ANSYS

2014 Regional Conference

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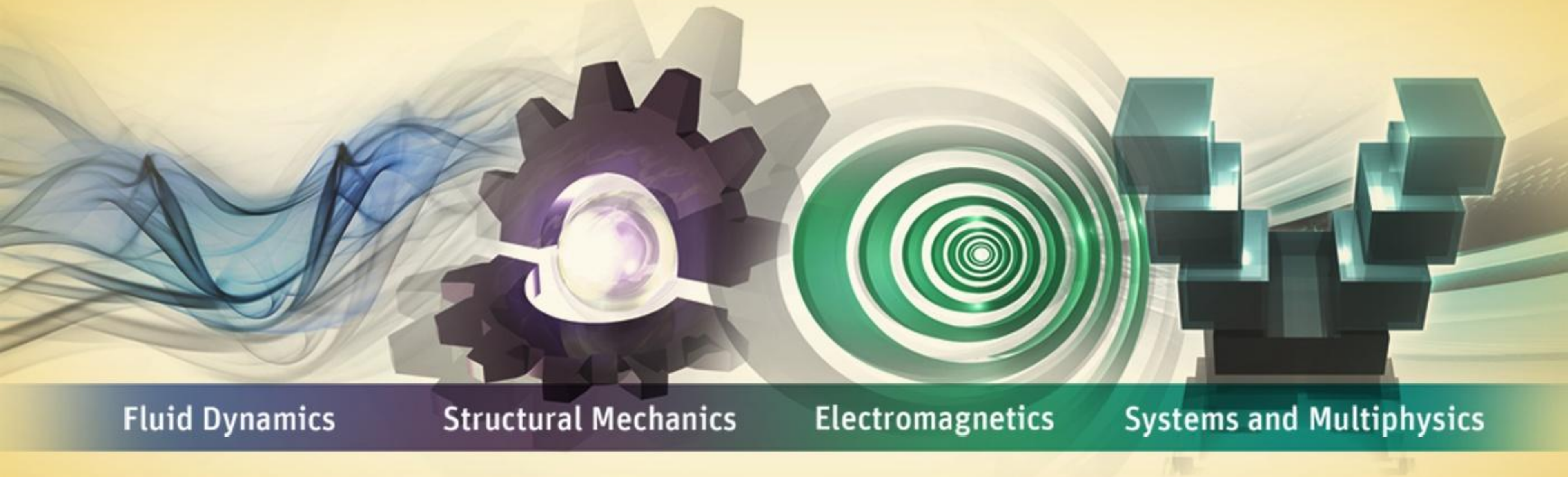
Experiments and Fitting of Advanced Polymer Models in ANSYS



Kurt Miller, Axel Products, Inc.

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physical testing services

Physical Testing Services

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Axel Products, Inc.

Provides testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics for users of ABAQUS, ANSYS, DIGIMAT, Marc, and Dyna.

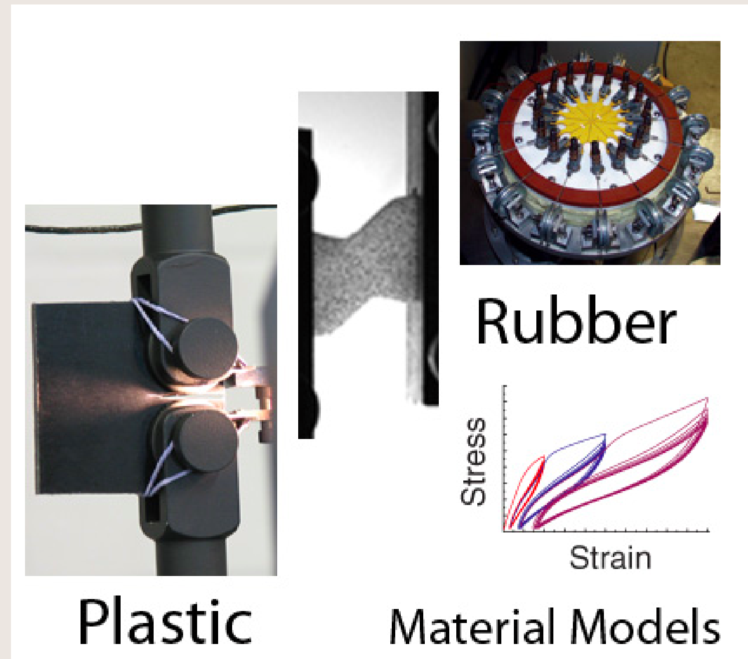
Testing Services

Related experiments, downloads and pricing by application.

- Elastomer (hyperelastic) Characterization
- Plastic Characterization
- Sponge Elastomer Characterization
- Vibration and Viscoelastic Experiments
- Thermal Properties Measurements
- High Strain Rate Experiments
- Medical Material Testing in Saline
- Friction Measurements
- Component Tests
- Durability and Crack Growth of Elastomers
- Fatigue and Crack Growth of Plastics
- Long Term Creep and Stress Relaxation Tests

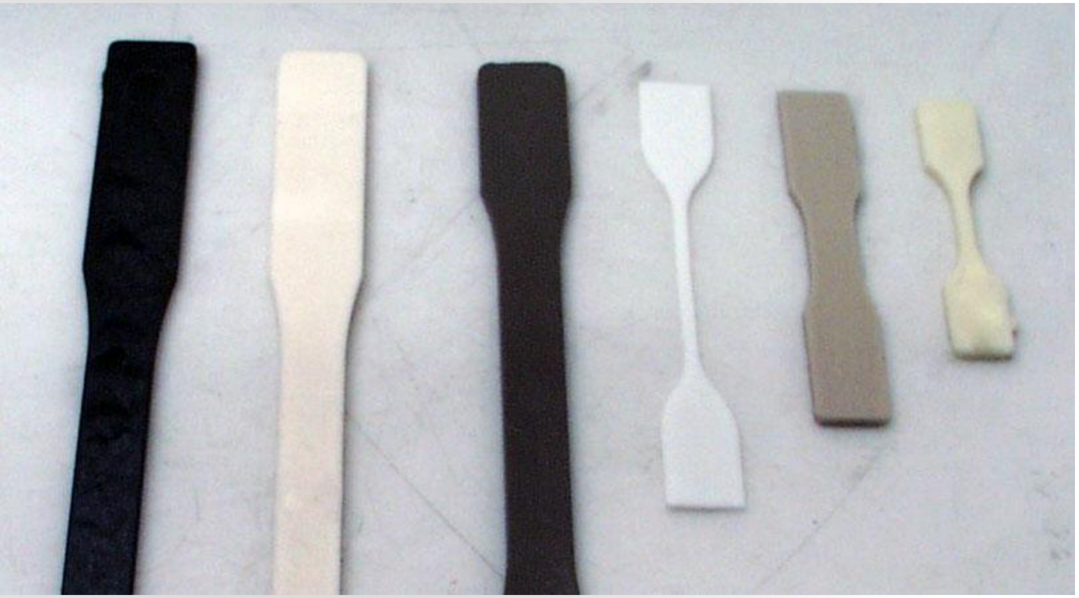
Technical Downloads

Popular downloads.

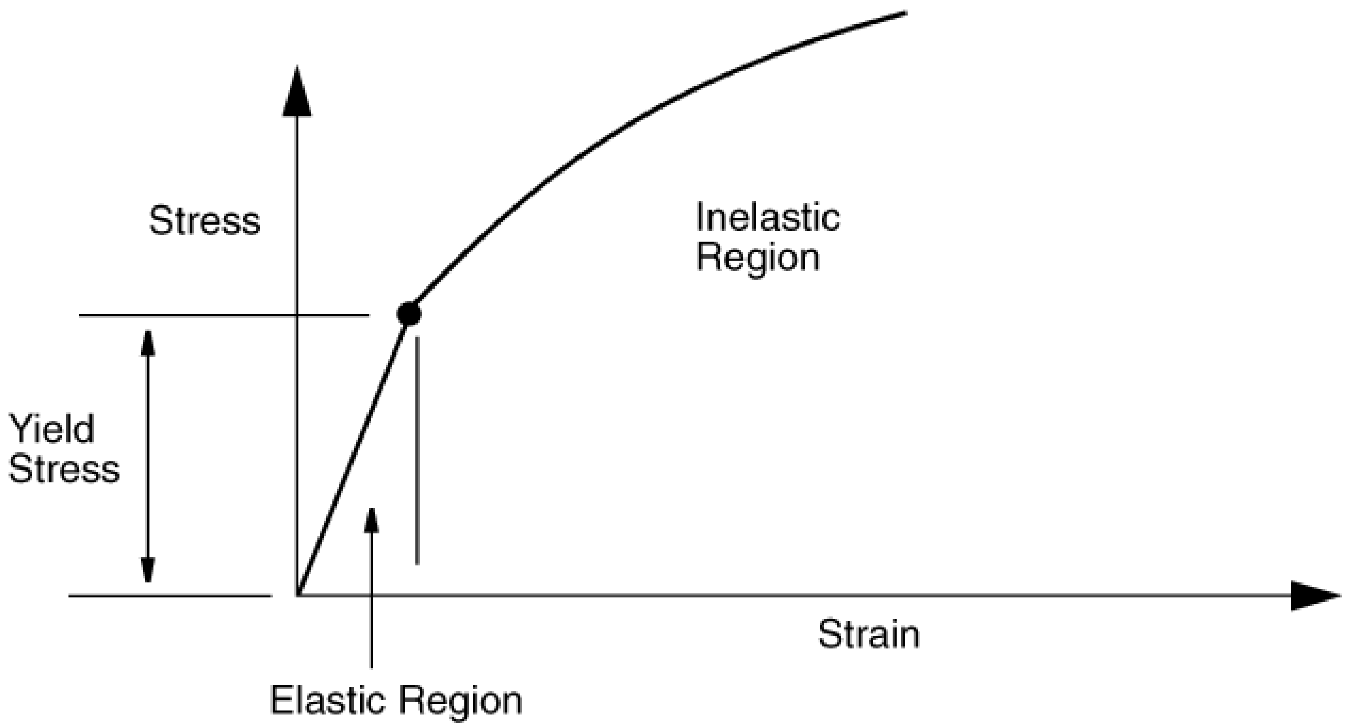


Training Courses

Structural Properties

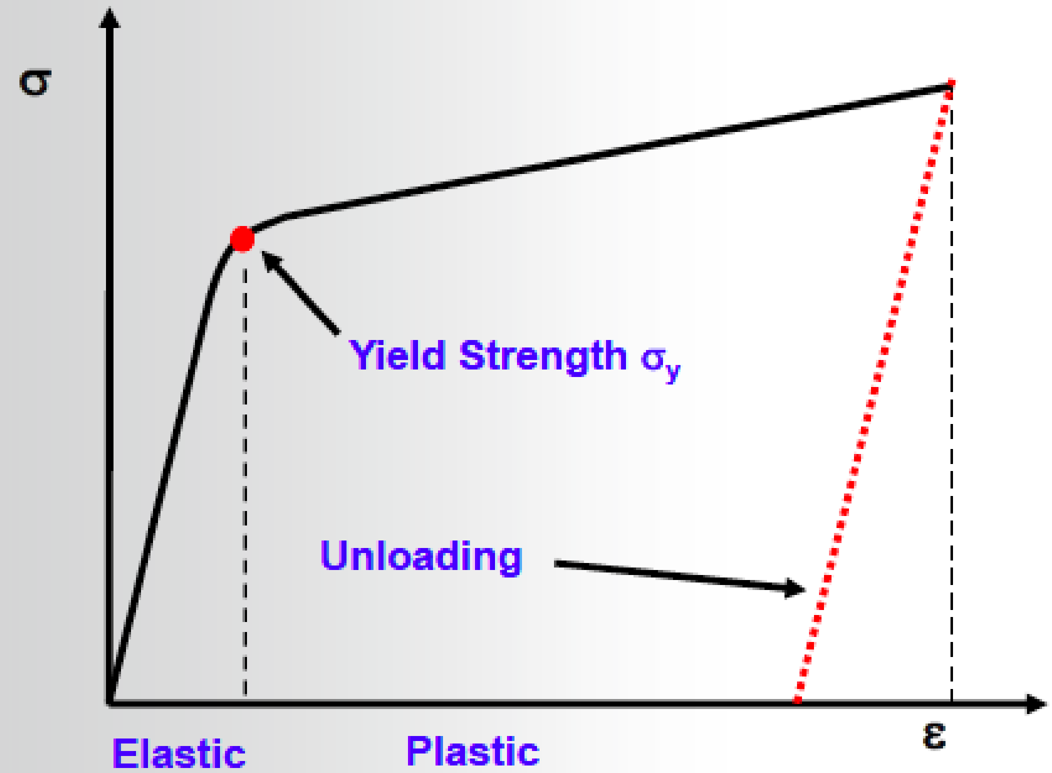


Structural Properties

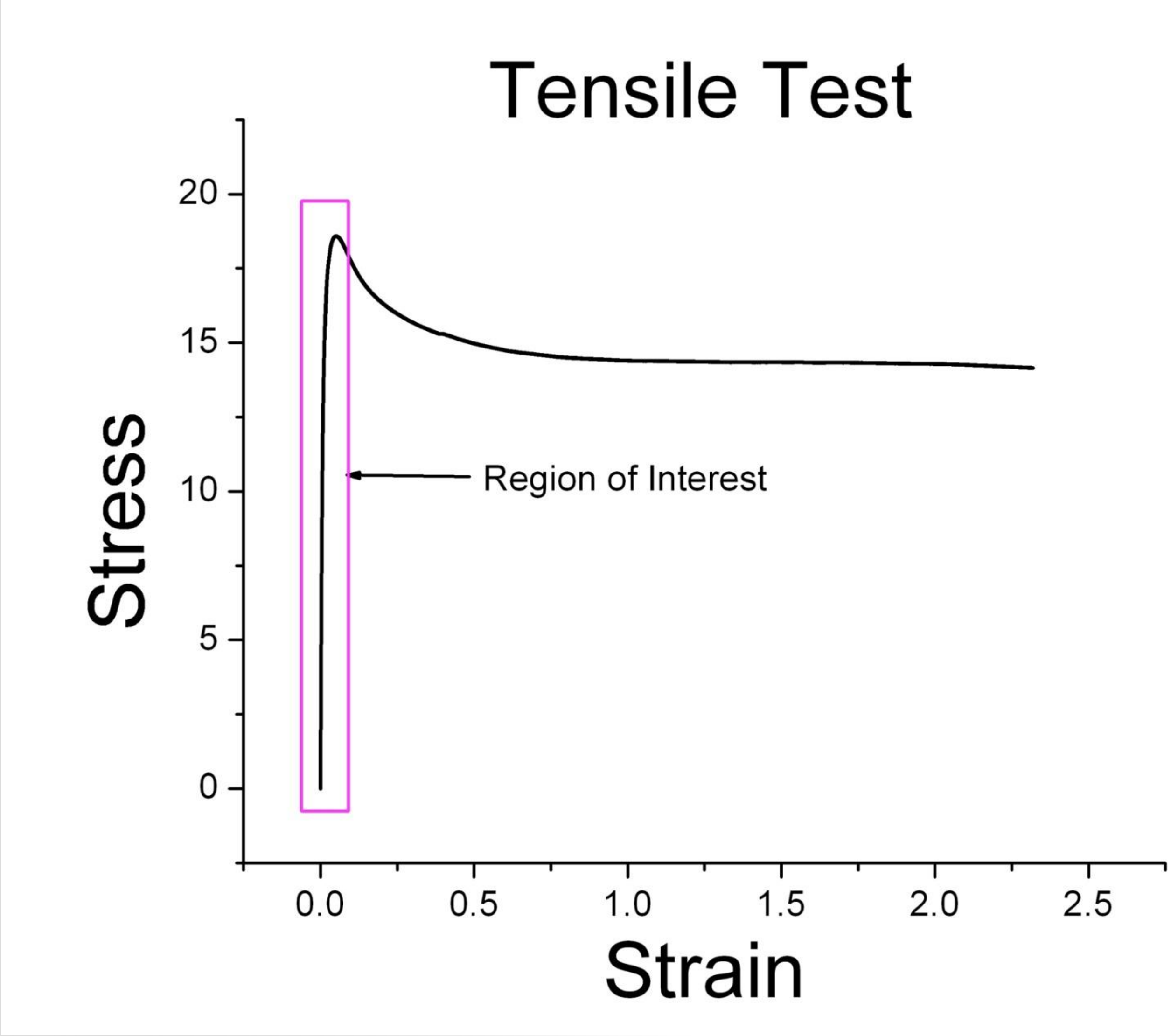


Note: Stress and strain are total quantities.

