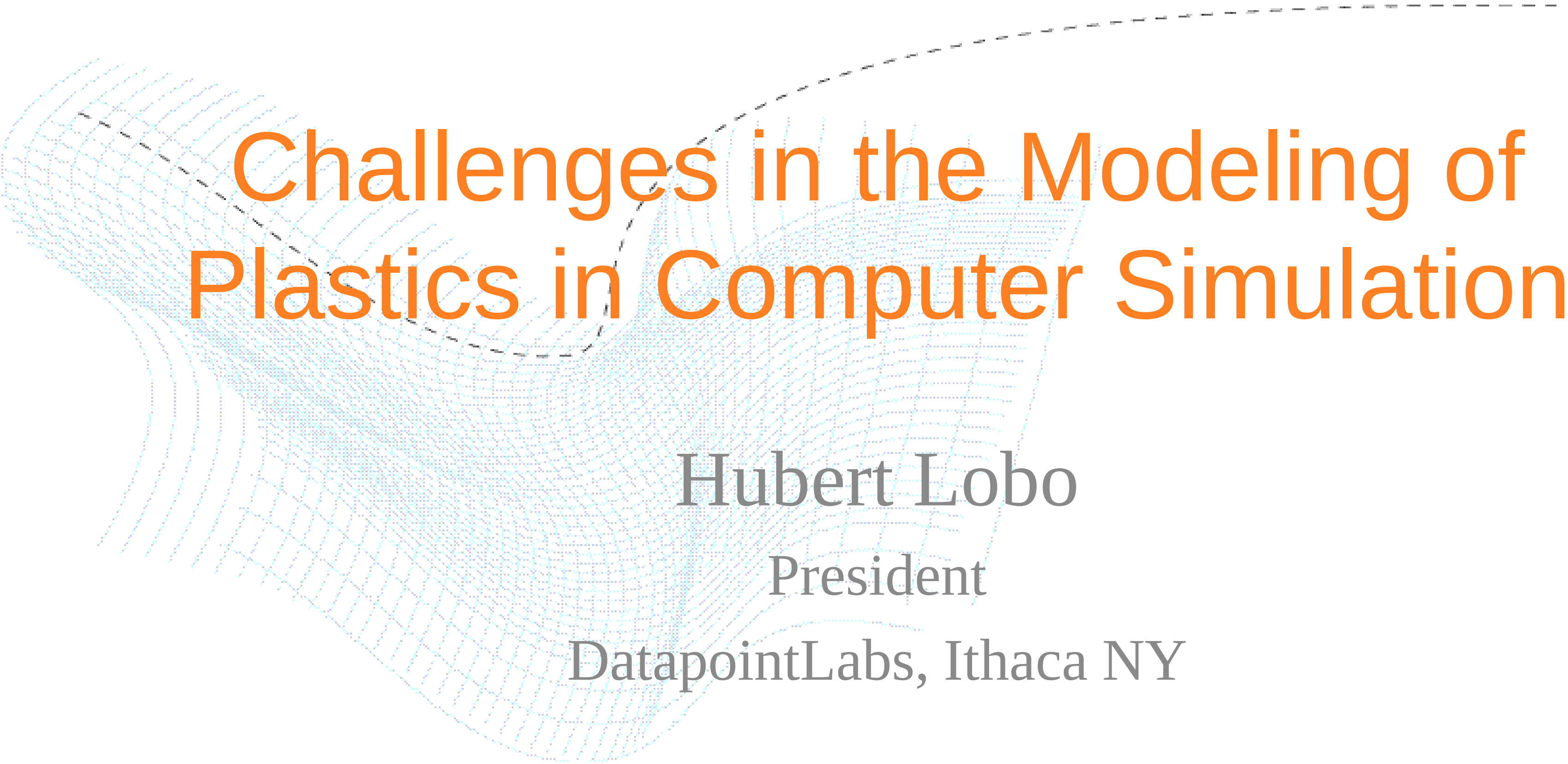


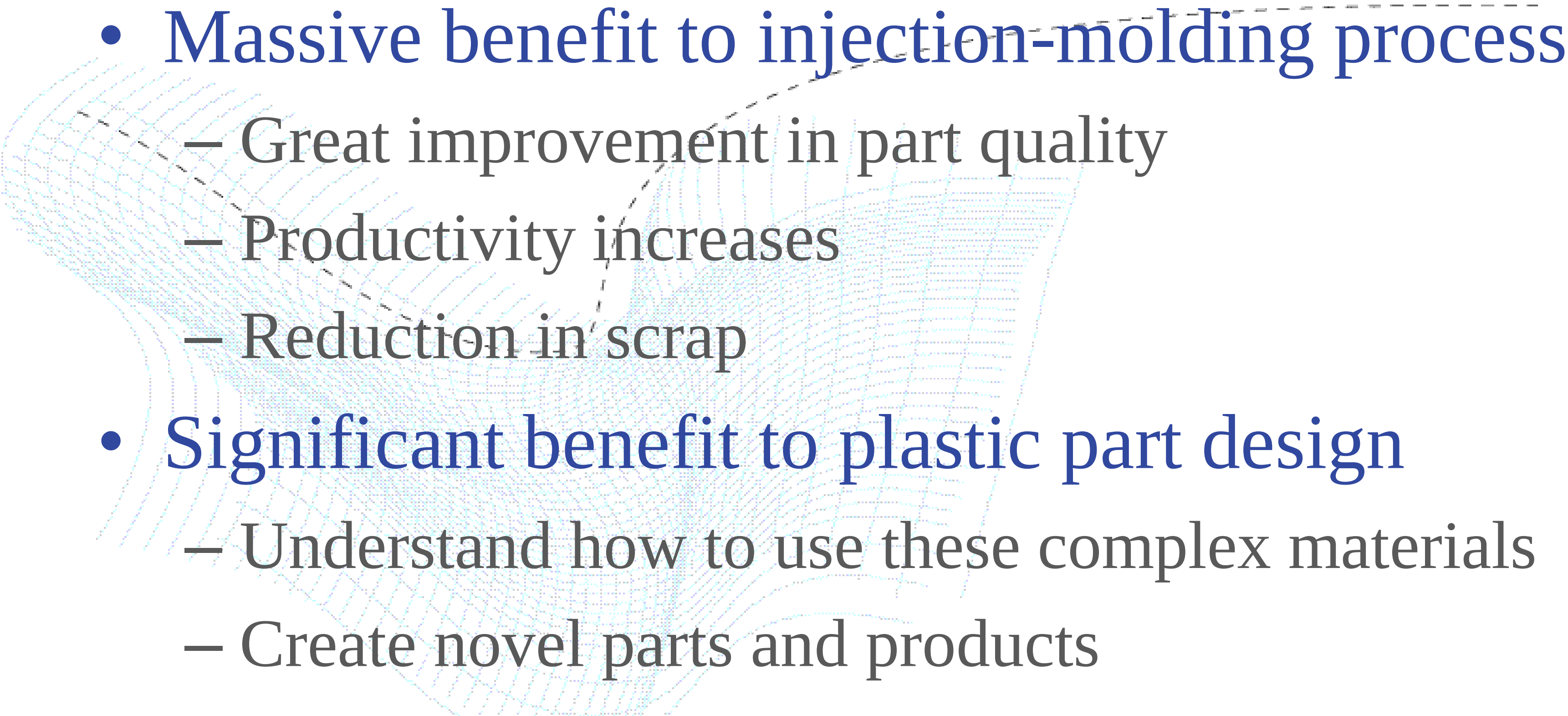
Challenges in the Modeling of Plastics in Computer Simulation

Hubert Lobo

President

DatapointLabs, Ithaca NY

Impact of Simulation



- Massive benefit to injection-molding process
  - Great improvement in part quality
  - Productivity increases
  - Reduction in scrap
- Significant benefit to plastic part design
  - Understand how to use these complex materials
  - Create novel parts and products
  - Prevent in-the-field part failure

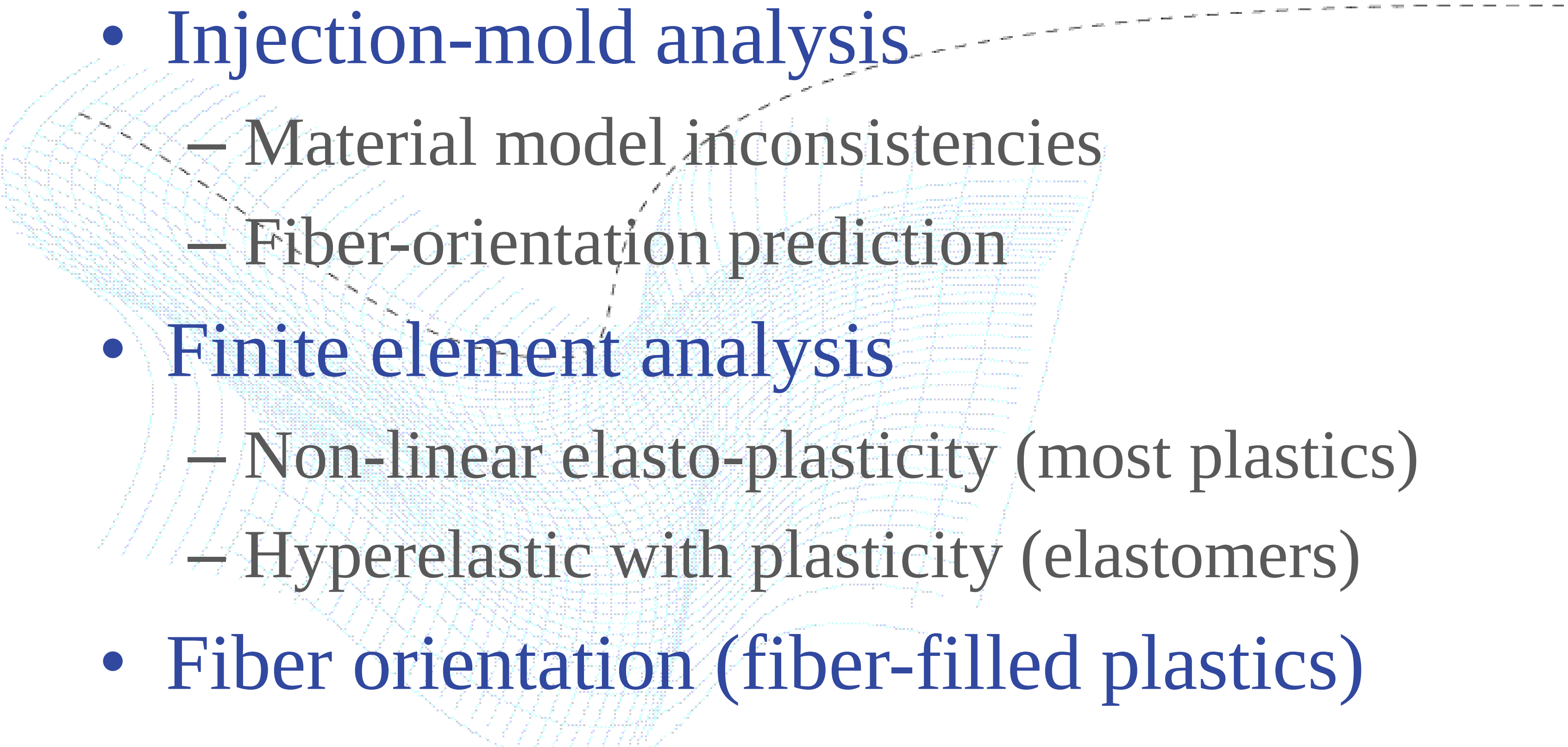
Challenges

- Plastics are very complex
  - – Not all behavior is well understood
  - – Experimental artifacts accompany the data
  - – Mathematical material models have limitations
  - – Behavior is not correctly represented in simulation
- These limitations can cause errors
- With proper understanding, good design decisions can be made

