ANSYS 2013 Regional Conference

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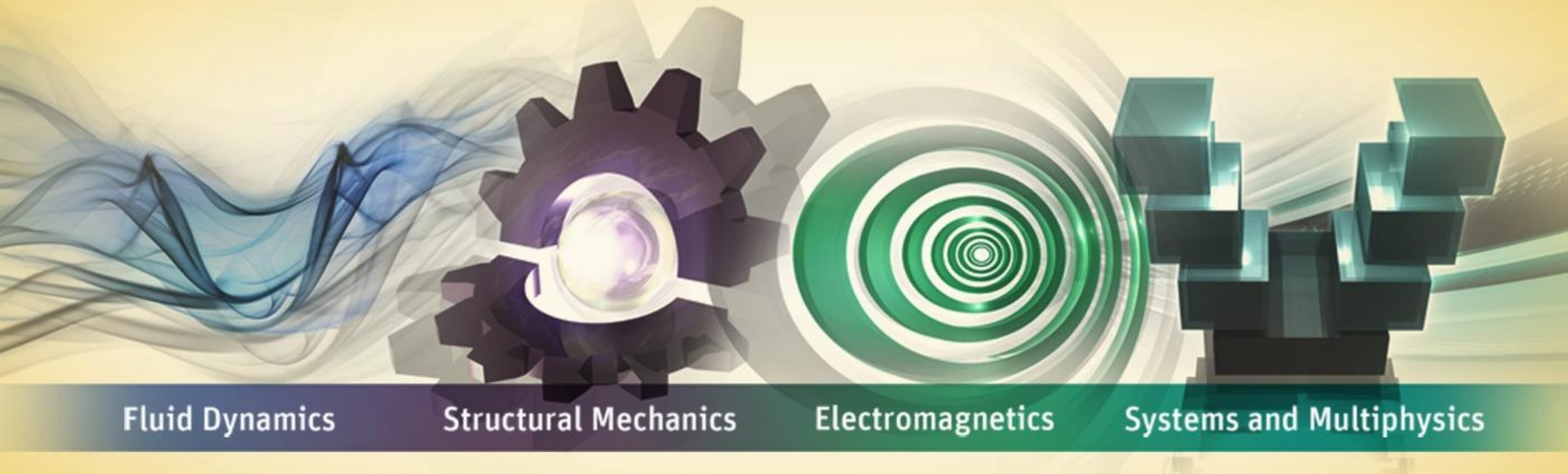
Testing of Elastomers and Plastics in Support of Analysis



Kurt Miller, Axel Products, Inc.

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ANSYS

axel physical testing services

Physical Testing Services

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Testing Services

- Elastomer (hyperelastic) Characterization
  - Simple Tension
  - Pure Shear
  - Equal Biaxial Extension
  - Volumetric Compression (Bulk Modulus)
  - Simple Compression
  - Elastomer Specimen Preparation
- Plastic Characterization
  - Tensile Test
  - Tensile Test with Transverse Strain Measurement
  - Loading and Unloading Experiments
  - Short Term Creep Experiment
  - Shear Test
  - Plastic Film Experiment
  - Compression
  - Plastic Specimen Preparation
- Sponge Elastomer Characterization
  - Compression Test
  - Simple Shear Test
  - Tensile Test with Lateral Strain Measurement
- Vibration and Viscoelastic Experiments
  - Viscoelastic Decay
  - Dynamic Vibration
- High Strain Rate Experiments
  - High Strain Rate Tensile Test
  - High Strain Rate Compression Test
  - High Strain Rate Bend Test
  - High Strain Rate Shear Test
- Medical Material Testing in Saline
  - Testing in Saline Solution
  - Testing Materials at Low Forces
- Friction Testing
  - Sled Style Friction Experiment
  - High Pressure Friction Experiment
- Fabric Characterization
  - Fabric Tensile Test with Imaging
  - Fabric Specimen Preparation
- Wire Testing
- Component Tests
  - Relaxation and Thermal Recovery Sequence
  - Bushing and Mount Characterization
  - Load Deflection Tests
  - Axial + Torsional Testing

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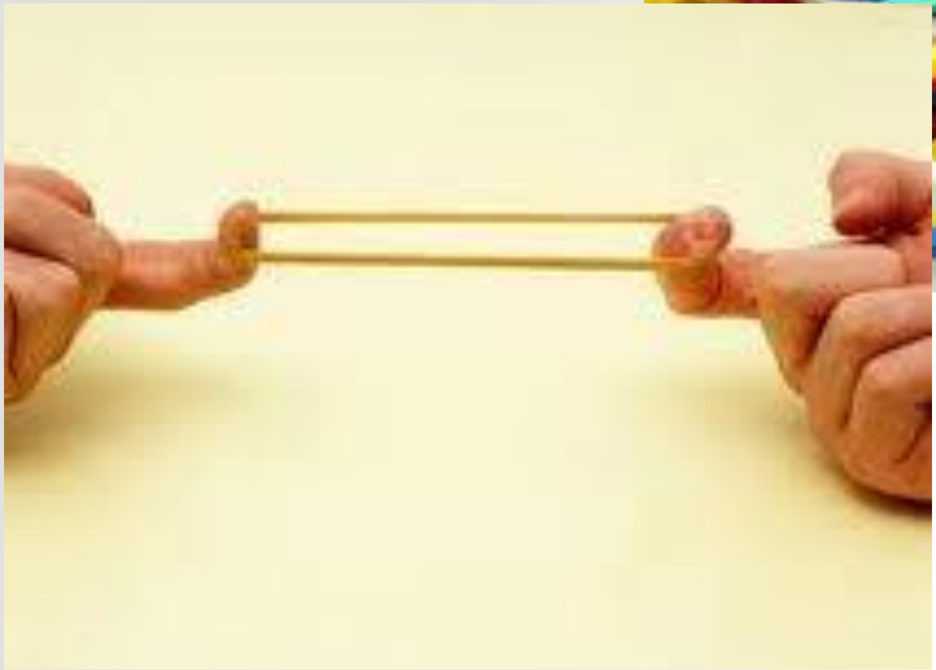
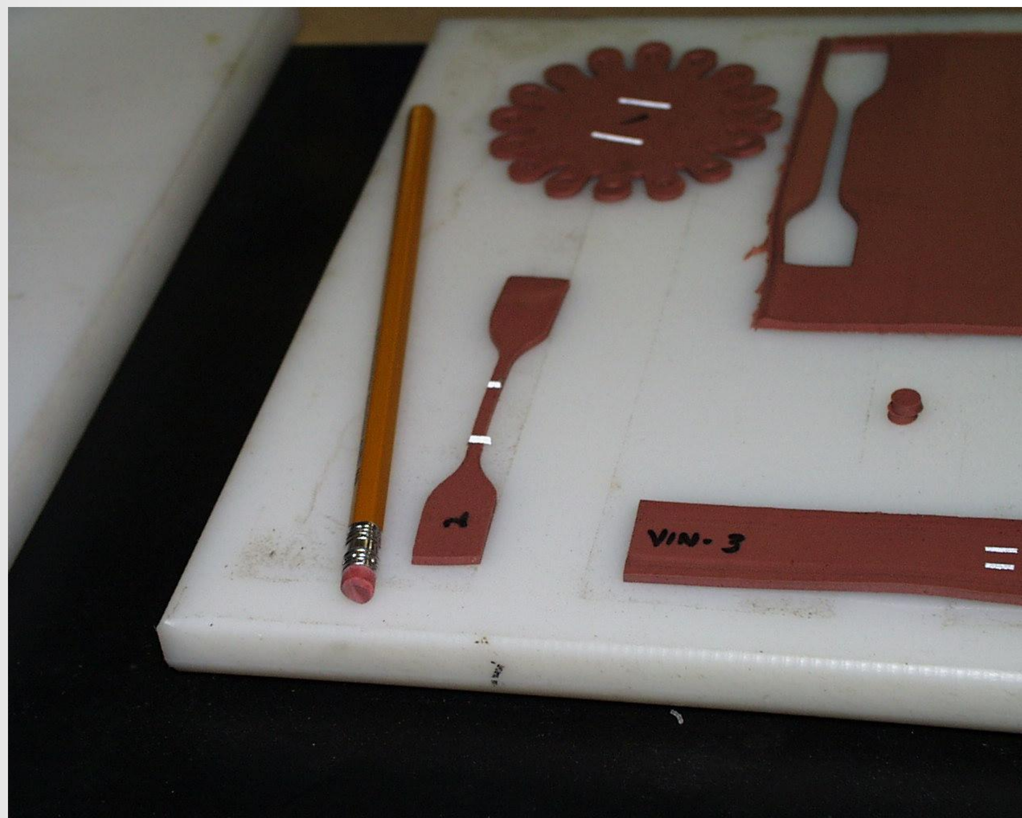
Rubber Bands