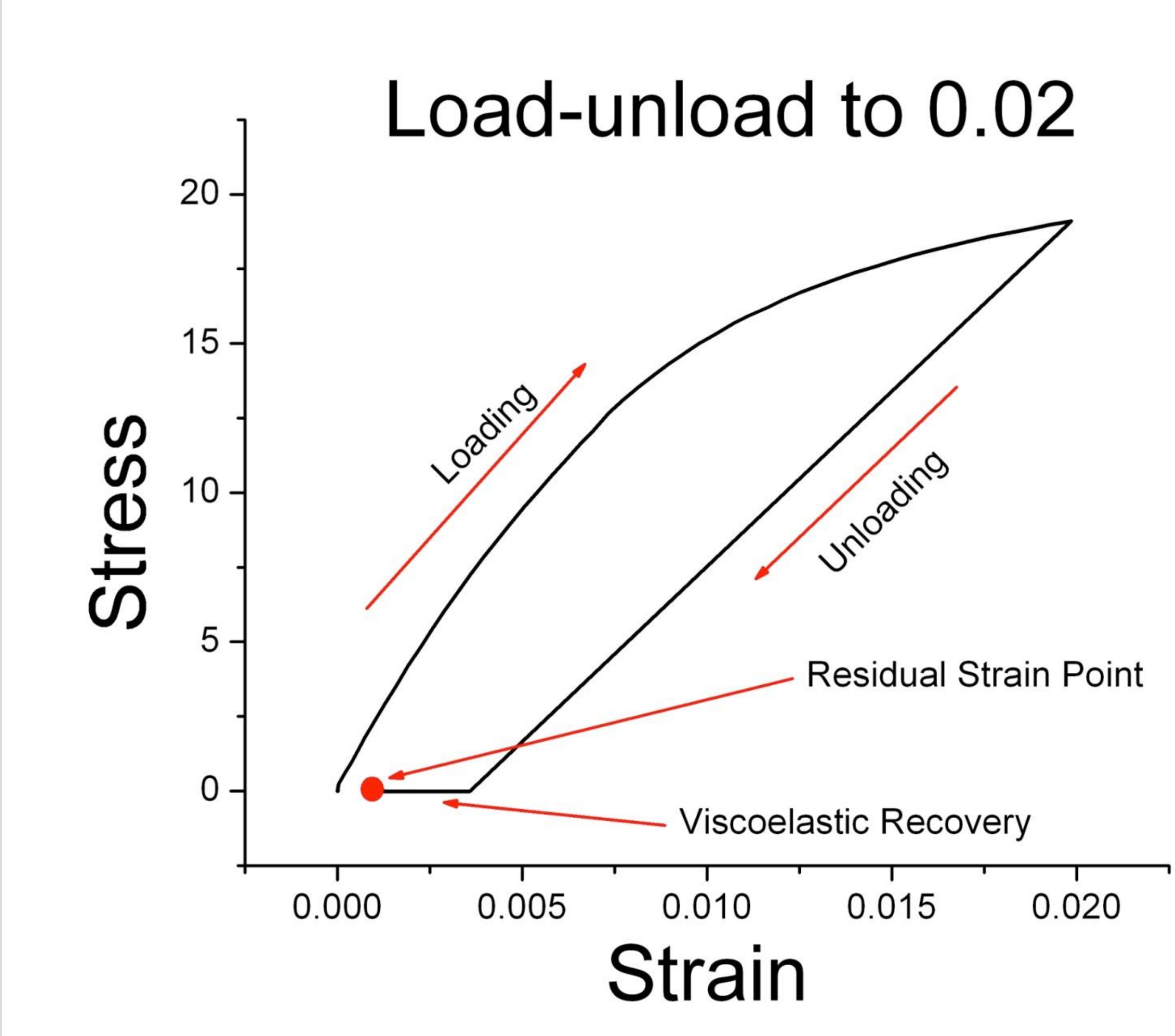
Structural Properties
(small deformation plasticity)



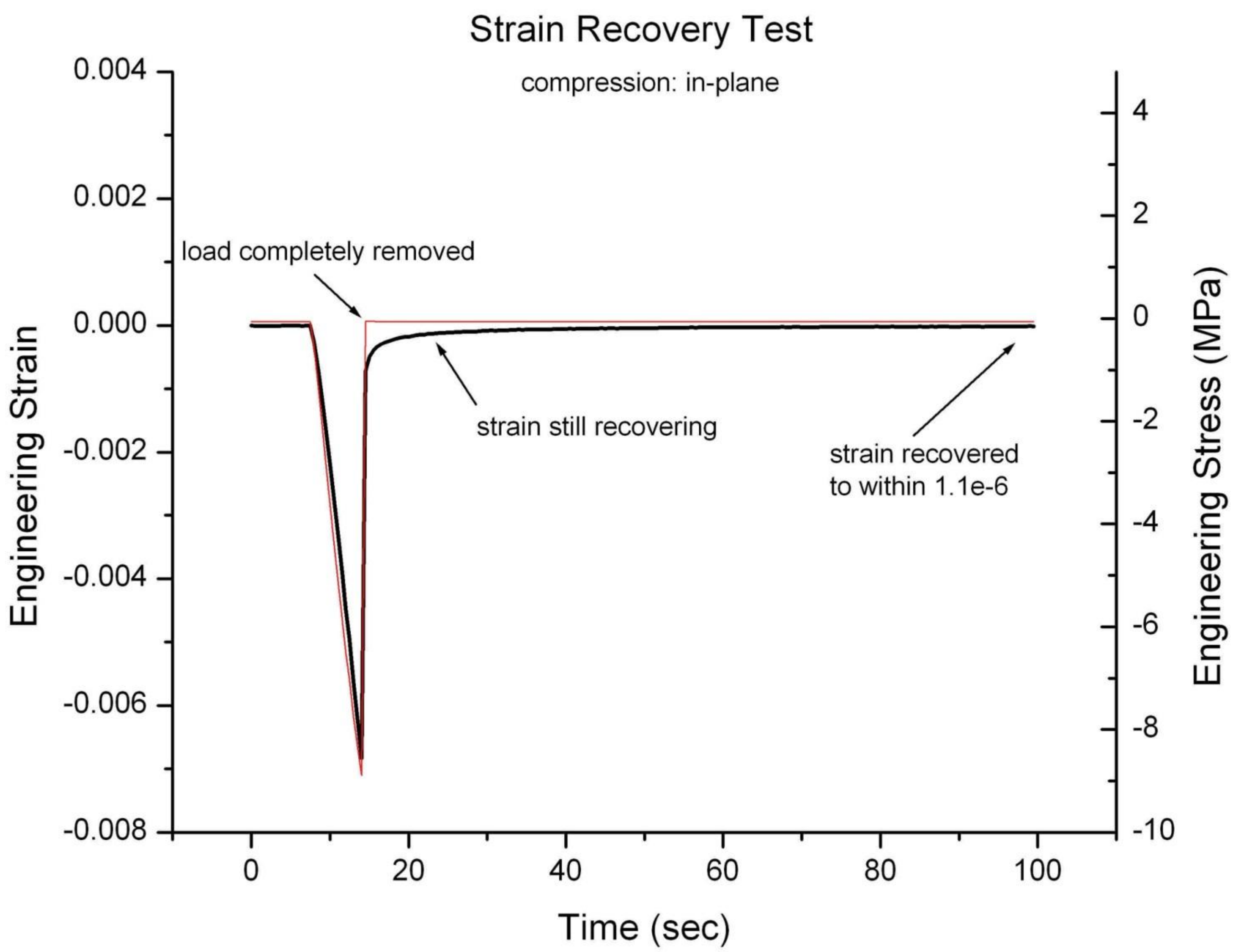
Plastic


Tensile Test
Stress
Strain
Region of Interest
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
2.5

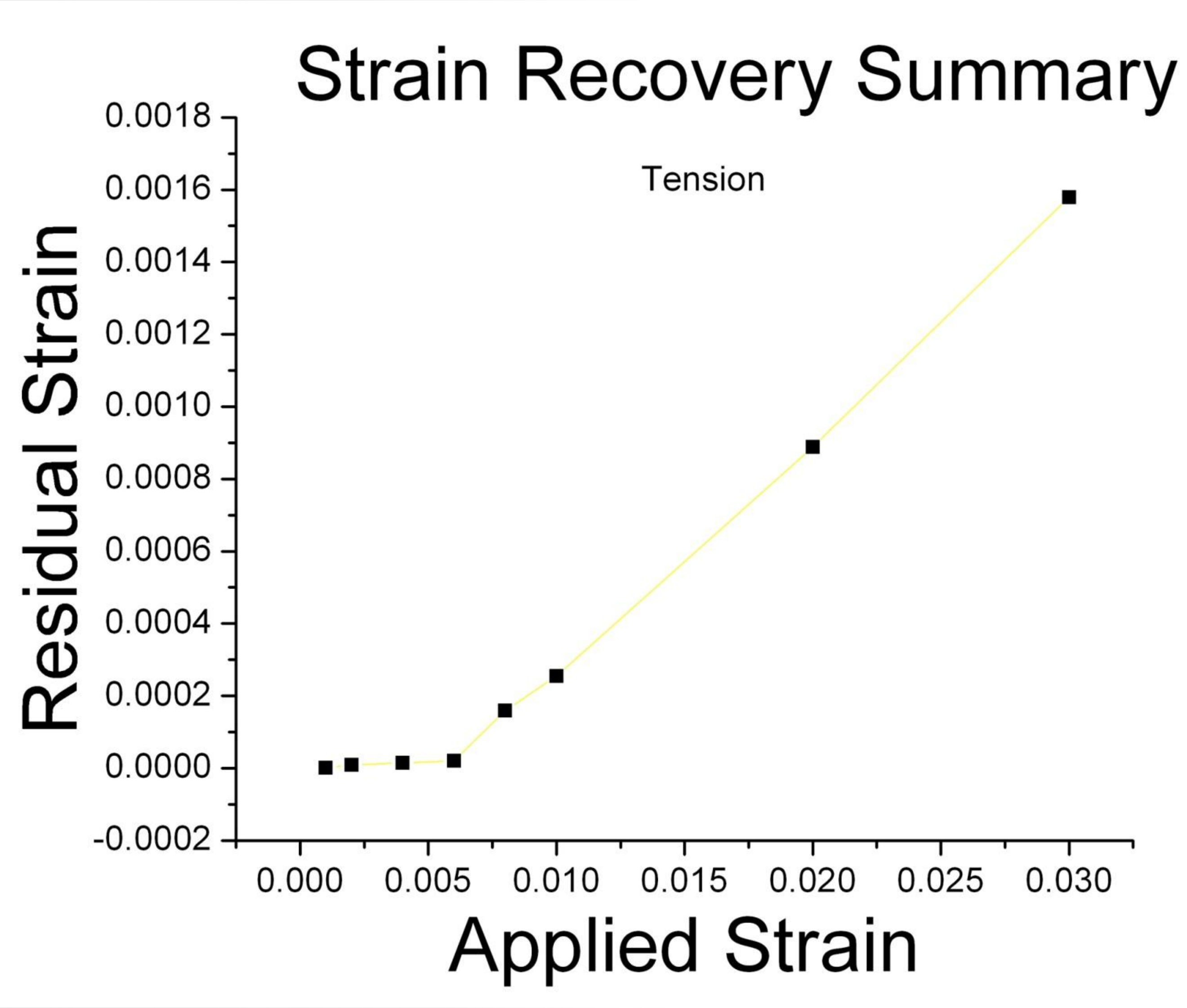
Plastic


Load-unload to 0.02
Stress
Strain
20
15
10
5
0
0.000
0.005
0.010
0.015
0.020
Loading
Unloading
Residual Strain Point
Viscoelastic Recovery

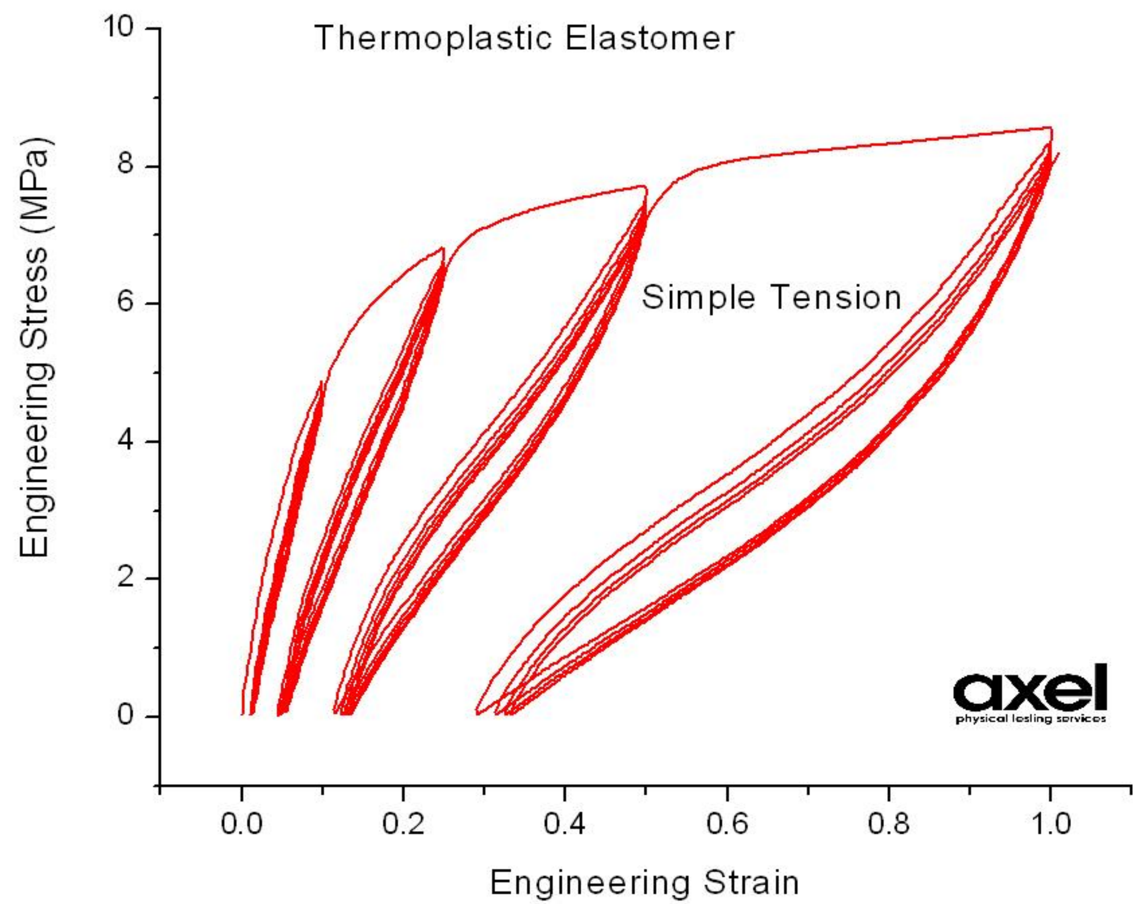
Plastic


Strain Recovery Test
compression: in-plane
load completely removed
strain still recovering
strain recovered
to within 1.1e-6
Engineering Strain
Engineering Stress (MPa)
Time (sec)
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
4
2
0
-2
-4
-6
-8
-10
0
20
40
60
80
100