What Makes Plastics Complex

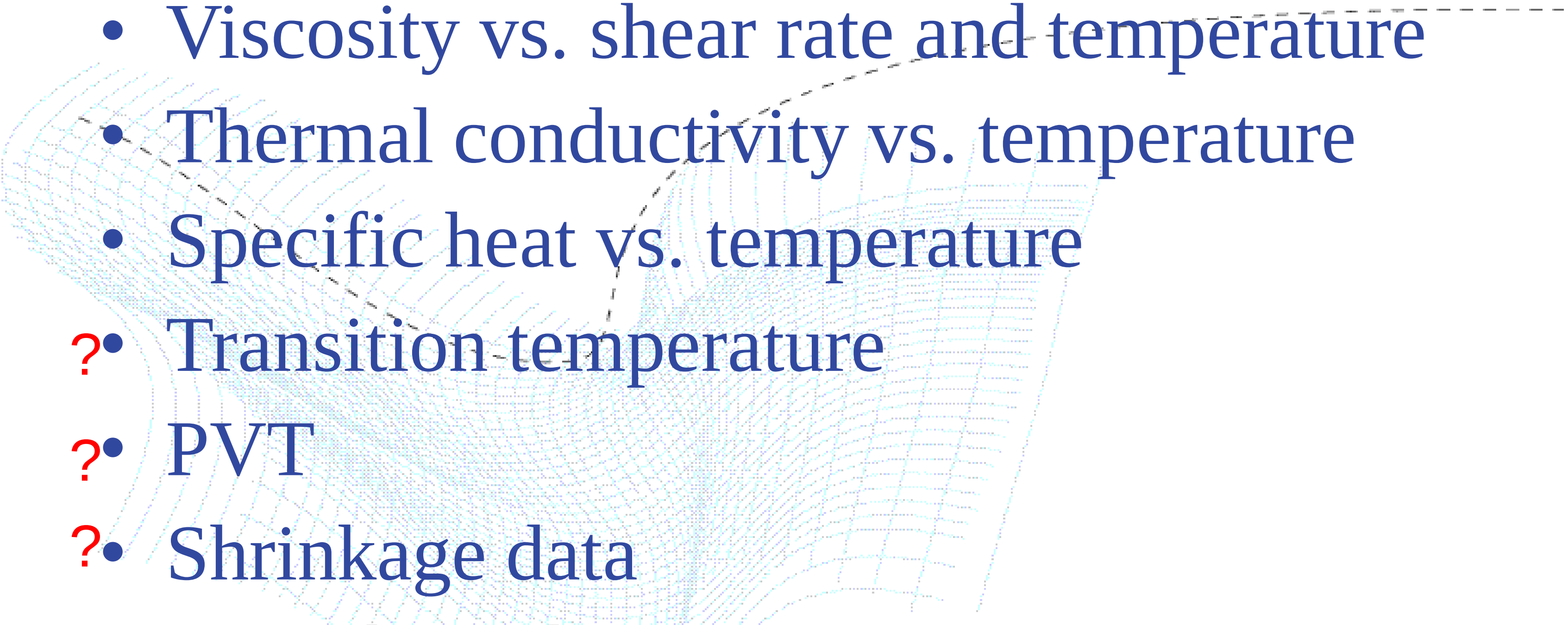
- Non-Newtonian, non-isothermal flow
- Cooling rate- and shear-dependent crystallization
- Viscoelastic (time-based behavior)
- Non-linear elasticity
- Complex plasticity (pre-yield, post-yield)
- Properties change over product operational temperature and environmental exposure

Current Topics



- Injection-mold analysis
  - Material model inconsistencies
  - Fiber-orientation prediction
- Finite element analysis
  - Non-linear elasto-plasticity (most plastics)
  - Hyperelastic with plasticity (elastomers)
- Fiber orientation (fiber-filled plastics)
- The promise of validation

Data for Injection-mold Analysis

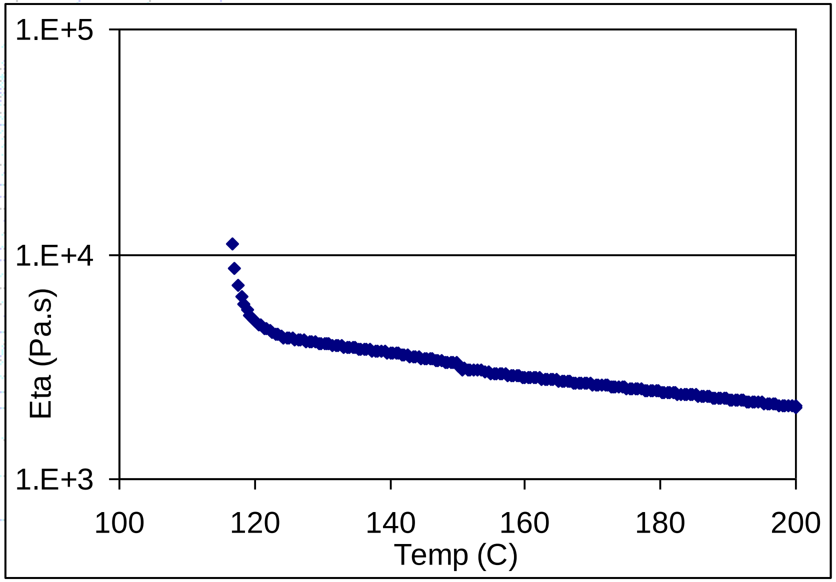


- Viscosity vs. shear rate and temperature
- Thermal conductivity vs. temperature
- Specific heat vs. temperature
- ? Transition temperature
- ? PVT
- ? Shrinkage data
  - Mechanical properties
  - CRIMS (Moldflow)

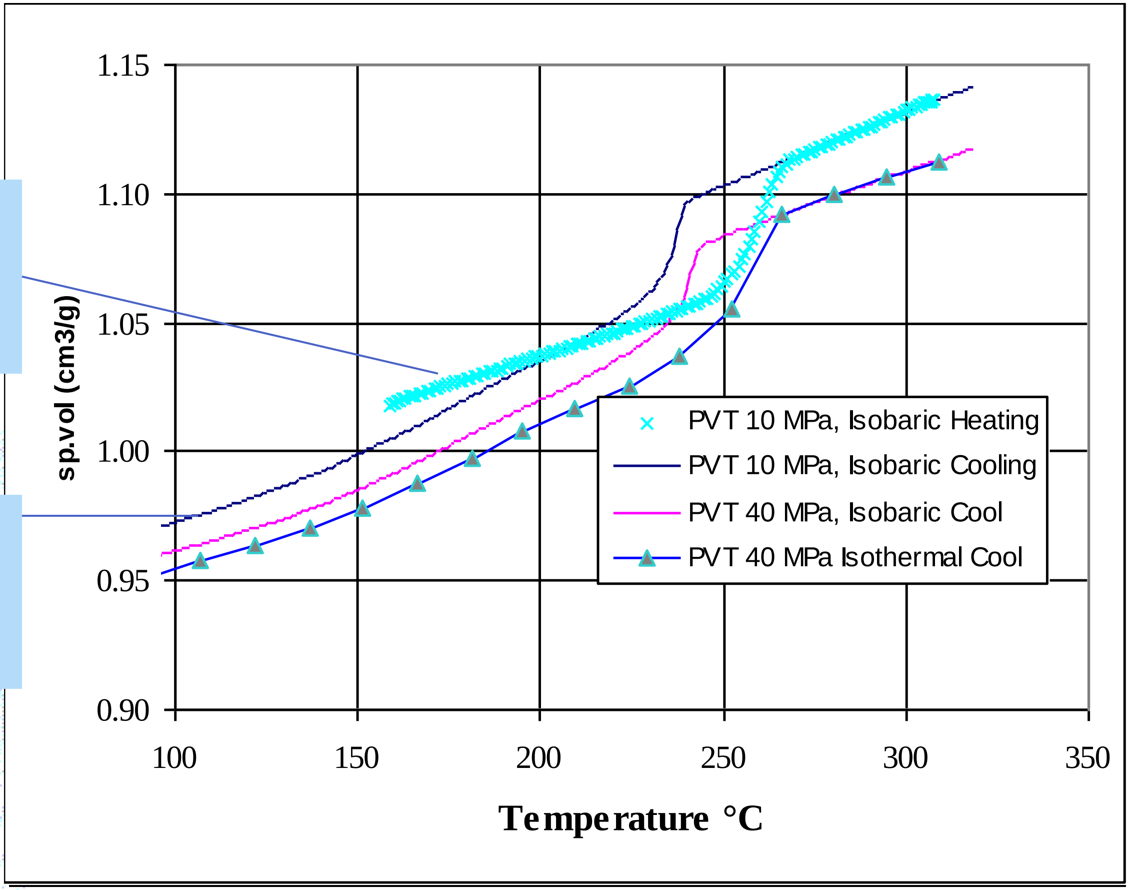
Transitions: No-flow Temperature

- When does the polymer solidify in the mold?
- Different test methods produce different transitions
- Transition inconsistency in semi-crystalline polymers
  - super-cooling
  - cooling rate effect
  - viscoelastic effects
- Impact on simulation unclear

DMA cooling dynamic scan (semi-crystalline polymer)



How to Measure PVT



Initial PVT data with injection-molded sample has lower solid density

Subsequent slow-cooled isobaric sample has higher, incorrect density

Shrinkage predictions can be affected

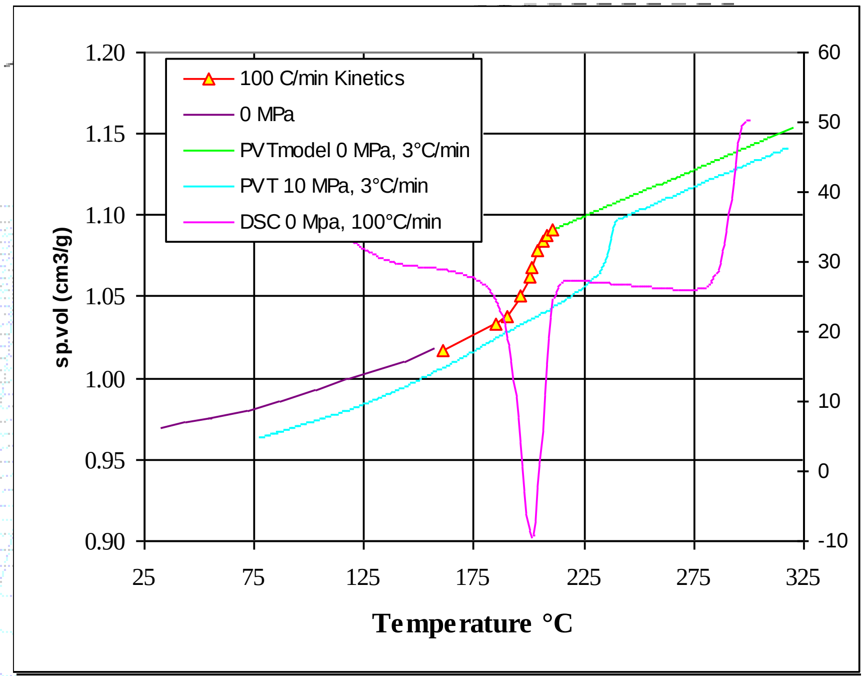
Accounting for Rate Effects in PVT

- Possible to correct PVT data using DSC high-cooling-rate curves

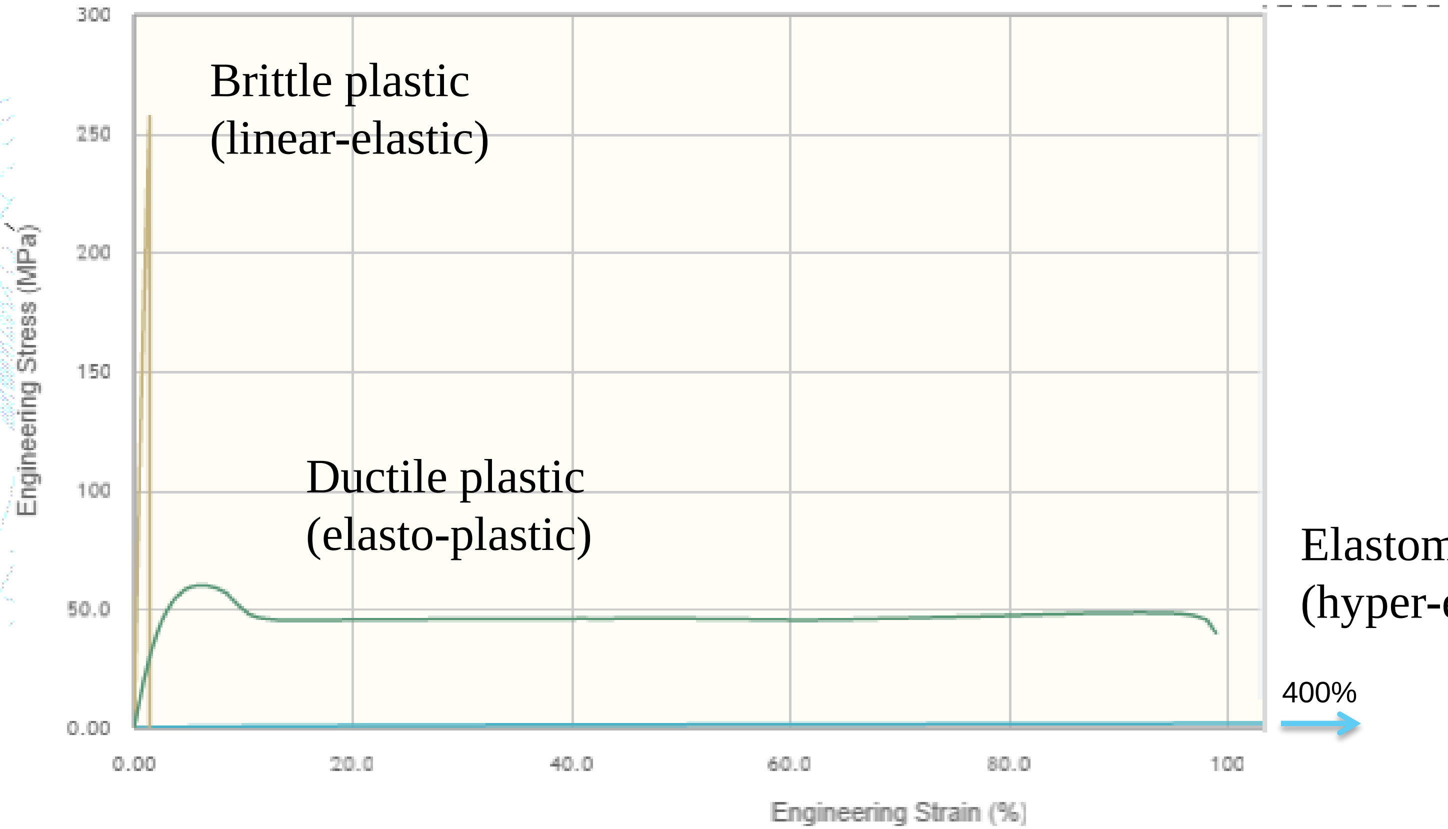
  (H. Lobo, ANTEC 1999)

