Comments on the Testing and Management of Plastics Material Data

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DatapointLabs + Matereality

automotive CAE Grand Challenge 2014

15th – 16th April, 2014

Introduction to the companies

DatapointLabs

technical center for materials

+

matereality

a DatapointLabs affiliate

EST 1995

ISO 17025 Quality

Inc. 5000 America's Fastest-Growing Private Companies

Materials

Testing ¤ Data Infrastructure ¤ Productivity Software

Heritage

1986 - Cornell Injection Molding Program (CIMP)

Research: Properties of molten plastics for CAE

1995 - Datapoint Testing Services

Commercialization: Properties of plastics for molding CAE

1998 - TestPaks Alliance Program

Partnerships with FEA companies – properties & modeling for FEA

2000 - Company rebranded as DatapointLabs

Supporting 8 simulation codes for plastics

2002 - Matereality started

R&D to create multivariate material database for plastics

2014 - Today

Testing any materials any properties, supporting 34 CAE codes

Super-database+software to analyze and transform material data

Challenge of testing and managing plastics data

Data of multi-dimensional complexity

- **Nonlinear**
- **Multivariate**
- **Anisotropic**
- **Effects of processing**

Maintain data self-consistency

- **Slicing data without introducing artefact from multi-varying parameters**

Data storage infrastructure must accommodate this complexity

- **Ability to house multivariate data of any kind**
- **Graphical tools for multivariate analytics (comparison, statistics)**
- **Slicing and translation of data into CAE material cards**

Range of plastics simulation

Performance

- Stiffness
- Failure
- Vibration
- Fatigue
- Creep and relaxation
- Impact

Process Simulation

- Injection molding
- Blow molding
- Thermoforming
- Extrusion

Key differences between plastics and metals

Stress-strain relationship is linear until yield

Properties do not change over operating temperature range

Properties do not change much with time

- **Rate effects are modest**
- **Creep/stress relaxation is not a big issue**

Generally isotropic or worst case, bi-directional

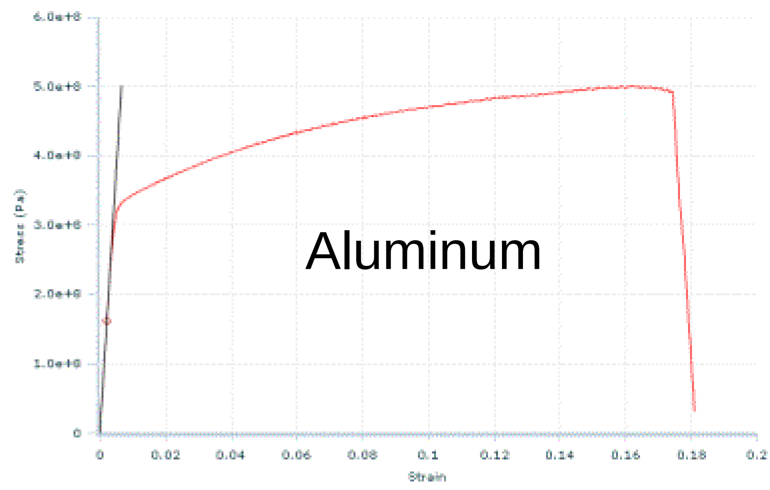
Well established material models mimic metal behavior

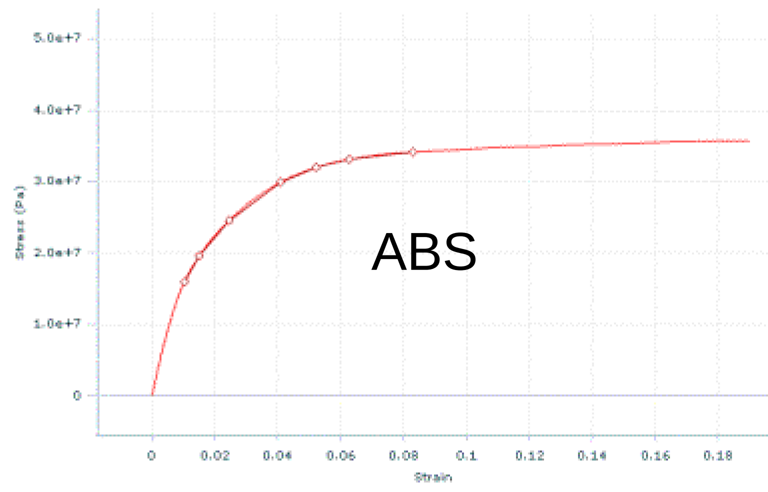
carhs.

Complexity: nonlinear

Stress-strain is nonlinear

- **Nonlinear elasticity**
- **Pre-yield plasticity**
- **Viscoelastic (time based effects)**
- **Volumetric straining at yield**
- **Localized necking**





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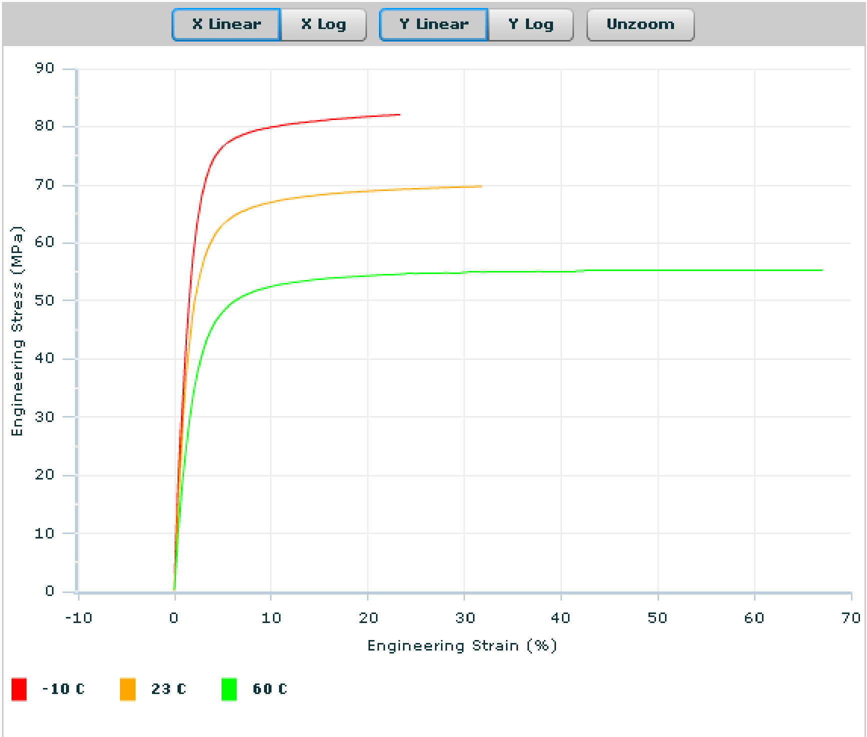
Properties change with

- **Temperature**
  - *Low temperature embrittlement*
- **Rate**
  - *Ductile-brittle transitions*
- **Humidity / Heat aging**
  - *Embrittlement*
- **Environment – Fluid soak**
  - *Lowering in modulus / viscoelastic characteristics*

