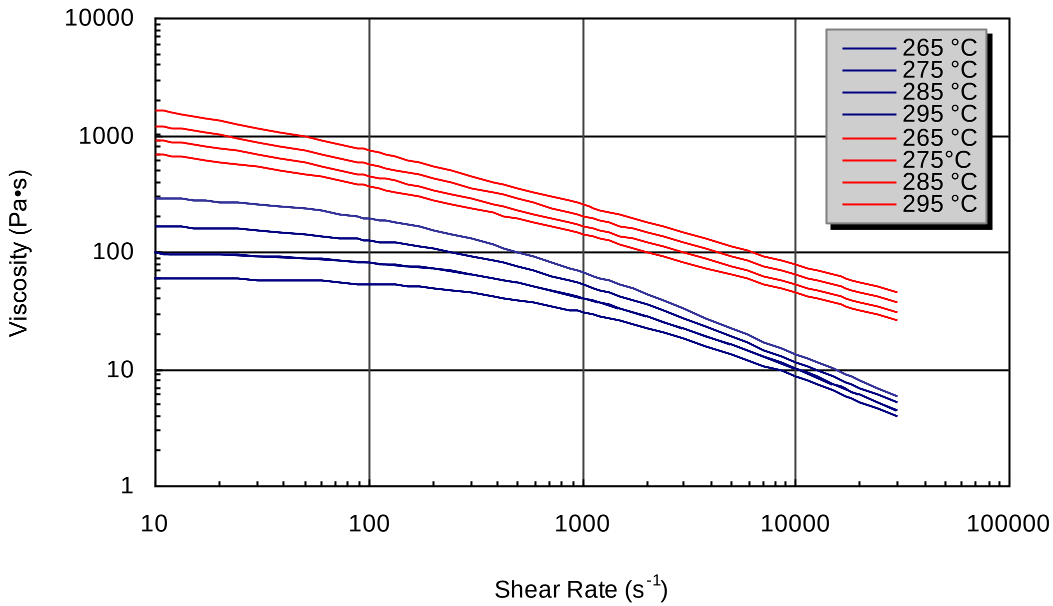
- Moisture sensitive materials
  - Improperly dried materials cause reduction in viscosity
  - Over-dried materials cause a rise in viscosity
  - PET, PA, PC, PBT etc.
- Highly fiber-filled materials
  - Need to account for fiber breakage during processing
  - Perform rheology with molded parts to get 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

- Drying Method Used (Dry)
  - Fluid bed dryer, 10 hrs 110°C
  - KFC titration
  - 0.109% moisture
- Humidification (Wet)
  - Tenny humidification chamber
  - 10 hrs 70% RH, 60°C
  - 0.351% moisture



Wet/Dry Viscosity Comparison



Coefficients (SI units) Dry

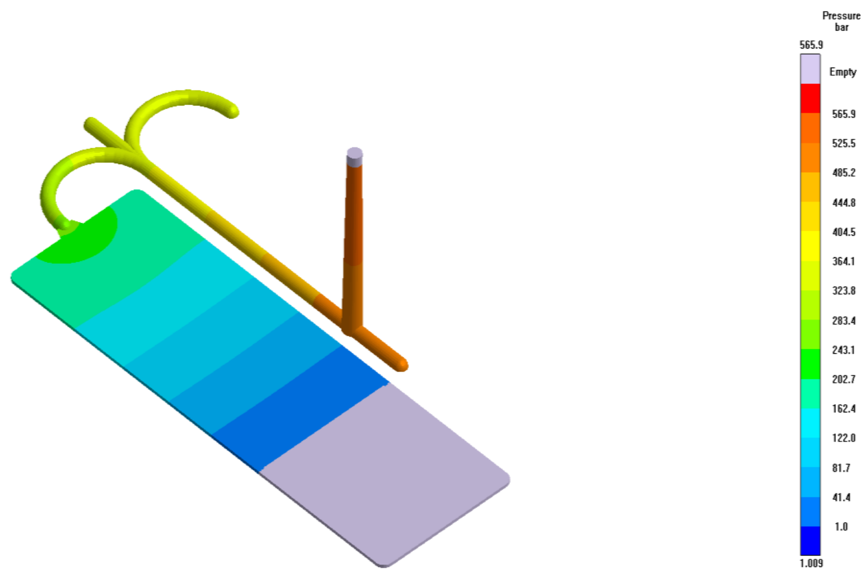
n	0.47213
τ*	28006.21
D1	5.43E+11
D2	413.15
A1	26.65
A2	51.6