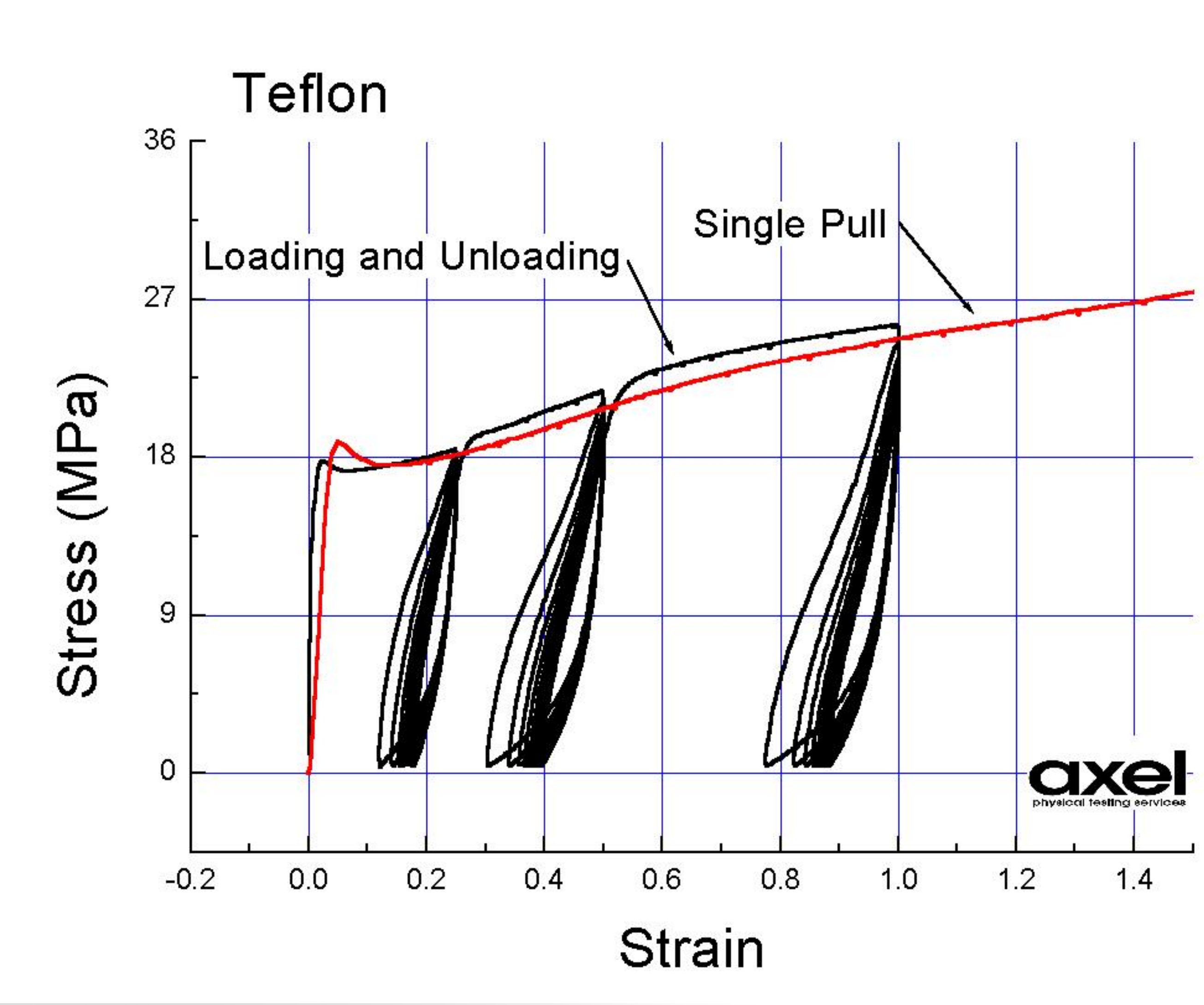
Plastic


Strain Recovery Summary
Tension
Residual Strain
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
-0.0002
0.000
0.005
0.010
0.015
0.020
0.025
0.030
Applied Strain

Thermoplastic Elastomers

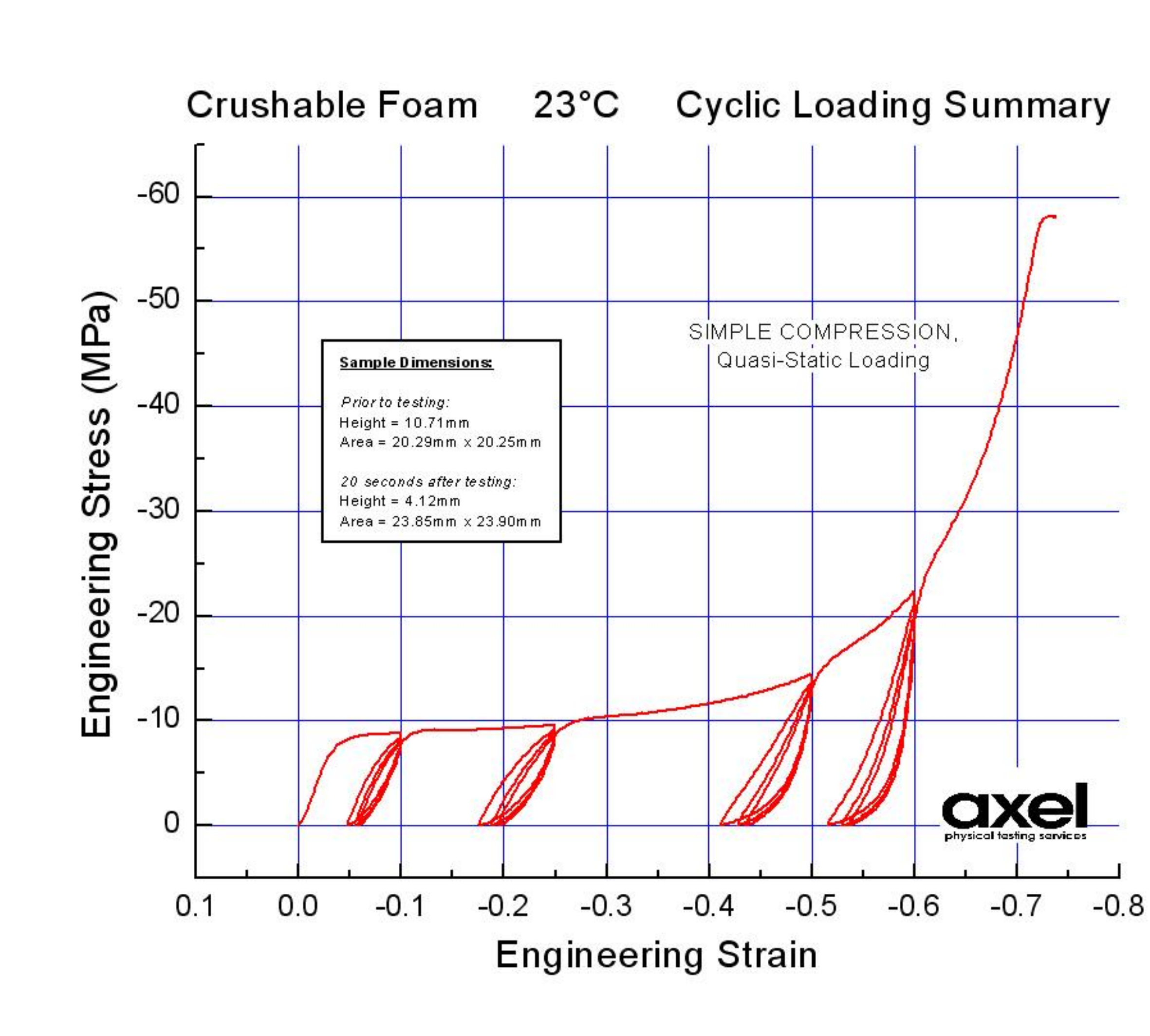


Teflon



Teflon
Single Pull
Loading and Unloading
36
27
18
9
0
Stress (MPa)
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Strain
axel
physical testing services