Effect of temperature

Engineering Tensile Stress-Strain Curves



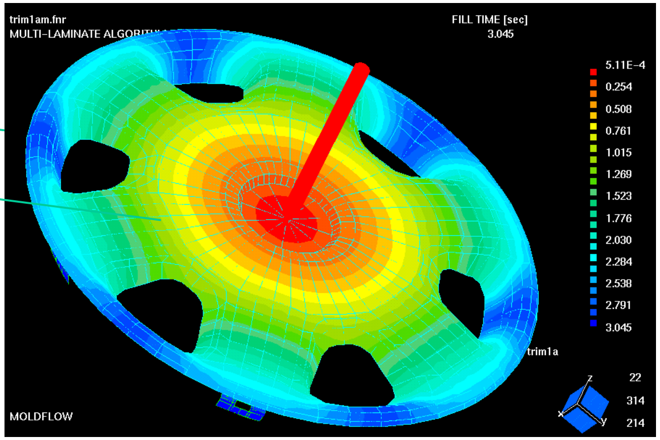
Properties affected by process

Injection-molded plastics

- *Skin-core-skin sandwich*
- *Weld lines*
- *Residual stresses*
- *Spatial variation in x-y plane with fiber-filled plastics*

Blow-mold/thermoform/extrusion

- *MD and CMD orientation*
- *Strong residual stresses*
- *Thickness variation*
- *Multi-layer effects*
- *Partial crystallization*



Procedure: handling the variation

Part 1 – for the plastic material

- **Identify the variables**
- **Test for the effect of variables (DOE?)**
- **Perform multivariate analytics to quantify effects**

Part 2 – for the plastic component

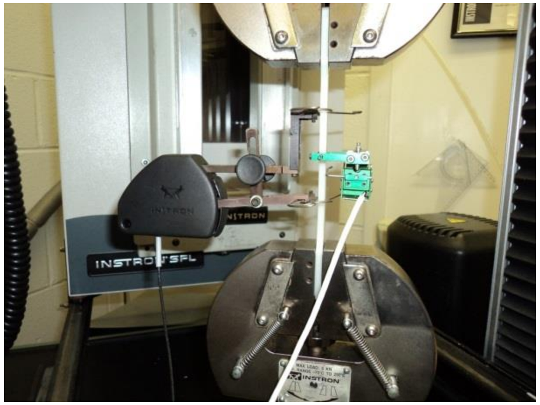
- **Identify the case under investigation**
- **Determine which variables to fix**
- **Obtain parameterized test data**
- **Convert to material model parameters**

Identify variables

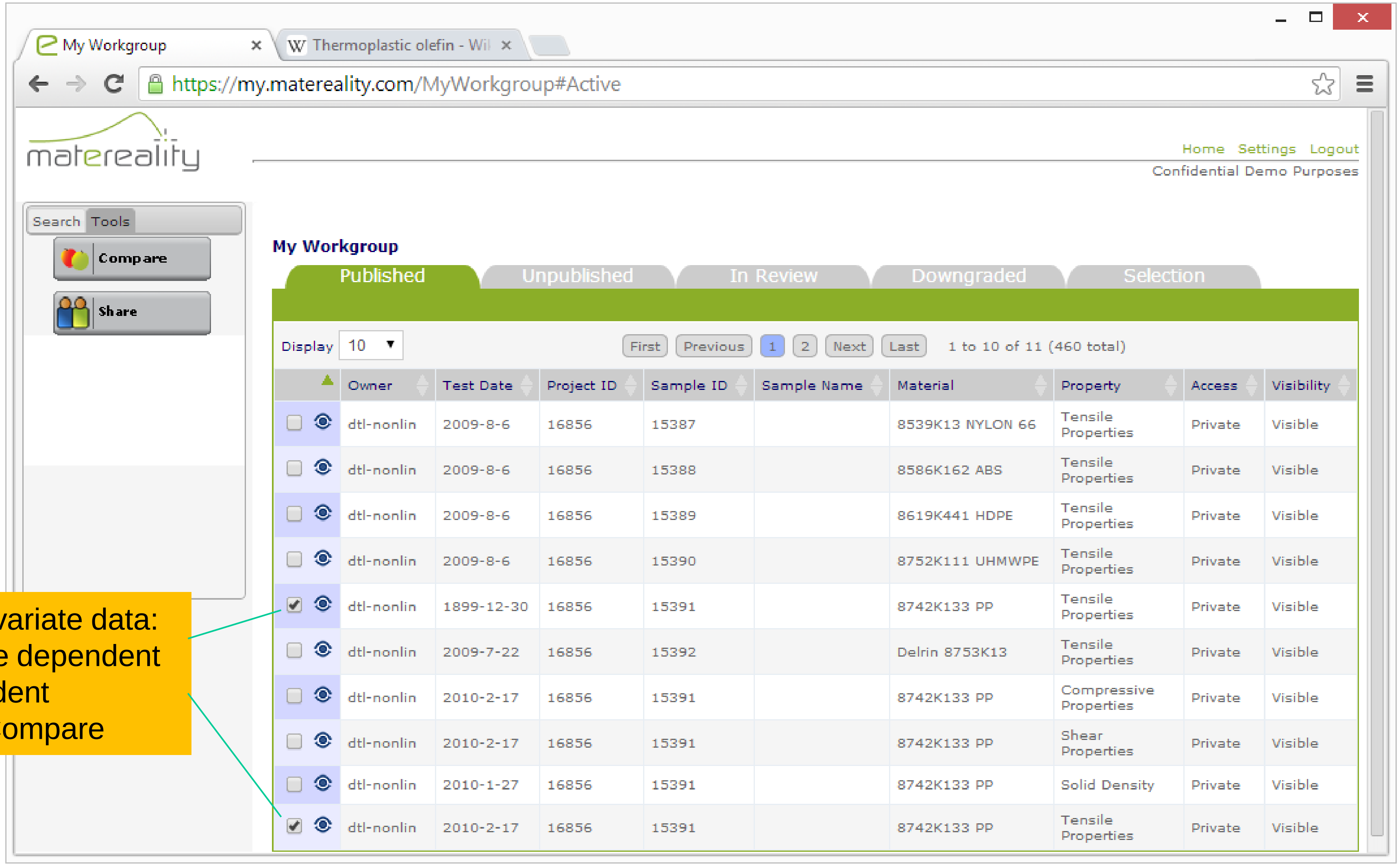
- **Temperature (-40 to 80C)**
- **Strain rate (.01 to 100/s)**
- **Creep/stress relaxation**
- **Environment**
  - *Sunlight*
  - *Paint/coatings*
  - *Salt/humidity*
- **Fiber filler: none**

Procedure

- Develop test matrix
- Select parameters and variables
- Perform tests
- Dump data into Matereality