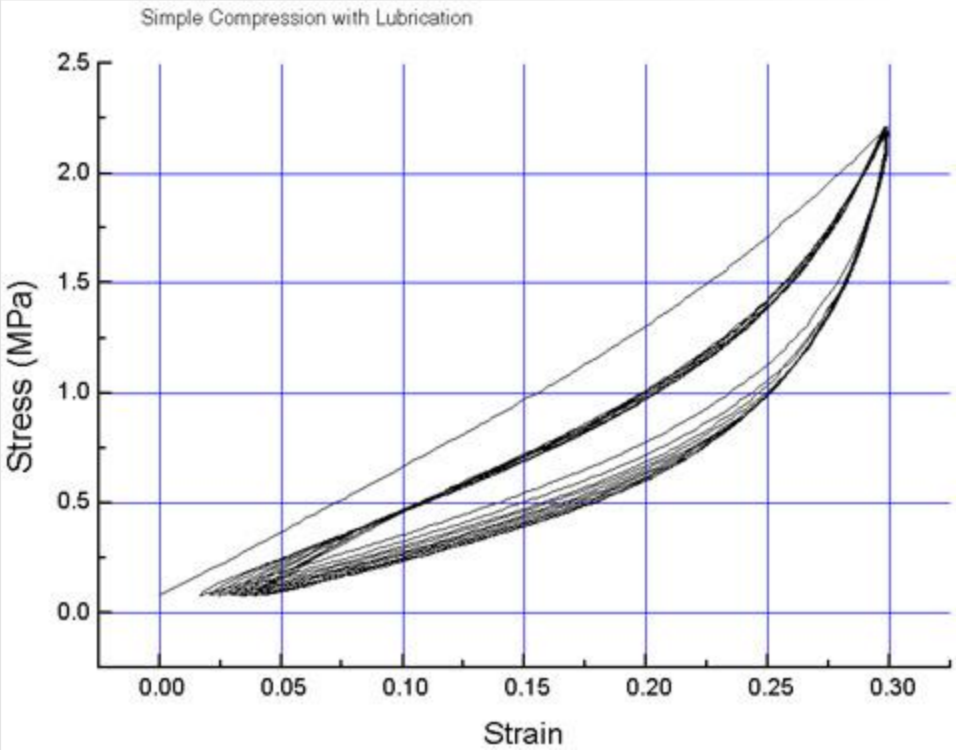
Compression

Rubber

1. High strain applications
2. No distinct modulus or yield
3. Bulk >>> Shear



Compression



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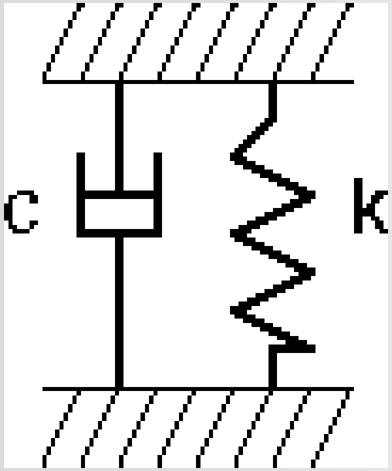
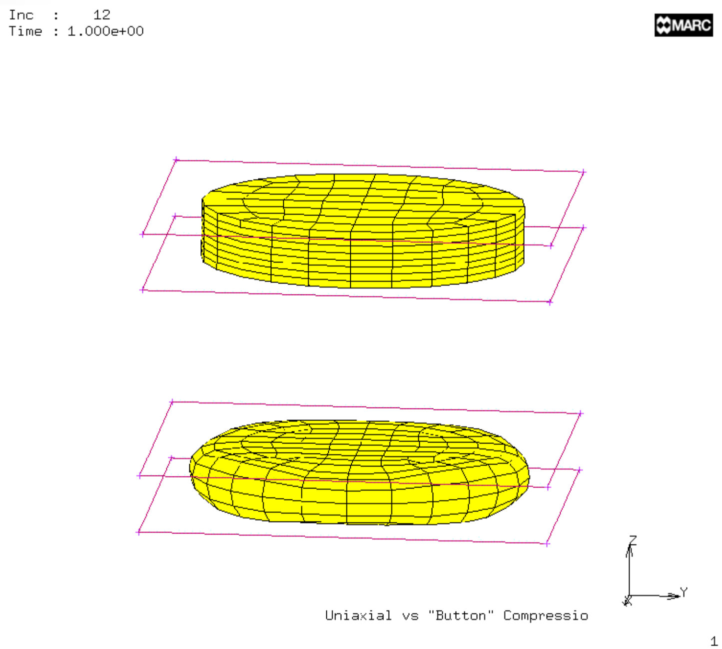
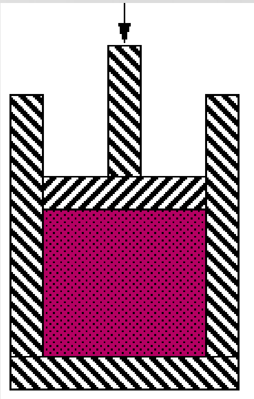
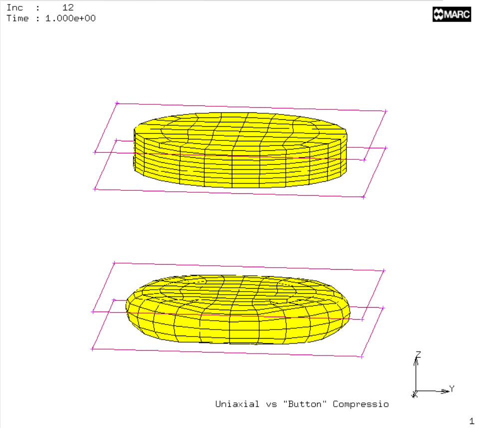
A Spring and a Dashpot?

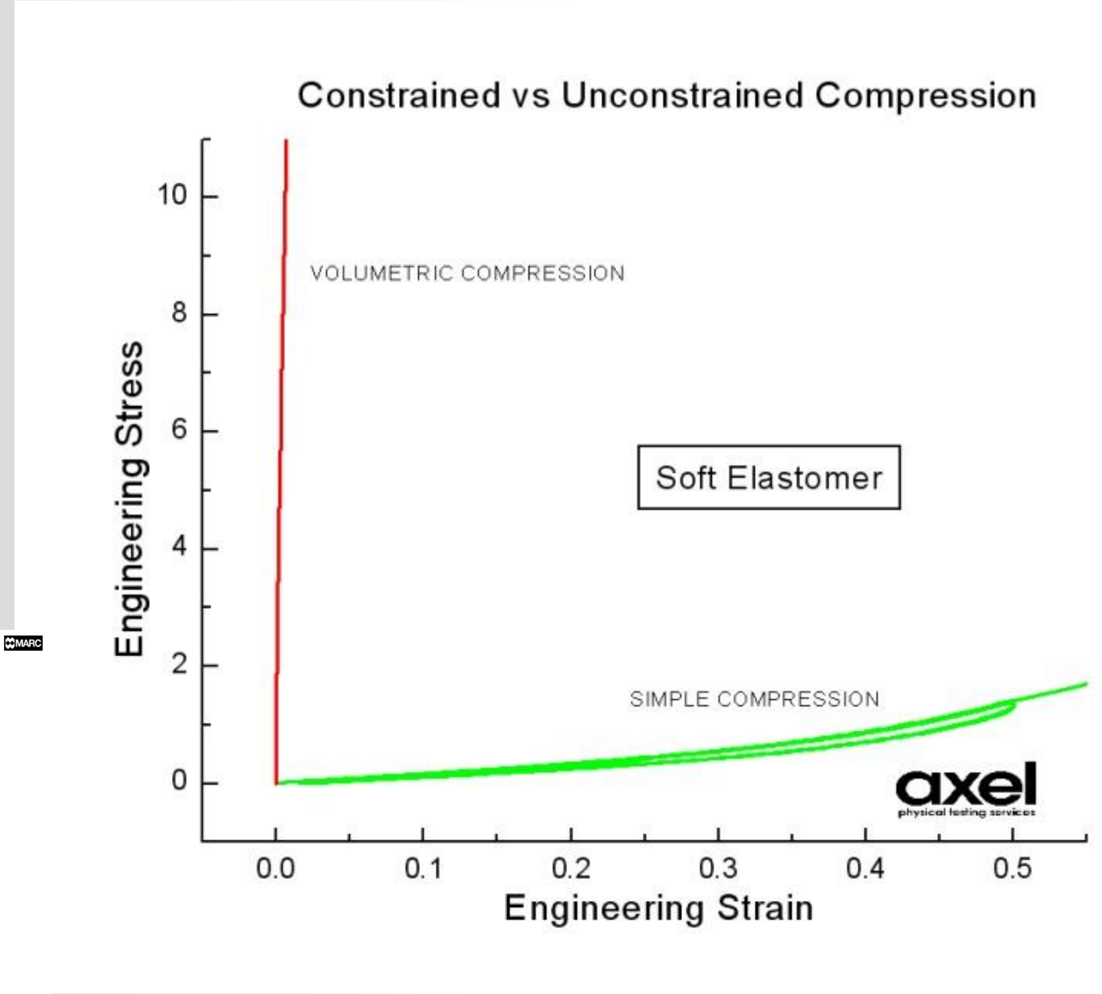




What does Incompressible Mean?





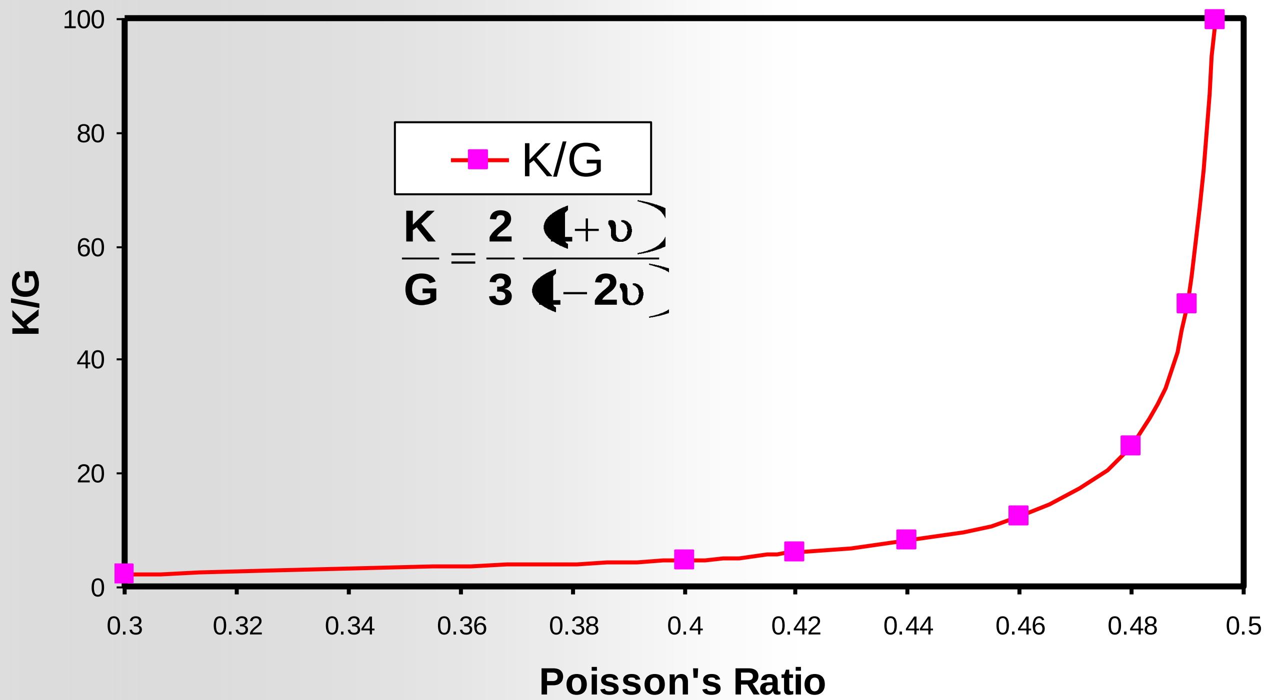


Volumetric Compression

Poisson's ratio approaching 0.5 means infinite bulk modulus, K

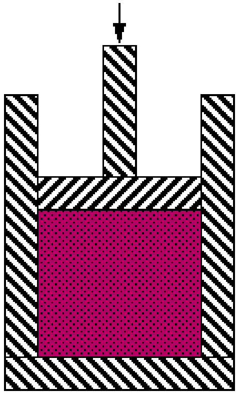
For elastomer materials Poisson's ratio is difficult or impossible to measure accurately. For plastic materials, it is hard to measure VC accurately. Measure Pressure-Volume directly, compute K (or D_1 in ABAQUS)

K/G Relationship to Poisson's Ratio



$$\frac{K}{G} = \frac{2}{3}\frac{(1+\upsilon)}{(1-2\upsilon)}$$

Incompressibility

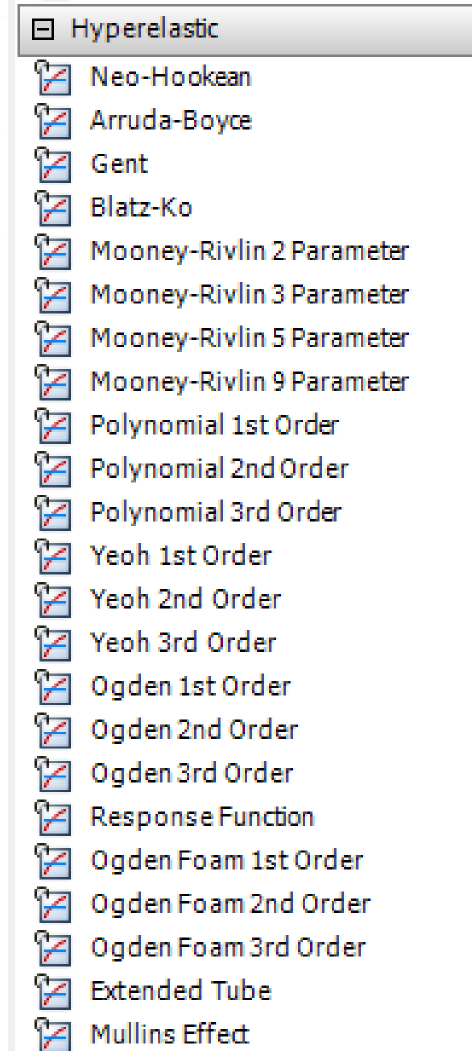


Not a spring and dashpot

Confinement can be Significant

Hyperelastic Models

- Material response is isotropic, isothermal, and elastic and is assumed fully or nearly incompressible.
- There are many hyperelastic models available in ANSYS which can cover wide varieties of elastomers used in Industries.