- Strategy is incorrect
  - DSC is quiescent: high super-cooling effect
  - Shear effects in molding mitigate super-cooling effect

  (Kennedy, Janeshitz-Kriegl)



Solid State Behavior of Polymers



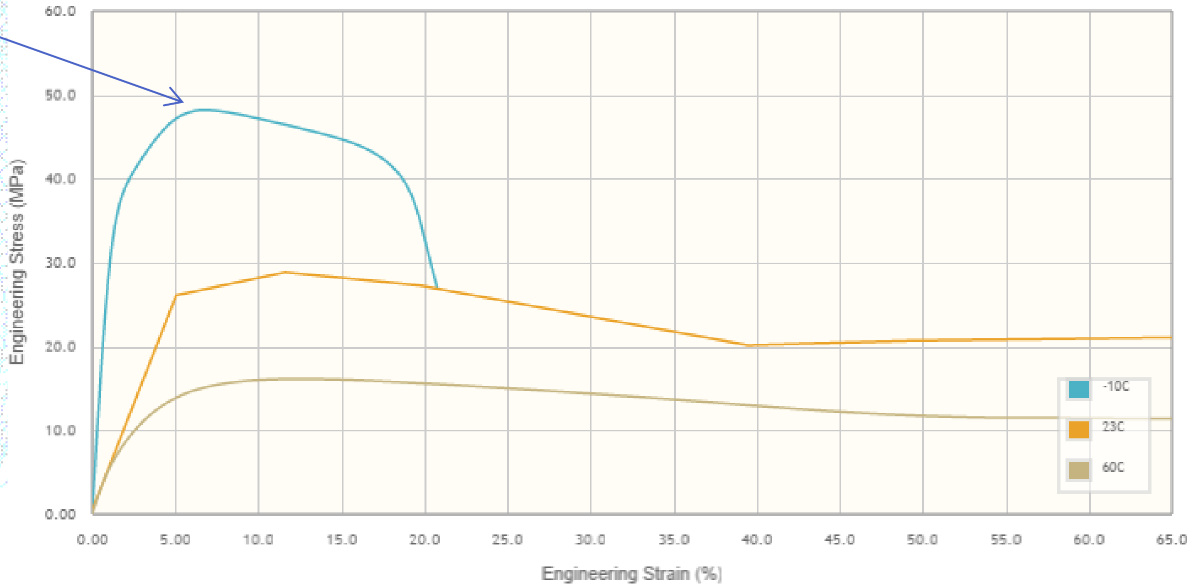
Brittle plastic
(linear-elastic)

Ductile plastic
(elasto-plastic)

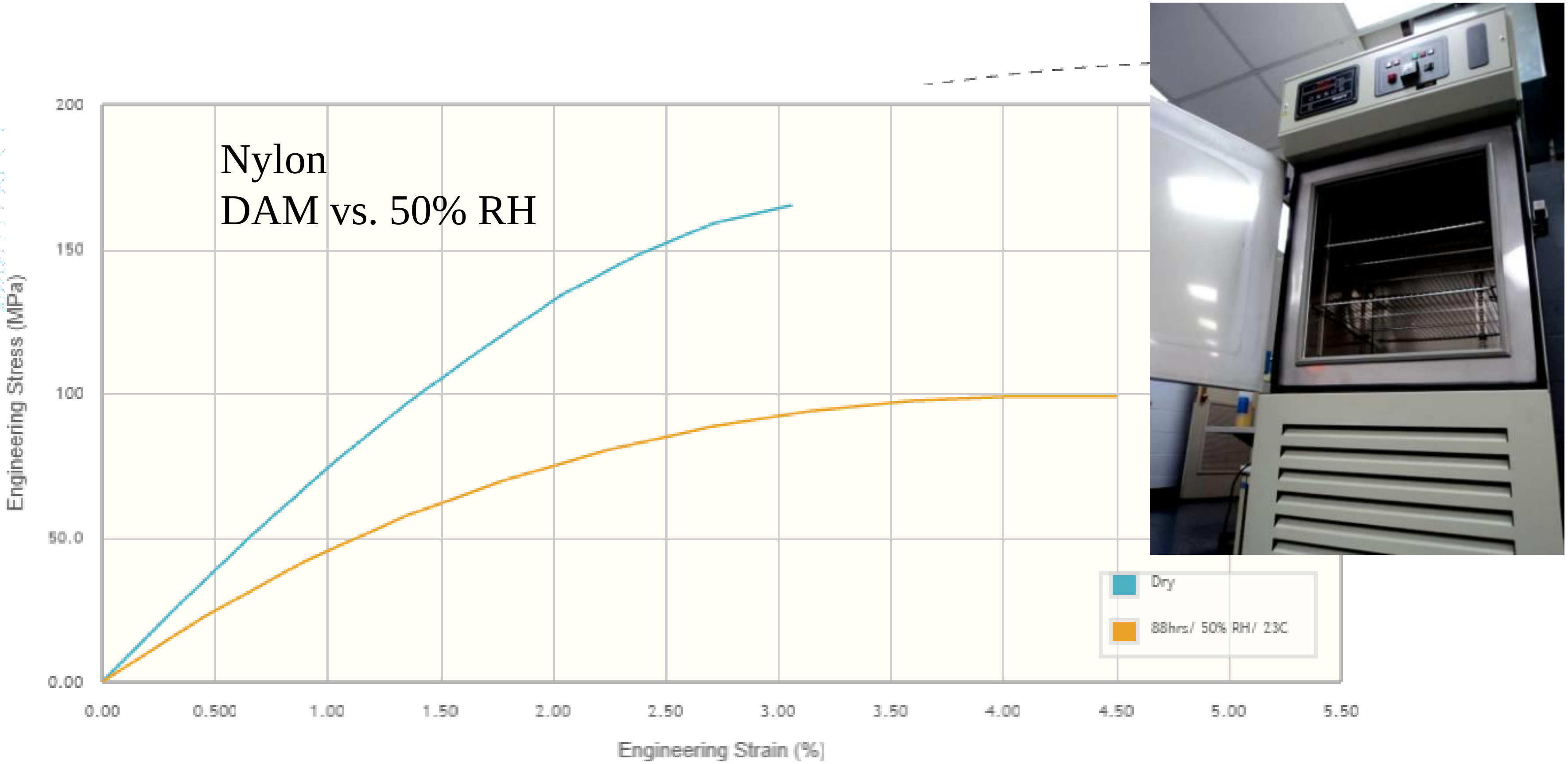
Elastomer
(hyper-elastic)

Effect of Environment: Temperature

- Properties and dependencies change with temperature
  - Modulus
  - Ductile-brittle transitions
  - Rate dependency

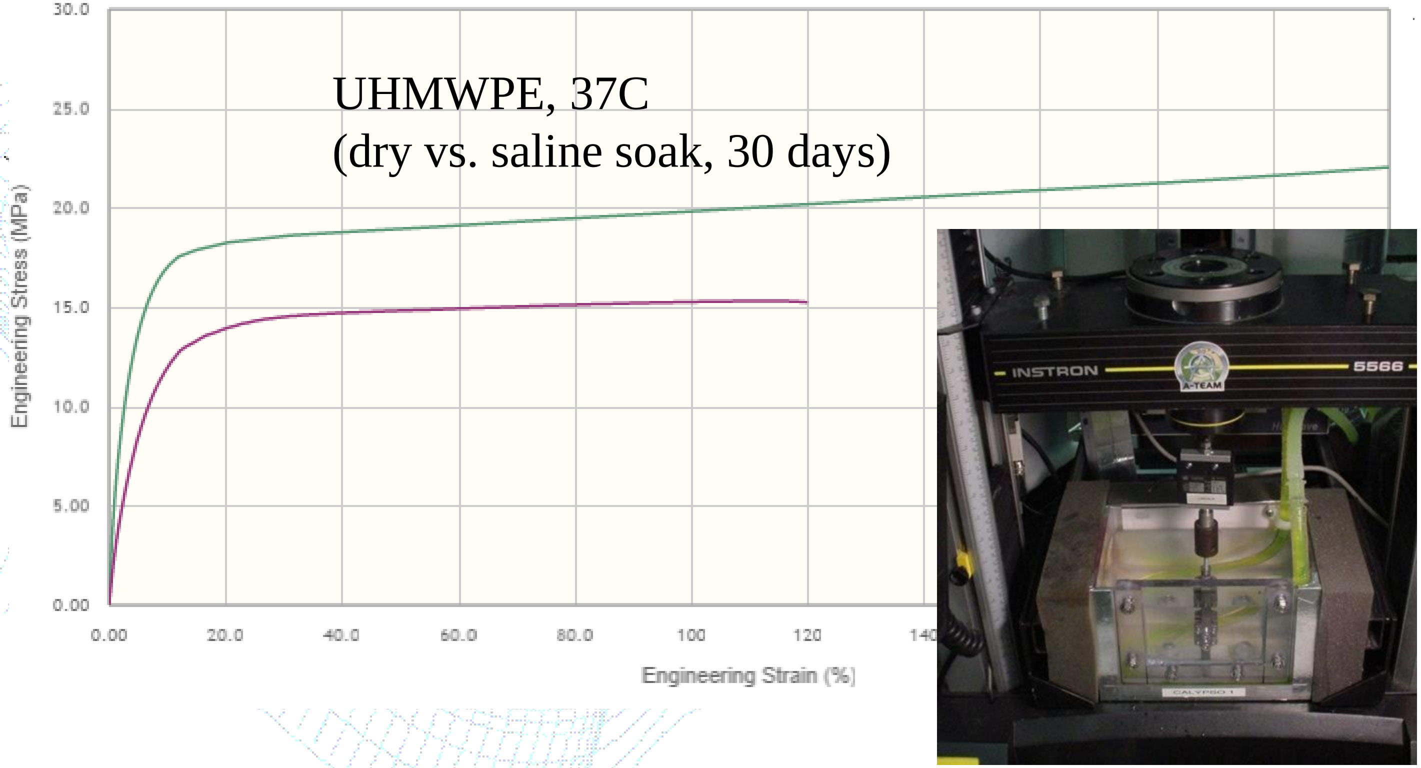


Effect of Environment: Moisture

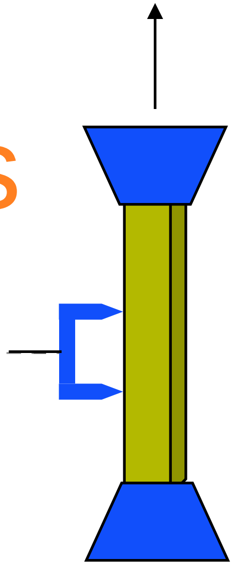


Nylon
DAM vs. 50% RH

Effect of Environment: *In-vivo*


UHMWPE, 37C
(dry vs. saline soak, 30 days)

Models for Ductile Plastics



- True stress-strain curves
  - UTM with extensometers
  - Testing to yield or break
- Material model: elasto-plasticity
  - Reduce to elasto-plasticity based on yield point
  - Bilinear
  - Multilinear
- Usage
  - Large deformation
  - von Mises yield