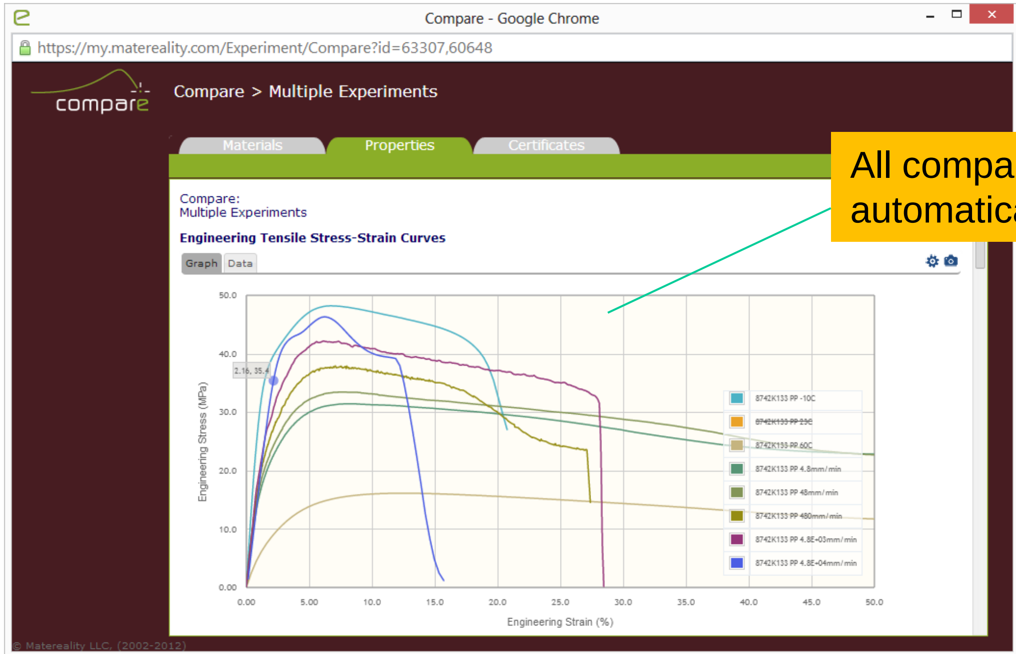


Using multivariate analytics

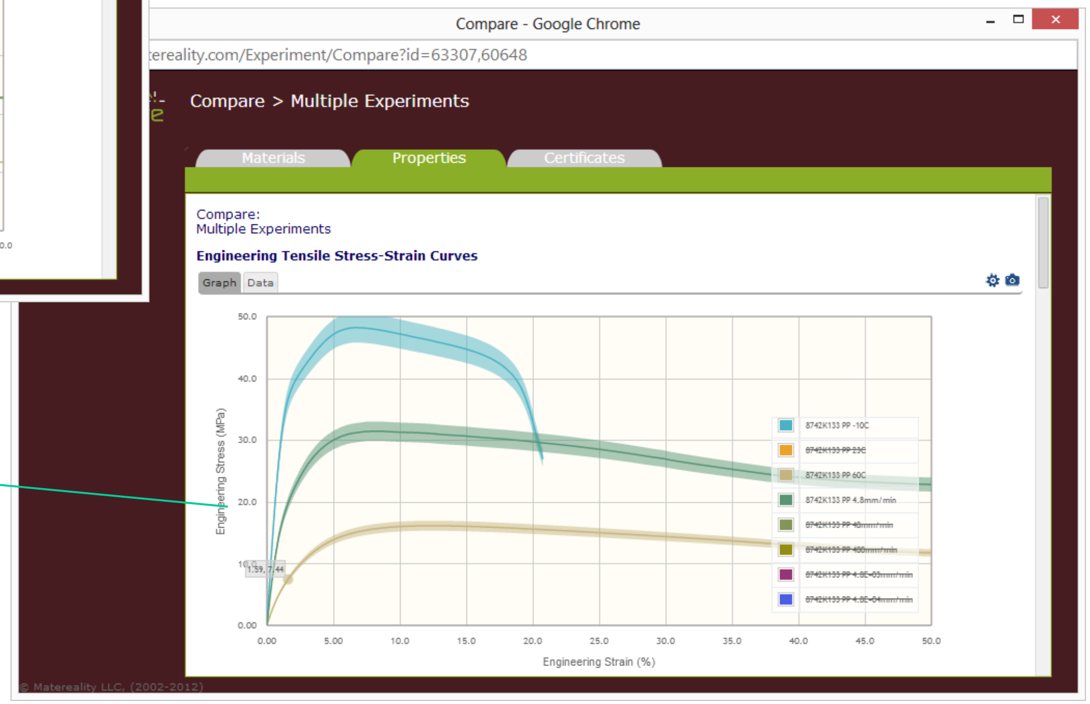


Select multivariate data:
-temperature dependent
-rate dependent
Then click Compare

Analytics: temperature effects



All comparable data is automatically cross-plotted



Turn curves on and off to evaluate thermal effects
Error band statistics aids decision making

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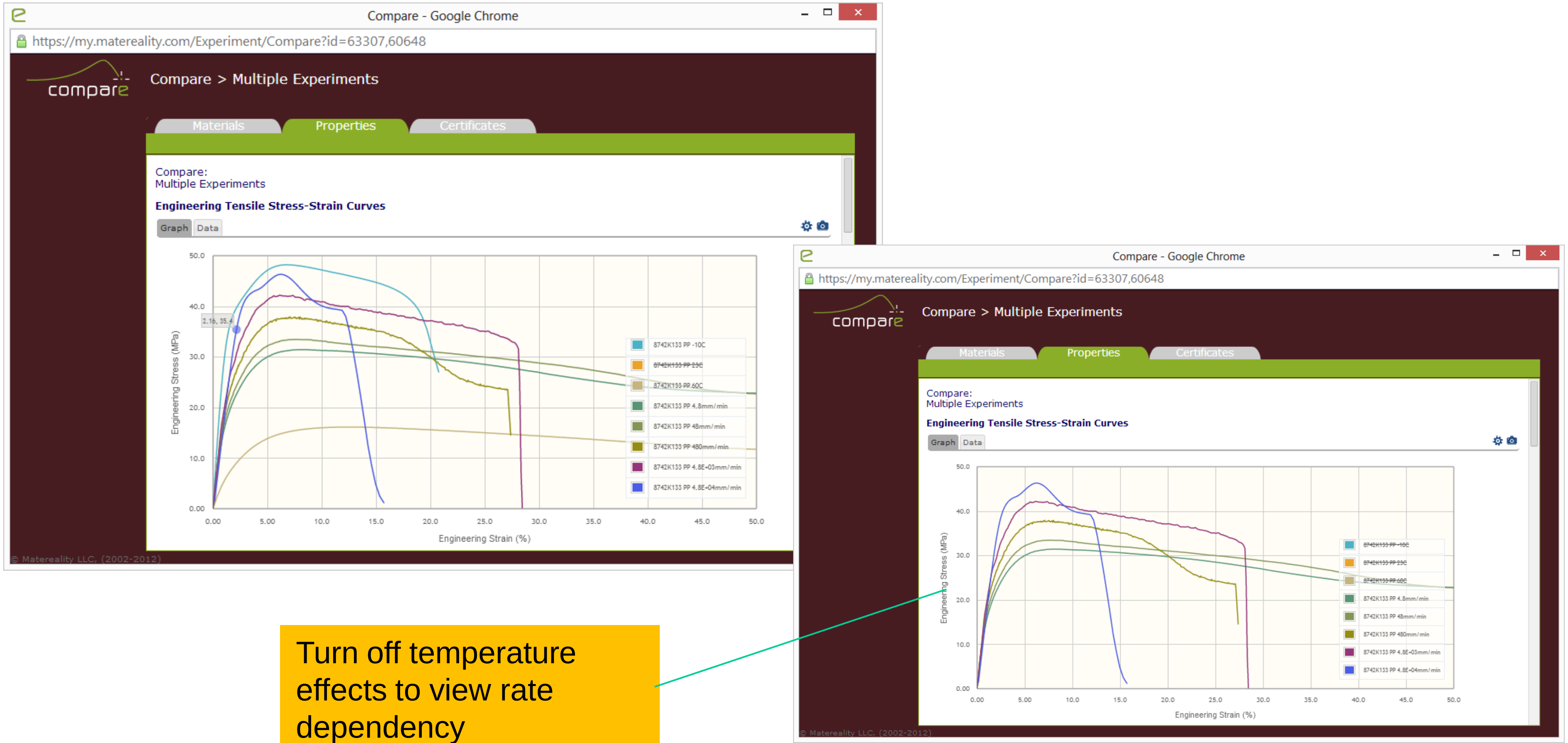
Analytics: rate effects