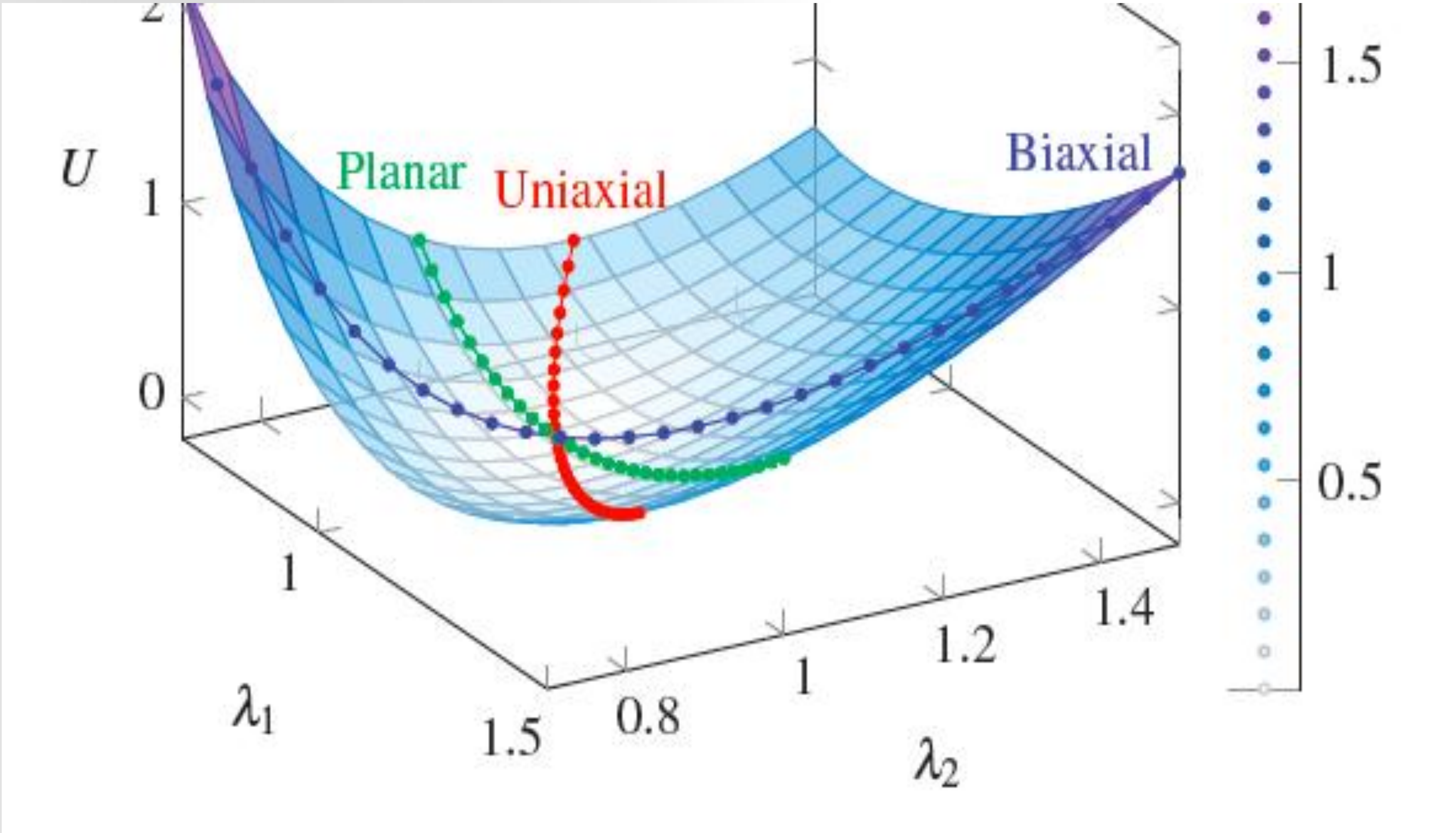
Available Hyperelastic models:

- Arruda-Boyce Hyperelastic Material
- Blatz-Ko Foam Hyperelastic Material
- Extended Tube Material
- Gent Hyperelastic Material
- Mooney-Rivlin Hyperelastic Material
- Neo-Hookean Hyperelastic Material
- Ogden Compressible Foam Hyperelastic Material
- Ogden Hyperelastic Material
- Polynomial Form Hyperelastic Material
- Response Function Hyperelastic Material
- Yeoh Hyperelastic Material

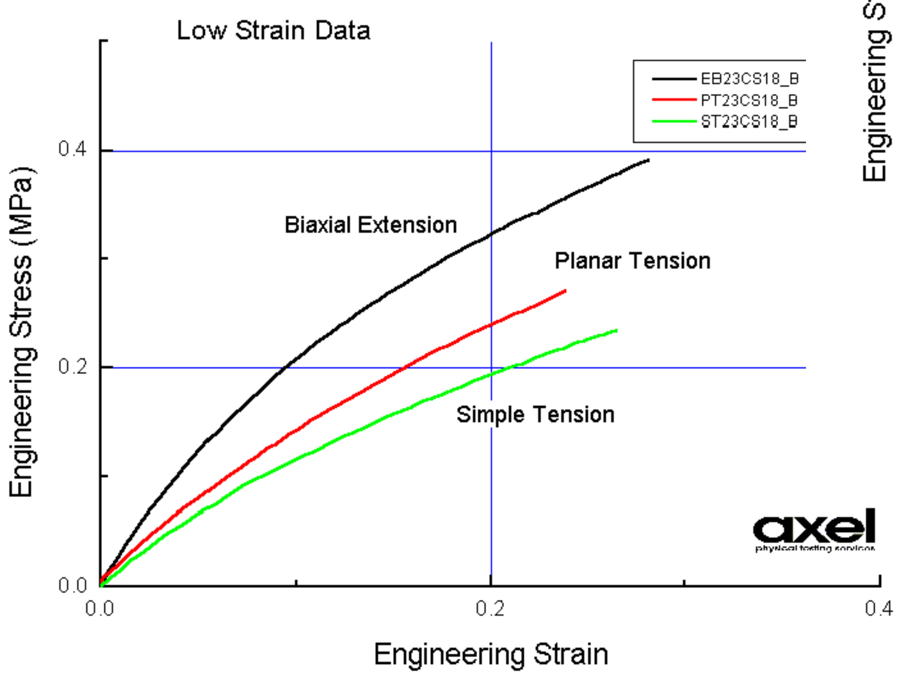
Specialized Hyperelastic models:

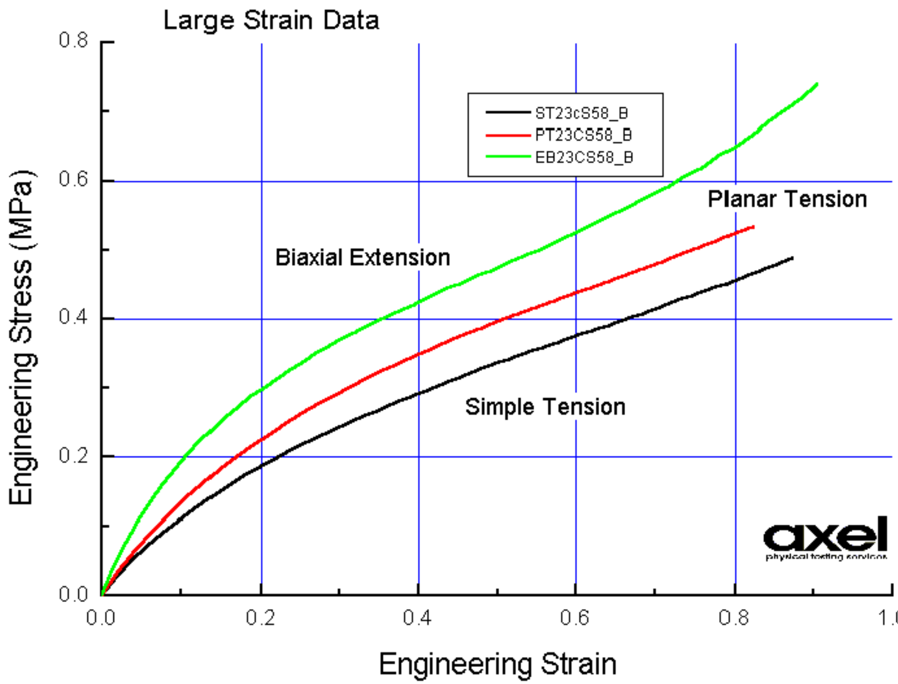
- Anisotropic Hyperelastic Material
- Bergstrom-Boyce Material
- Mullins effect
- User-Defined Hyperelastic Material

Hyperelastic Models Define a Surface



Rubber

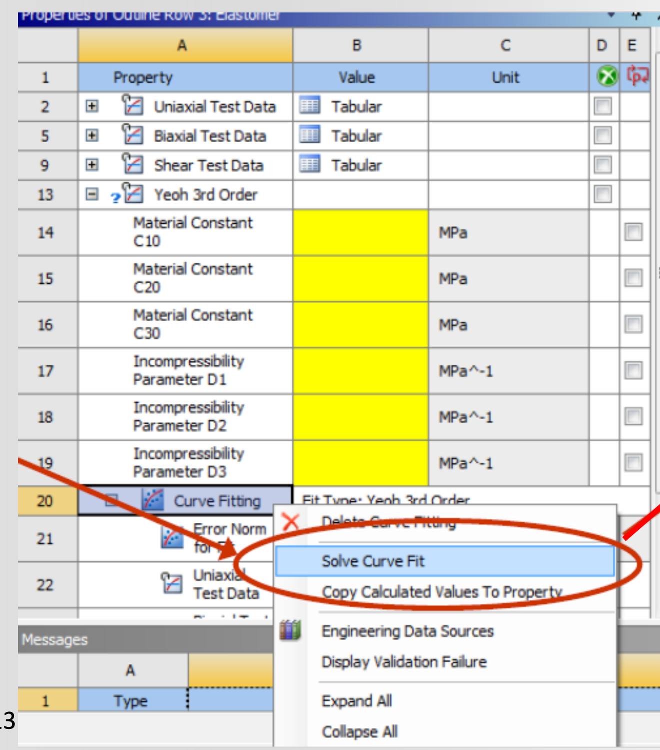

Low Strain Data
EB23CS18_B
PT23CS18_B
ST23CS18_B
Biaxial Extension
Planar Tension
Simple Tension
Engineering Stress (MPa)
Engineering Strain
0.0
0.2
0.4
axel

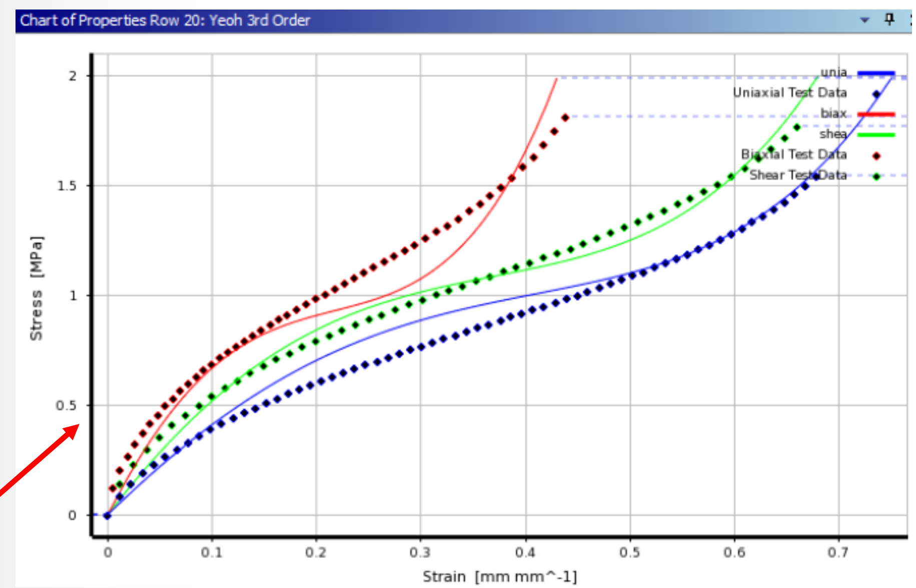

Large Strain Data
ST23cS58_B
PT23CS58_B
EB23CS58_B
Planar Tension
Biaxial Extension
Simple Tension
Engineering Stress (MPa)
Engineering Strain
0.0
0.2
0.4
0.6
0.8
1.0
axel

Hyperelastic Models

Curve Fitting feature

- Material curve fitting allows you to derive coefficients from experimental data that you provide for your material.
- With this capability, you compare experimental data versus program-calculated data for different nonlinear models and determine the best material model to use.
- ANSYS provides curve-fitting, based on experimental data, for all of the available hyperelastic models. Any of the hyperelasticity models in ANSYS can be used.

