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Measuring Material Properties to Build Material Models in FEA

Kurt Miller

www.axelproducts.com

Who is Axel Products, Inc.

Physical Testing Services for Engineering and Analysis

The testing images and data sets were created in the Axel Products laboratory. The testing methods discussed are available as a service to analysts around the world.

For additional information, visit us at:

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Directions and Map

About Axel

e-mail us

Training

ABAQUS Testing and Analysis of Elastomers with ABAQUS October 3-5, 2000.

Technical Information

1. "Compression or Biaxial Extension?" (PDF: 304 KB / 3 pages).

2. "Measuring the Dynamic Properties of Elastomers for Analysis": (PDF: 834 KB / 7 pages).

3. "Testing Elastomers for Hyperelastic Material Models in Finite Element Analysis": (PDF: 775 KB / 8 pages).

more...

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Hyperelastic Properties of Elastomers

Experiments:	*Data for:*
Simple Tension	Ogden
Pure Shear	Mooney-Rivlin
Equal Biaxial	Arruda-Boyce
Compression & Volumetric	Damage Models
	Viscoelastic Decay

Elastic-Plastic Properties of Plastics

Experiments:	*Data for:*
Modulus	
Poisson's Ratio	

A Strategy for Material Model Development

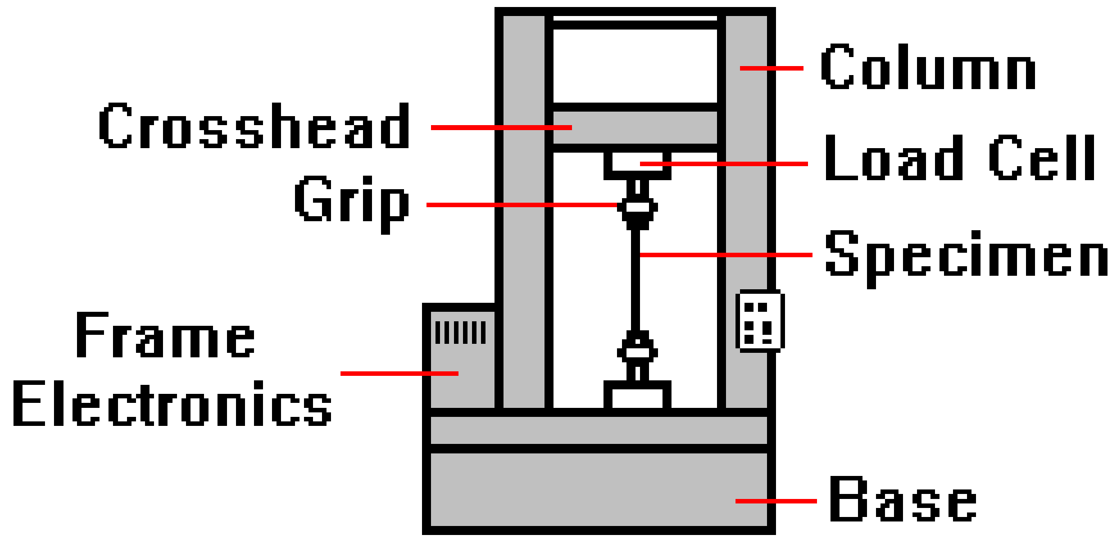
- Understand the Loading Conditions of the Part
- Understand the General Behavior of the Materials Involved
- Select the Material Behaviors Significant to the Simulation Effort
- Use Existing or Develop Material Models to Describe the Behavior
- Verify the Performance of the Material Model