Turn off temperature effects to view rate dependency

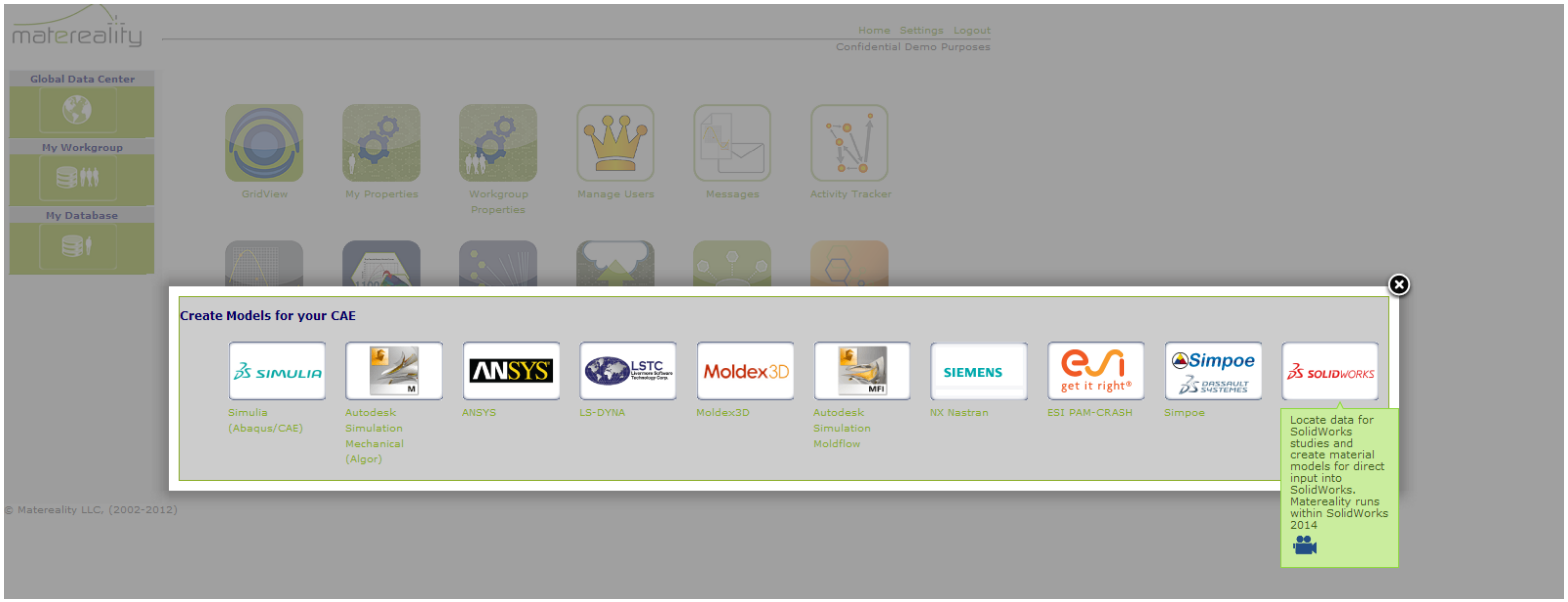
Use of CAE Modelers to send data to simulation

CAE Modeler slices multivariate data into CAE-consumable slices

- rate dependency for LS-DYNA, PAMCRASH, ANSYS, ABAQUS…
- temperature dependency for ABAQUS, ANSYS…
- flow/thermal/PVT/shrinkage data for Moldflow, Moldex3D, Simpoe…

Converts material data to model parameters

Writes files to Material Model Library



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Adding complexity to the structural analysis

Abaqus FeFp

- **Nonlinear elasticity with pre-yield plasticity**

Abaqus PRF (evaluation project with Simulia)

- **Viscoelasticity and nonlinear viscoelasticity**

SAMP-1

- **Post-yield non-Mises behavior**

MATFEM MF GenYld+CrachFEM (evaluation project with MATFEM)

- **Post-yield non-Mises behavior and failure**

DIGIMAT

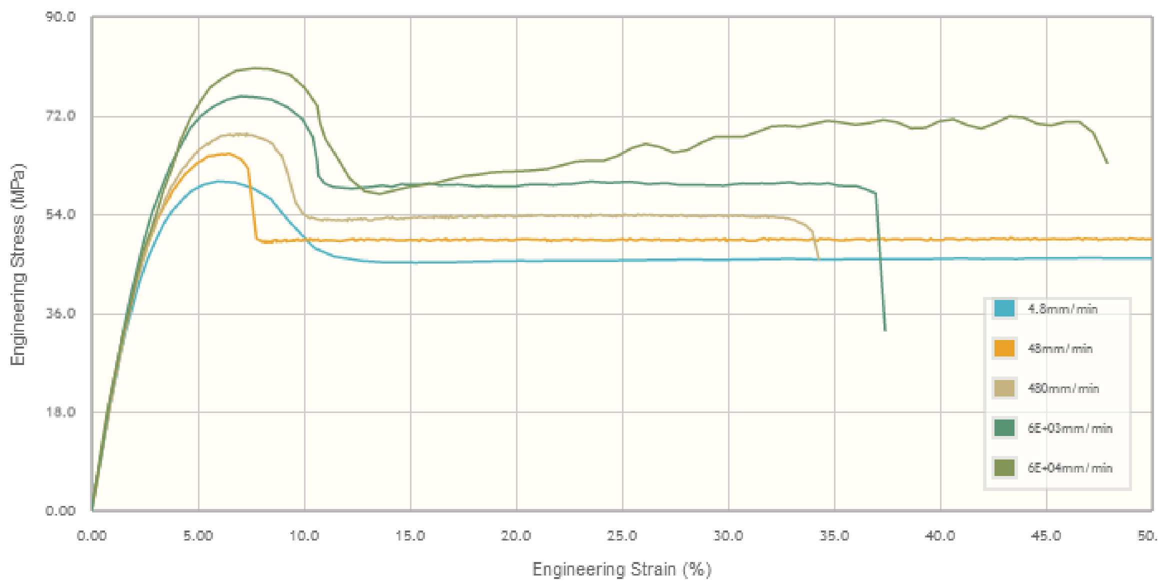
- **Spatial variation of properties due to fiber-orientation**
- **Rate dependency, creep, viscoelasticity, fatigue and failure**