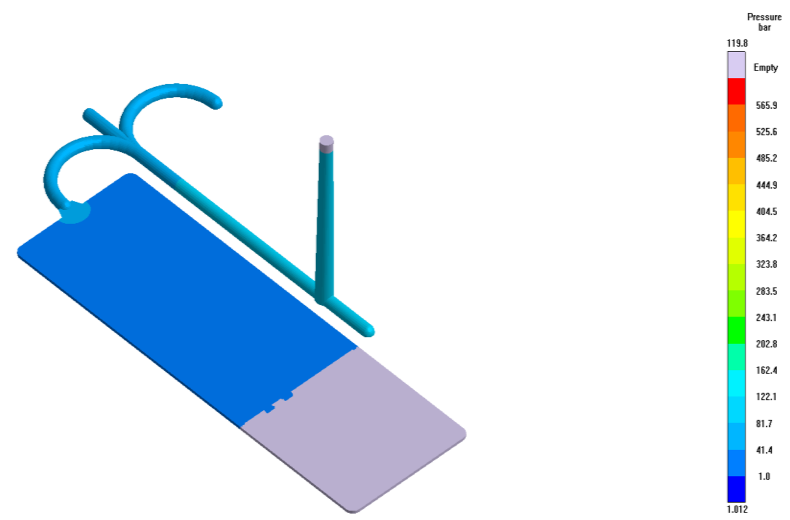
Coefficients (SI units) Wet

n	0.21509
τ*	60816.386
D1	1.34E+20
D2	378.07371
A1	53.68
A2	51.6

Mold Filling Pressure

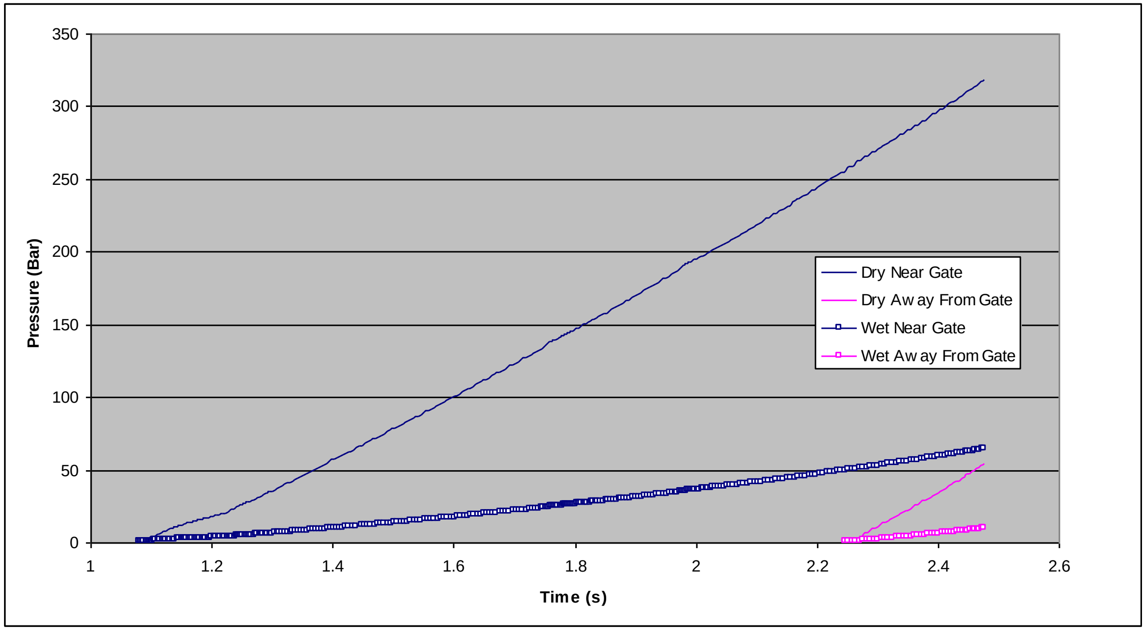
- Look at approx. 75% fill
  - Dry→566 bar inlet pressure
  - Wet→120 bar inlet pressure