Understanding the General Behavior of the Materials Involved

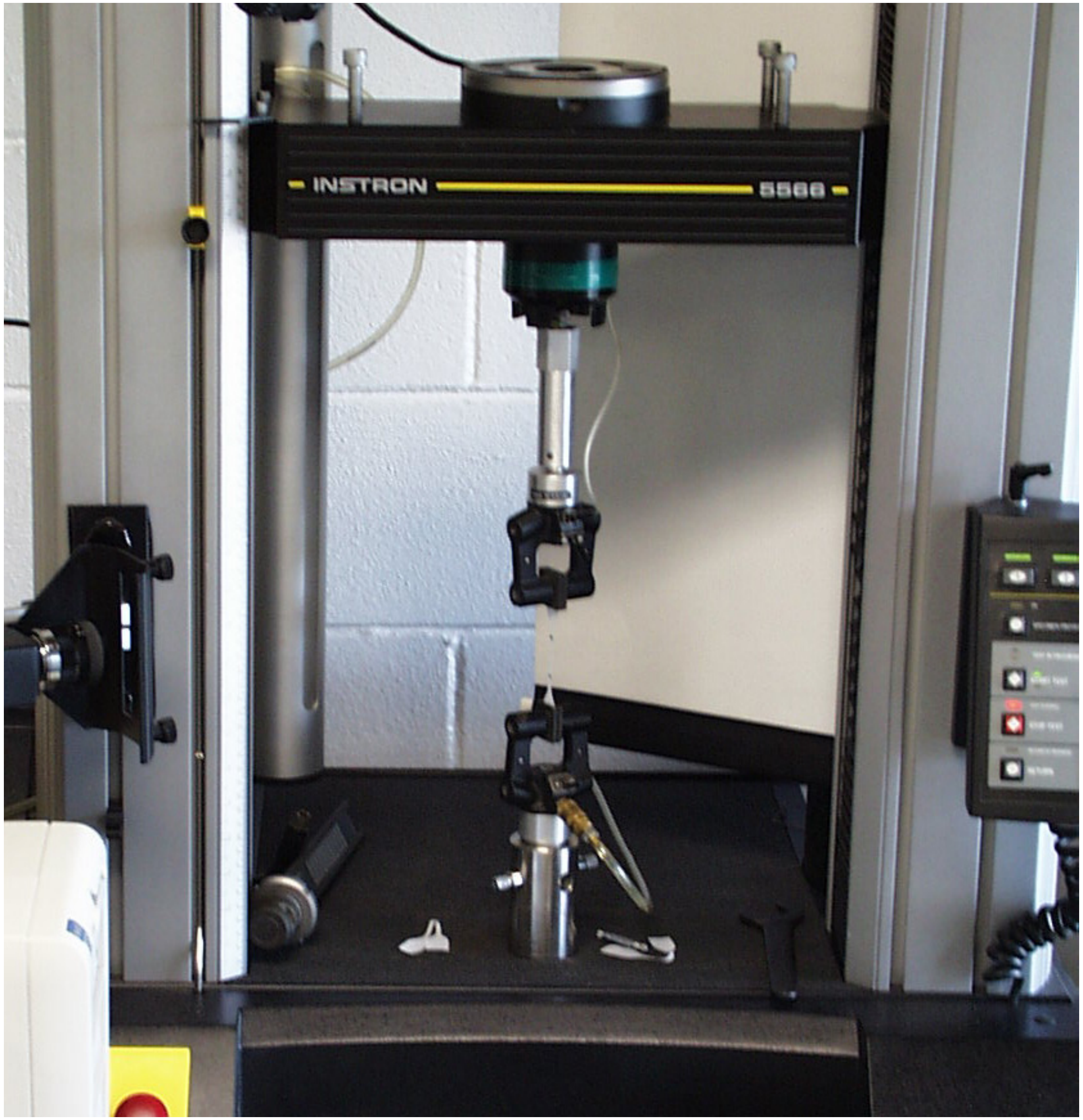
- Static Behavior
  - Plastics
  - Elastomers
- Temperature
- Dynamic Loadings
  - Rate
  - Noise and Vibration
- Fatigue and Aging