SAMP-1 case study: polycarbonate for headlight lens

Features
- **Isotropic material model**
- **Tensile rate dependency**
- **Deviatoric and volumetric plasticity**
- **Non-Mises yield locus**

Application
- **Post-yield plasticity**
- **Not specified for failure prediction**

Testing Requirements
- **Rate dependent tensile data**
- **Yield locus**
- **Plastic Poisson's ratio**



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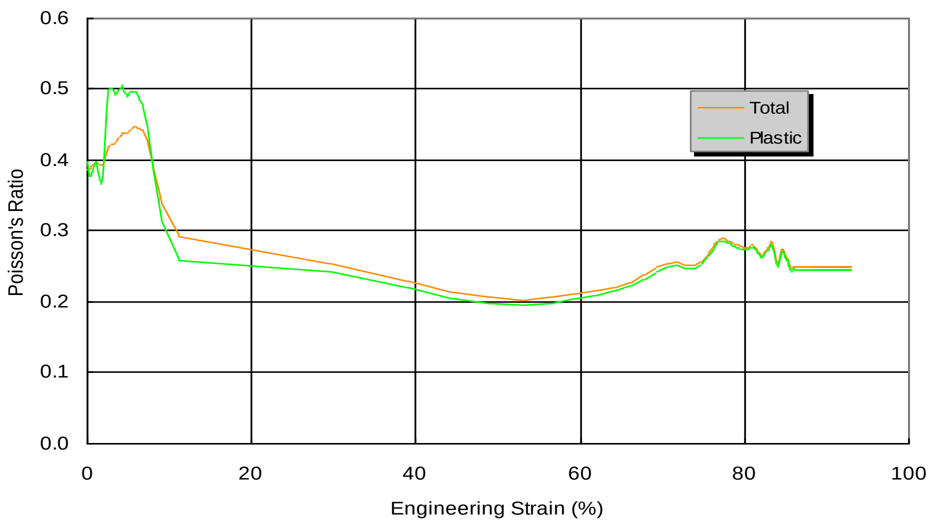
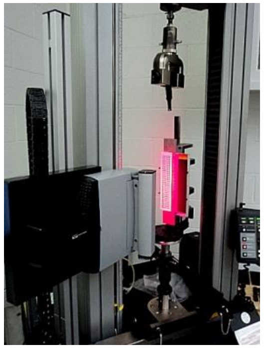
SAMP-1 Poisson's ratio v. strain

- Quantifies the volumetric change that accompanies plasticity
- Large volumetric change at yield