Pressure Profile Near Gate and Away

- Dramatic difference in pressure in mold
- Almost 5 times pressure for only 0.25 % moisture

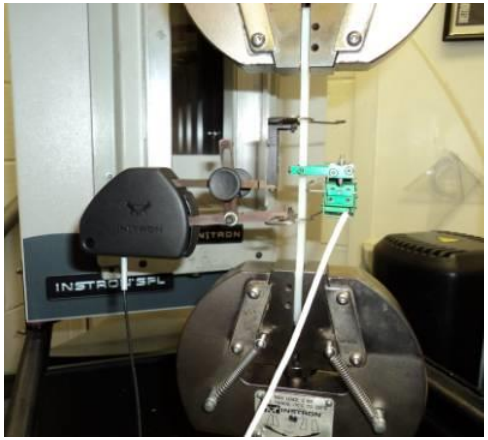


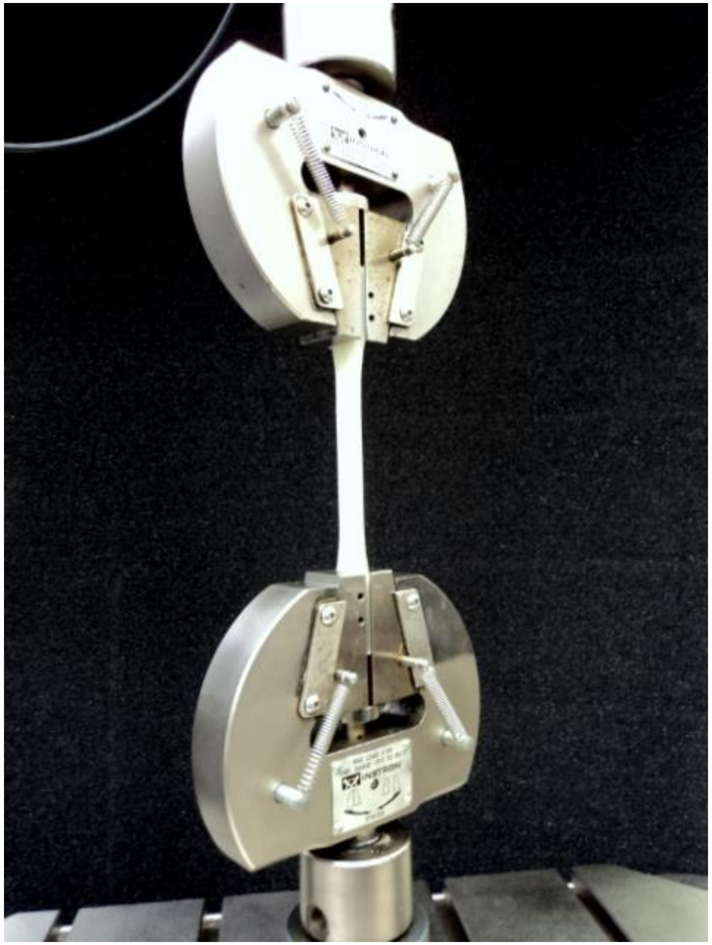
Required Testing for Structural analysis

- Stress-strain curves
  - Temperature
  - Strain-rate
  - Orientation (fiber-filled plastics)
  - Environmental exposure
- Time effects
  - Viscoelasticity
  - Creep
  - Stress relaxation