Static Behavior

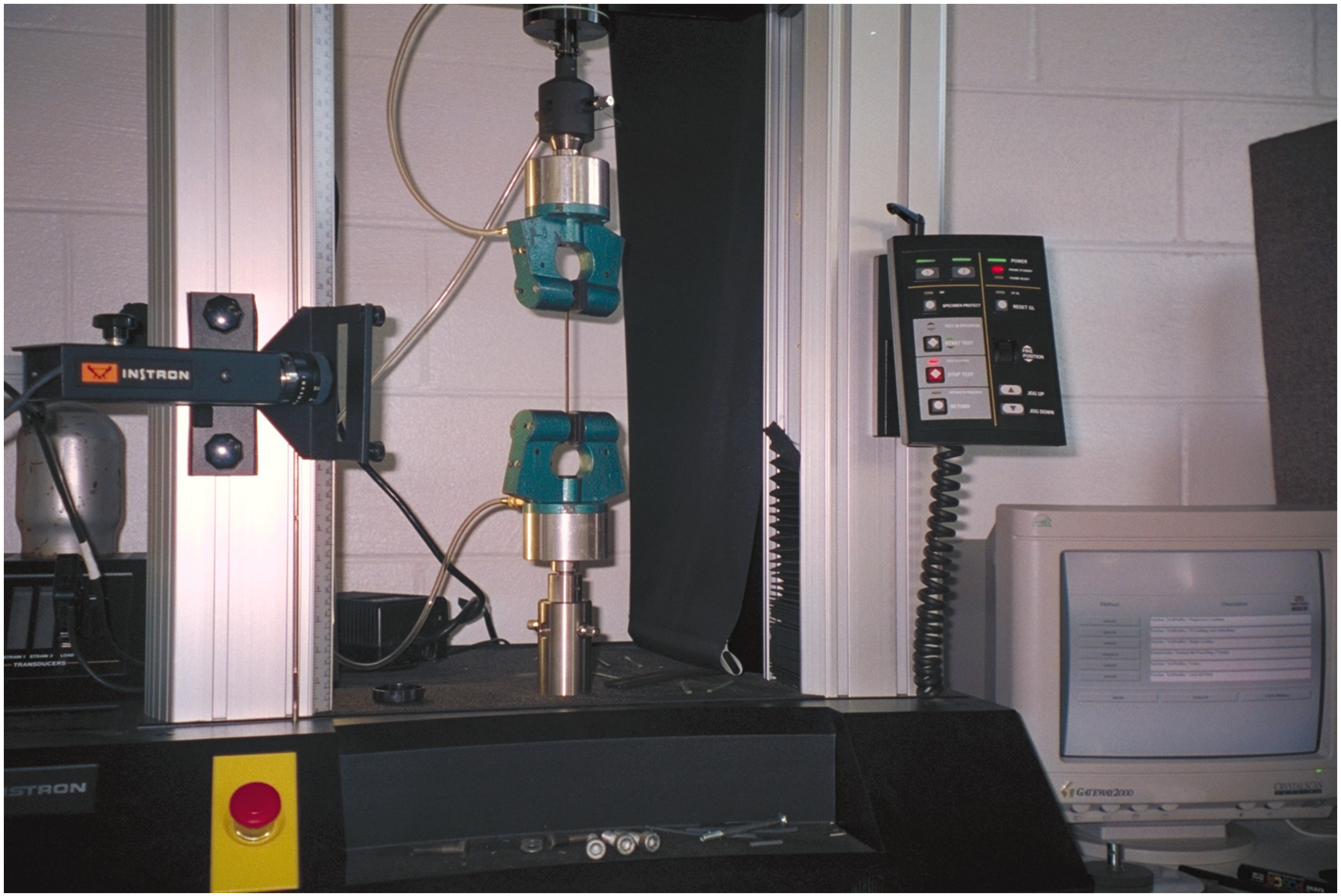
Load Frame



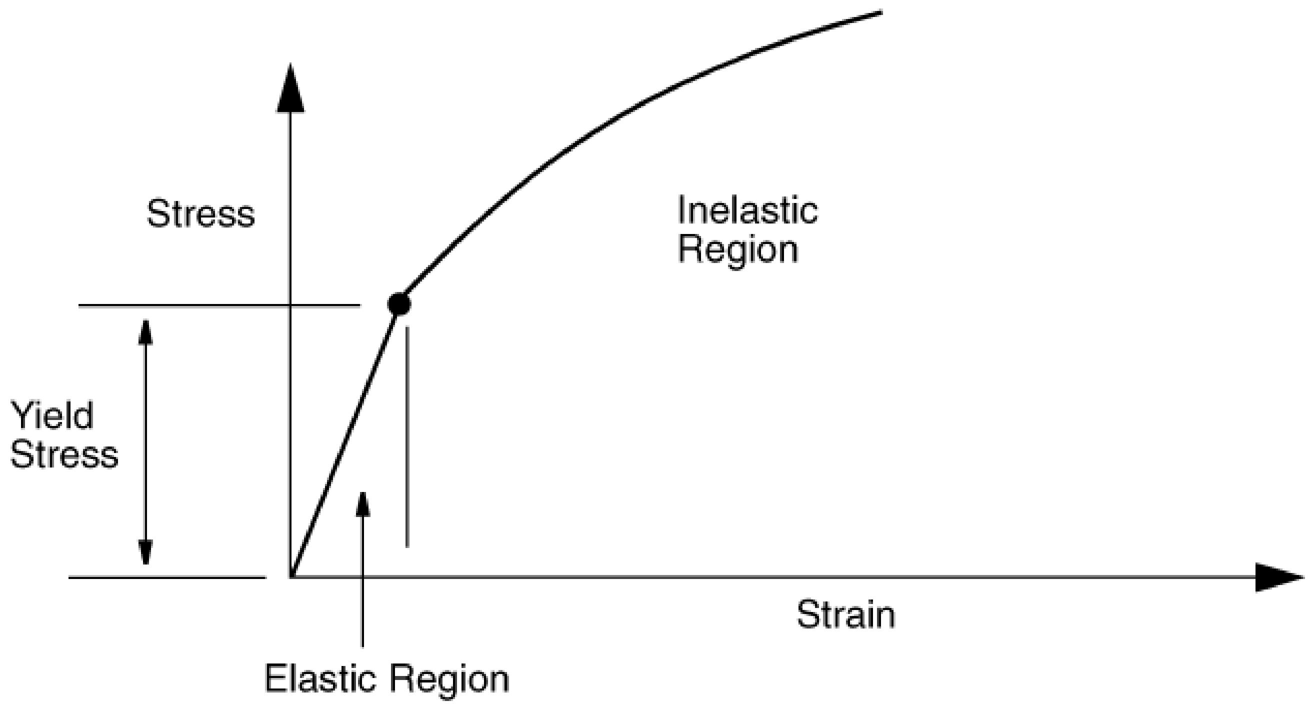