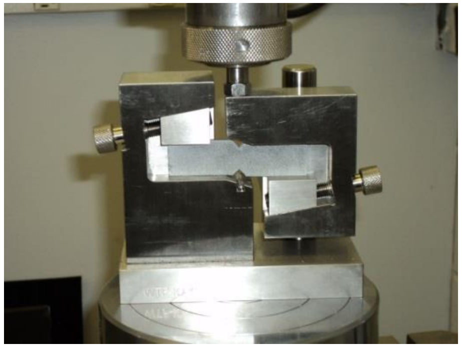


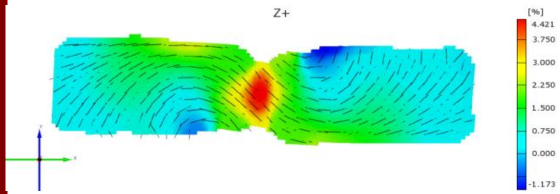


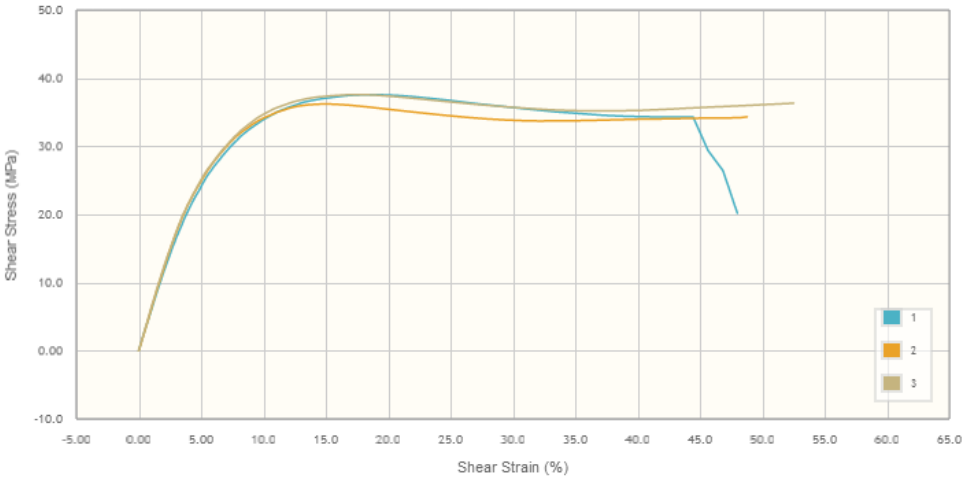
Iosipescu methods

DIC

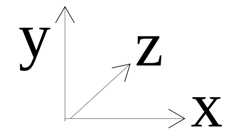
Shear stress-strain for PC

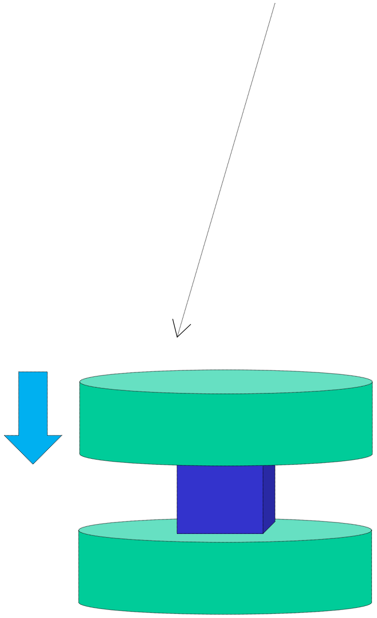


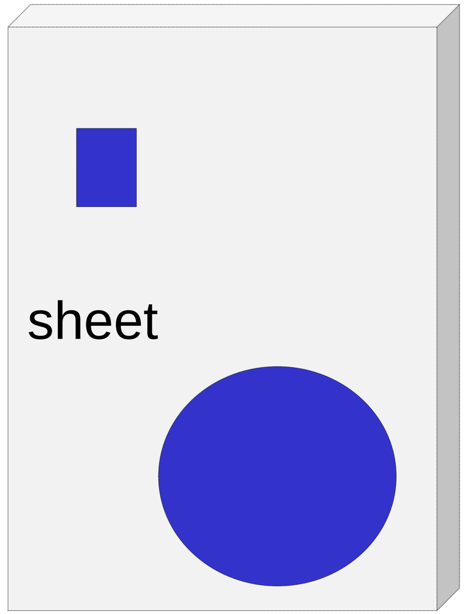


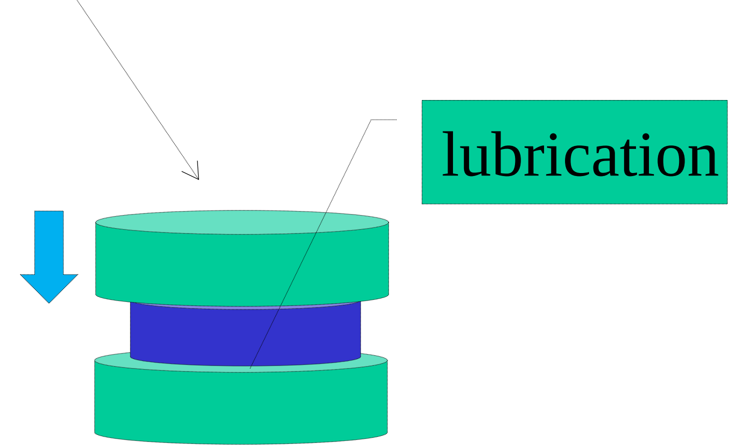


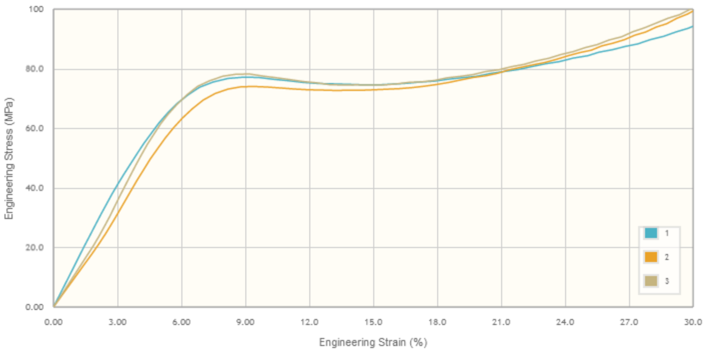
SAMP-1 Compressive and biaxial tests

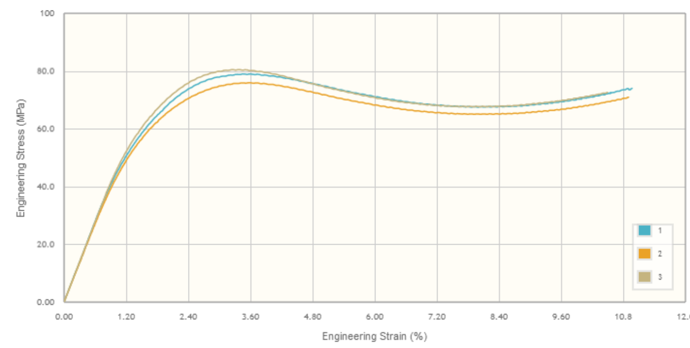












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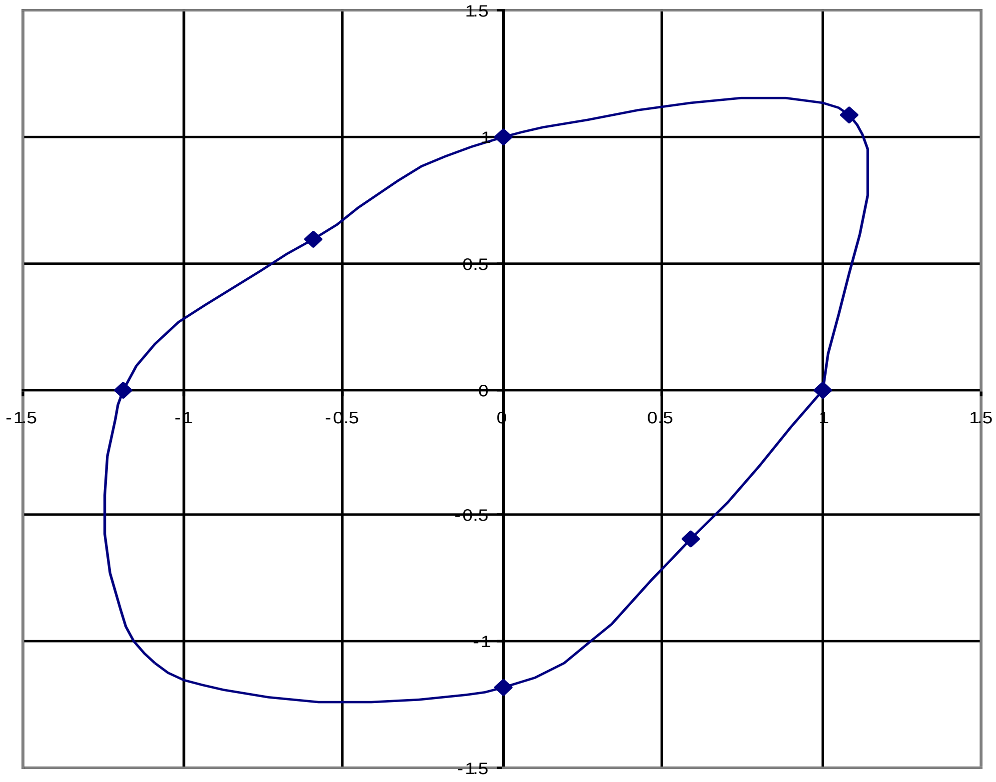
SAMP-1 yield locus for polycarbonate

May not follow von Mises criterion



Bringing in process simulation

Melt state properties (injection molding)

- **Non-Newtonian temperature dependent viscosity**
- **Thermal properties**
- **Pressure-volume-temperature (PVT)**

Solid state properties

- **Mechanical & thermal properties for shrinkage/warpage**

Viscoelastic properties (blow-molding/thermoforming/extrusion)