Measuring Stress-strain

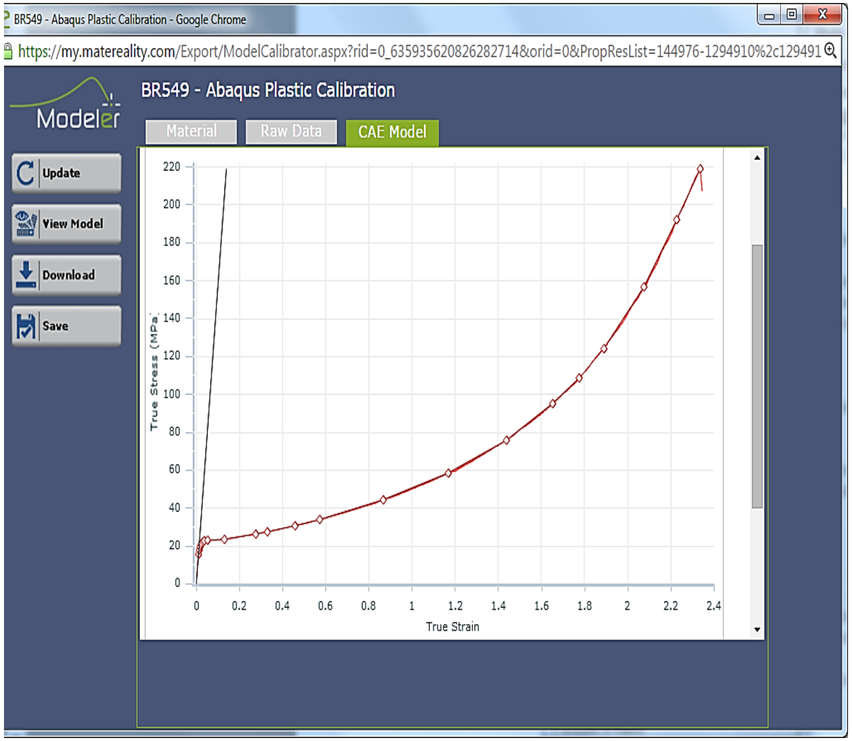
- Universal Testing M/c
- Extensometry for strain
- Stress-strain data
  - Modulus, Poisson's ratio
  - Stress v. plastic strain

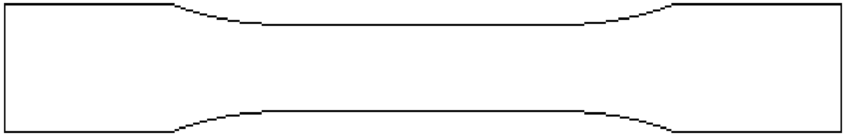




Material Model

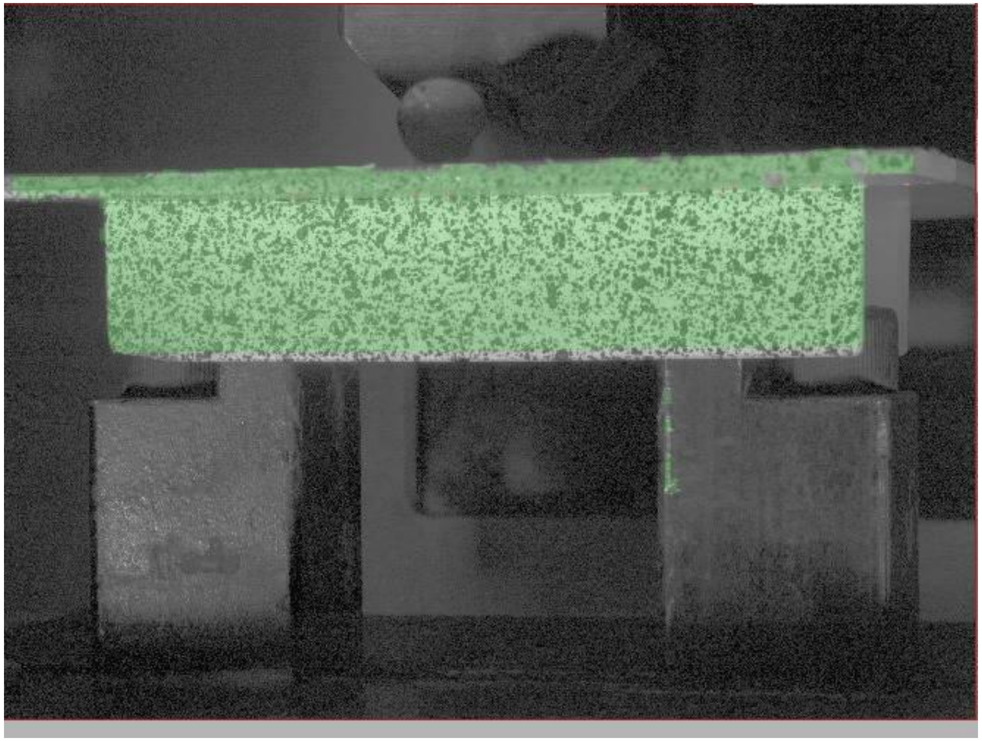
- Tensile and Density Tests
- Elastic
  - E = 1572 [MPa]
  - υ = 0.29
- Plastic curve (Right)
- Density
  - ρ = 7.9 E-06 [tonne/mm^3]
- Measured at QS speeds