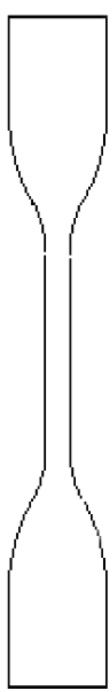


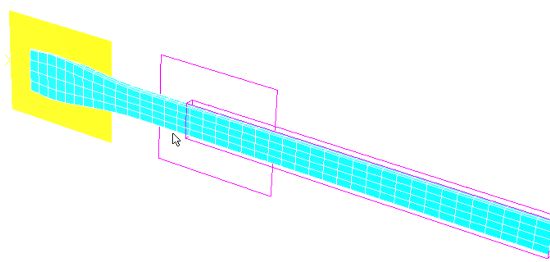


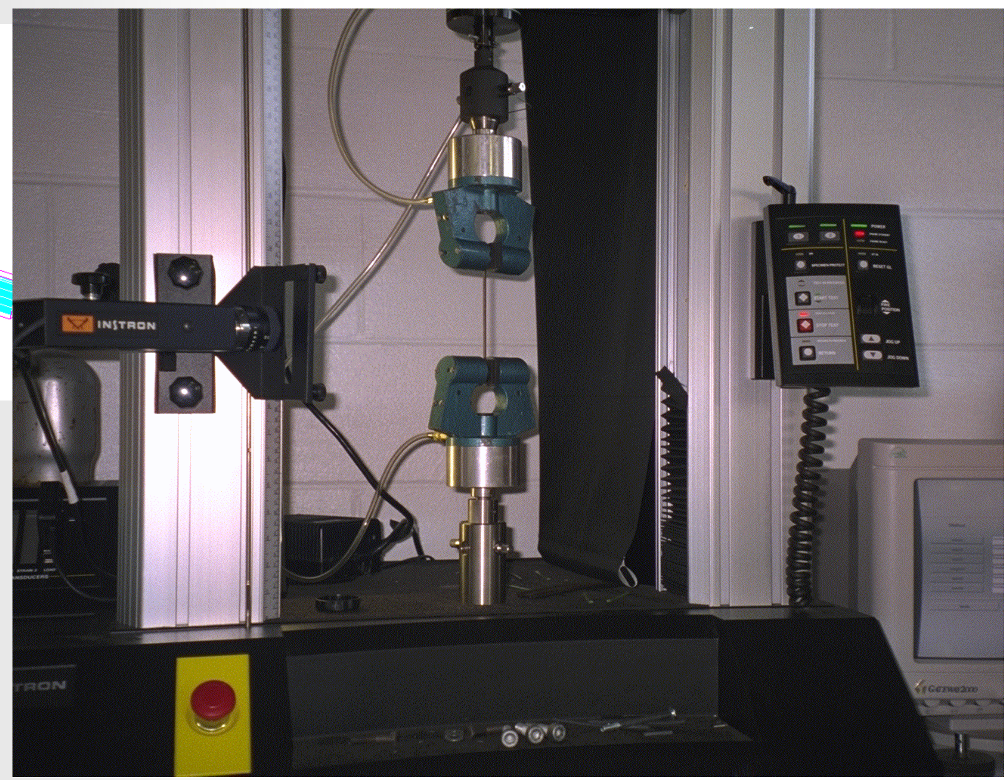
Simple Tension

- Uniaxial loading
- Free of lateral constraint

Gage Section:
Length:Width
>10:1

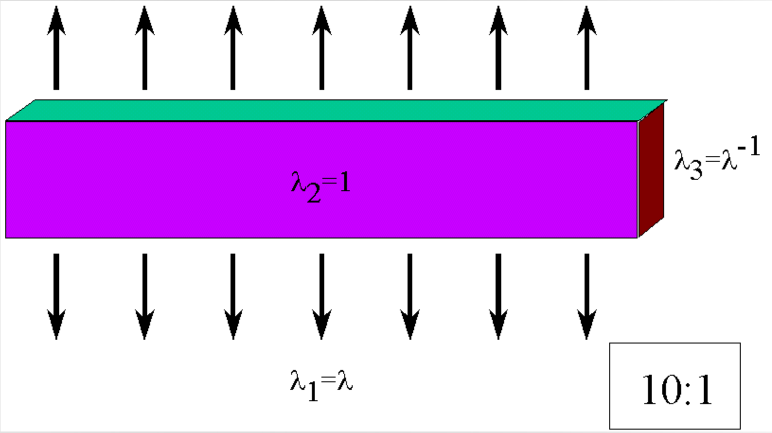






Planar Tension

1. Uniaxial loading
2. Perfect lateral constraint
3. All thinning occurs in one direction



Equal Biaxial Extension

Why?

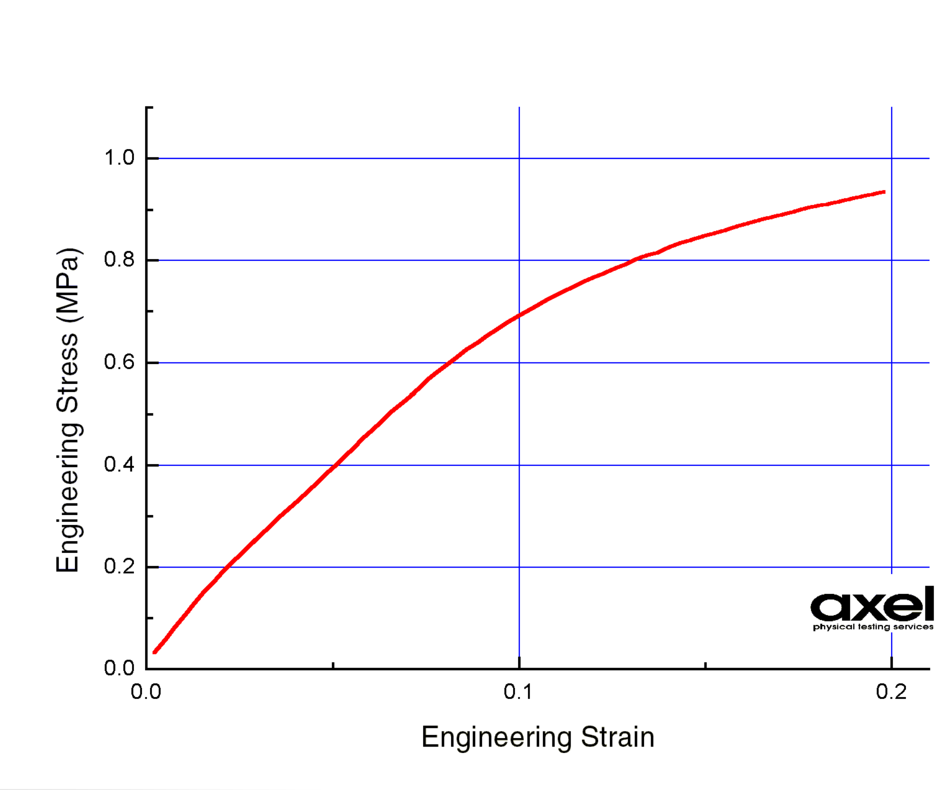
1. Same Strain State as Compression
2. Can Not Do Pure Compression
3. Can Do Pure Biaxial

Loading Conditions

Some common Elastomers exhibit dramatic strain amplitude and cycling effects at moderate strain levels

Conclusions:

1. Test to Realistic Strain Levels
2. Use Application Specific Loadings to Generate Material Data
3. Need to load and unload to separate elastic from plastic



Loading Conditions

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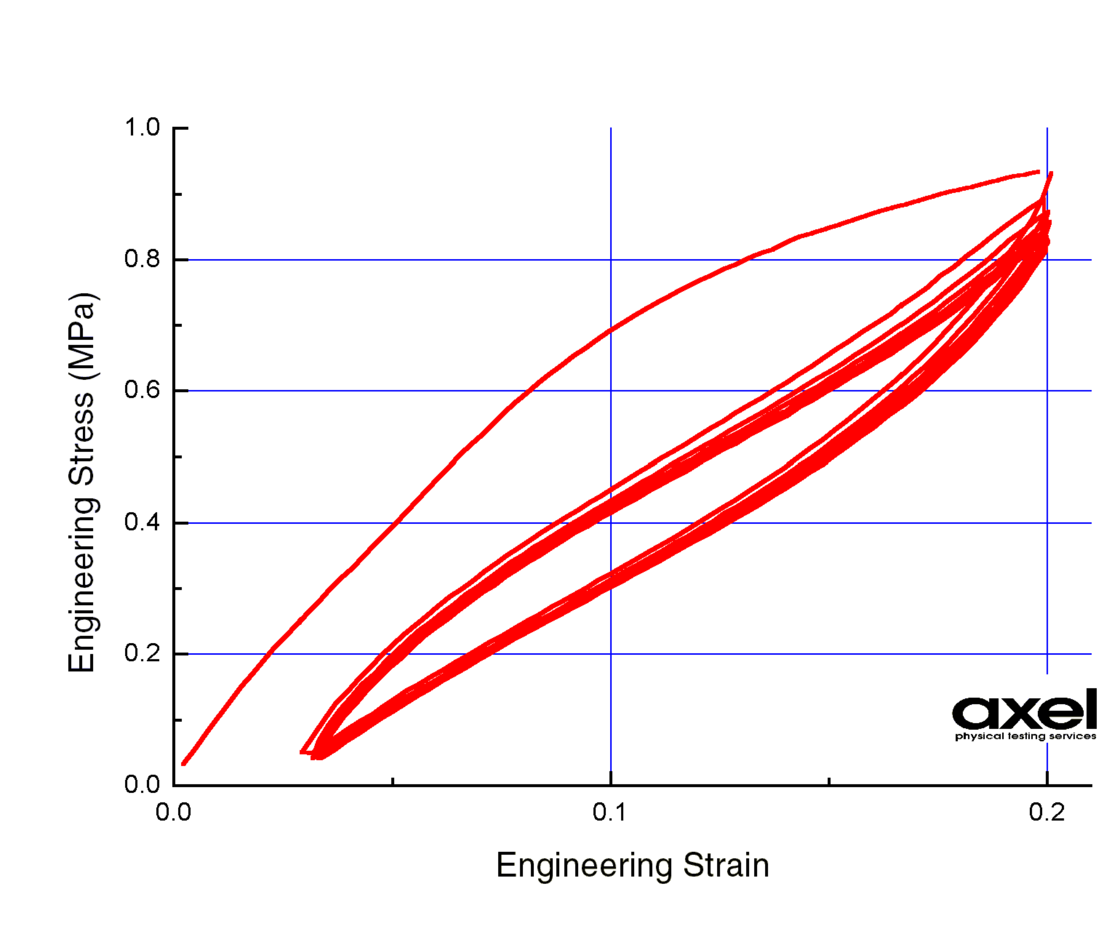
   plastic