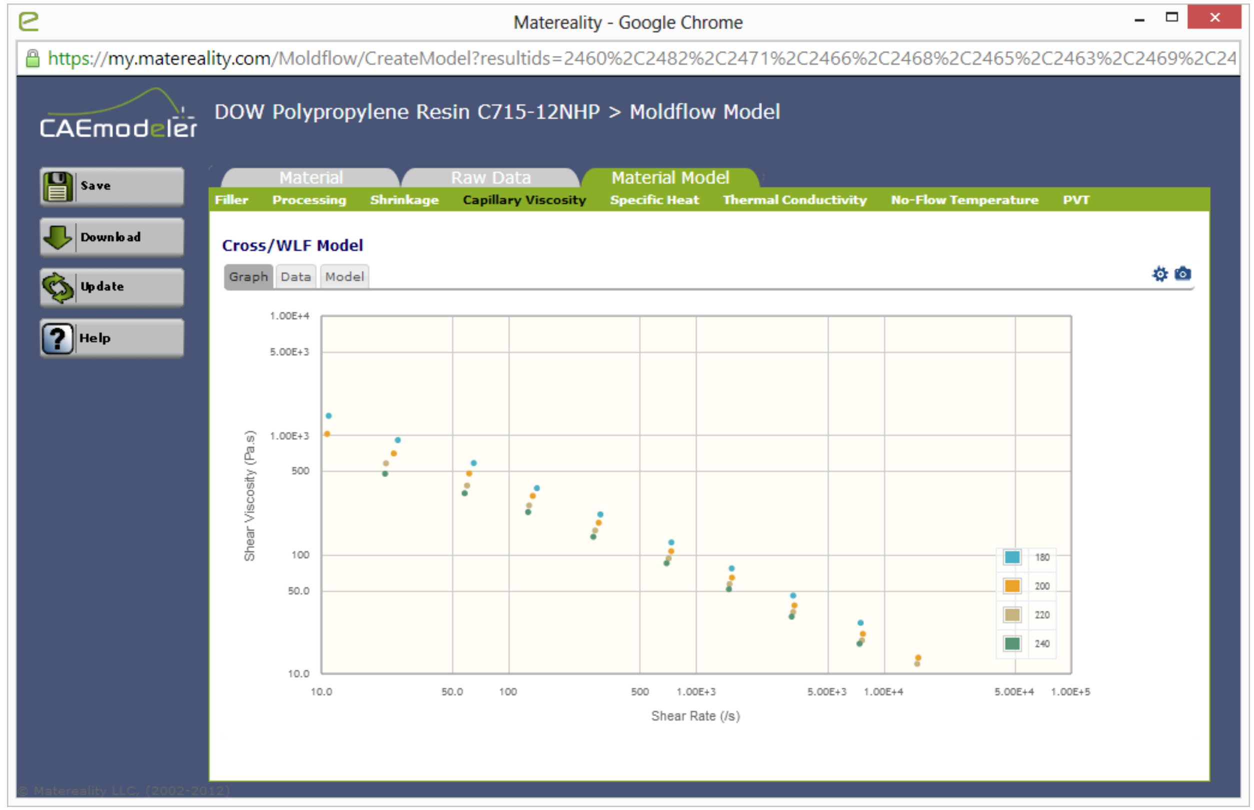
- **Frequency or time based response in melt state**
- **Rate dependent biaxial properties in melt**