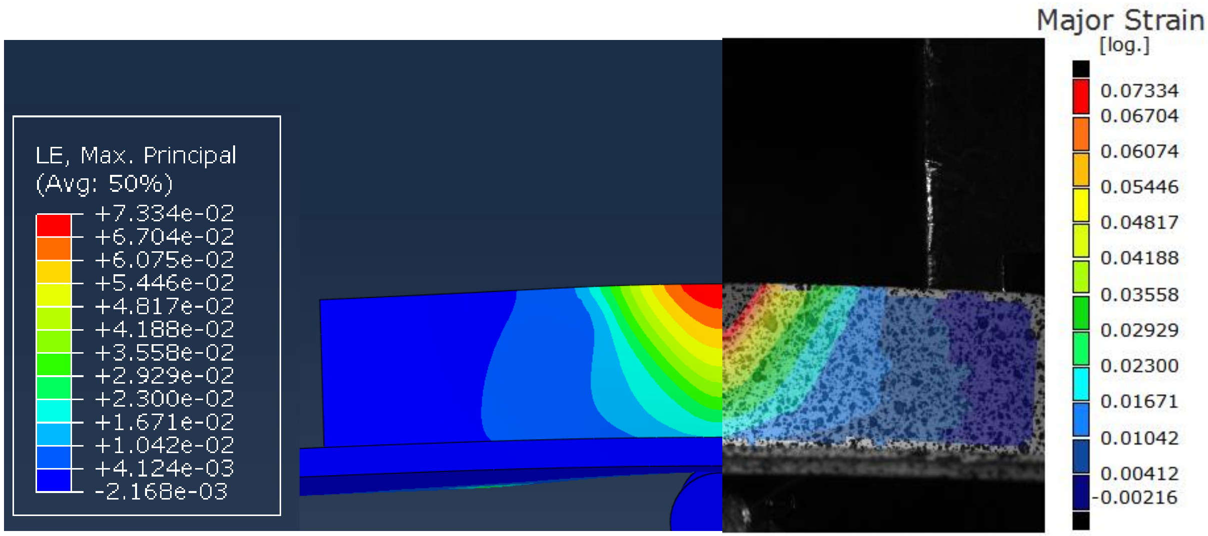


Using Validation to Check Simulation Quality

- 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

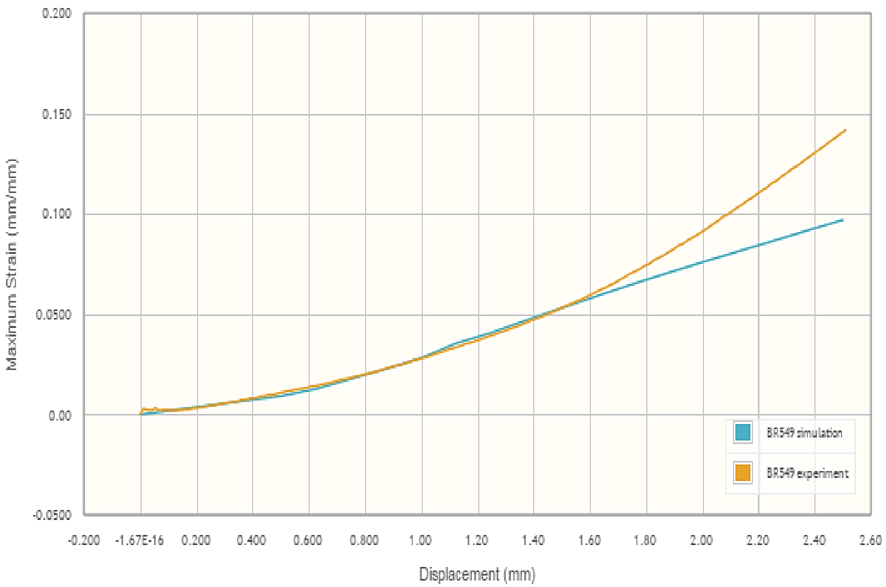


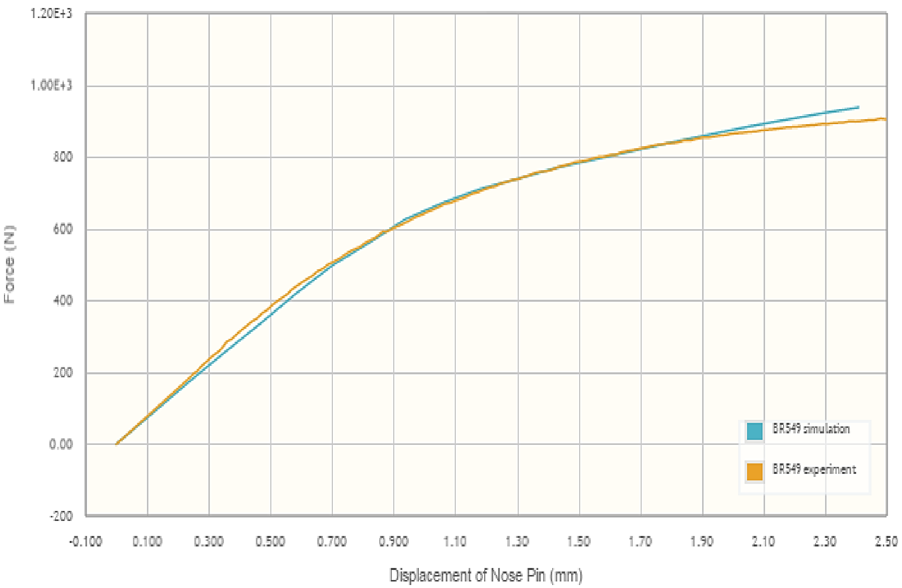
Side by Side Comparison of Strains



- 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



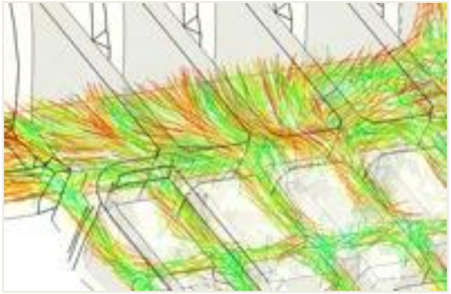


- Strain vs. Displacement
  - Diverges after 2 mm
  - Onset of yield