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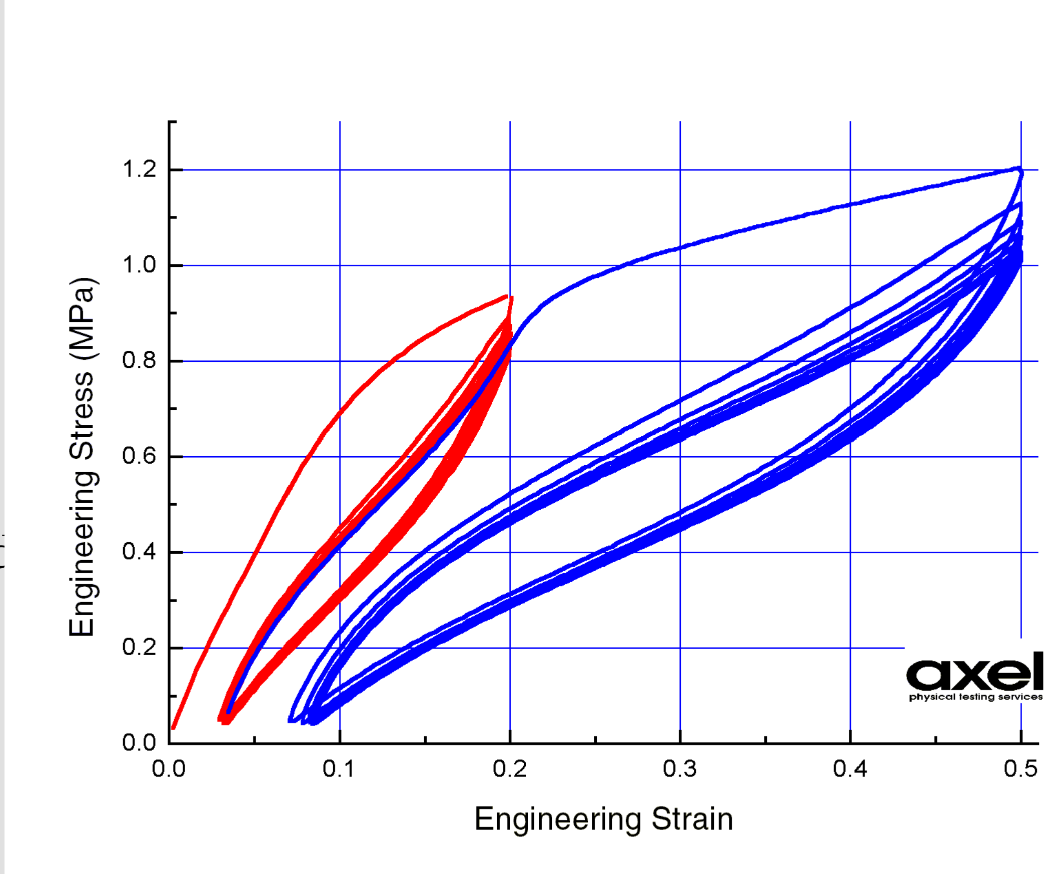
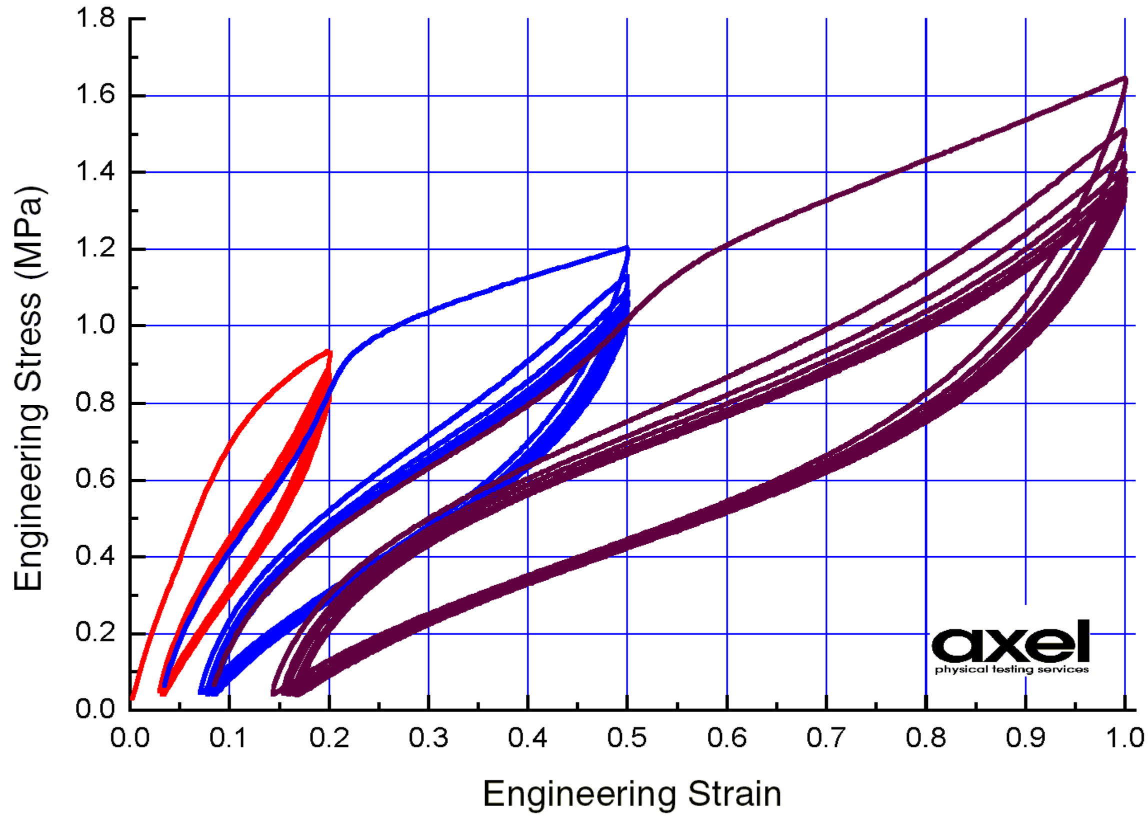


Loading Conditions

Some common elastomers exhibit dramatic strain amplitude and cycling effects at moderate strain levels

Conclusions:

1. Pick one level
2. Use Mullins Model
3. Use FeFp
4. Use large strain hysteresis model



Thermoplastic Elastomers

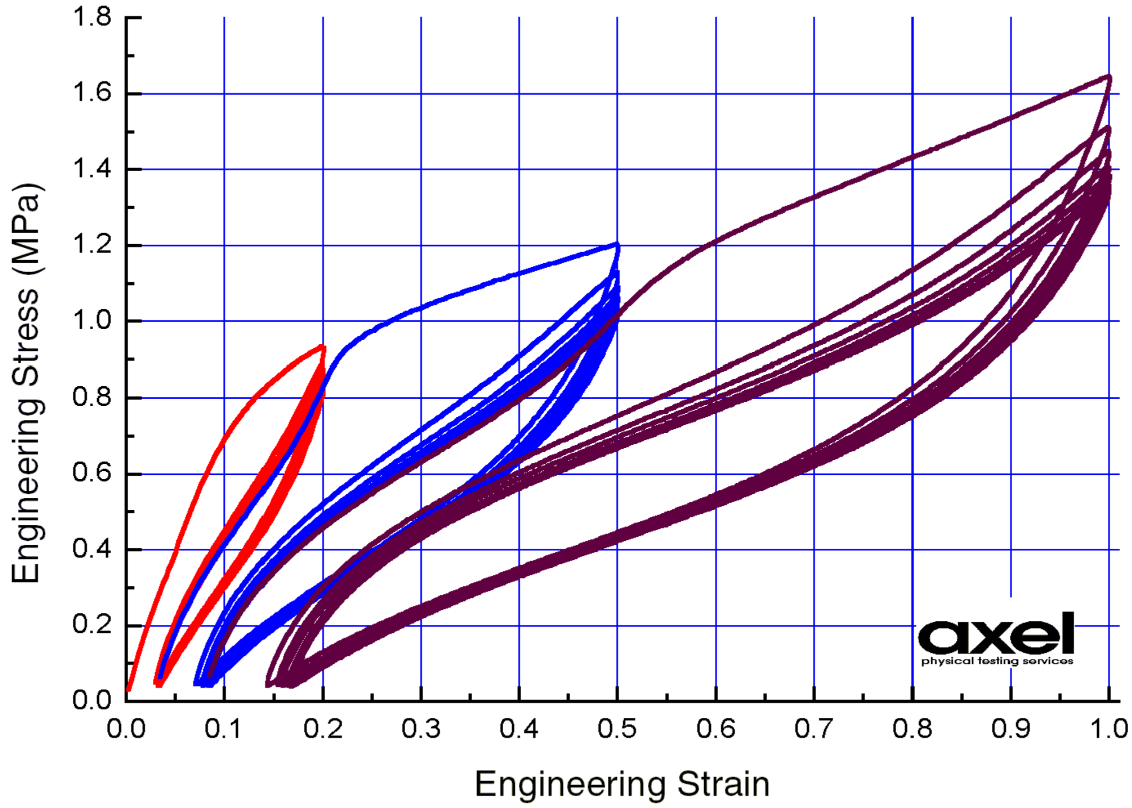
Increasingly used to replace elastomers

Rubber inside of plastic

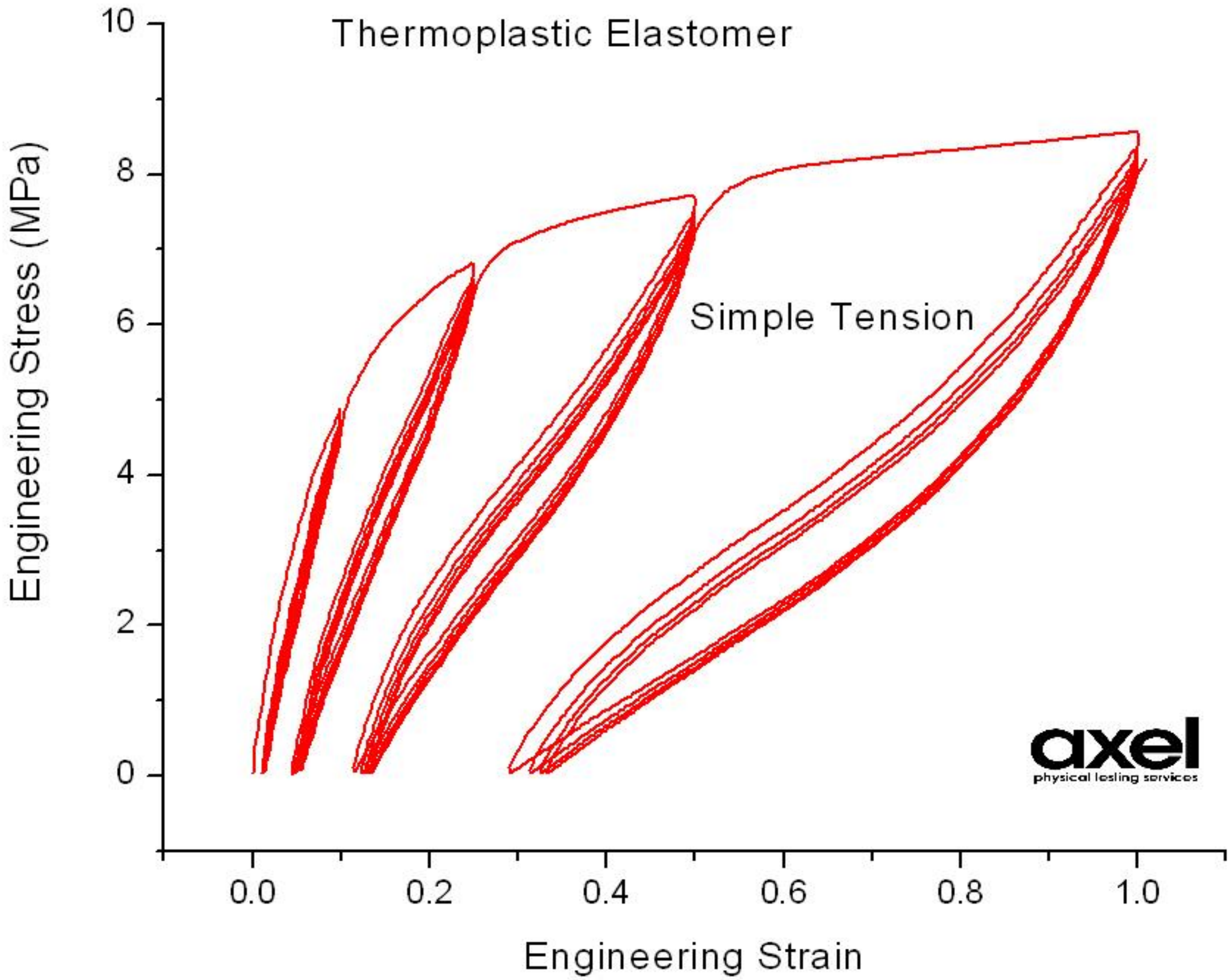
Plasticity and Flow

Conclusions:

1. Pick one level
2. Use Mullins Model
3. Use Viscoelastic
4. Use large strain hysteresis model



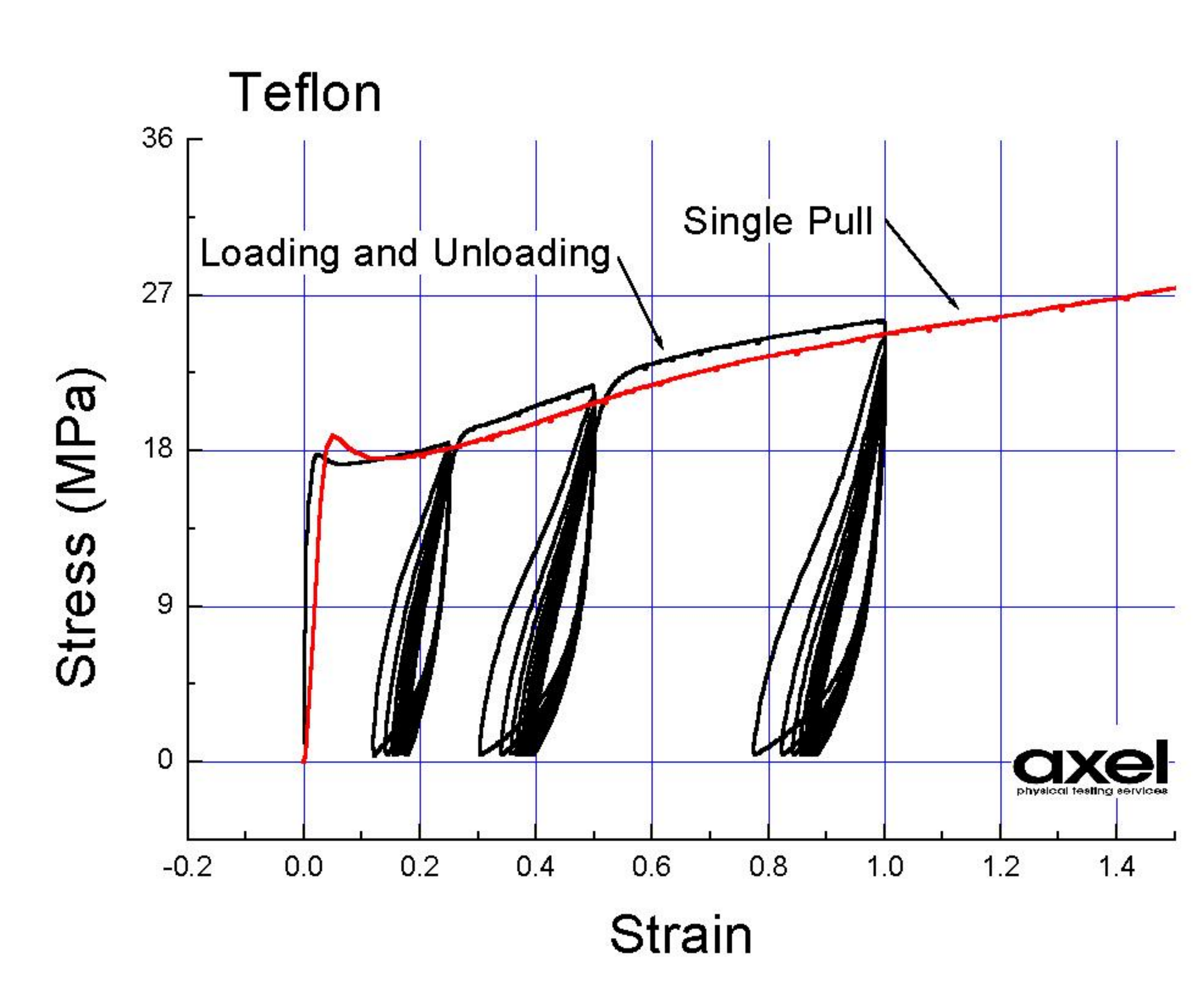
Thermoplastic Elastomers



Teflon

Conclusions:

1. Pick one level
2. Use FeFp



  June 3, 2013

A General Strategy

1. Understand the loading conditions of the part
2. Understand the general behavior of the materials involved
3. Select the significant material behaviors
4. Use existing or develop material models to describe the behavior
5. Verify the performance of the material model

Bergstrom-Boyce Model

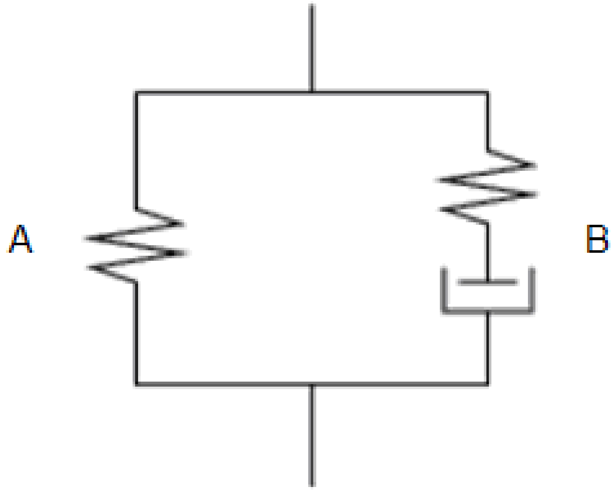
The Bergstrom-Boyce material model is a phenomenological-based, highly nonlinear material model used to model typical elastomers and biological materials.

It allows for a nonlinear stress-strain relationship, creep, and rate-dependence.

It assumes an inelastic response only for shear distortional behavior. The response for volumetric is still purely elastic

The model is based on a spring (A) in parallel with a spring and damper (B) in series.

All components (springs and damper) are highly nonlinear.



… Bergstrom-Boyce Model

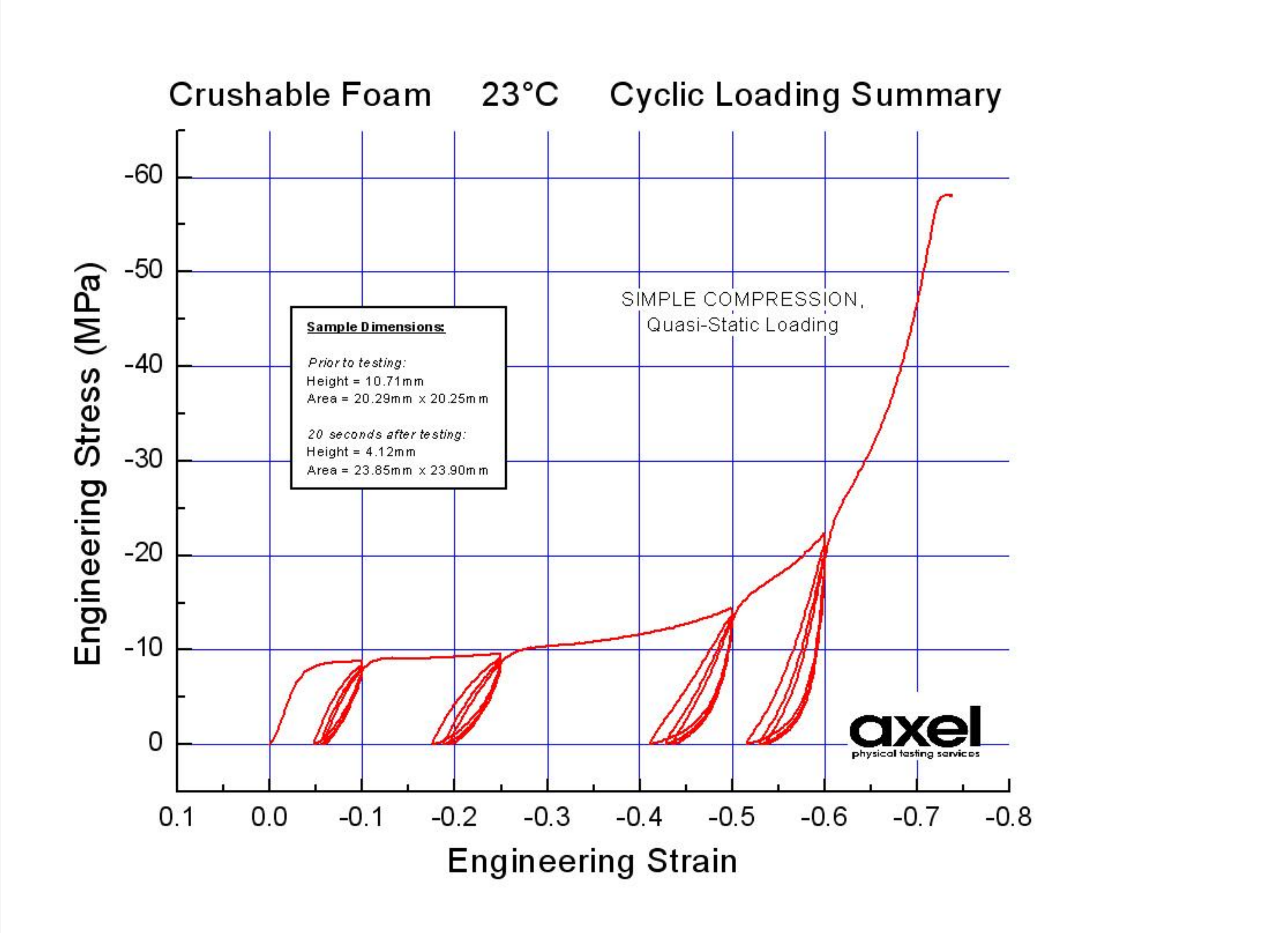
The stress state in A can be found in the tensor form of the deformation gradient tensor ($F = dx_i / dX_j$) and material parameters, as follows:

$$\sigma_A = \frac{1}{J_A}\frac{\mu_A}{3}\frac{L^{-1}\left(\bar{\lambda}_A^* / \lambda_A^{lock}\right)}{\bar{\lambda}_A^* / \lambda_A^{lock}}\,\mathrm{dev}\left[\tilde{B}_A^*\right] + K\left[J_A - 1\right]\tilde{I}$$

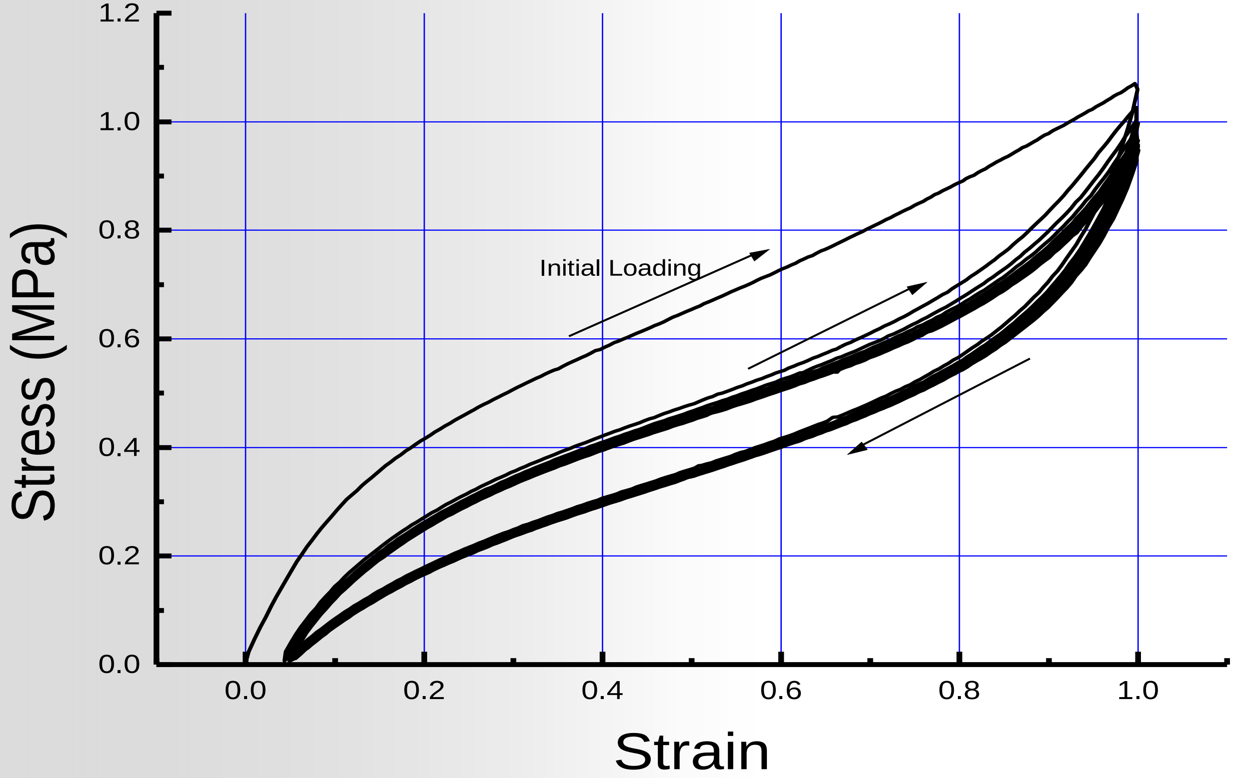
where

σ_A	=	stress state in A
μ_A	=	initial shear modulus of A
λ_A^{lock}	=	limiting chain stretch of A
K	=	bulk modulus
J_A	=	det[F]
$\tilde{B}_A^*$	=	$J^{-2/3}\tilde{F}\tilde{F}^T$
$\bar{\lambda}_A^*$	=	$\sqrt{tr[\tilde{B}^*]/3}$