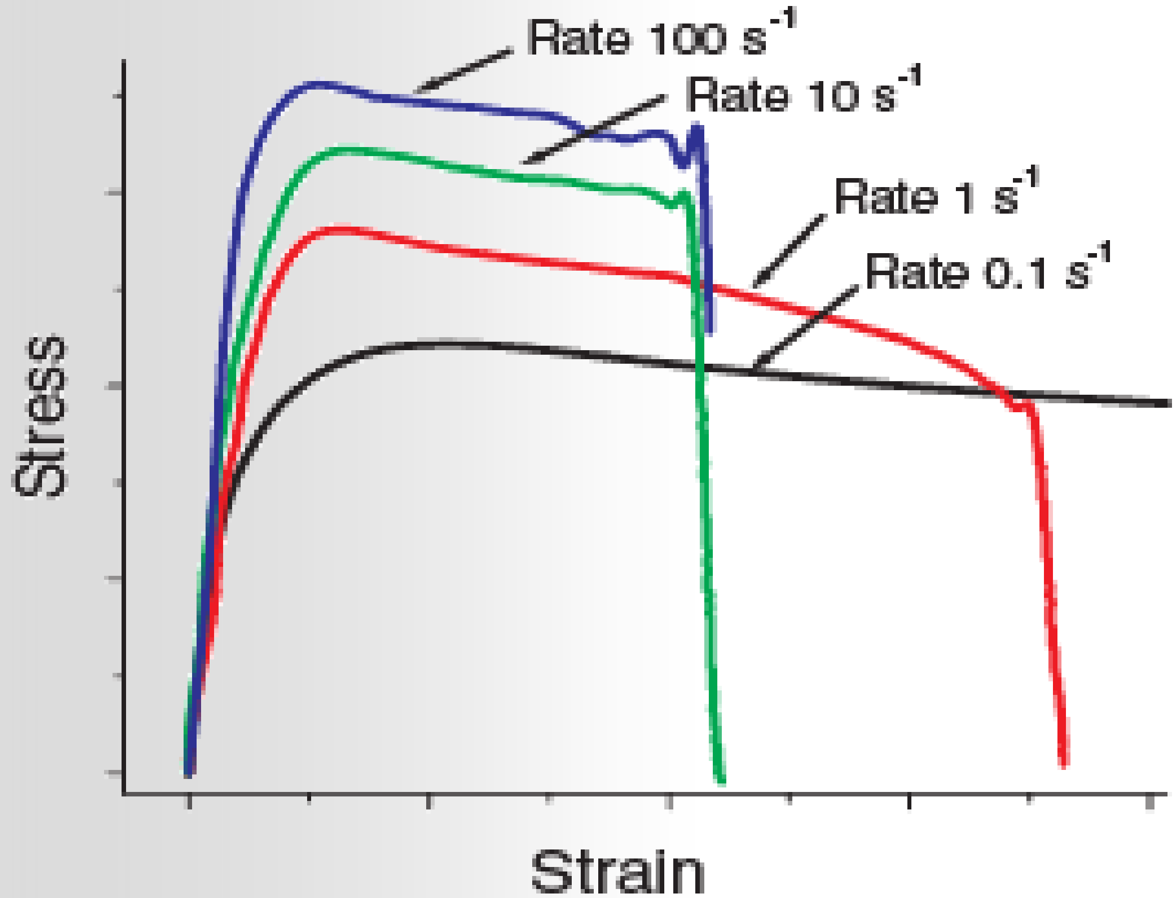
Crushable Foam



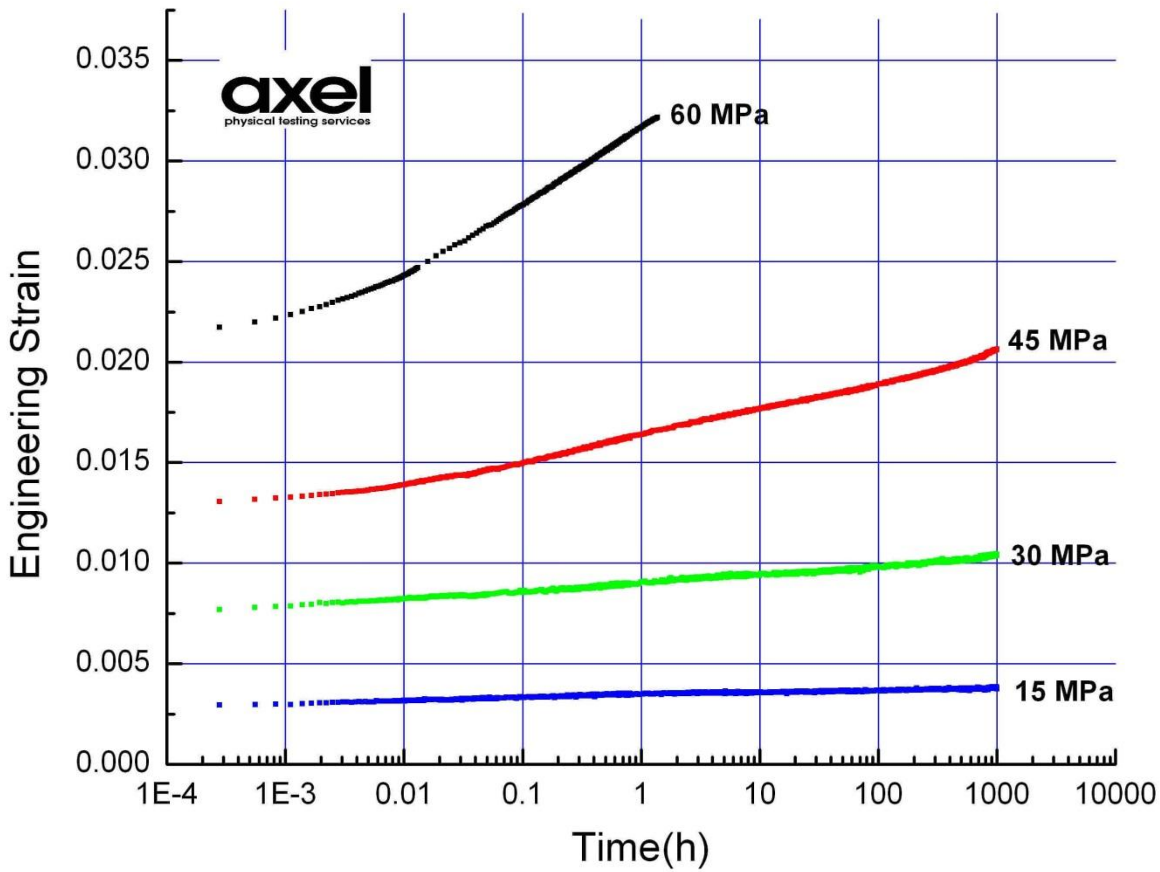
A General Strategy

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

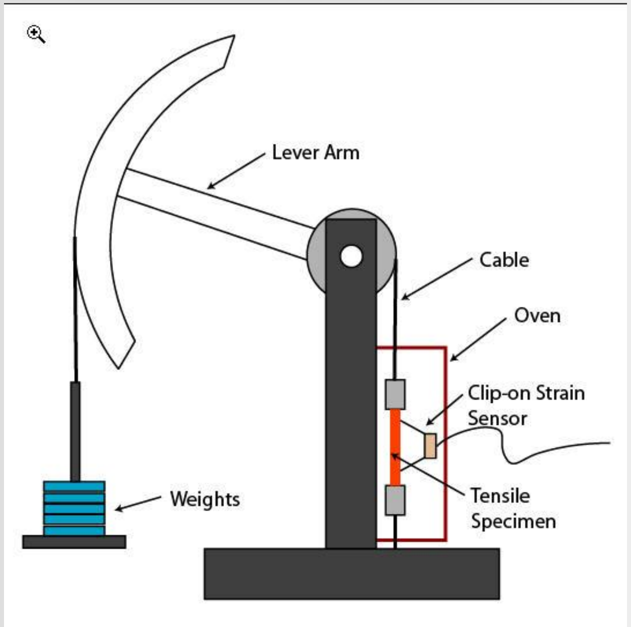
Plastic



Long Term Creep



Plastic



- Long Term Creep Experiments
  - Often Required for Metal Replacement Applications
  - Structural Applications May Require a Range of Stress Levels and Temperatures

Time

ANSYS

Summary of rate-dependent plasticity models in ANSYS:

	CREEP	RATE [1]	ANAND[4]
Behavior	Strain rate- or time-dependent		
	Isotropic or anisotropic creep (see HILL below)	Isotropic or anisotropic viscoplasticity (see HILL below)	Isotropic
Yield Surface	No explicitly defined yield surface	Includes yield surface	No explicitly defined yield surface. However, includes evolution equation.
Combination with rate-independent plasticity	Possible to combine with plasticity, which is decoupled with creep strains	Rate-independent plasticity model is required. Inelastic strains are coupled	No additional rate-independent plasticity allowed. Inelastic strains are coupled
	BISO, MISO, NLISO, BKIN, HILL	BISO, MISO, NLISO, HILL	None
Strain Rates	Suitable for small strain rates	Suitable for large strain rates	Suitable for small strain rates
Time scale	Long periods, creep and plasticity have different time scales	Short periods, usually for impact-type problems	Short/medium periods
Temperature Effects	Temperature effects included as part of equation (or material constants can be temperature-dependent) [2]	Can input temperature-dependent material constants, but equations do not consider temp effects directly	Anand's equation considers temperature effects directly. No need to input temperature-dependent material constants
Supported Element Types [3]	Implicit - core and 18x Explicit - core and misc	Core and 18x	VISCO106-108

[1] "RATE" includes Peirce and Perzyna models.

[2] Temperature-dependent material constants available for implicit creep

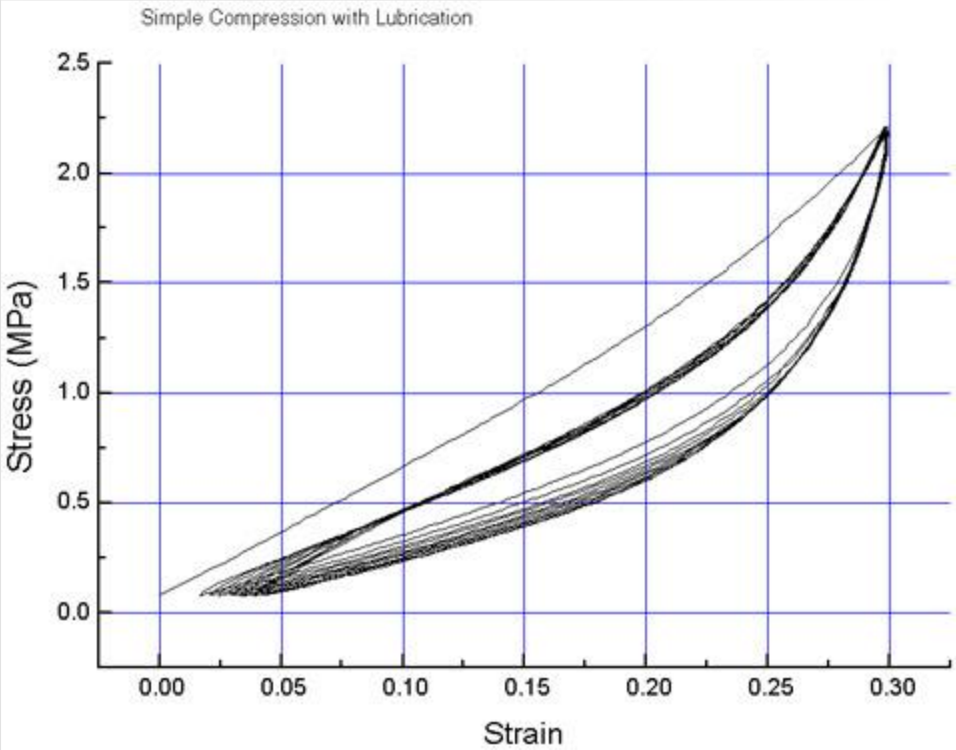
[3] Core Elements = PLANE42, SOLID45, PLANE82, SOLID92, SOLID95

18x Elements = LINK180, SHELL181, PLANE182-183, SOLID185-187, BEAM188-189, SOLSH190, SHELL208-209

[4] Anand's Model is discussed in Appendix A

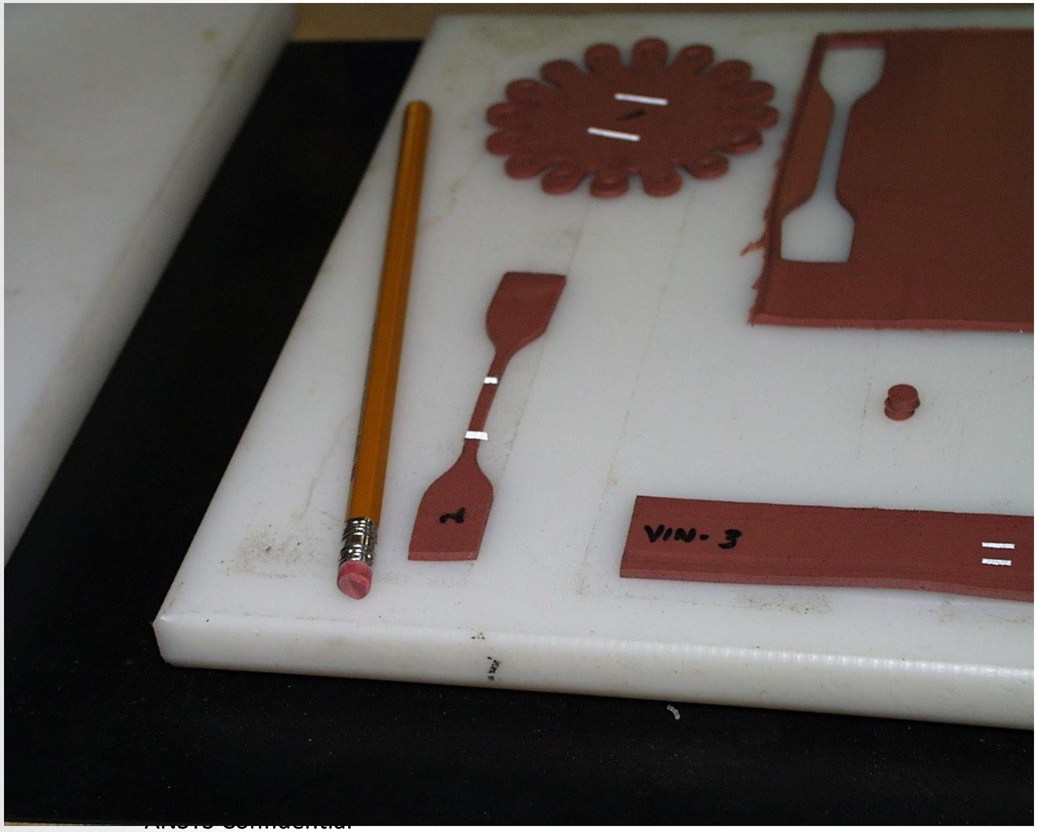
Compression

Compression

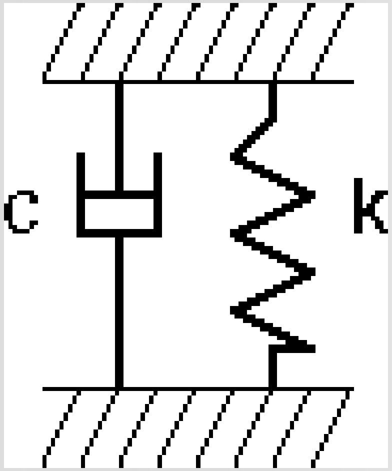


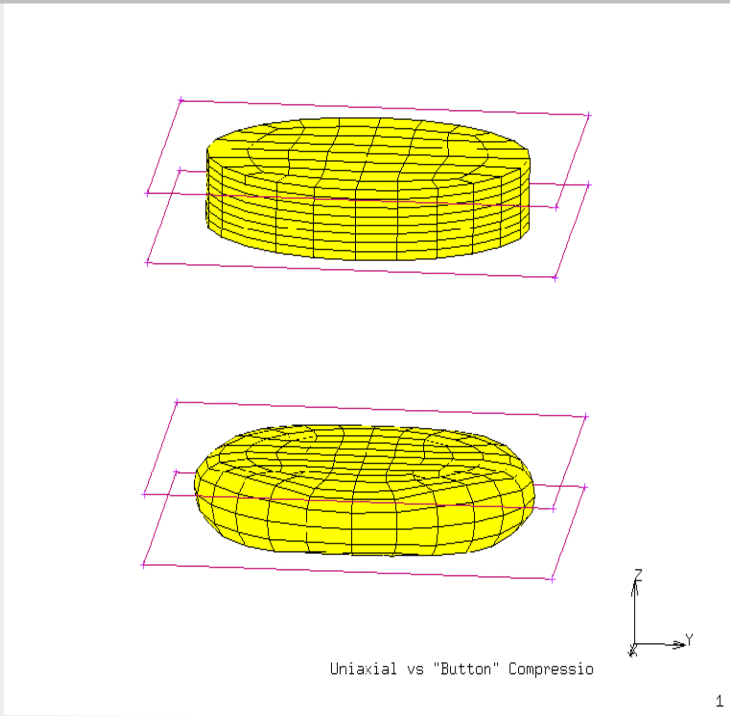
Rubber

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

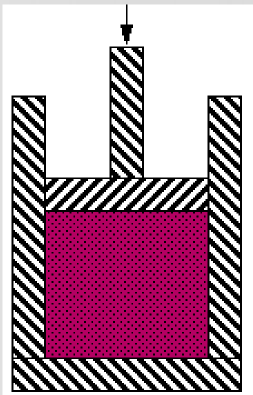


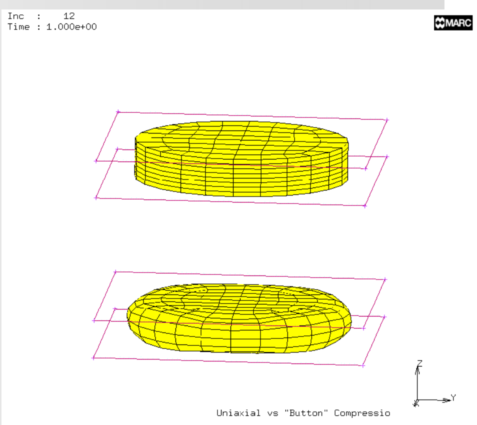
A Spring and a Dashpot?

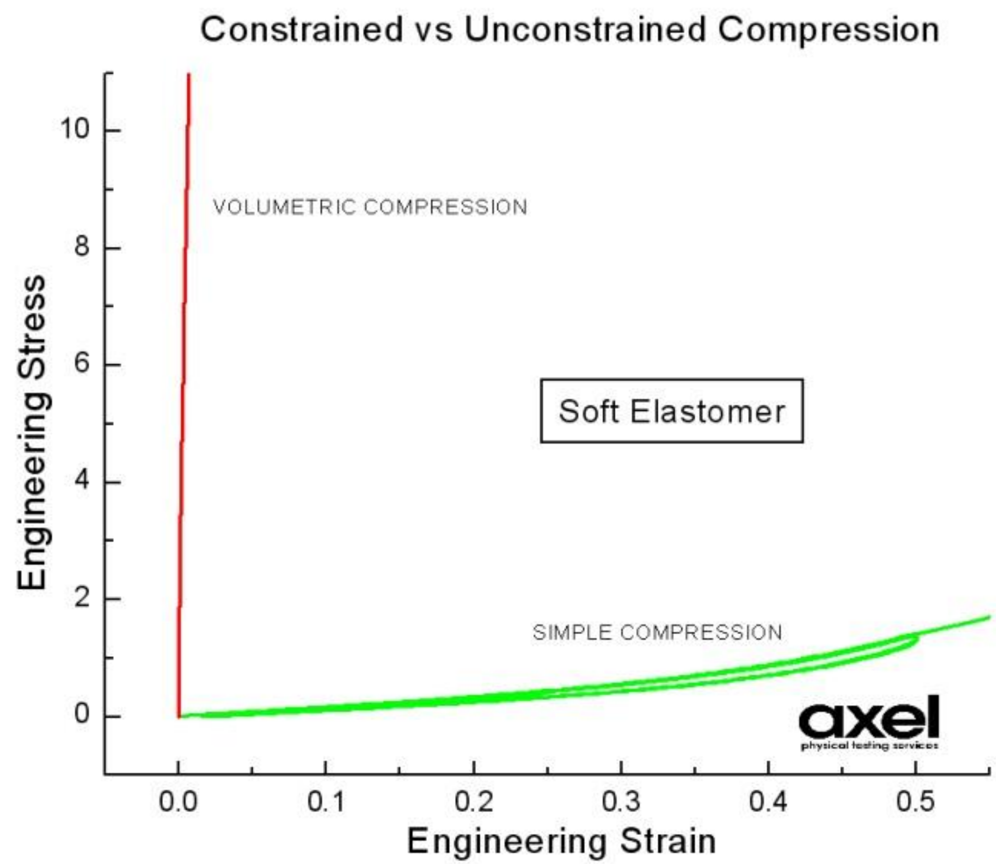




What does Incompressible Mean?