  - Volumetric strain not accounted for

- Force vs. Displacement
  - Similar response throughout

Fiber-filled Plastics

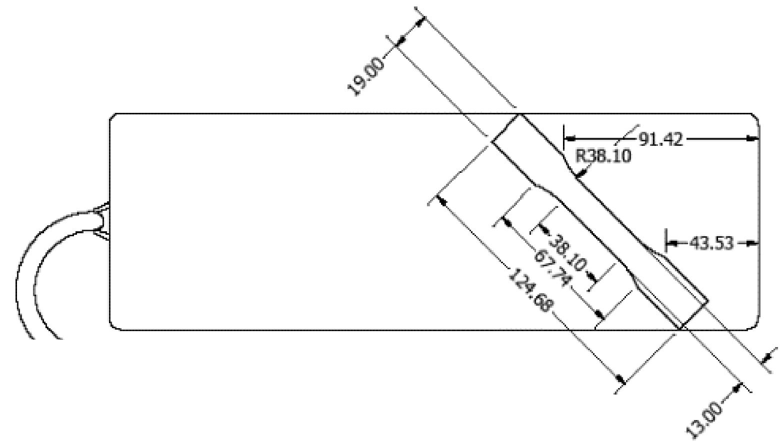
- Spatial orientation of fibers
  - Properties vary spatially
- Can be approximated
  - Worst case: use cross-flow data
- Fiber orientation material modeling
  - Perform injection-molding simulation
  - Obtain fiber orientations
  - Calculate local orientation-based properties
  - Send to FEA