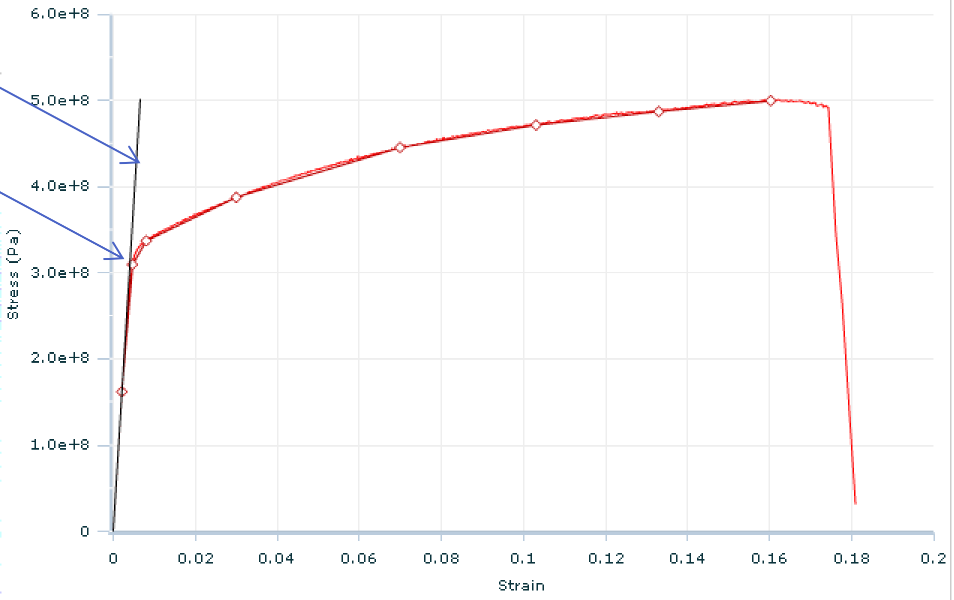
Elasto-plasticity in Metals

- Evaluate a modulus
- Define elastic limit
- Calculate multi-point plasticity

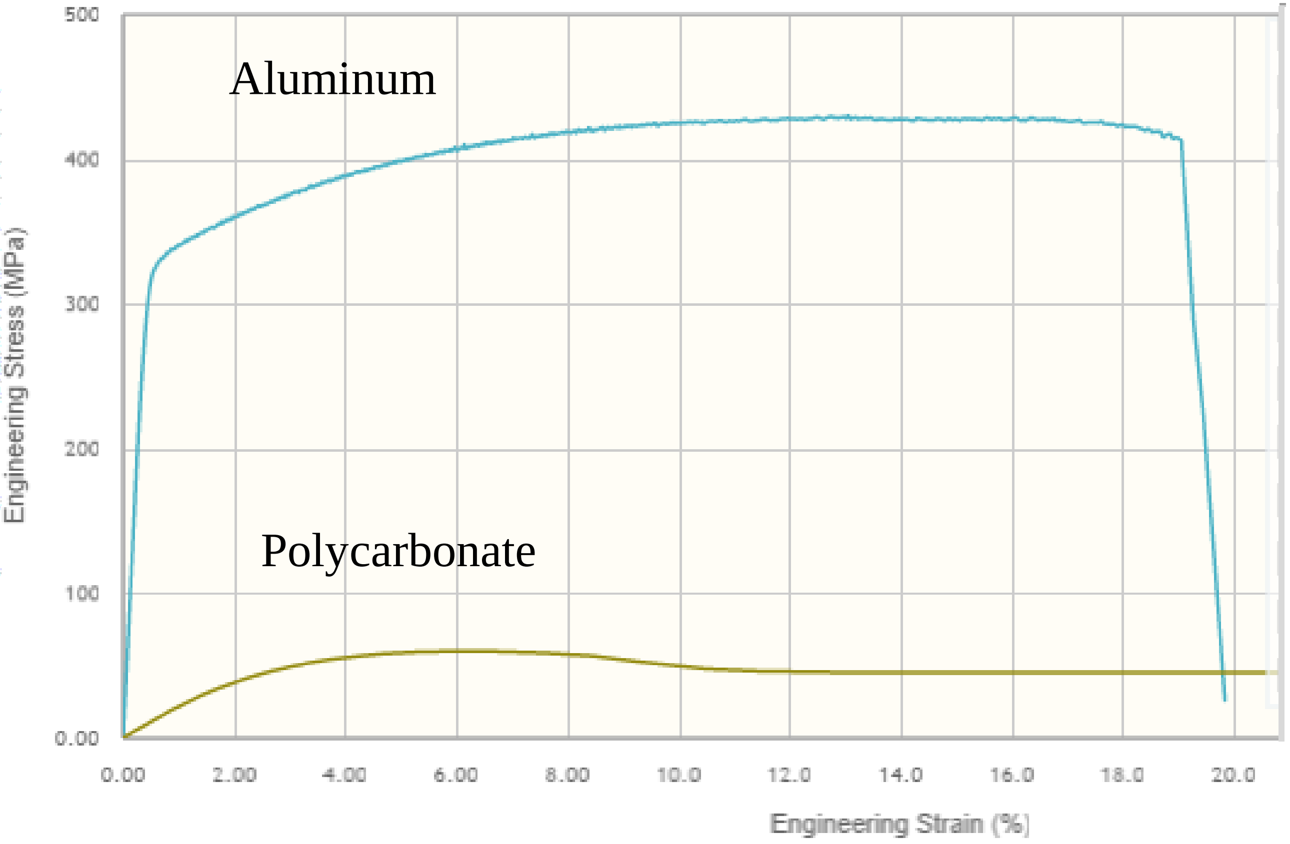
$$\varepsilon_t = \underline{E} + \varepsilon_p$$

$$\sigma$$

where,
E = elastic modulus (MPa)
σ_t = true stress (MPa)

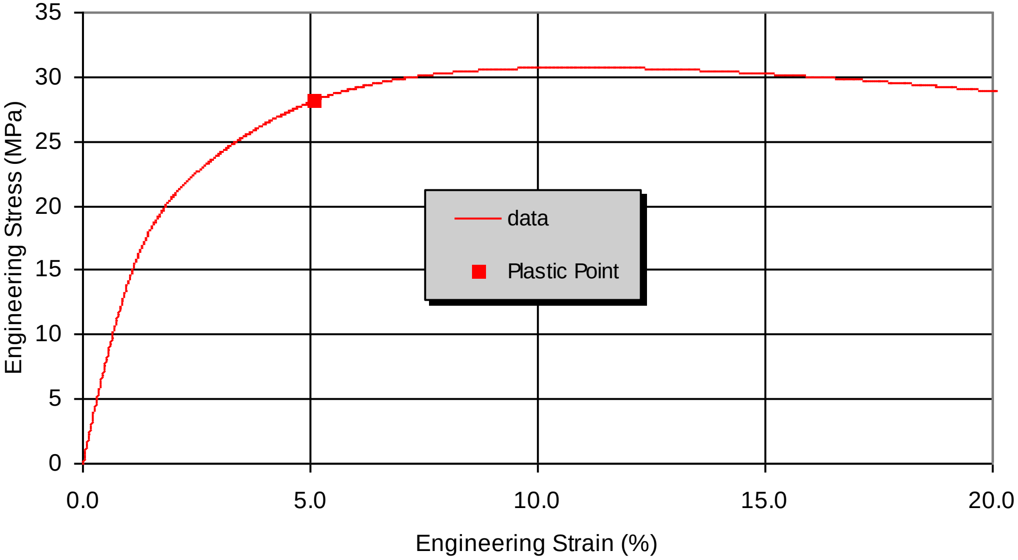


Comparing Metal to Plastic



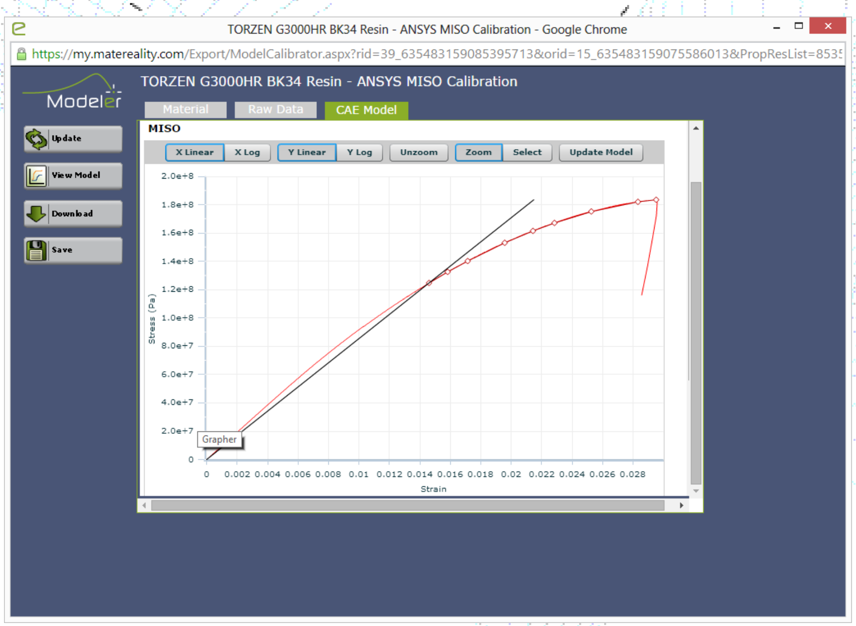
Polymer Elasto-plasticity

- Non-linear elasticity
- Elastic limit well below classical yield point
- Significant plastic strains prior to yield
- Post-yield with necking behavior

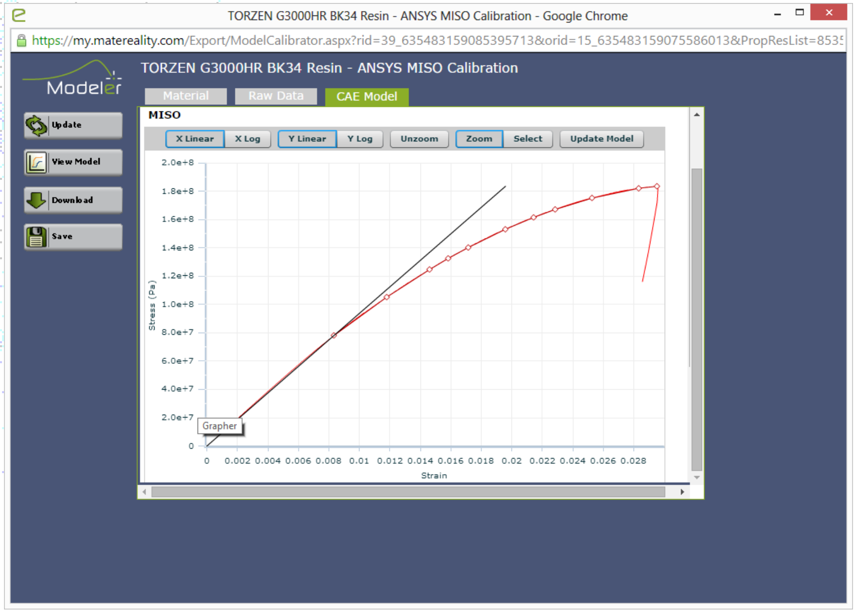


Modeling Options

Fidelity to plastic point

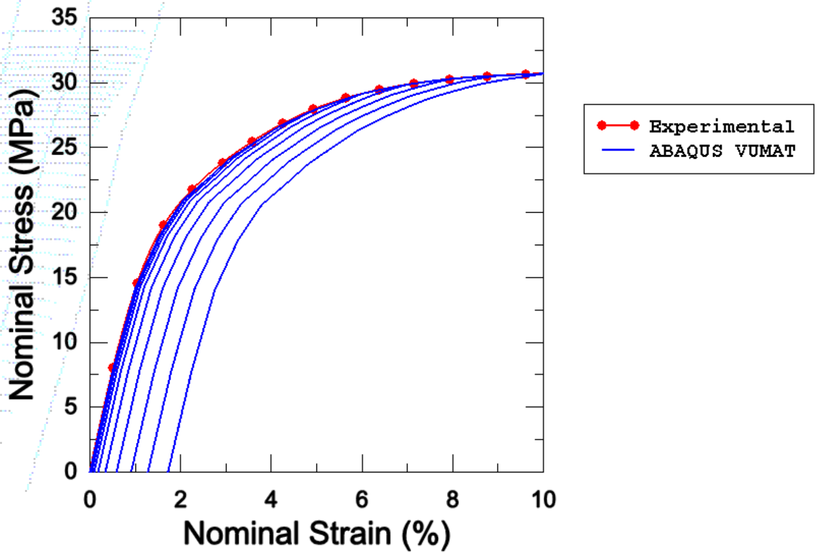


Fidelity to curve shape



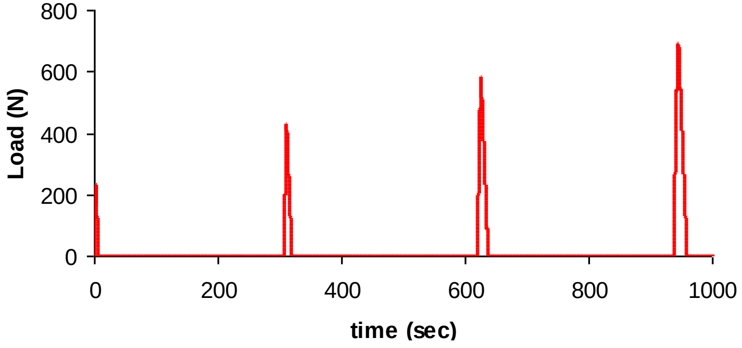
Applying Abaqus FeFp Model

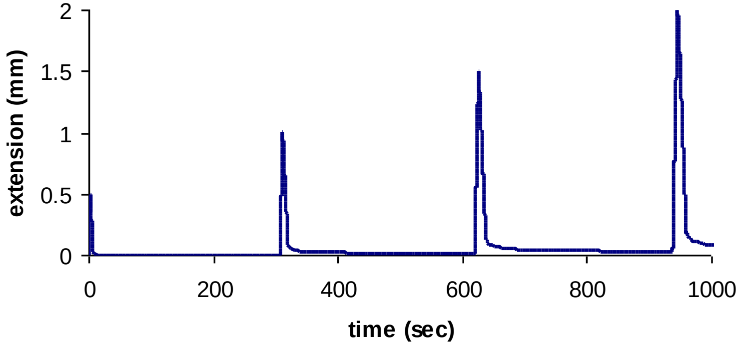
- Non-linear hyper-elasticity with pre-yield plasticity
- Accurate representation of elastic behavior
- Accurate representation of plasticity