Crushable Foam

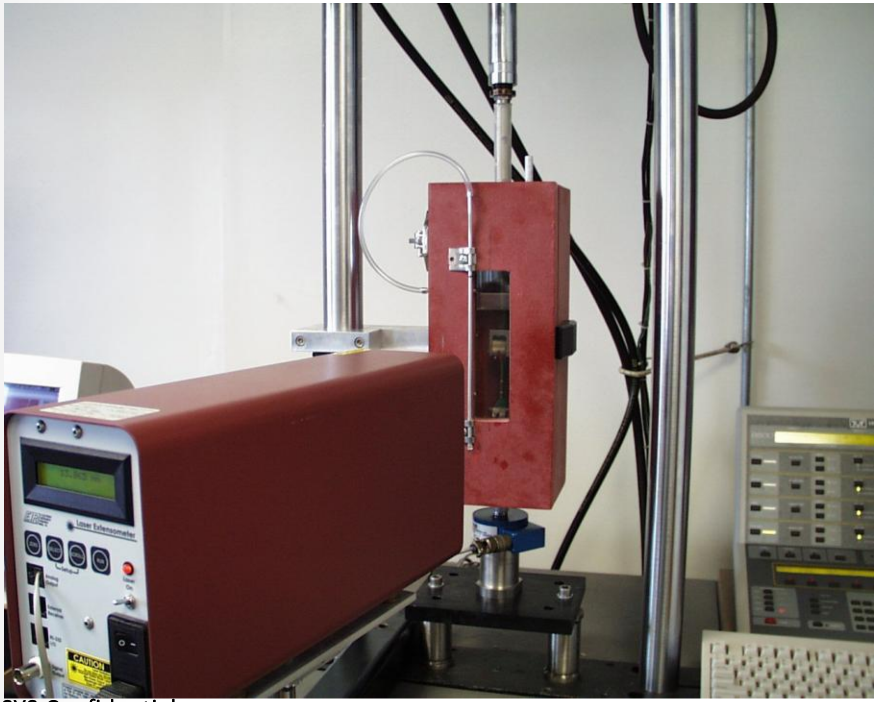


Large strain hysteresis model



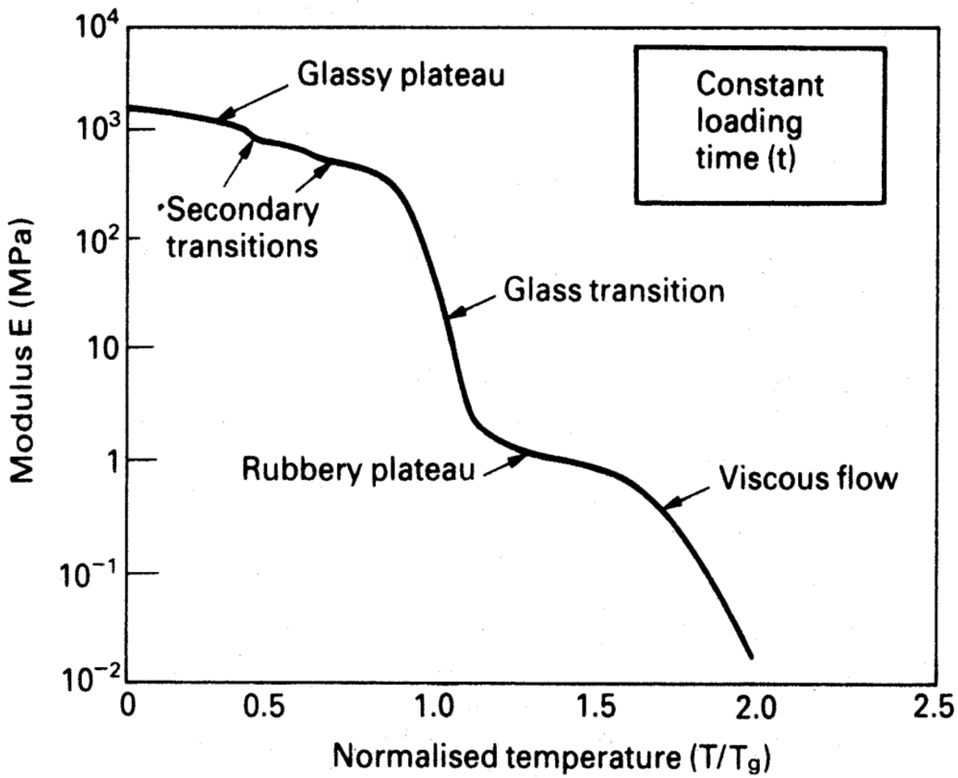
Thermal Effects

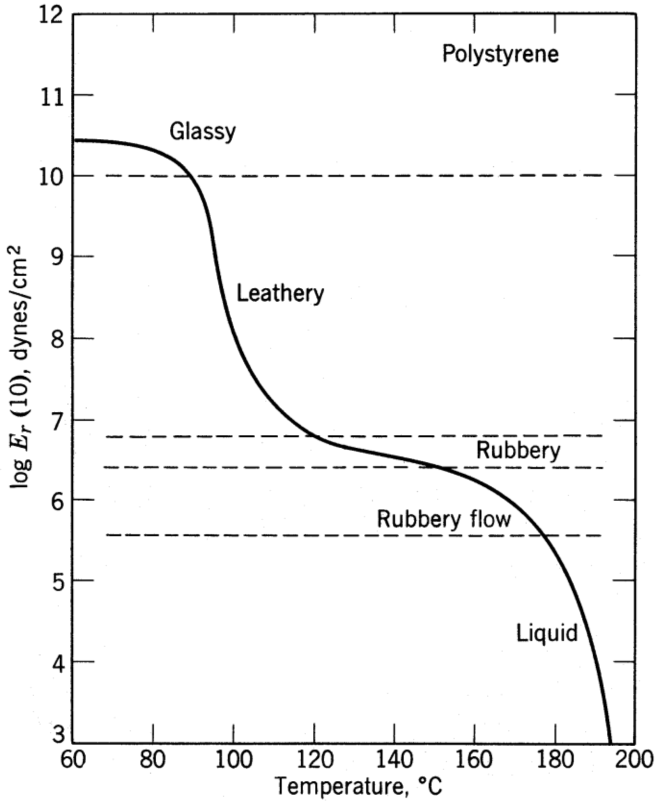
1. Cold and Hot
2. Thermal Conductivity
3. Thermal Expansion



Cold and Hot

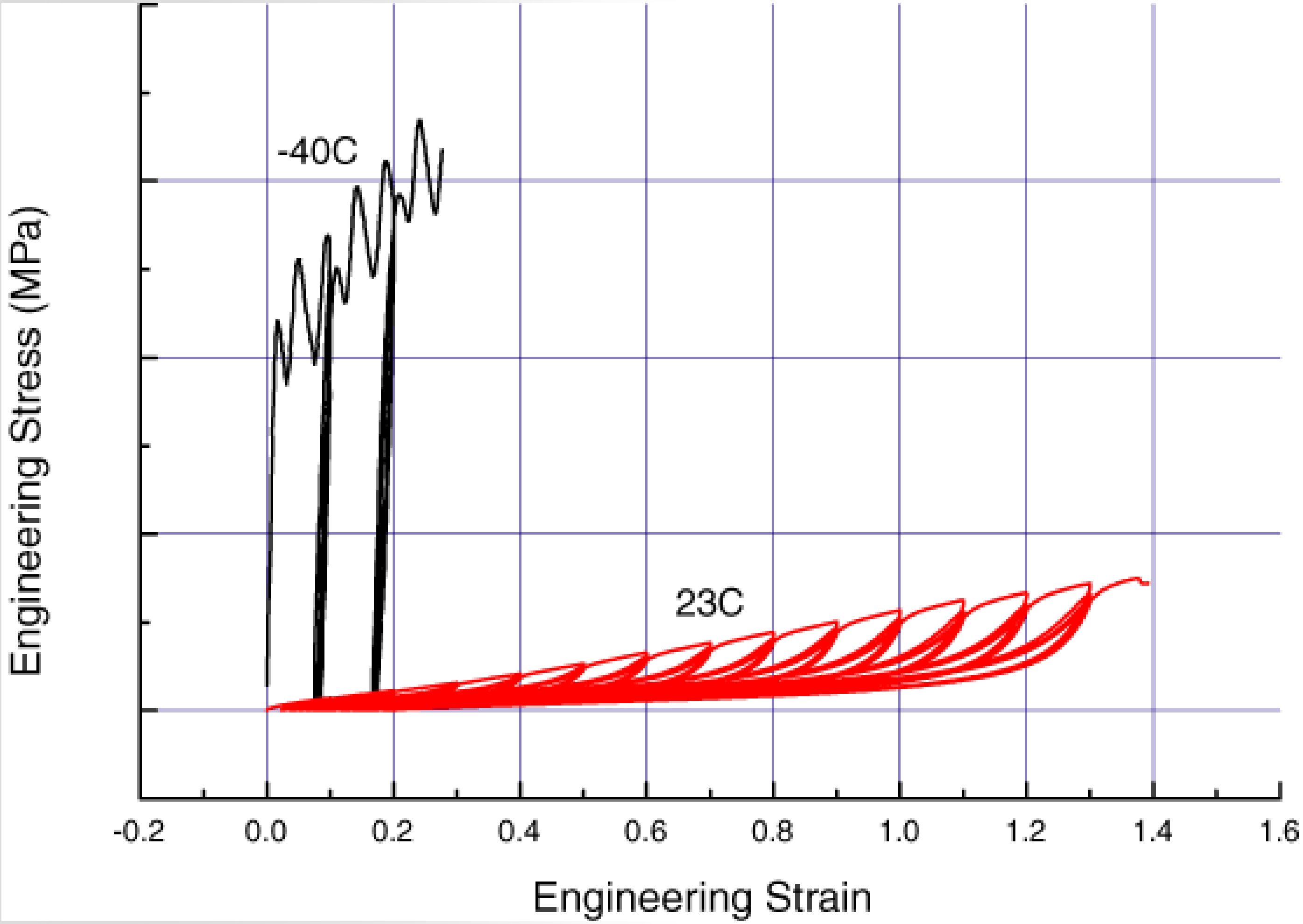
Typical T_G diagrams for polymer materials





Cold and Hot

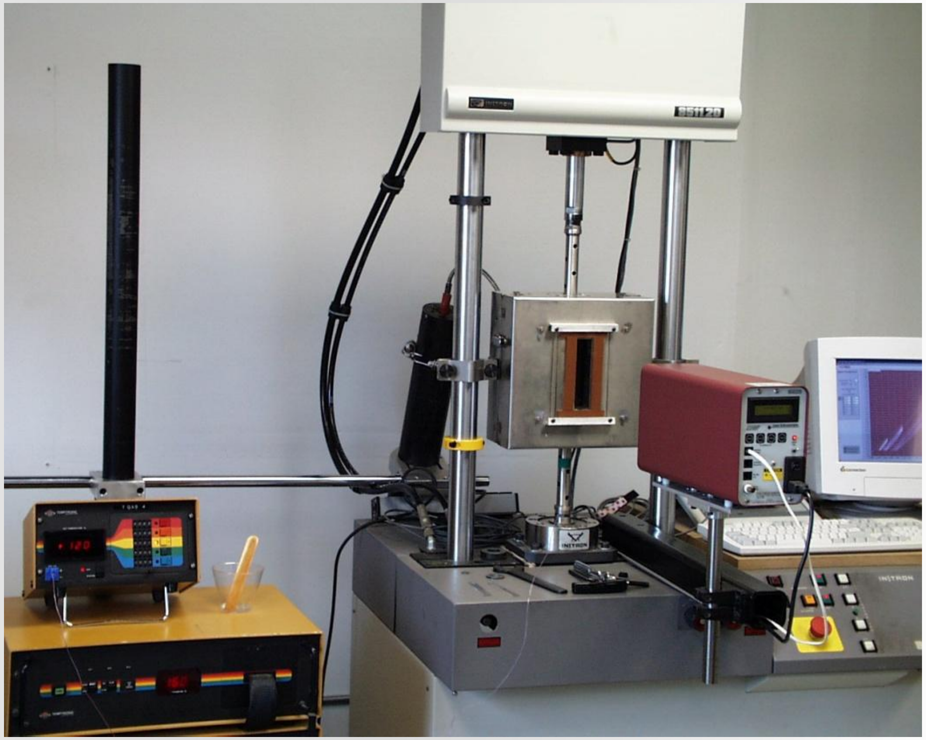
Elastomers Properties Can Change by Orders of Magnitude in the Application Temperature Range.