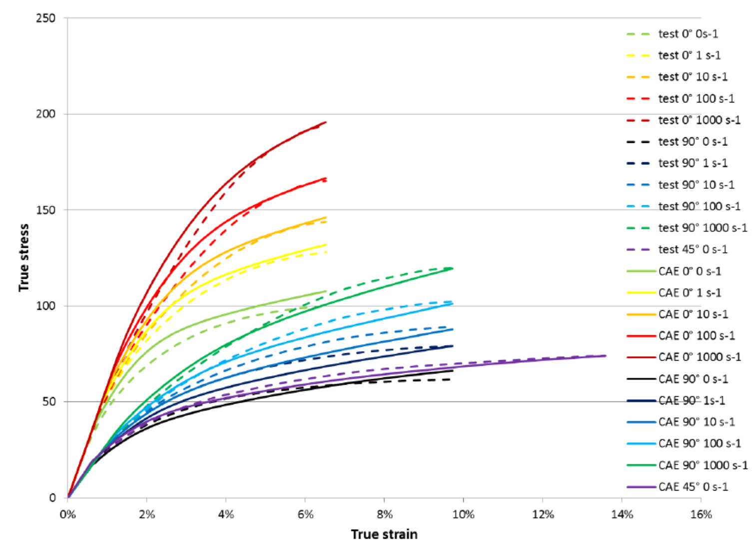


Source:e-Xstream

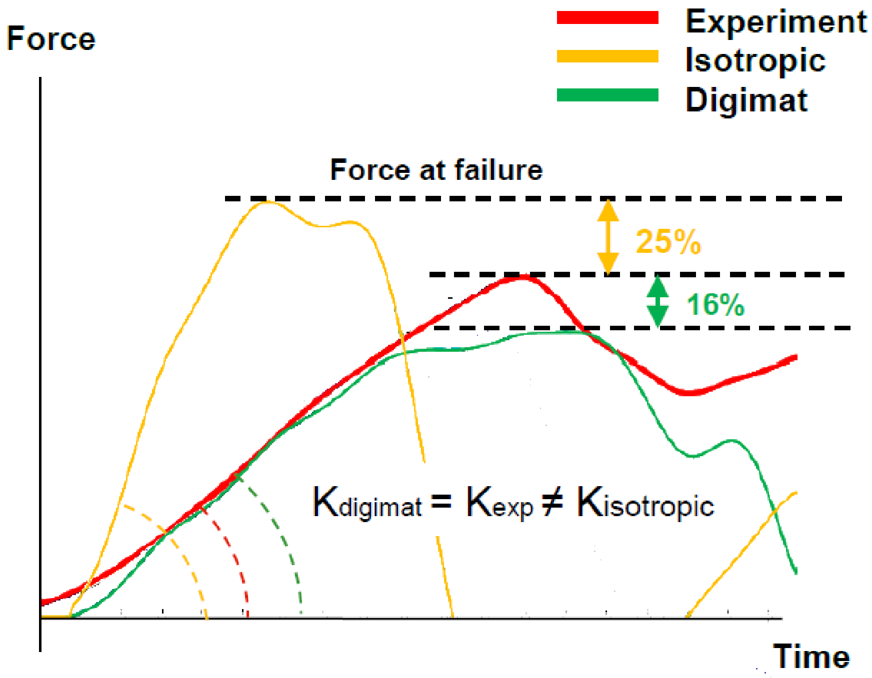
Typical Test Protocol

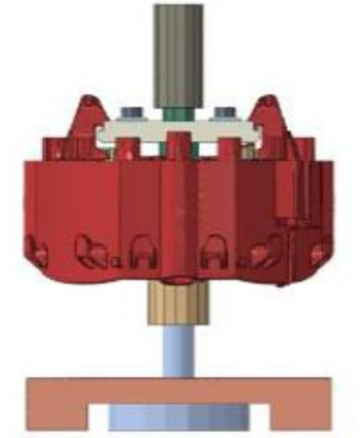
- Mold long plaques
  - Edge gated: short-end
  - Fully developed flow
  - High fiber orientation
- Cut test specimens
  - 0°, 90°, 45°, …
- Obtain true stress-strain data
- Calibrate material model