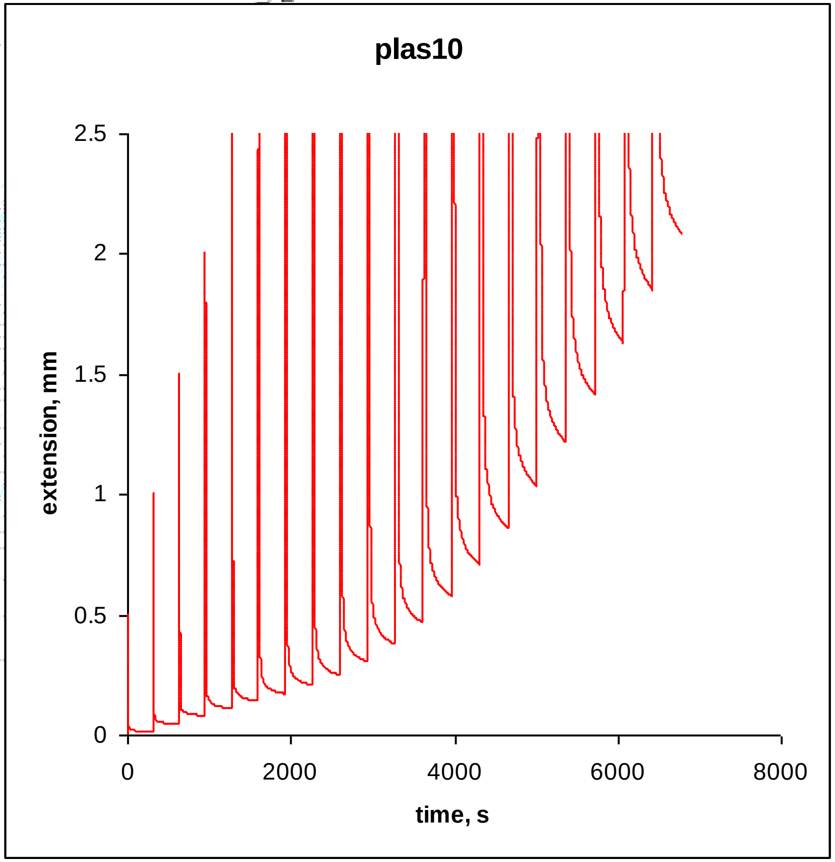


(Lobo & Hurtado, Abaqus 2006)

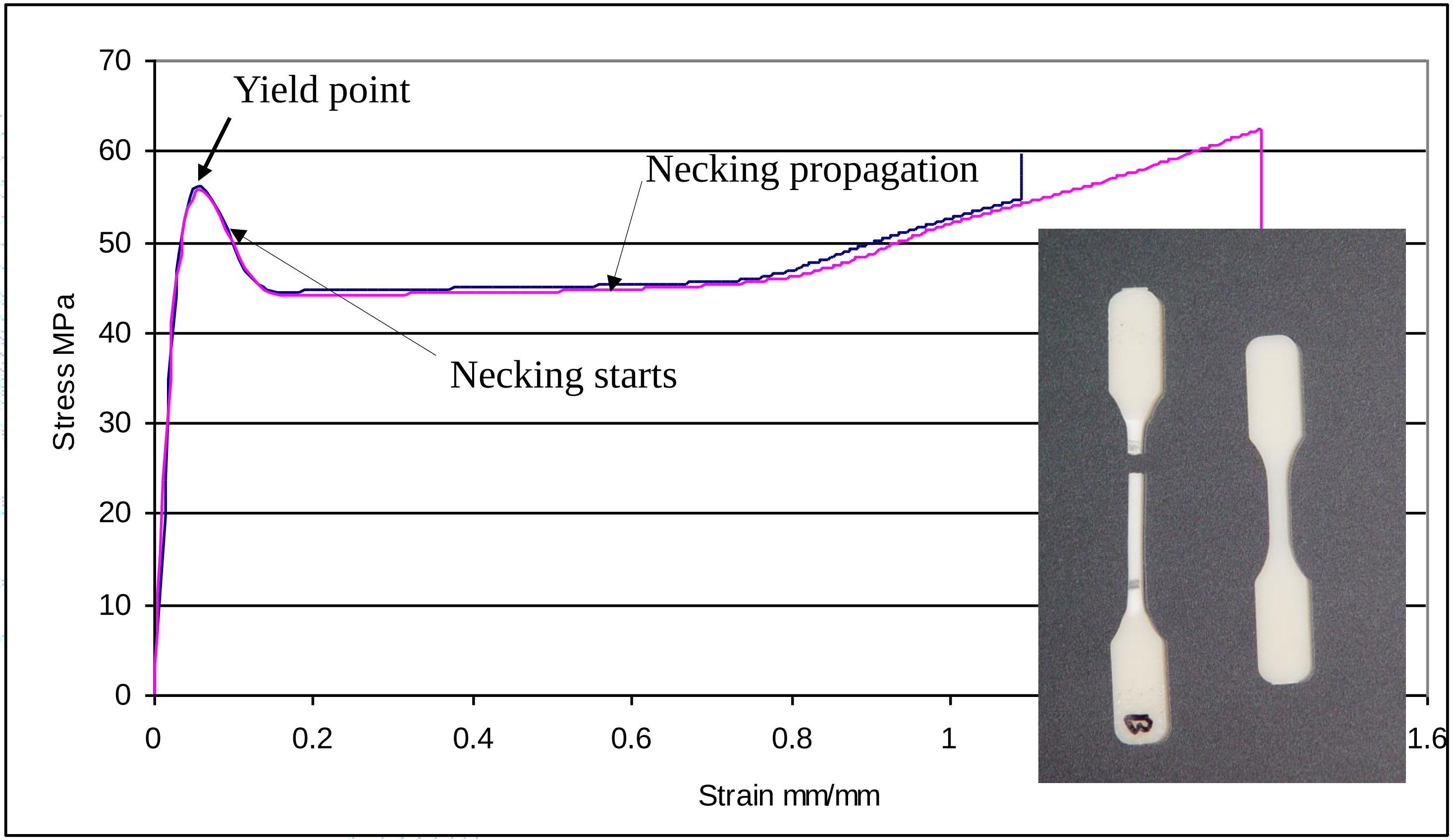
A True Representation of Plasticity







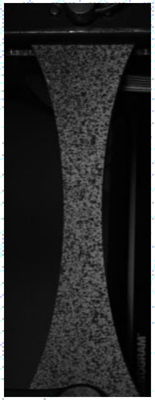
Post-yield Ductile Behavior

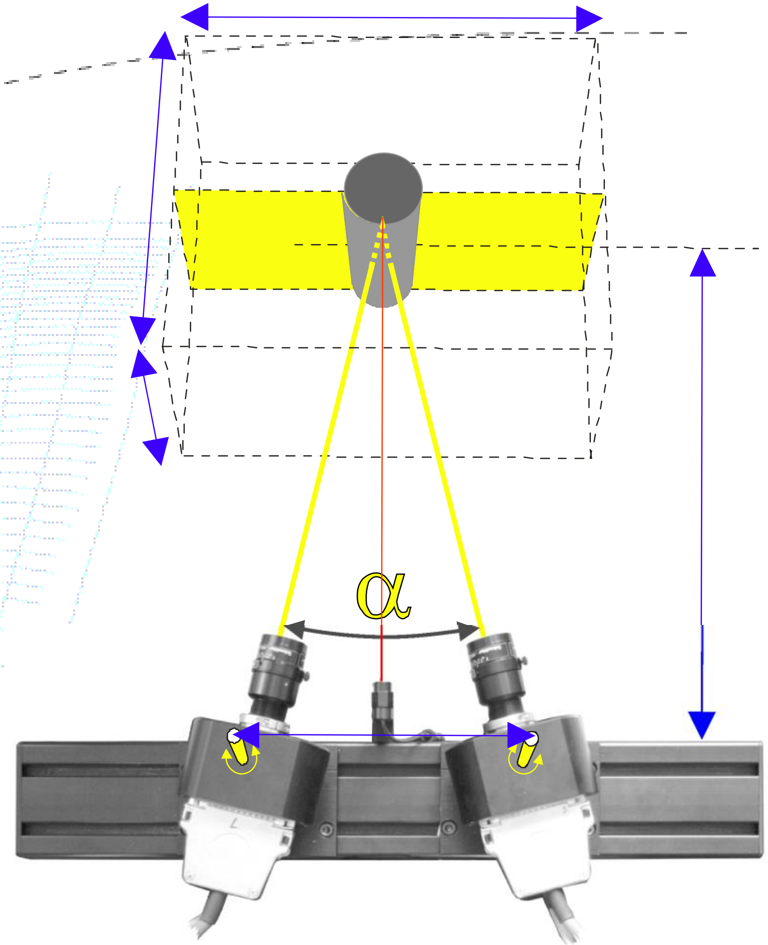


Digital Image Correlation (DIC)

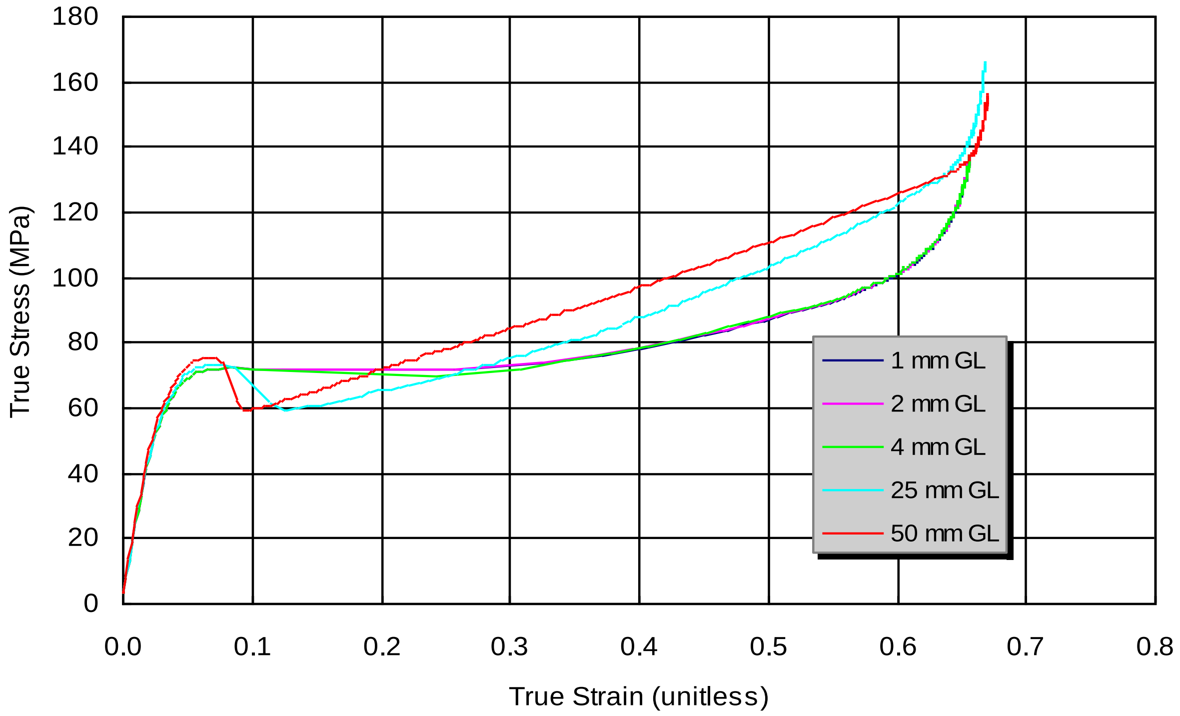
- Stereo camera system (ARAMIS)
- Simultaneous XYZ dimension change
- Complete surface is measured
- Post-measurement selection of region of interest