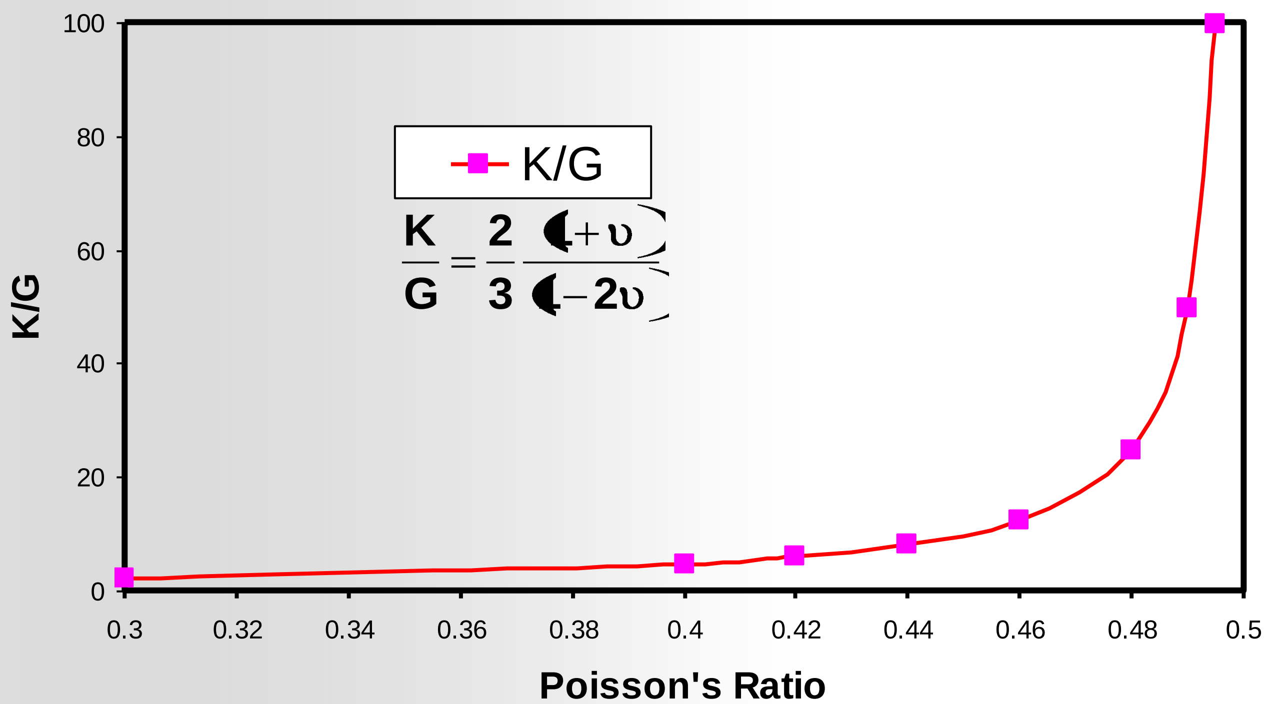


Volumetric Compression

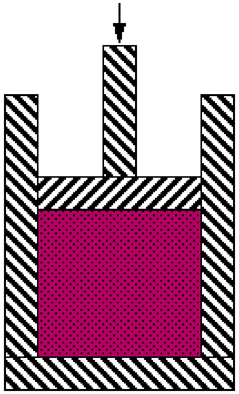
Poisson's ratio approaching 0.5 means infinite bulk modulus, K

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.

K/G Relationship to Poisson's Ratio

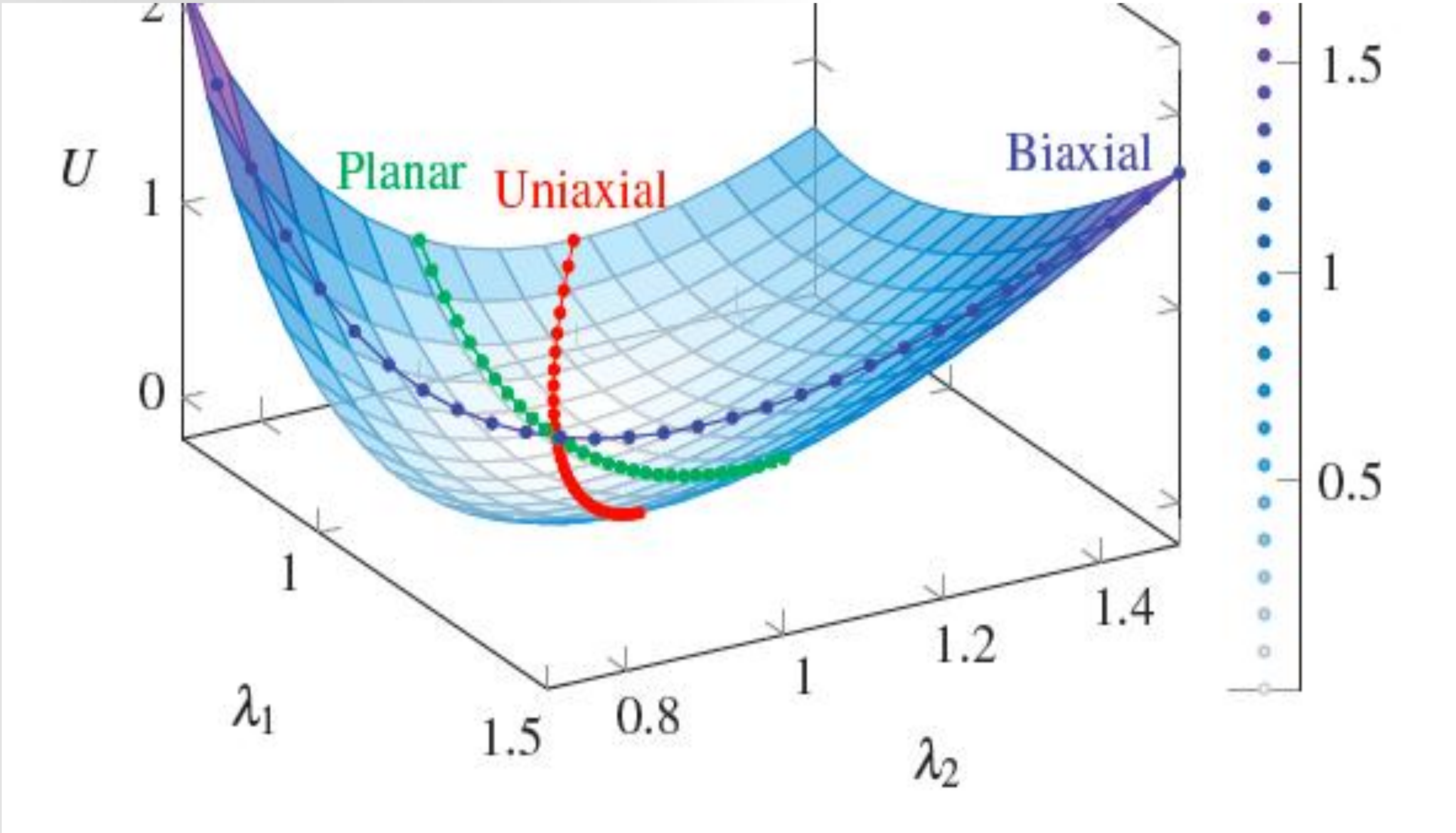


Incompressibility



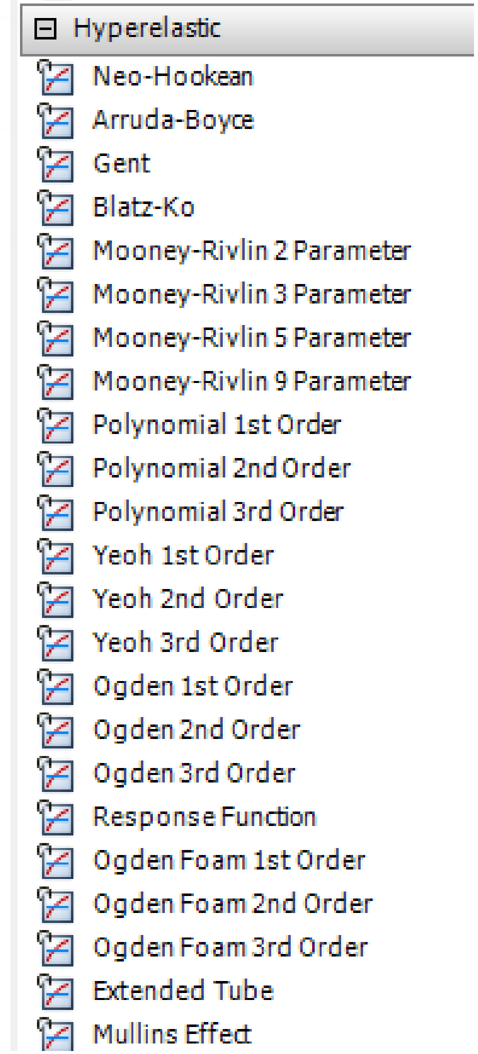
Not a spring and dashpot

Hyperelastic Models Define a Surface



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.



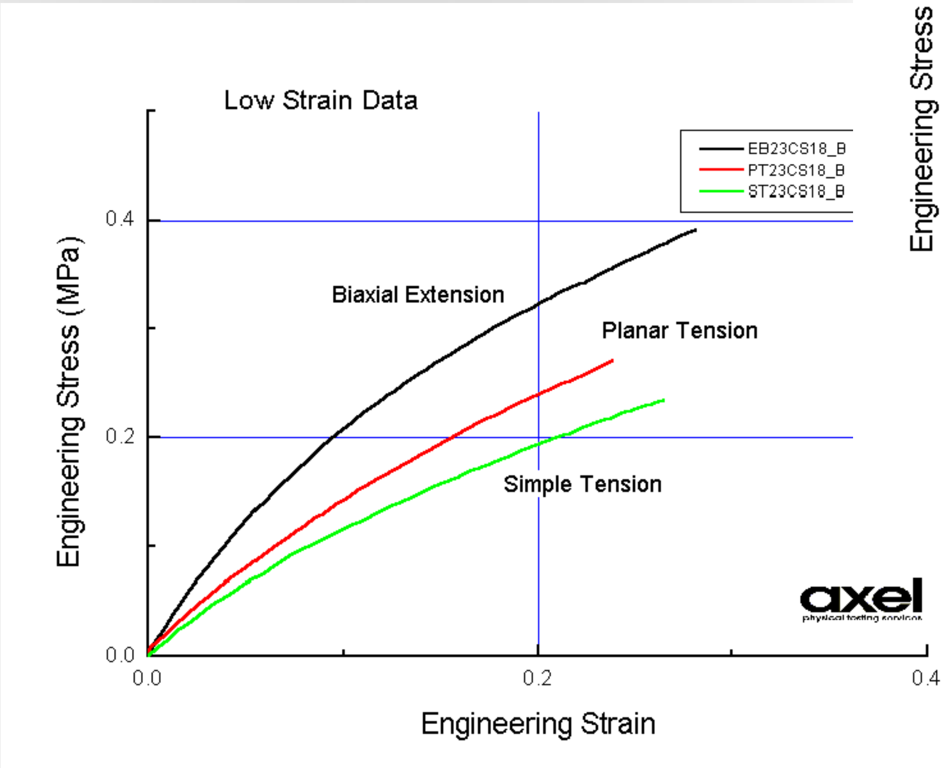
Available Hyperelastic models:

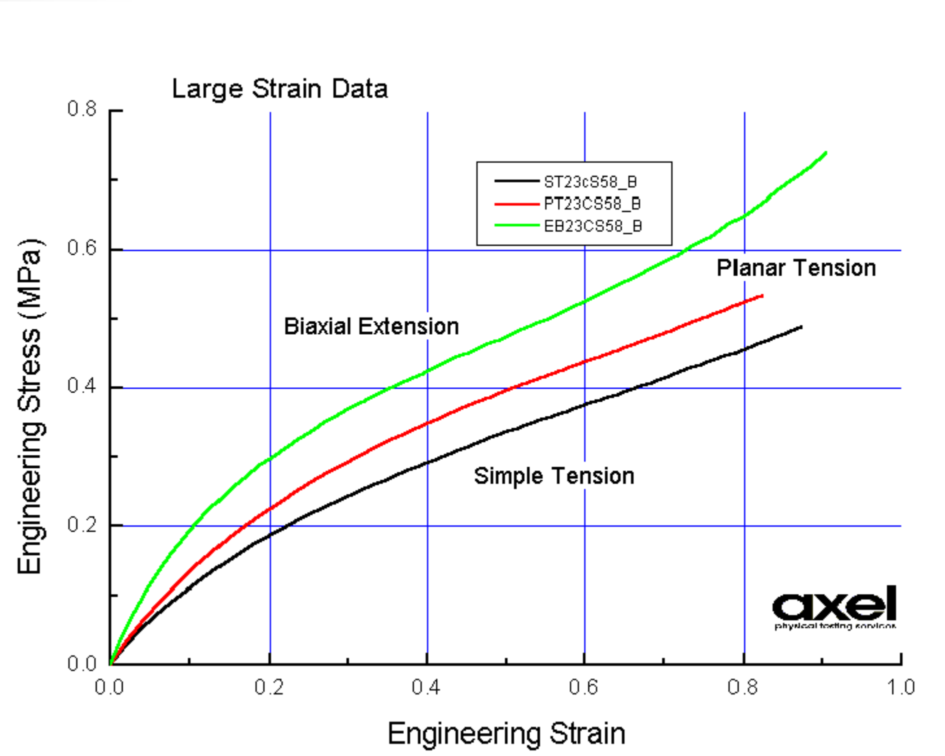
- Arruda-Boyce Hyperelastic Material
- Blatz-Ko Foam Hyperelastic Material
- Extended Tube Material
- Gent Hyperelastic Material
- Mooney-Rivlin Hyperelastic Material
- Neo-Hookean Hyperelastic Material
- Ogden Compressible Foam Hyperelastic Material
- Ogden Hyperelastic Material
- Polynomial Form Hyperelastic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

Specialized Hyperelastic models:

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

Rubber

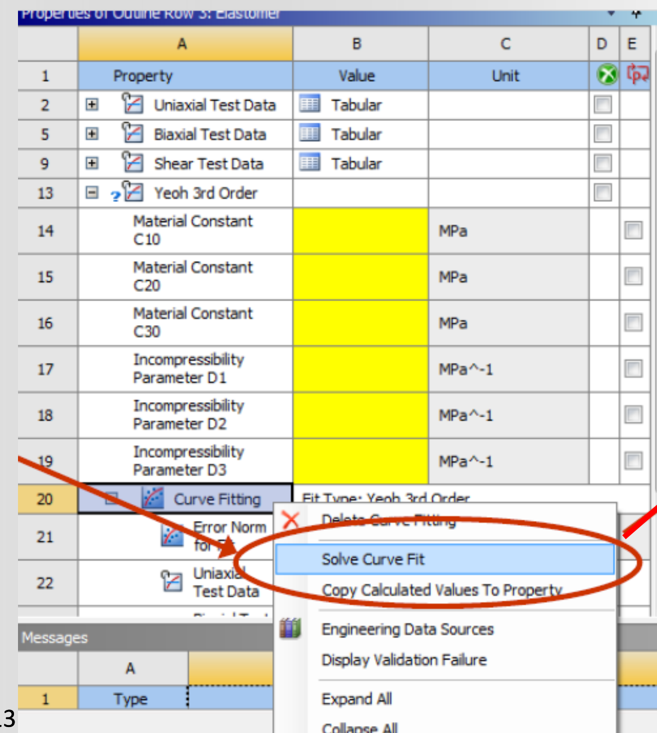

Low Strain Data
EB23CS18_B
PT23CS18_B
ST23CS18_B
Biaxial Extension
Planar Tension
Simple Tension
Engineering Stress (MPa)
Engineering Strain
0.0
0.2
0.4
axel

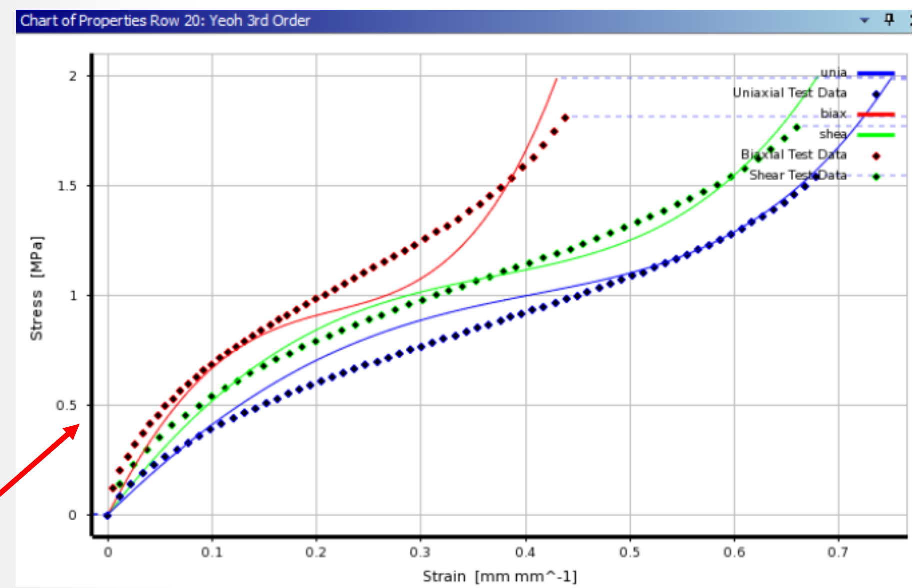

Large Strain Data
ST23cS58_B
PT23CS58_B
EB23CS58_B
Biaxial Extension
Planar Tension
Simple Tension
Engineering Stress (MPa)
Engineering Strain
0.0
0.2
0.4
0.6
0.8
1.0
axel

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.

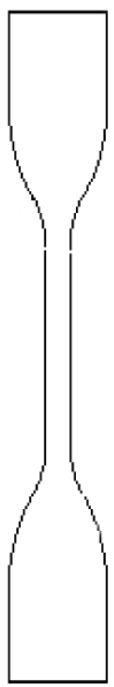


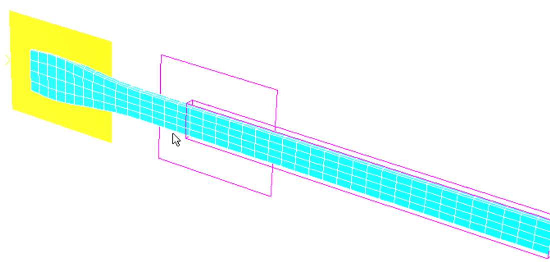


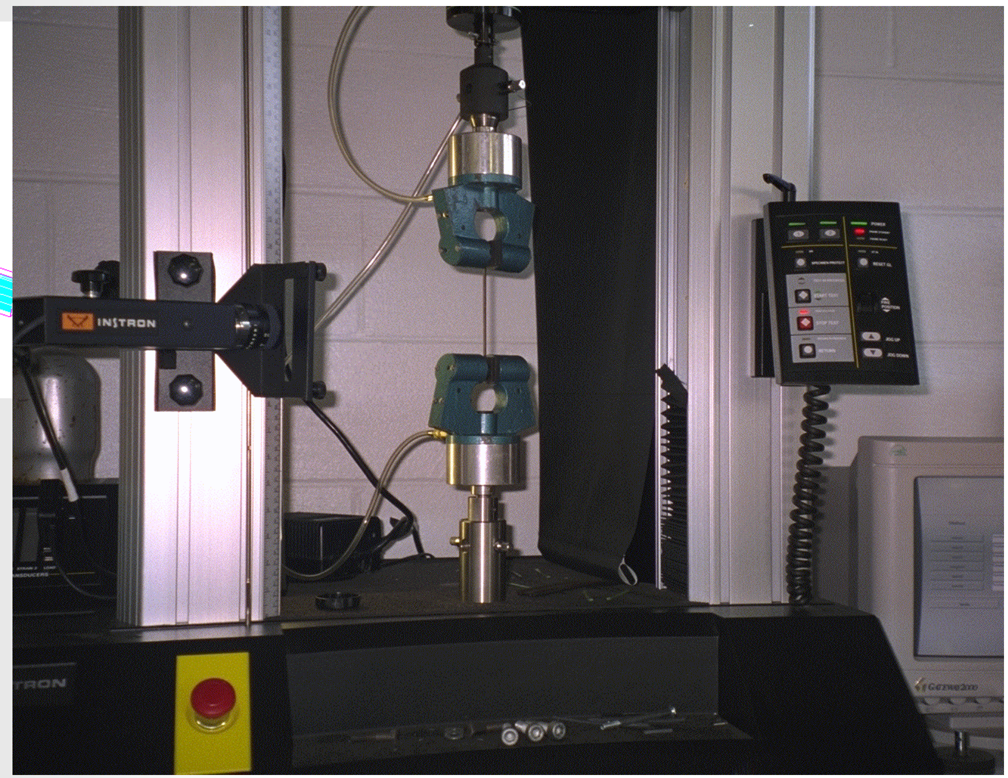
Simple Tension

- Uniaxial loading
- Free of lateral constraint

Gage Section:
Length:Width
>10:1

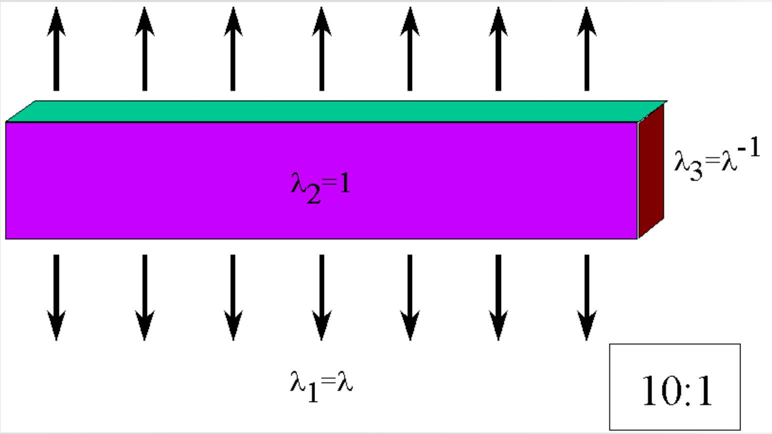






Planar Tension

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



Equal Biaxial Extension

Why?

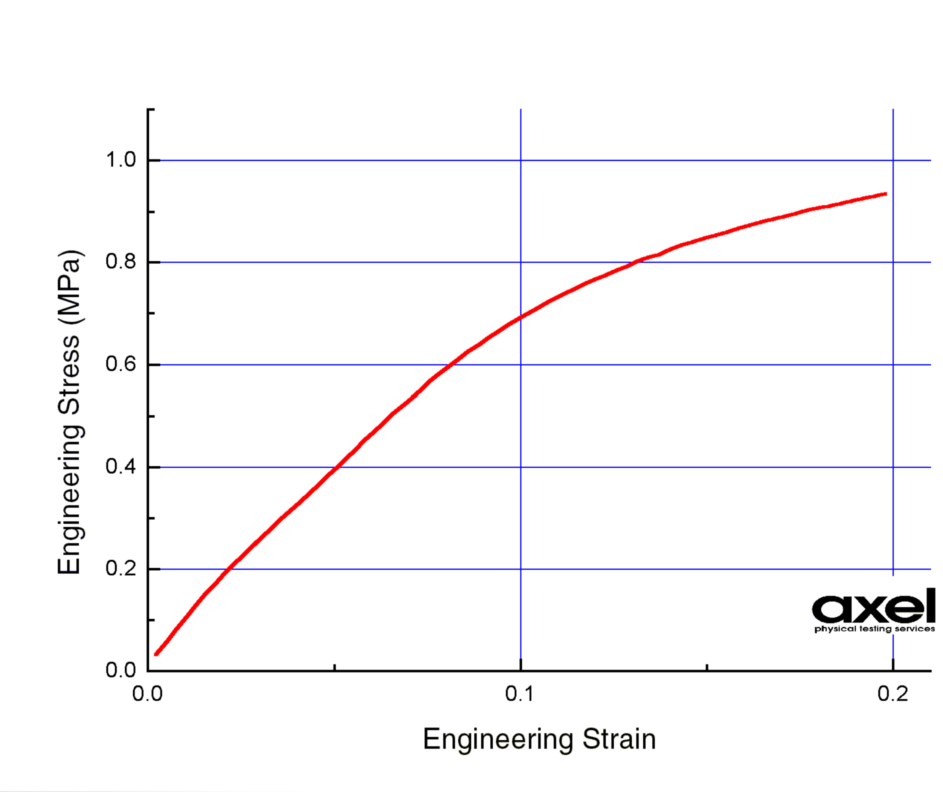
1. Same Strain State as Compression
2. Can Not Do Pure Compression
3. Can Do Pure Biaxial

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



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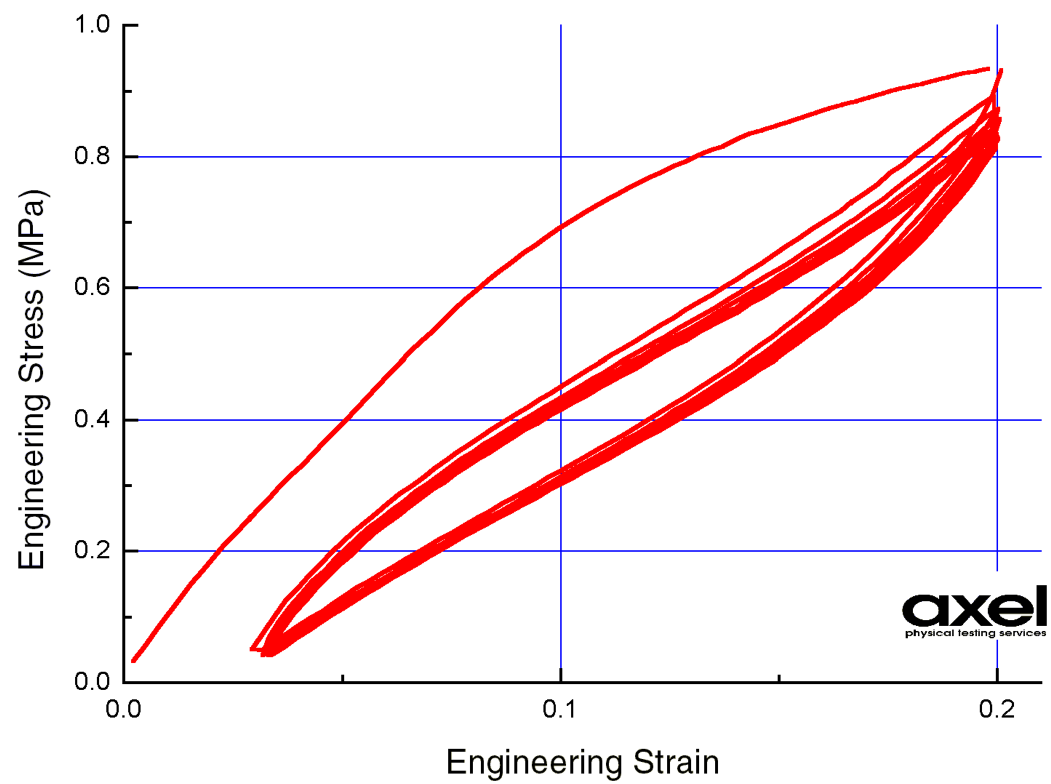