Testing for molding simulation: rheology

3-4 temperatures

Effect of shear rate

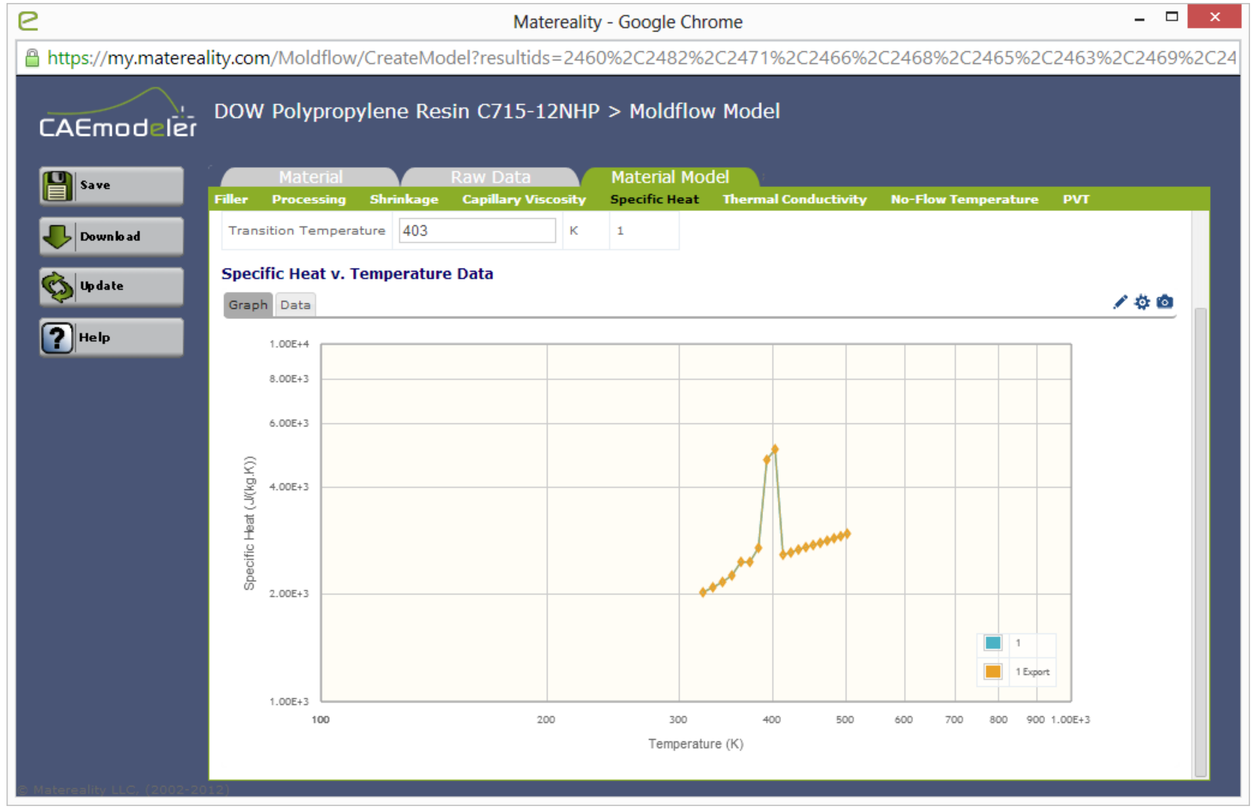
Data corrections



Testing for molding simulation: specific heat

Cooling

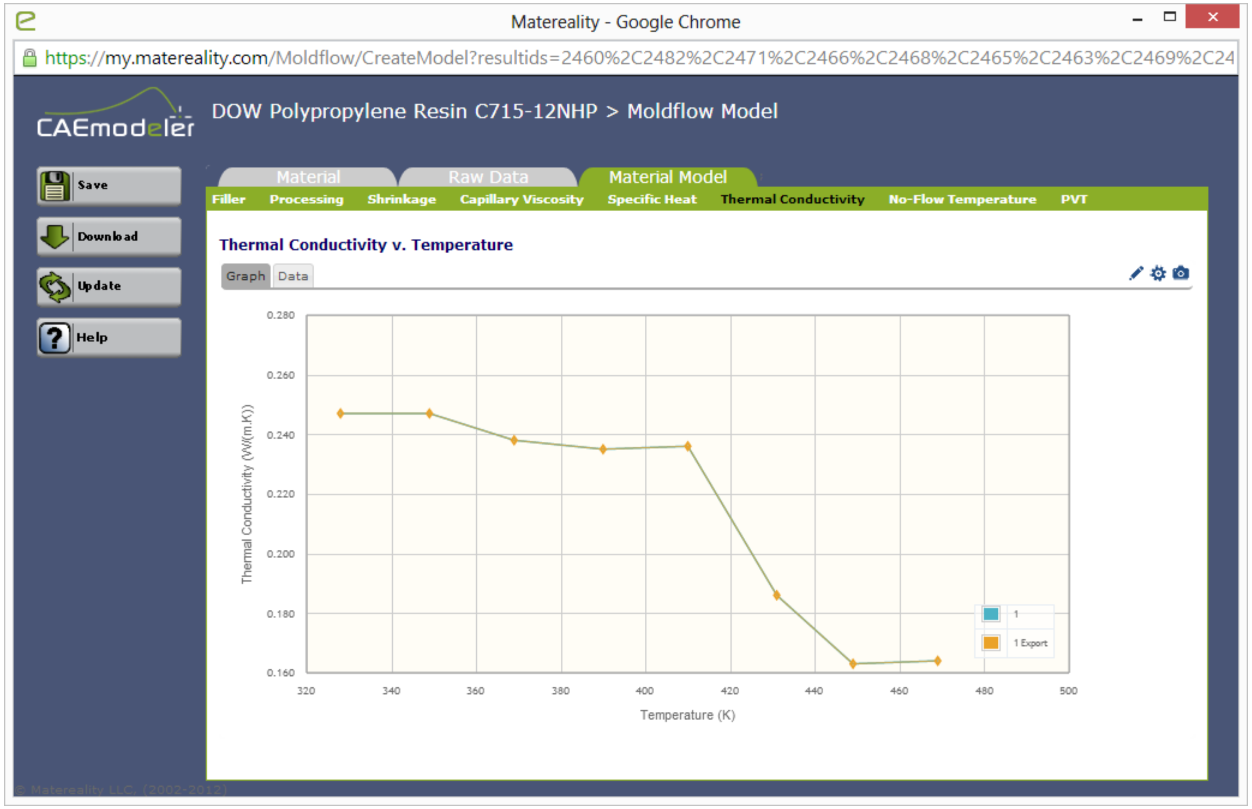
Mark the transitions



Testing for molding simulation: thermal conductivity

Cooling

Mark the transitions

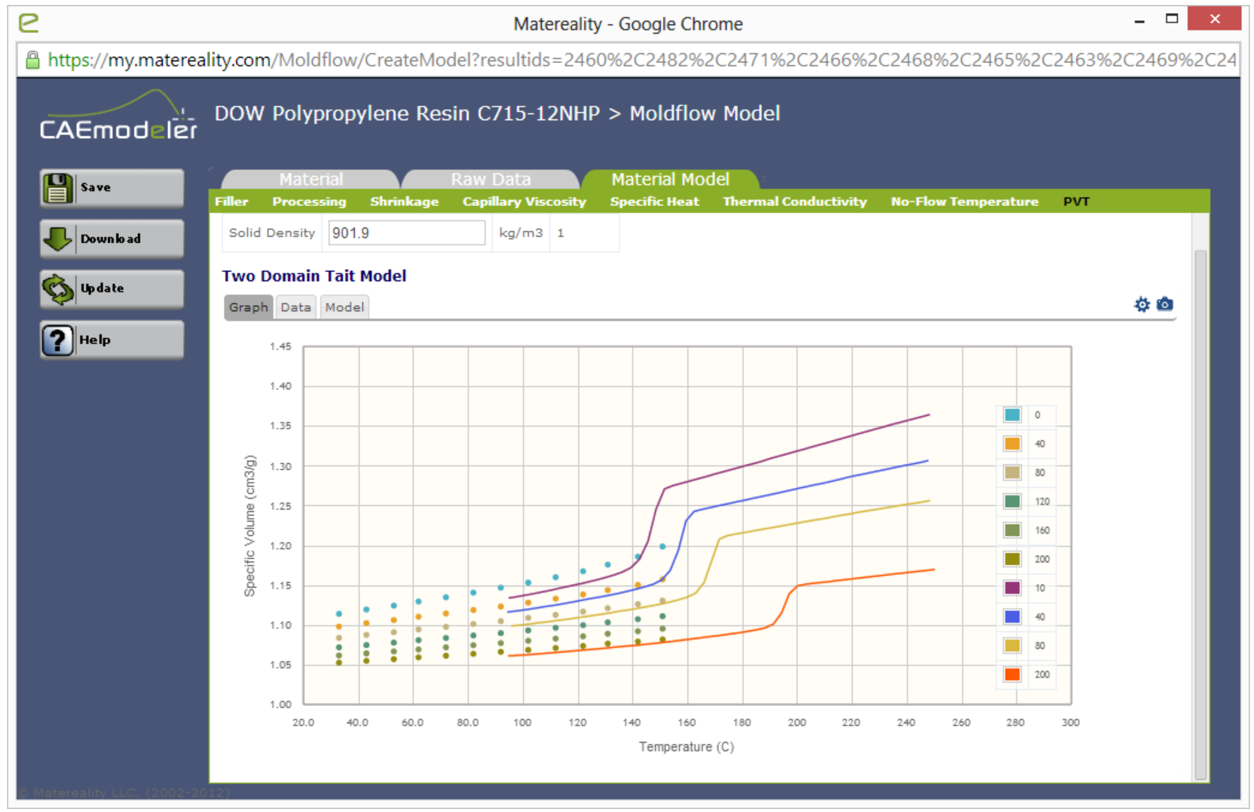


Testing for molding simulation: PVT

Many schemes possible

- *Isothermal heating*
- *Isobaric cooling*

Mark transitions



Testing for molding simulation: shrink/warp

Many schemes possible

- **Orthotropic**
    - *Moldflow, Moldex3D, SIMPOE*
- **Orthotropy with viscoelastic**
    - *Sigmasoft*
- **CRIMS**
    - *Moldflow*

Coupling mold analysis with FEA: DIGIMAT

DIGIMAT- for process-induced spatial variation of properties

Case Study: Automotive Instrument Panel (PP/GF)

Process

- **Obtains orientations input from process simulation**
- **Applies a DIGIMAT material model to scale properties based on orientation**
- **Transfers model with spatially varying properties to FEA**

Available material models

- **Stiffness**
- **Failure**
- **Crash simulation**
- **Creep and viscoelasticity**
- **Fatigue**

Testing for DIGIMAT

Mold 100X200X3.16mm plaques

- **Edge gated on 100 mm end**
- **Long flow length**
- **Fully developed flow**
- **High fiber orientation**

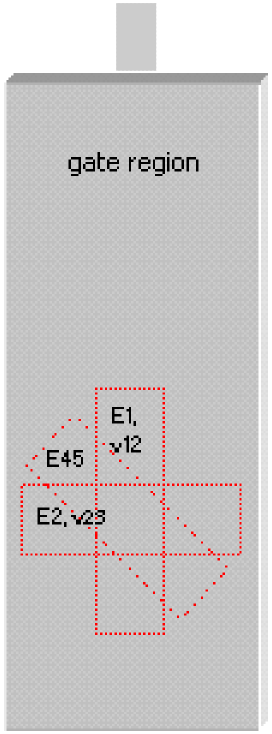
Cut test specimens by CNC

5 specimens each (0°, 45 °, 90°)

Obtain true stress-strain data

Test for other characteristics

- **creep, fatigue, viscoelasticity**



Conclusions

Plastics are challenging materials

Plastics bring important business advantages over conventional materials

Plastics carry considerable risk if improperly used

Understanding the behavior of your plastics is vital

Knowing how the plastics will perform in **your** products is critical

Material testing is key to developing this understanding

Material data is often **not** generic but specific to the products (Dr. Kolk, BMW 2013)

Valuable and expensive test data must be carefully kept and consistently used

Thank You!