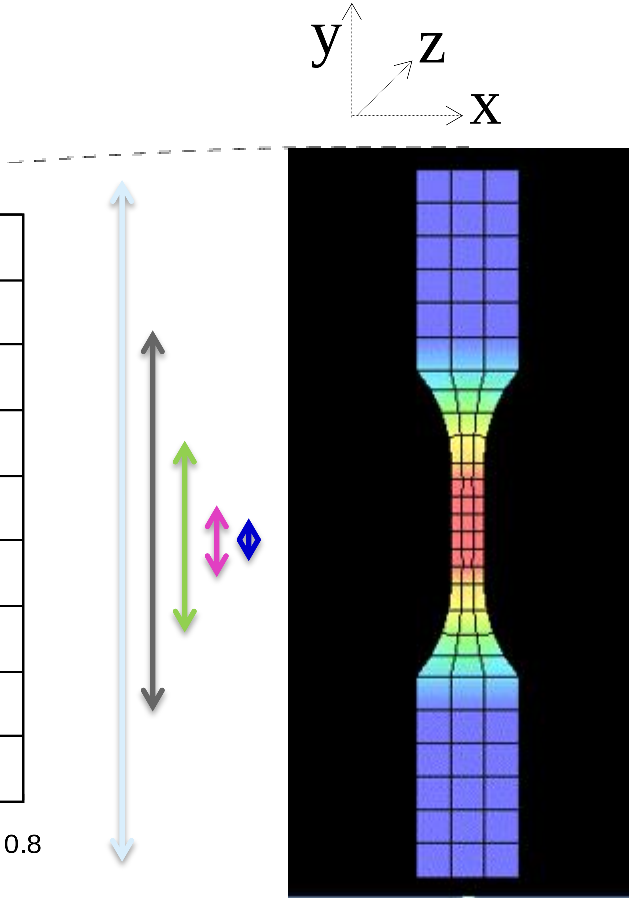
(Lobo et al., LS-DYNA 2013)



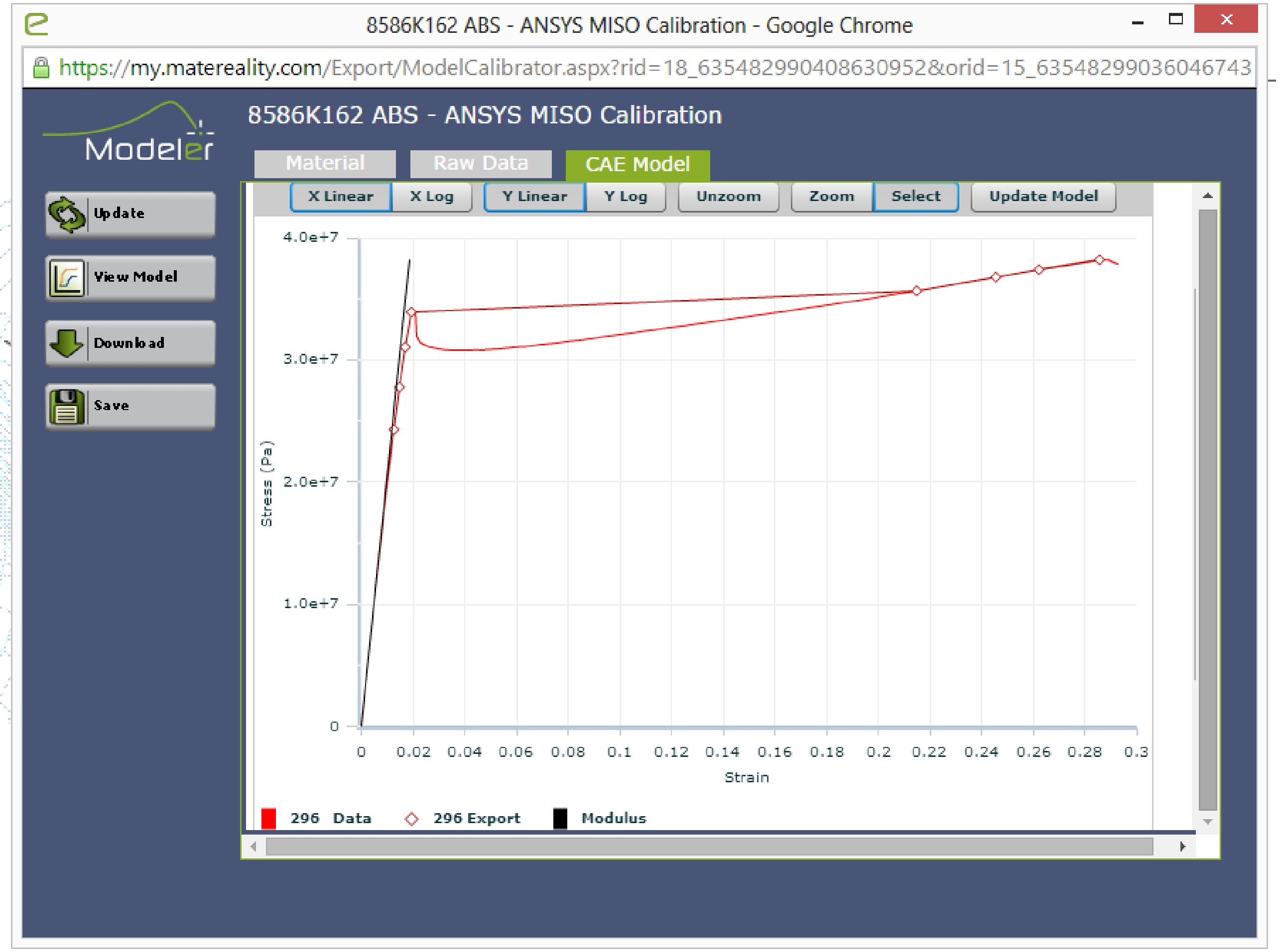


Measuring Post-yield Stress-Strain





Reasonable Post-yield Approximation

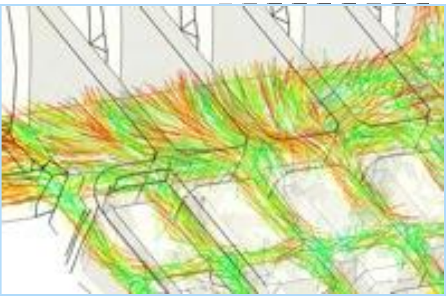


8586K162 ABS - ANSYS MISO Calibration - Google Chrome

https://my.matereality.com/Export/ModelCalibrator.aspx?rid=18_635482990408630952&orid=15_63548299036046743

8586K162 ABS - ANSYS MISO Calibration

Fiber-filled Plastics

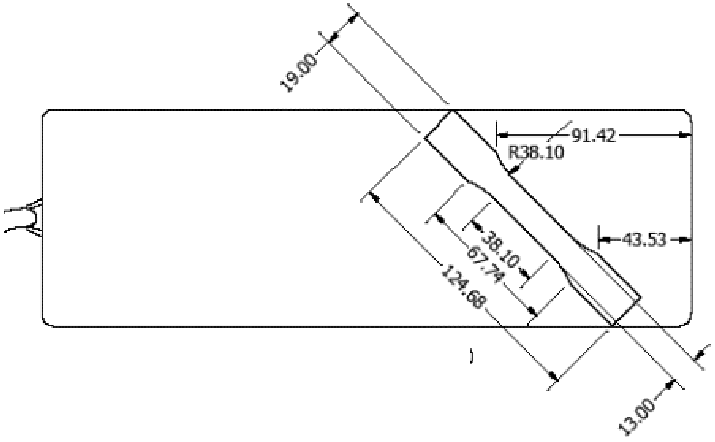


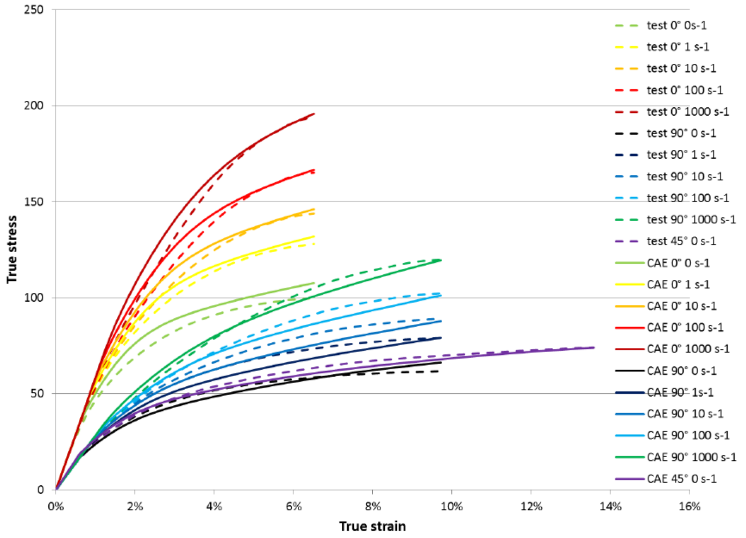
Source:e-Xstream

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

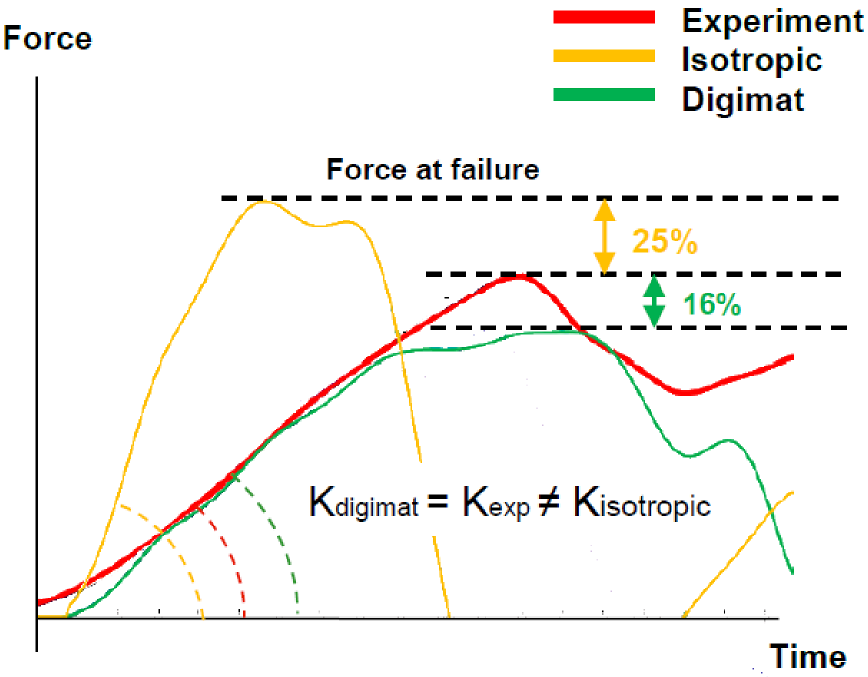
Typical Test Protocol

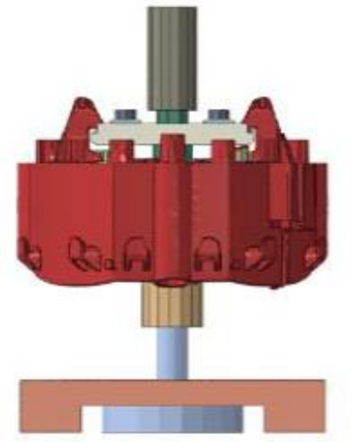
- Mold long plaques
  - Edge gated: short end
  - Fully developed flow
  - High fiber orientation
- Cut test specimens
  - 0°, 90°, 45°, …
- Obtain true stress-strain data
- Calibrate material model