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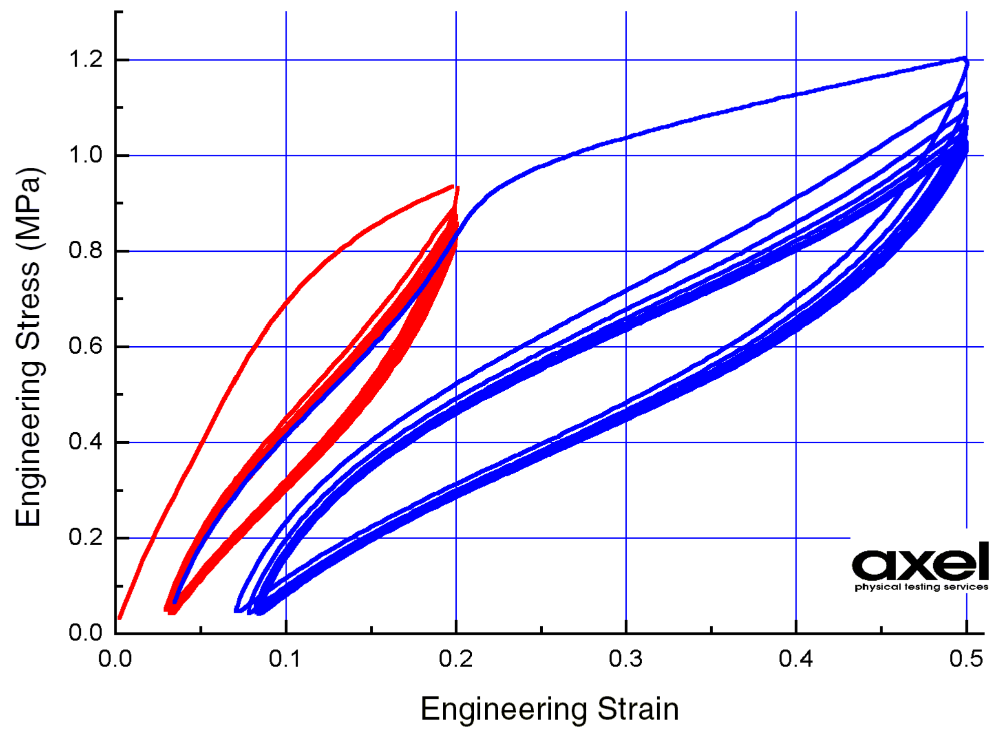
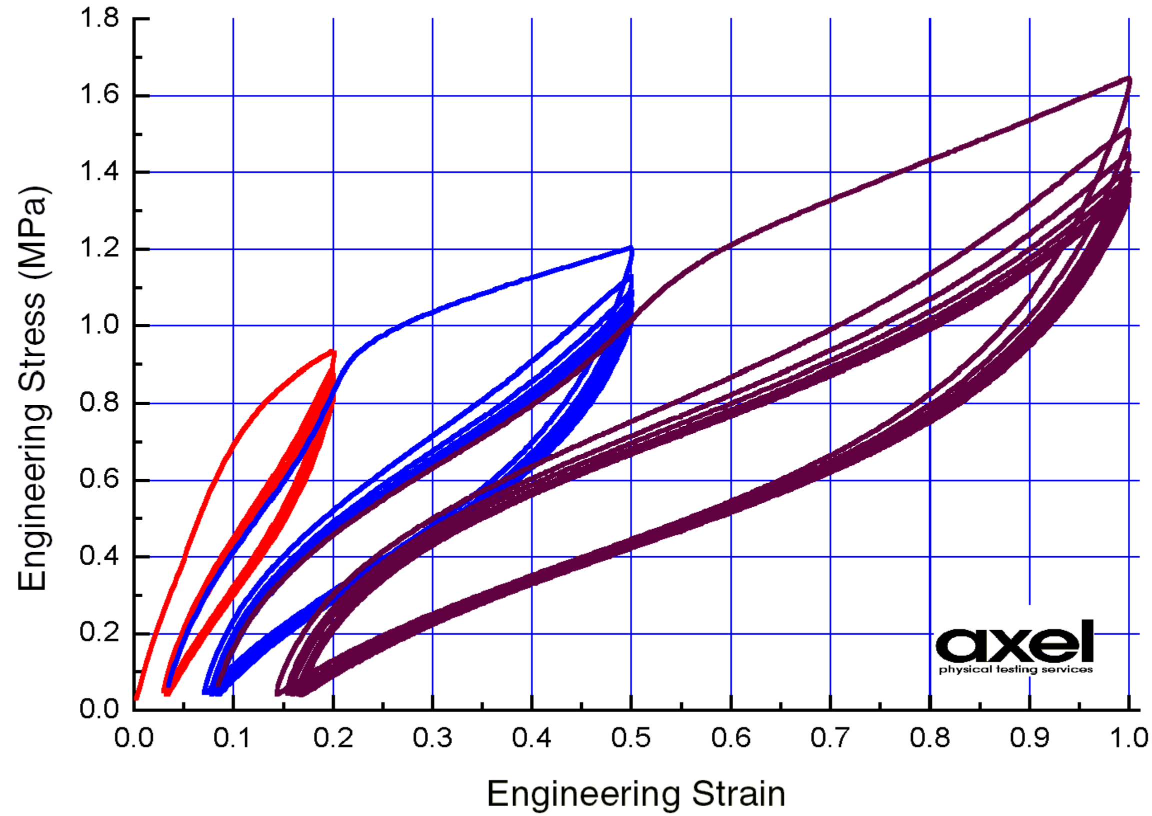


Loading Conditions

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 BB Model



…Mullins Effect in Elastomers

The modified Ogden-Roxburgh damage function available in ANSYS has the following functional form of the damage variable

$$\eta = 1 - \frac{1}{r} erf\left[\frac{W_m - W_O}{m + \beta L_m}\right]$$

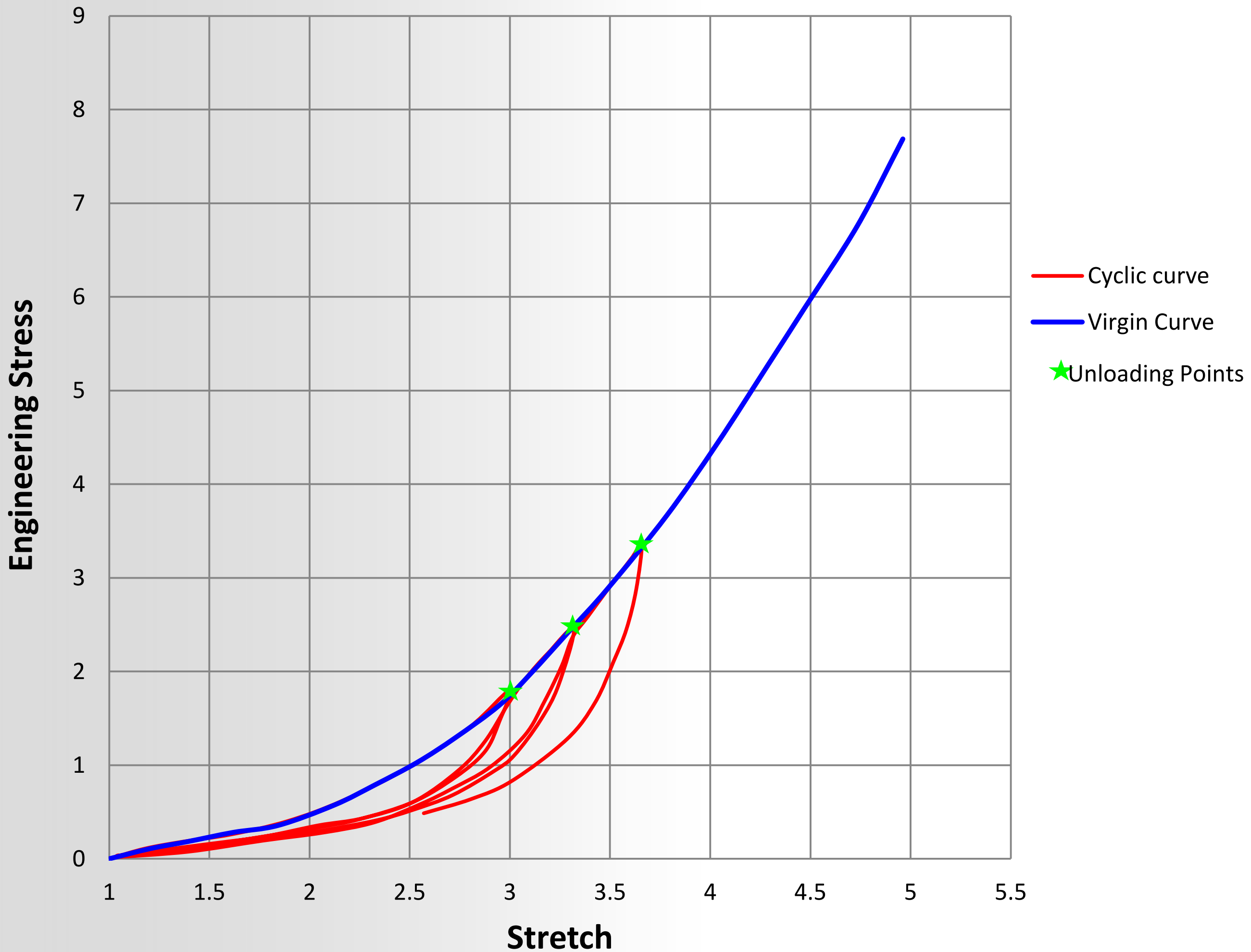
Where: **r, m and β are user defined material damage parameters**

$W_m = \max\left[W_O(t)\right]$ **is the maximum virgin potential over the time interval** $t \in \left[0, t_0\right]$ **or the potential from which the unloading starts.**

The parameters used in the Ogden-Roxburgh damage are directly available in WB-Mechanical

Note: ANSYS currently do not offer curve fitting for this material model.

...Mullins Effect in Elastomers



A General Strategy

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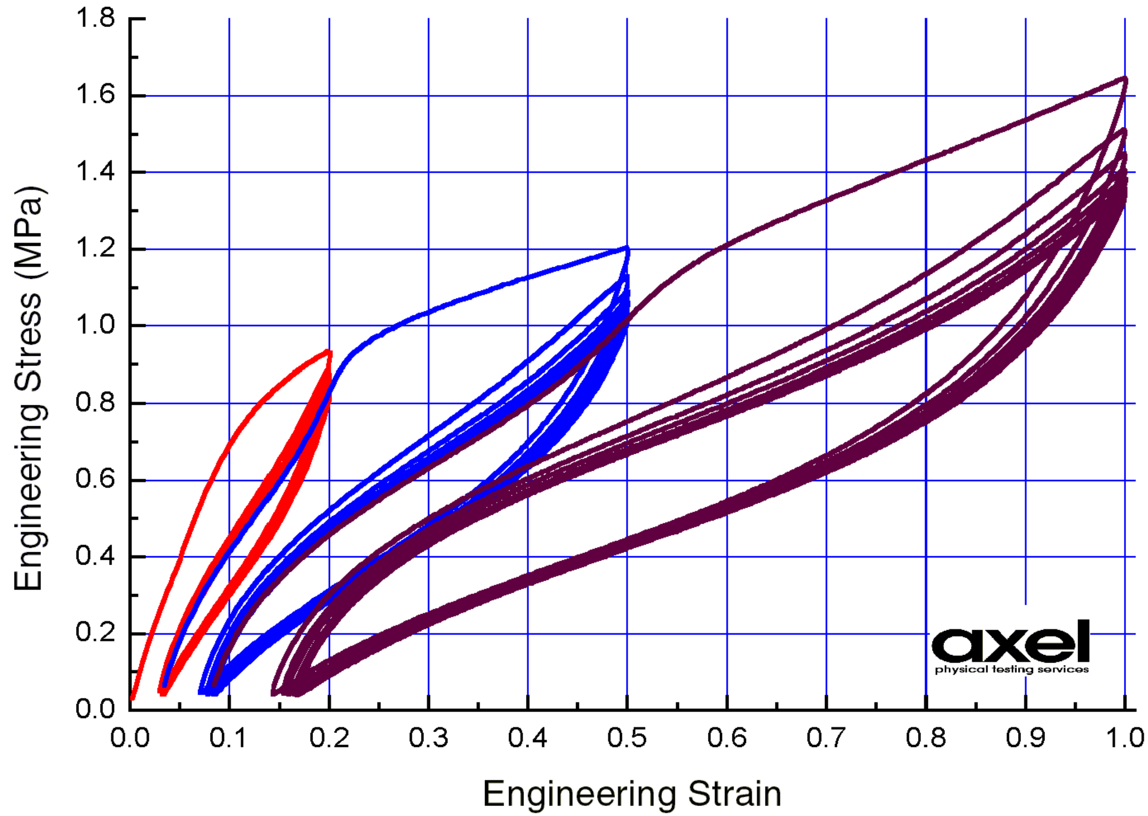


Bergstrom-Boyce Model

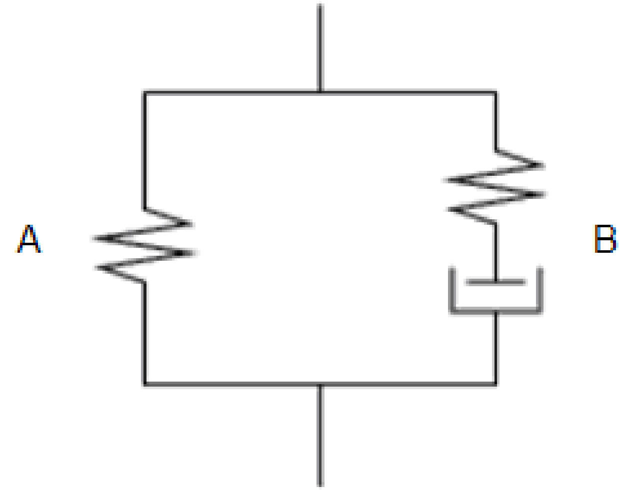
The Bergstrom-Boyce material model is a phenomenological-based, highly nonlinear material model used to model typical elastomers and biological materials.

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

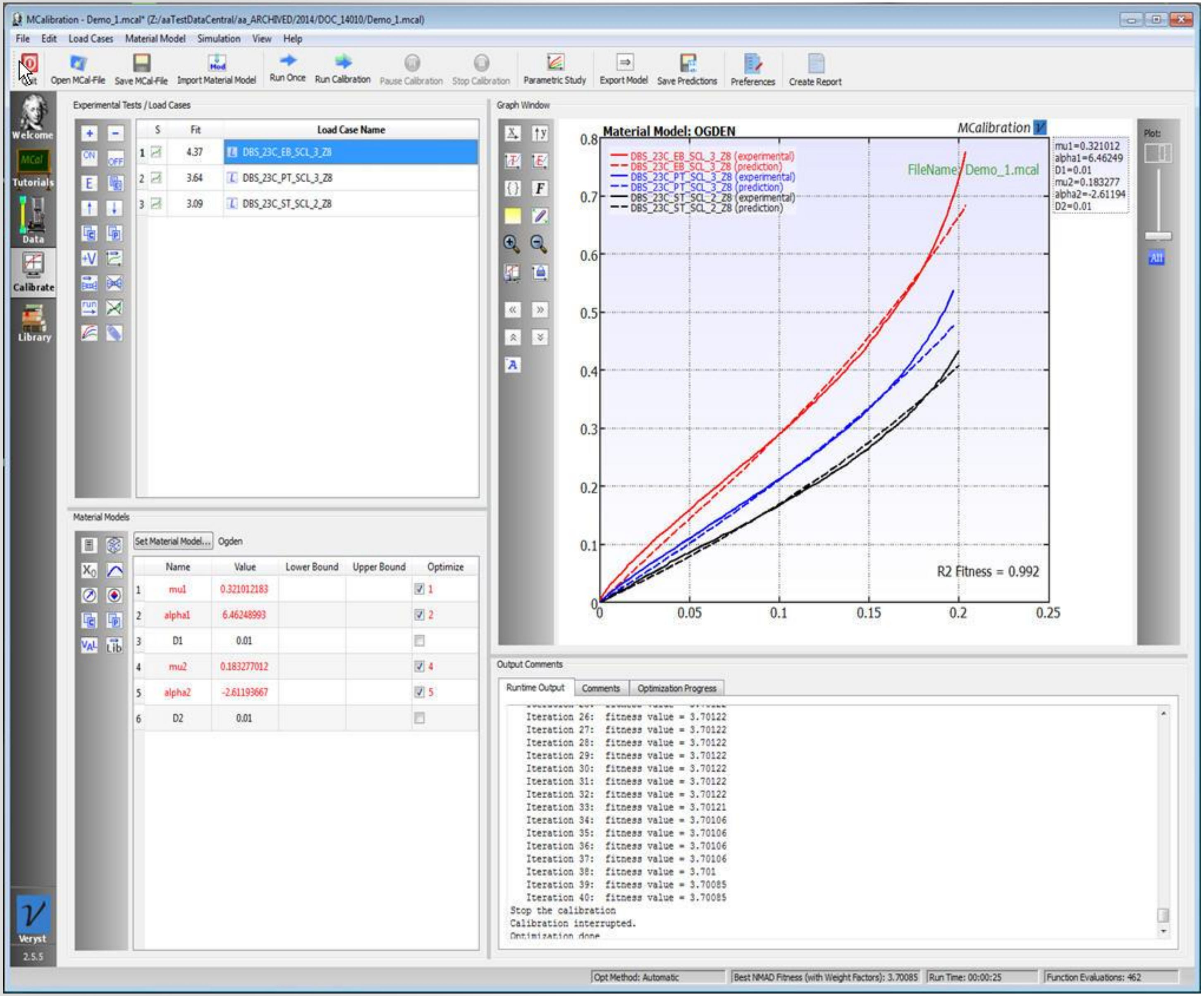
The stress state in A can be found in the tensor form of the deformation gradient tensor ($F = dx_i / dX_j$) and material parameters, as follows:

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

where

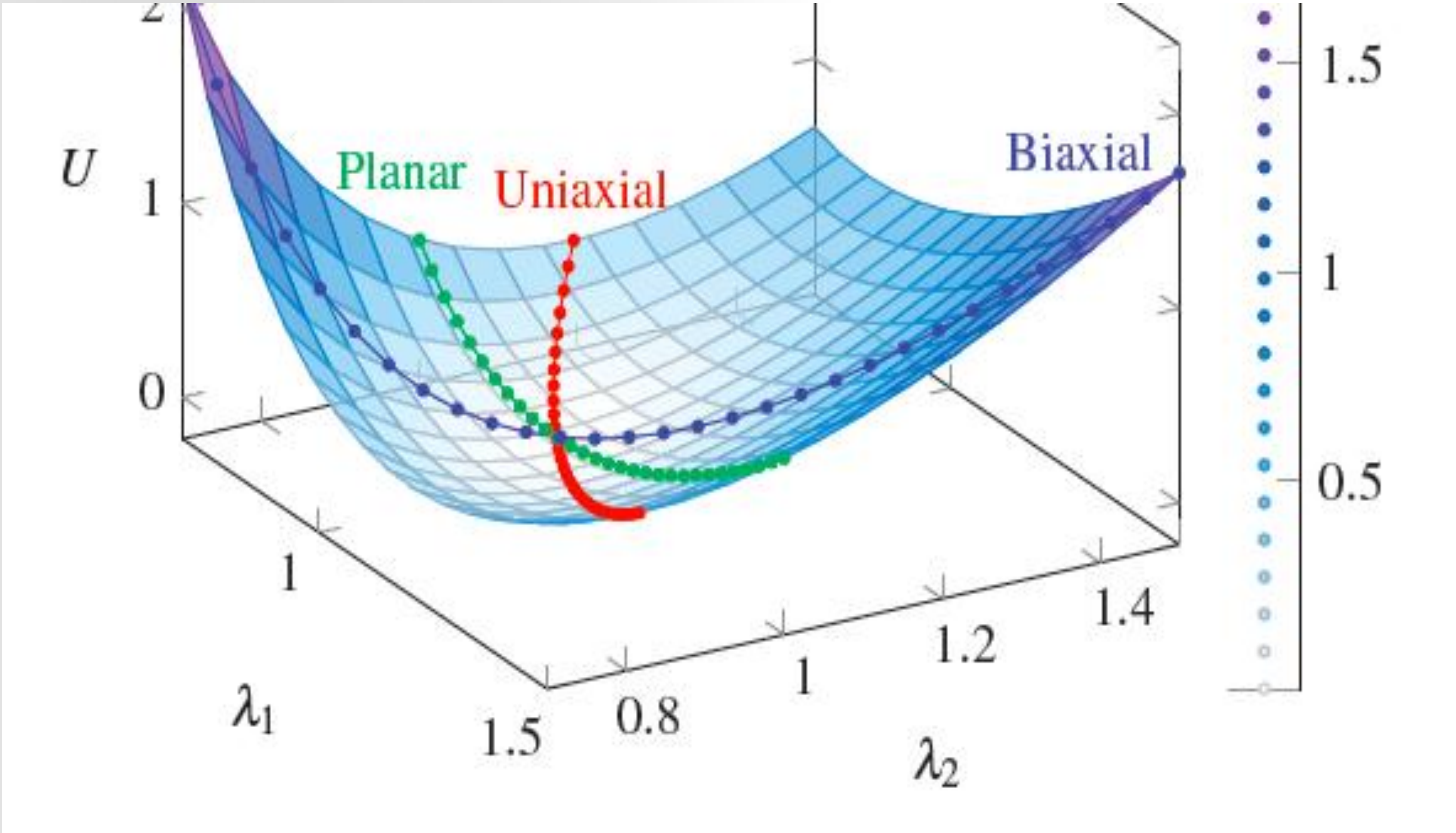
σ_A	=	stress state in A
μ_A	=	initial shear modulus of A
λ_A^{lock}	=	limiting chain stretch of A
K	=	bulk modulus
J_A	=	det[F]
$\tilde{B}_A^{*}$	=	$J^{-2/3}\tilde{F}\tilde{F}^T$
$\bar{\lambda}_A^{*}$	=	$\sqrt{tr[\tilde{B}^{*}]/3}$

Commercial Fitting Tool, MCalibration



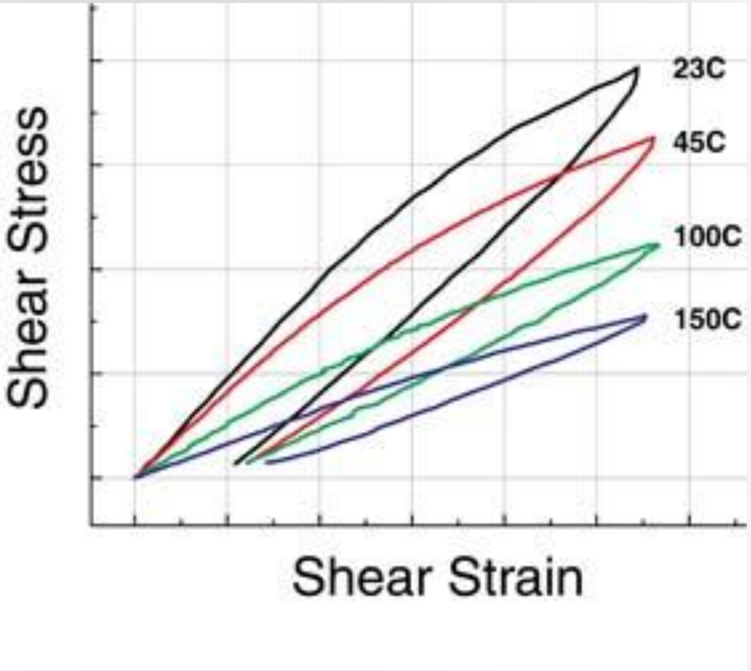
  June 4, 2014

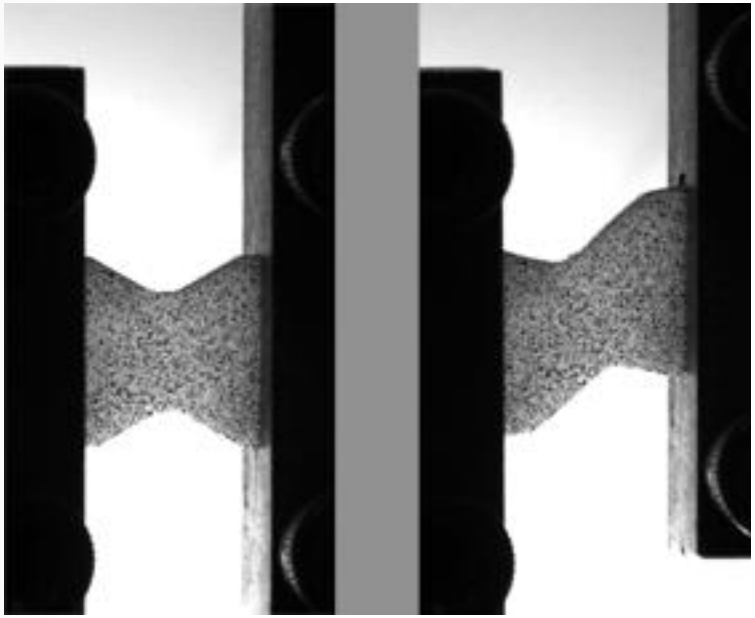
Hyperelastic Models Define a Surface



Simple Shear

1. **Additional Strain State**
2. **Using DIC Strain Measuring**





Model Verification

Attributes of a good model verification experiment

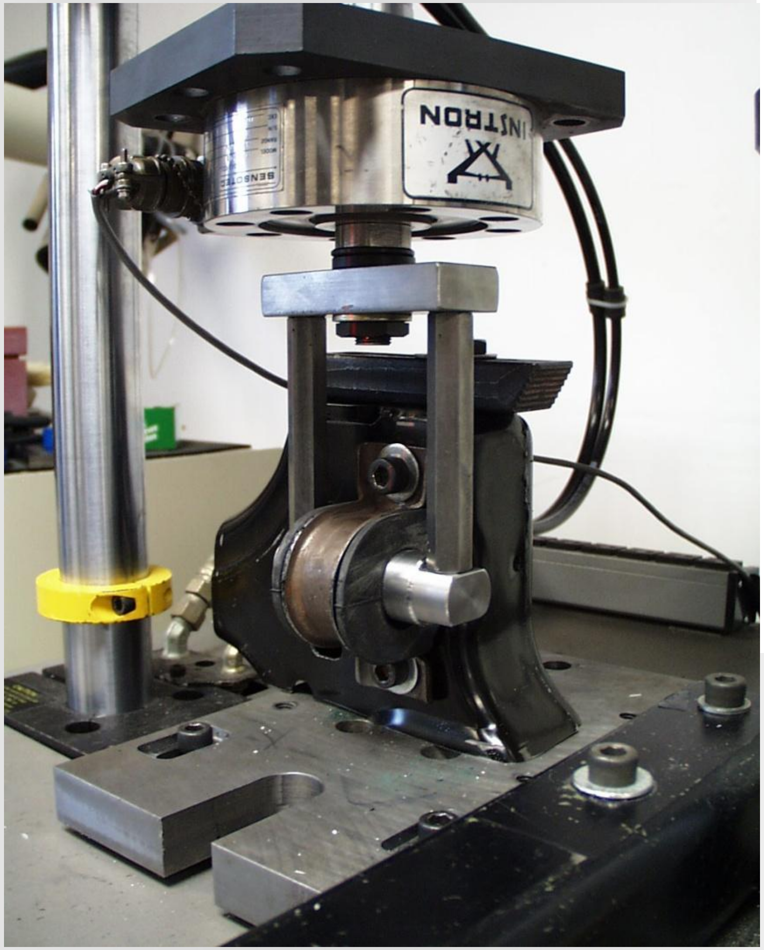
The geometry is realistic.

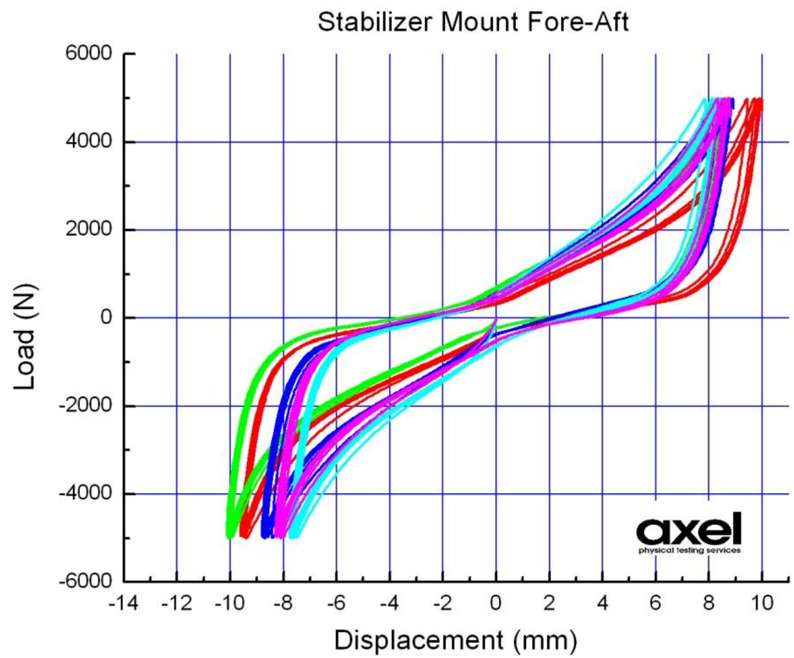
All relevant constraints are measurable.

The analytical model is well understood

Confinement can be Significant

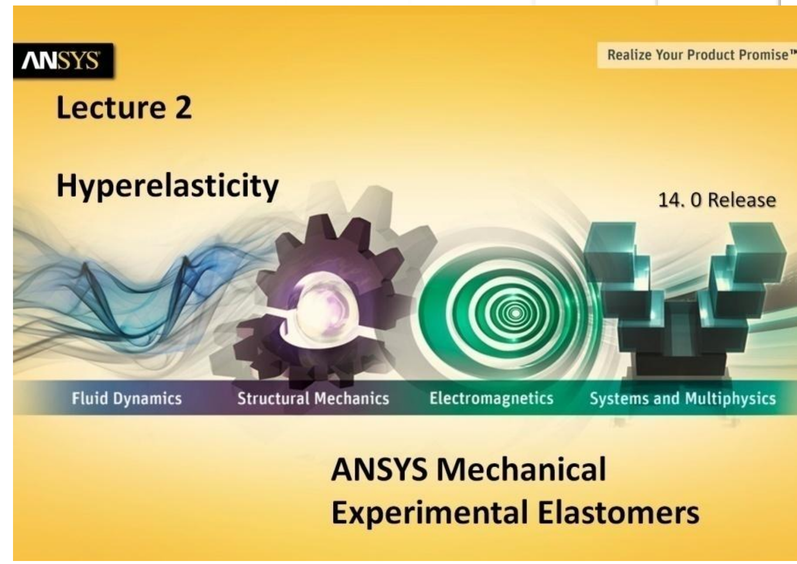
Model Verification

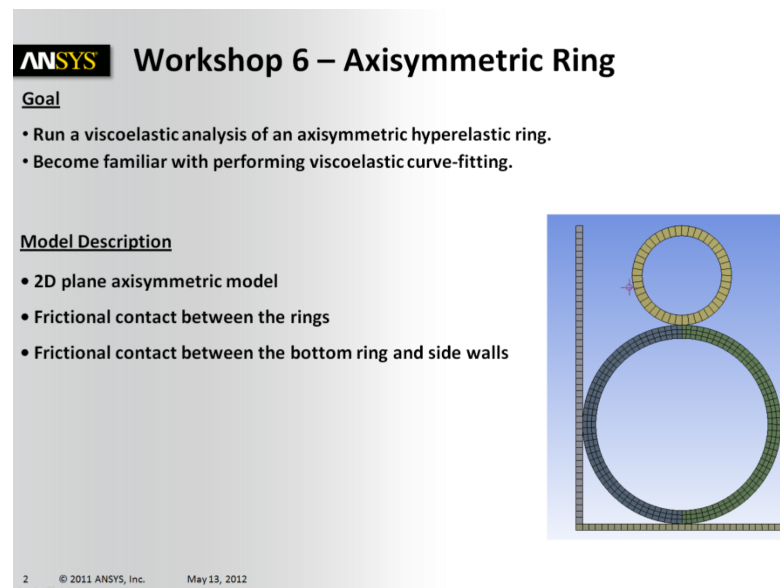




ANSYS Experimental Elastomers Training at Axel Products

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.





ANSYS Experimental Structural Plastic 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 structural plastics such as Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC) etc.