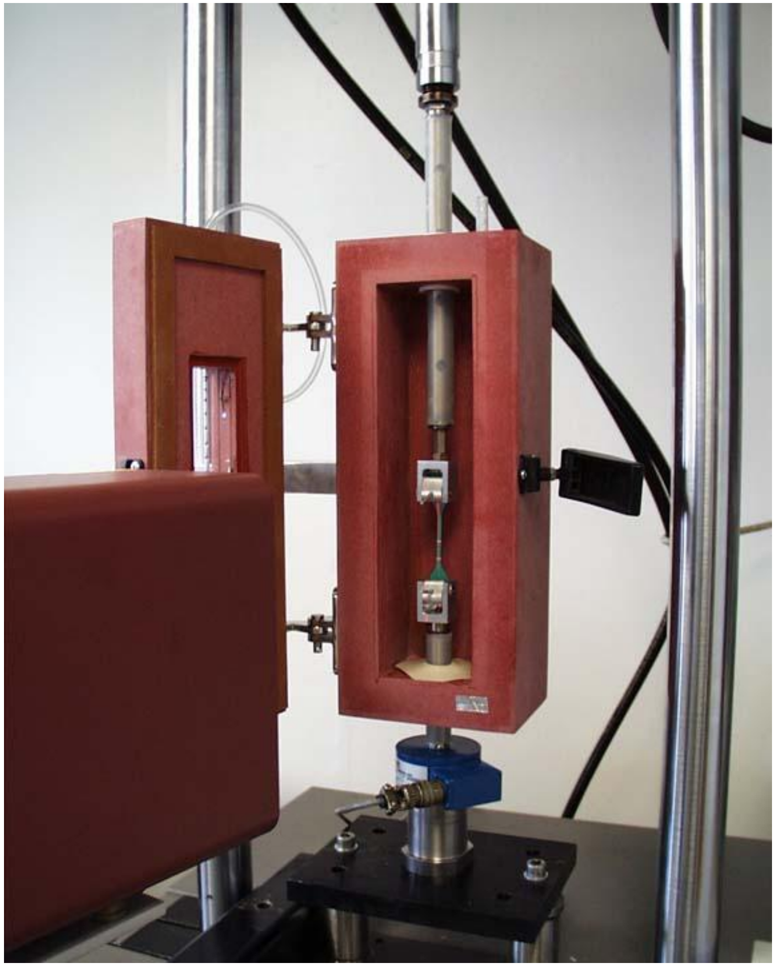


Cold and Hot

Testing at the Application Temperature

1. **Measure Strain at the Right Location**
2. **Perform Realistic Loadings**





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Model Verification

Attributes of a good model verification experiment

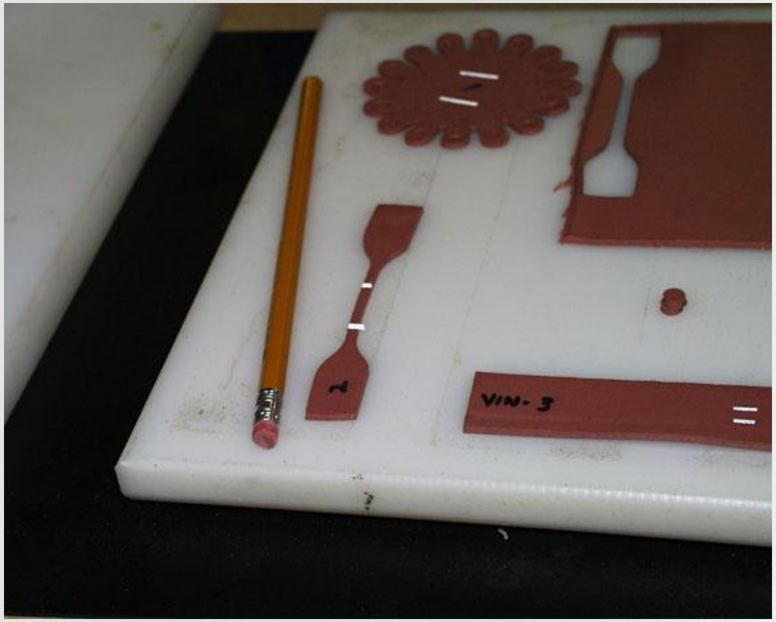
The geometry is realistic.

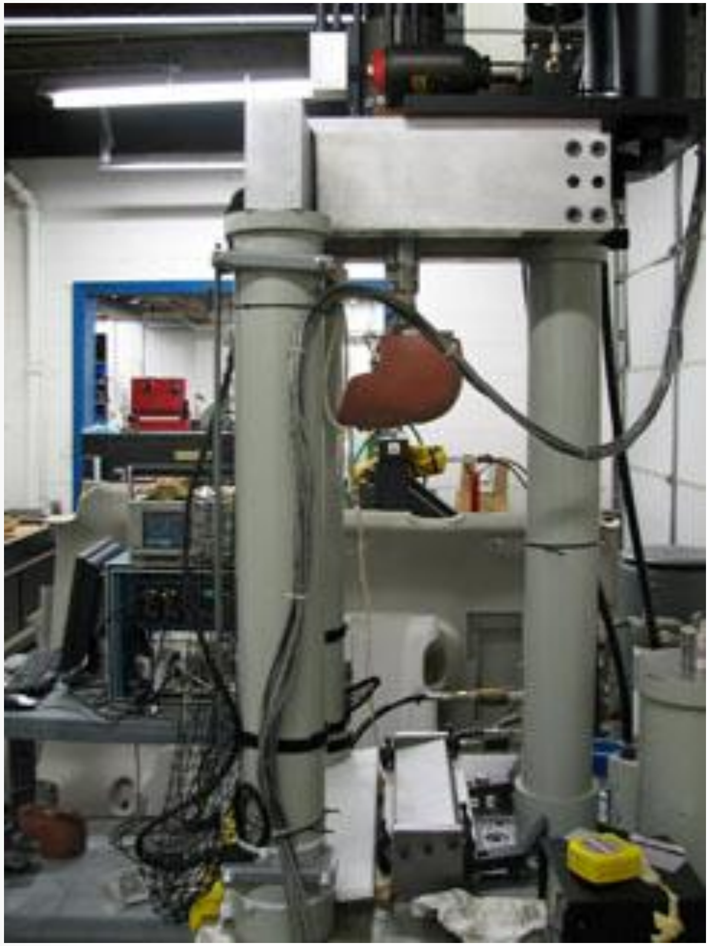
All relevant constraints are measurable.

The analytical model is well understood

Confinement can be Significant

Model Verification





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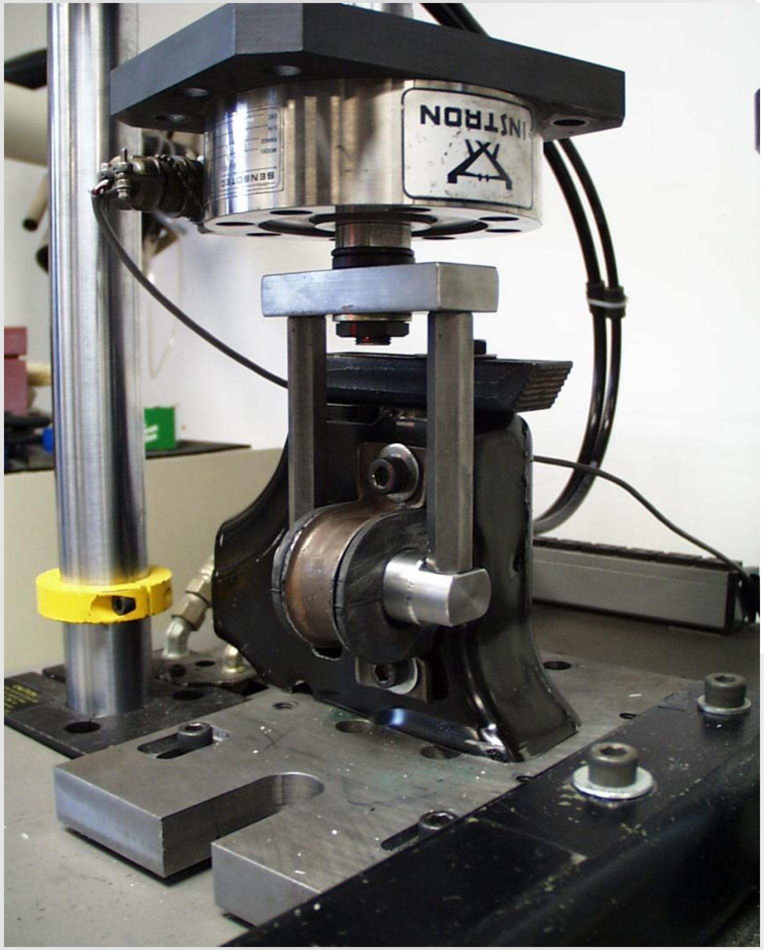

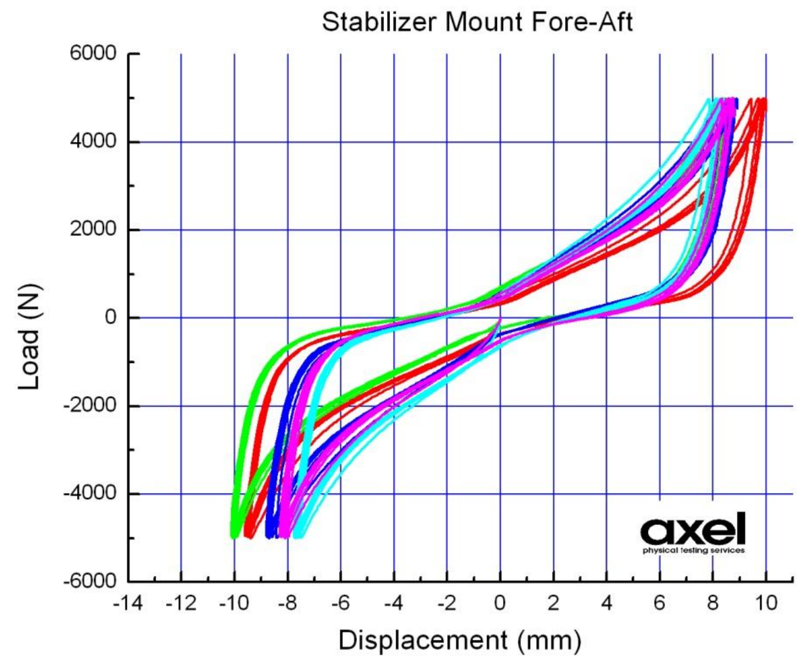

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Experimental Elastomers Training at Axel Products

ANSYS teams with Axel Product, Inc. (www.axelproducts.com) to offer this course that covers material testing, material modeling and finite element analysis of elastomers.