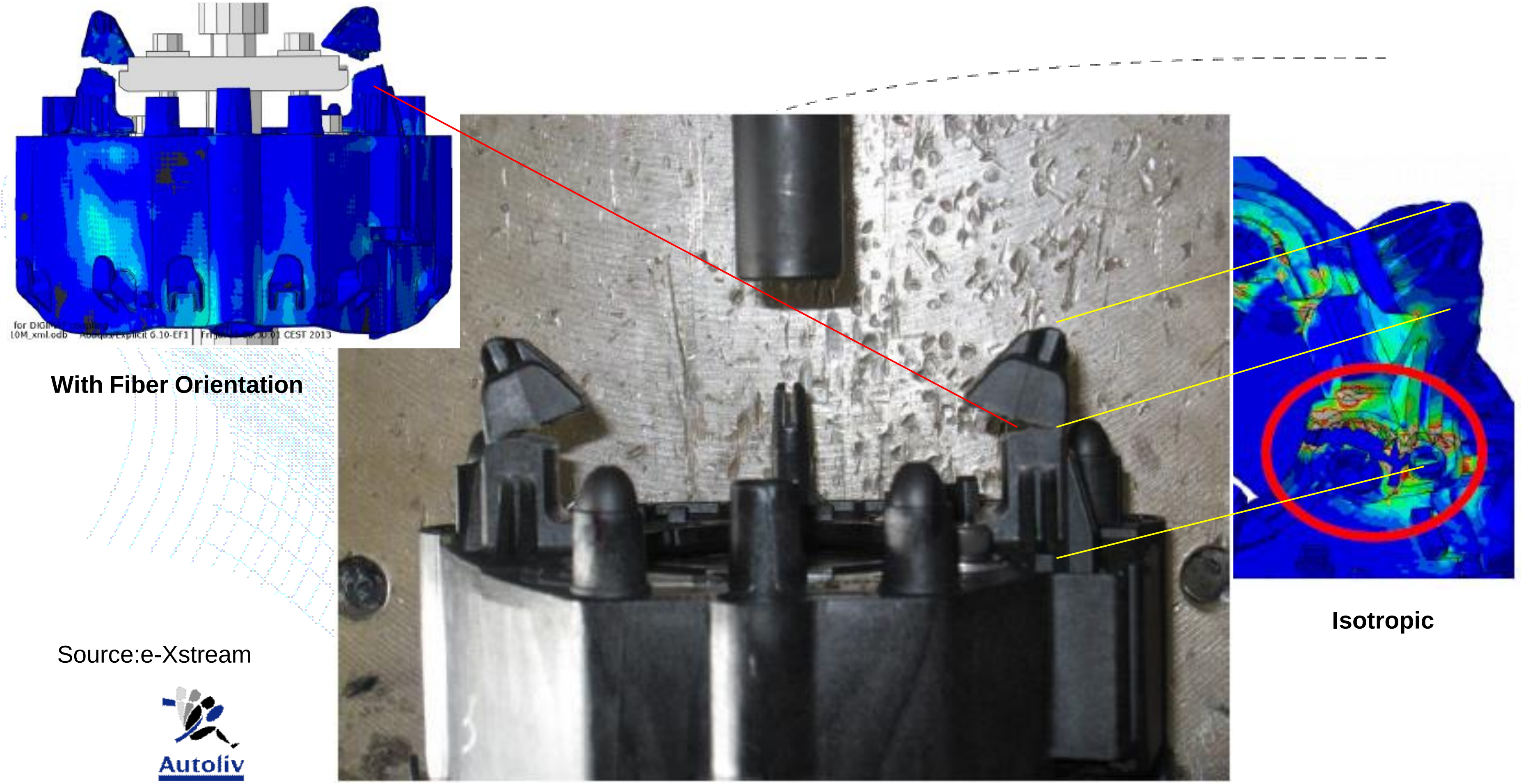
Example: Airbag Housing





Source:e-Xstream

Impact on Failure



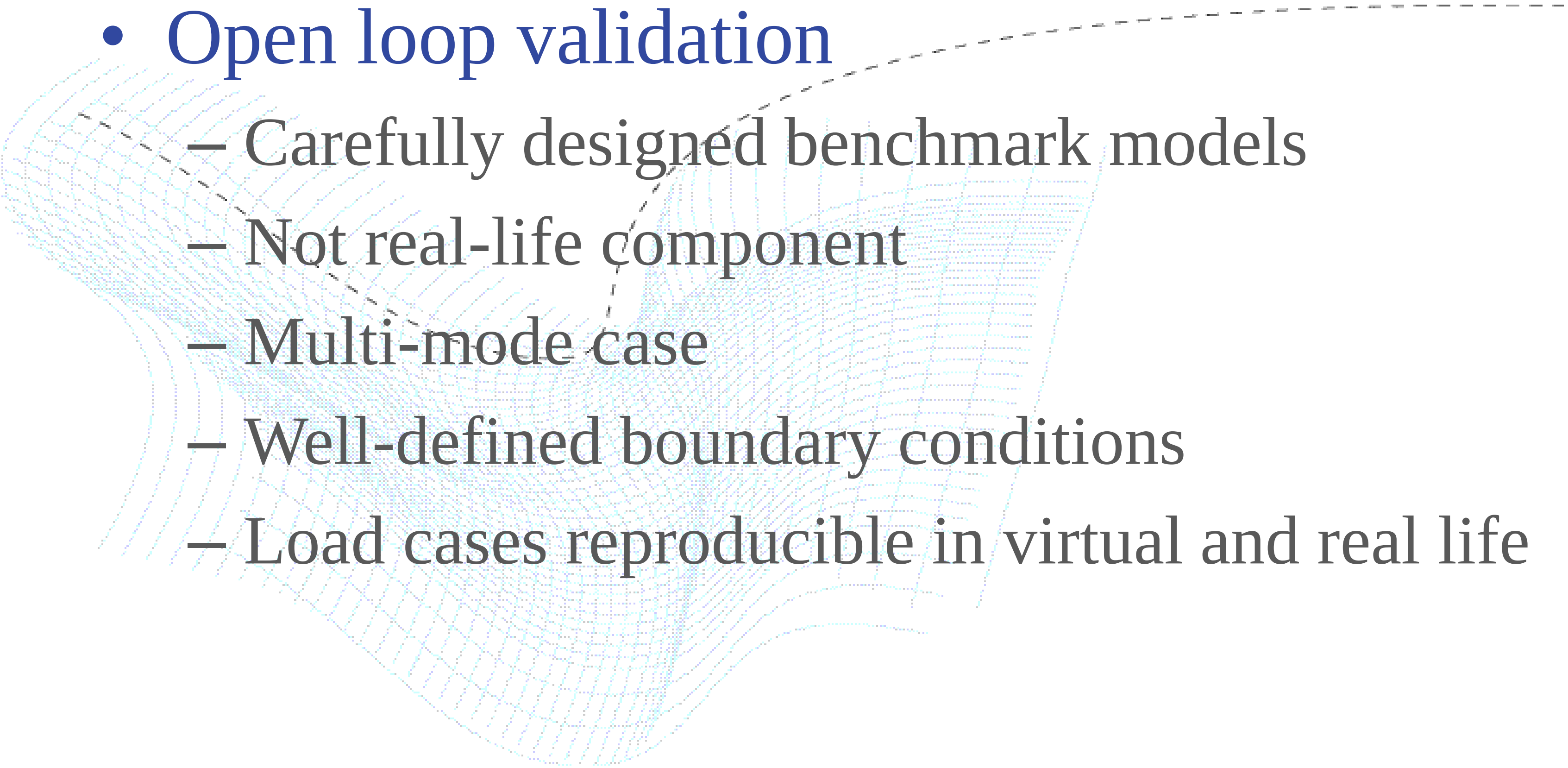
With Fiber Orientation

Isotropic

Source:e-Xstream

Autoliv

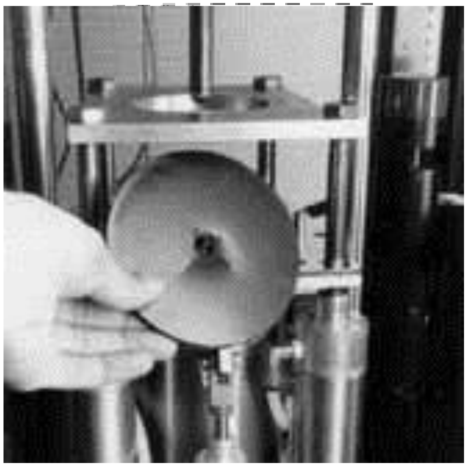
The Promise of Validation



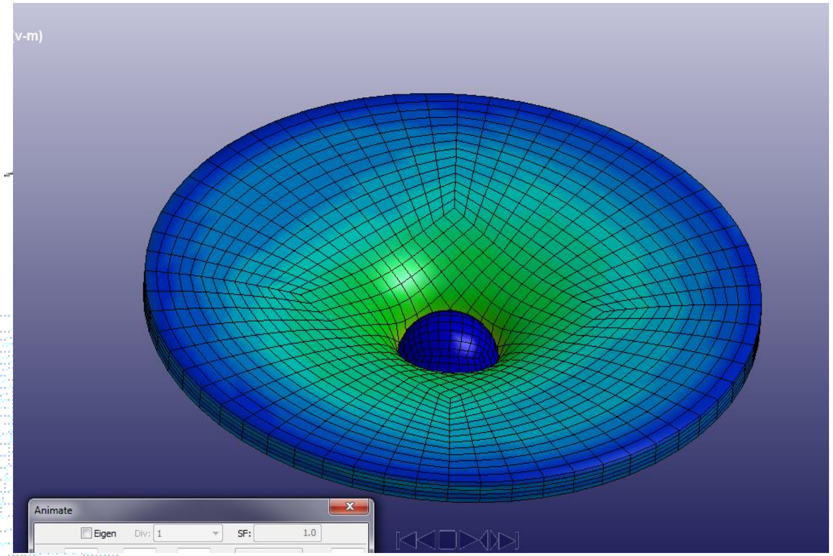
- Open loop validation
  - – Carefully designed benchmark models
  - – Not real-life component
  - – Multi-mode case
  - – Well-defined boundary conditions
  - – Load cases reproducible in virtual and real life

Dynamic FEA TestBench Model

- ASTM D3763 falling dart impact
- Multi-axial loading with well-defined boundary conditions
  - – Dart with a ½-inch rounded tip
  - – Dart weight of 22.68 kg
  - – Disk dimensions
    - Thickness = ~3 mm
    - Diameter = 76 mm
  - – B.C.s: fixed edges
  - – I.C.s: initial velocity of 3.3m/s



Model Complexities

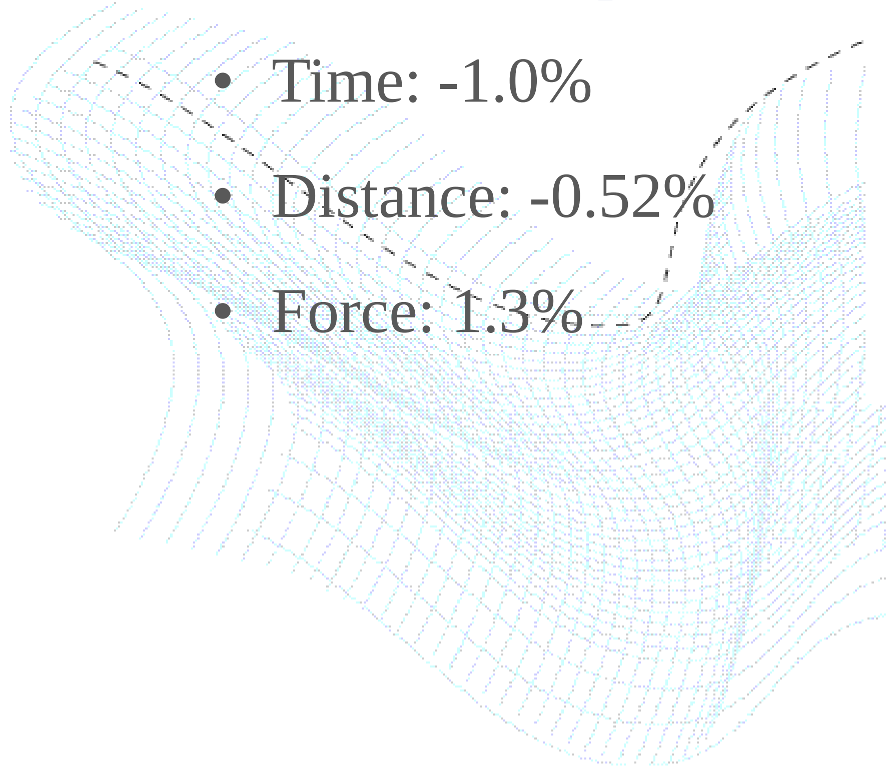


Div: 1
SF: 1.0

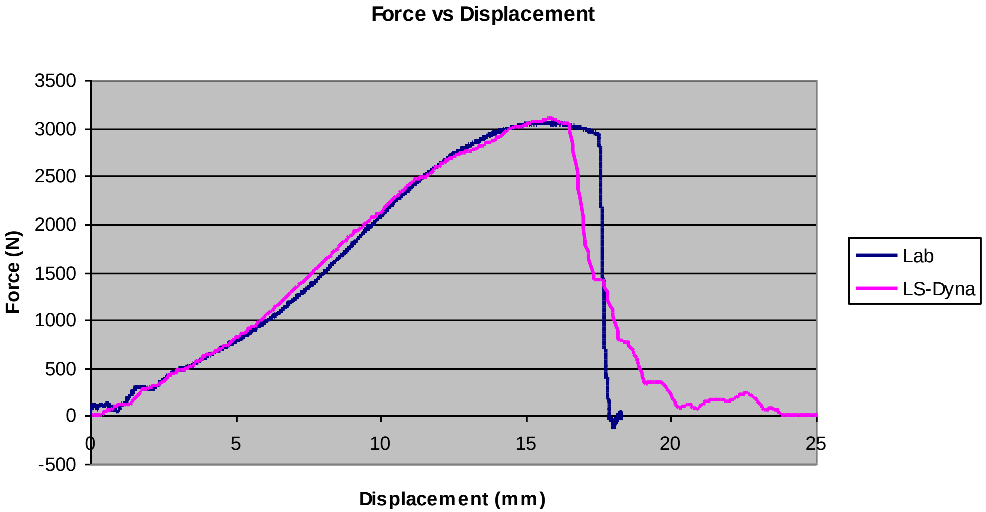
- Stress modes
  - Biaxial
  - Shear
  - Bending
- Rate-dependent plasticity
- Complex failure