Example: Airbag Housing





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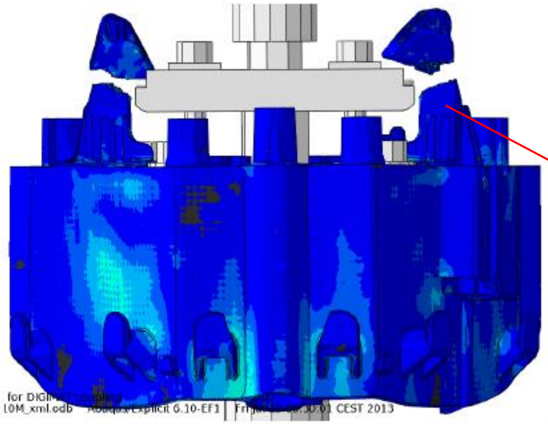
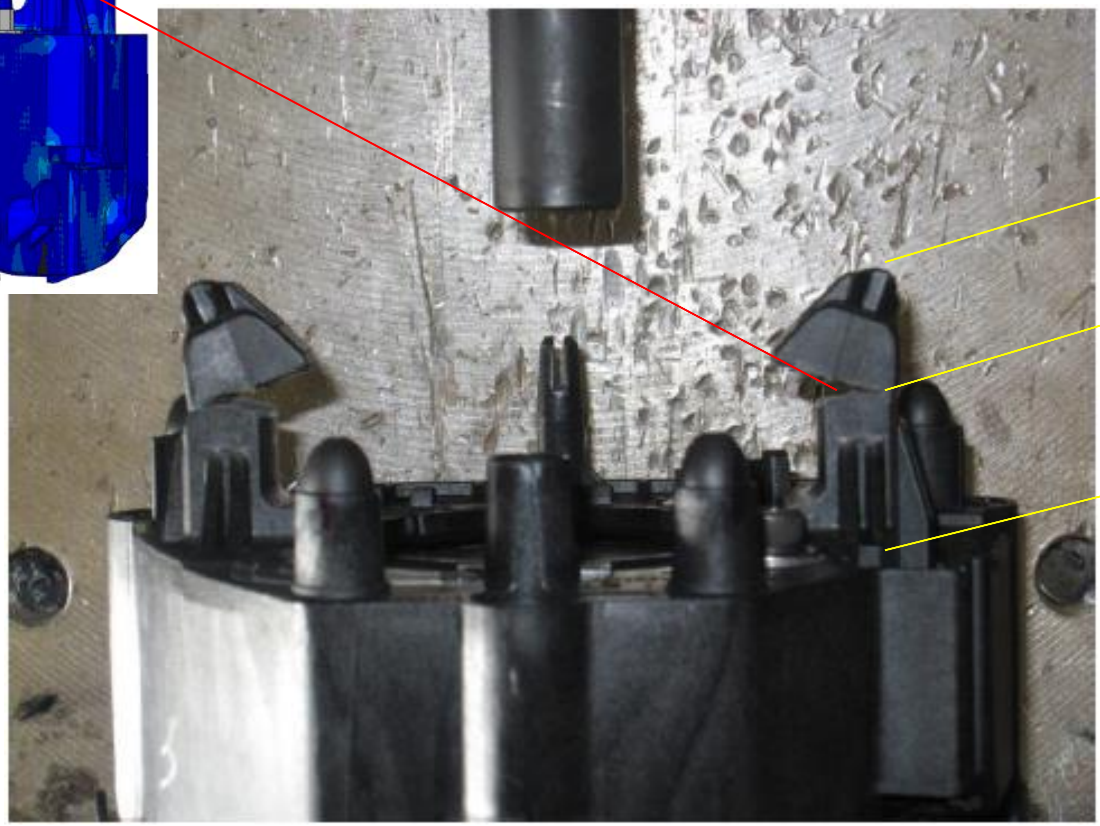
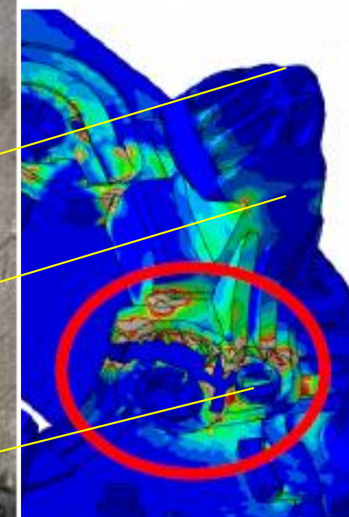
Impact on Failure



With Fiber Orientation





Isotropic

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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/

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