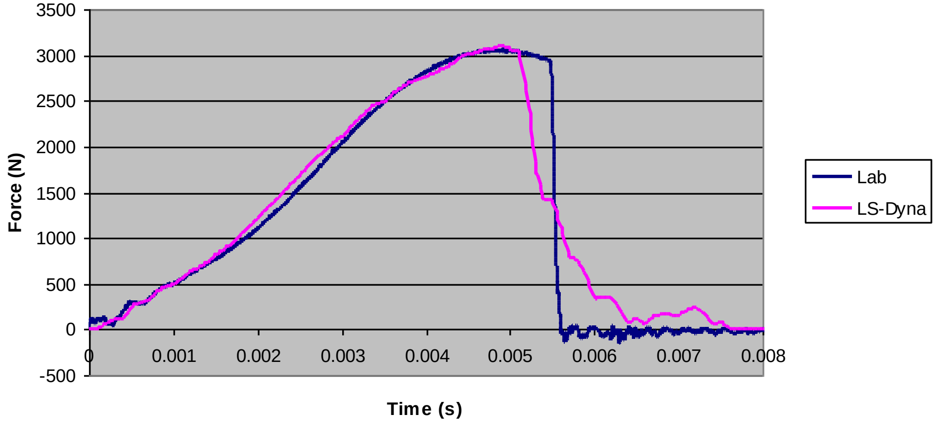
Simulation v. Test

- Percent error at peak force
  - Time: -1.0%
  - Distance: -0.52%
  - Force: 1.3%

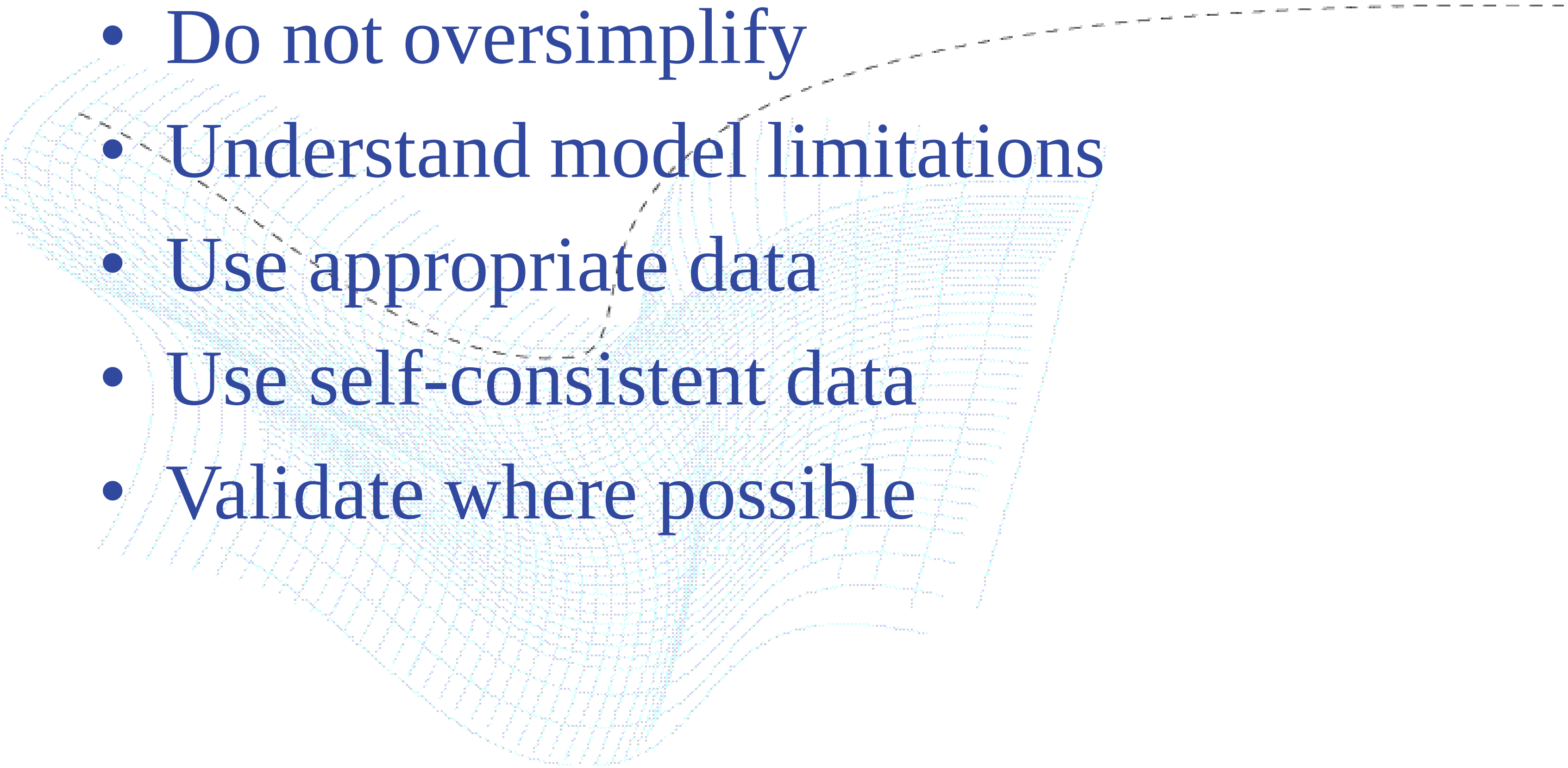


Force vs Displacement



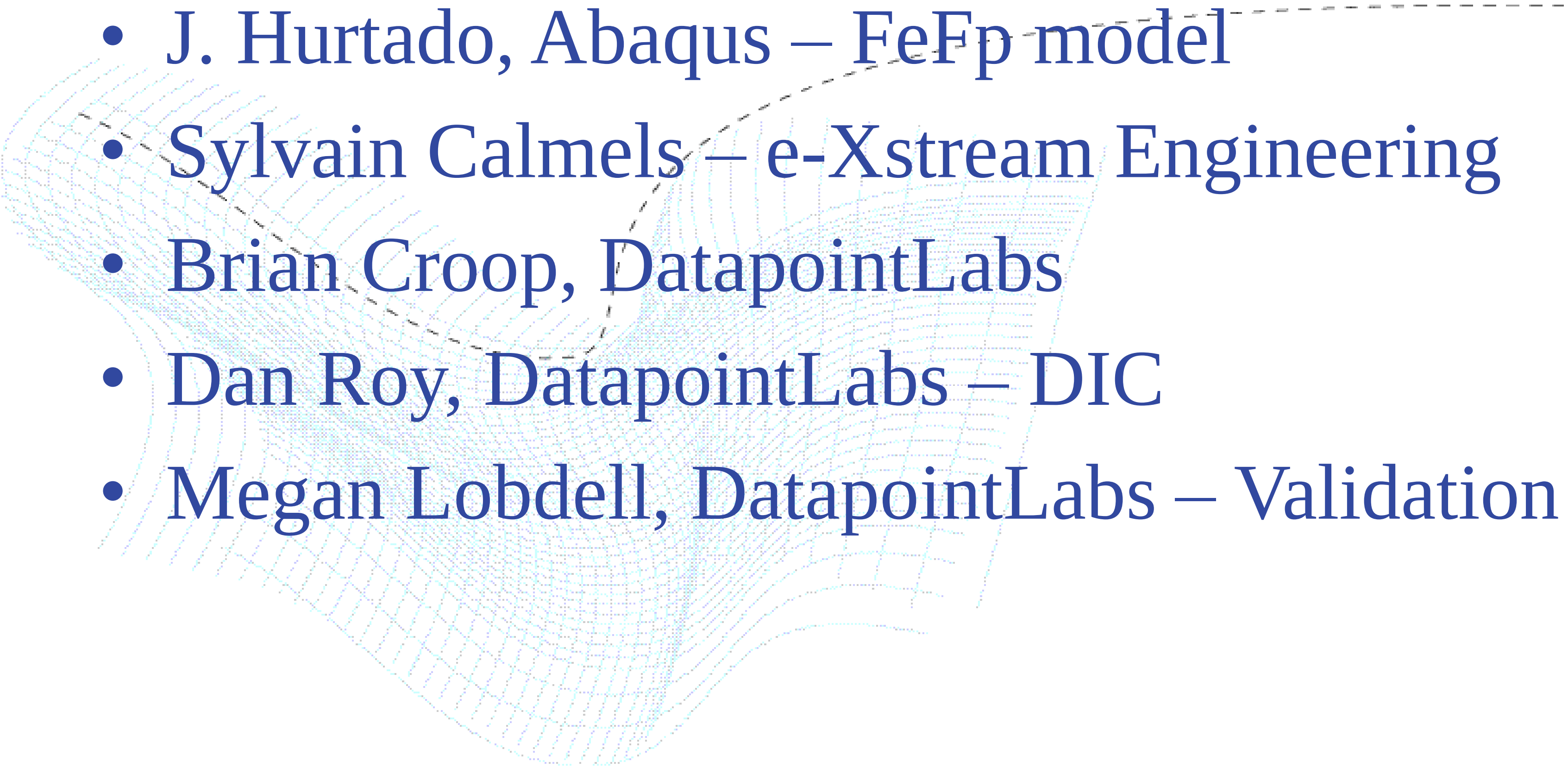


In Closing...



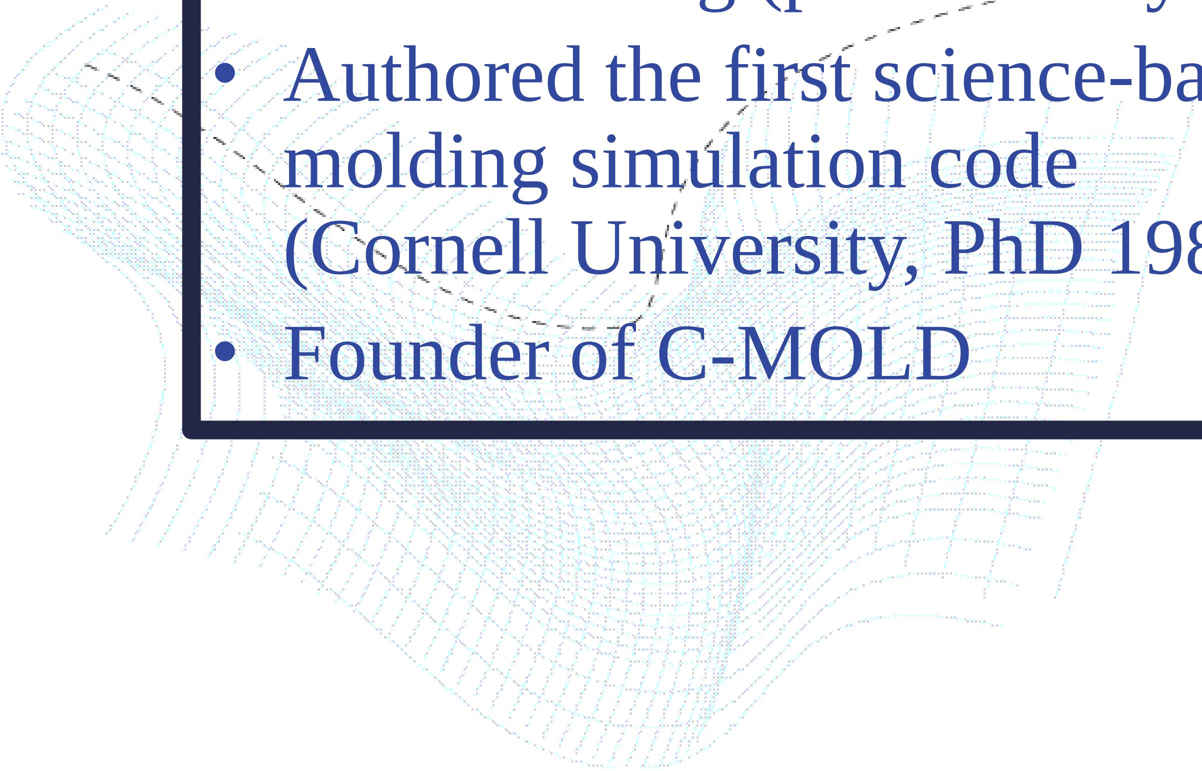
- Do not oversimplify
- Understand model limitations
- Use appropriate data
- Use self-consistent data
- Validate where possible

Acknowledgements



- J. Hurtado, Abaqus – FeFp model
- Sylvain Calmels – e-Xstream Engineering
- Brian Croop, DatapointLabs
- Dan Roy, DatapointLabs – DIC
- Megan Lobdell, DatapointLabs – Validation

Remembrance



- Dr. VW Wang (passed away Dec 10th 2014)
- Authored the first science-based injection-molding simulation code (Cornell University, PhD 1985)
- Founder of C-MOLD