Static Behavior



Static Behavior

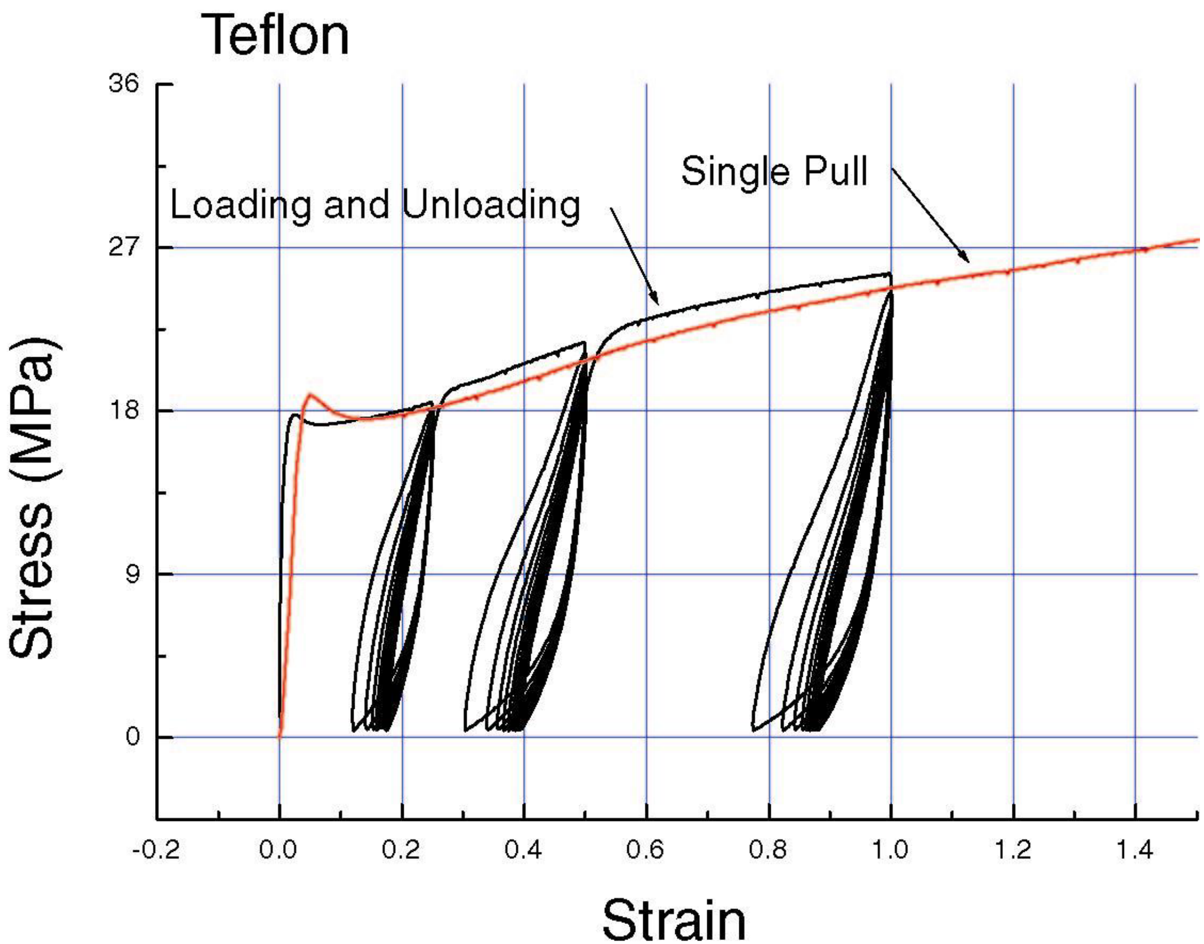


Static Behavior

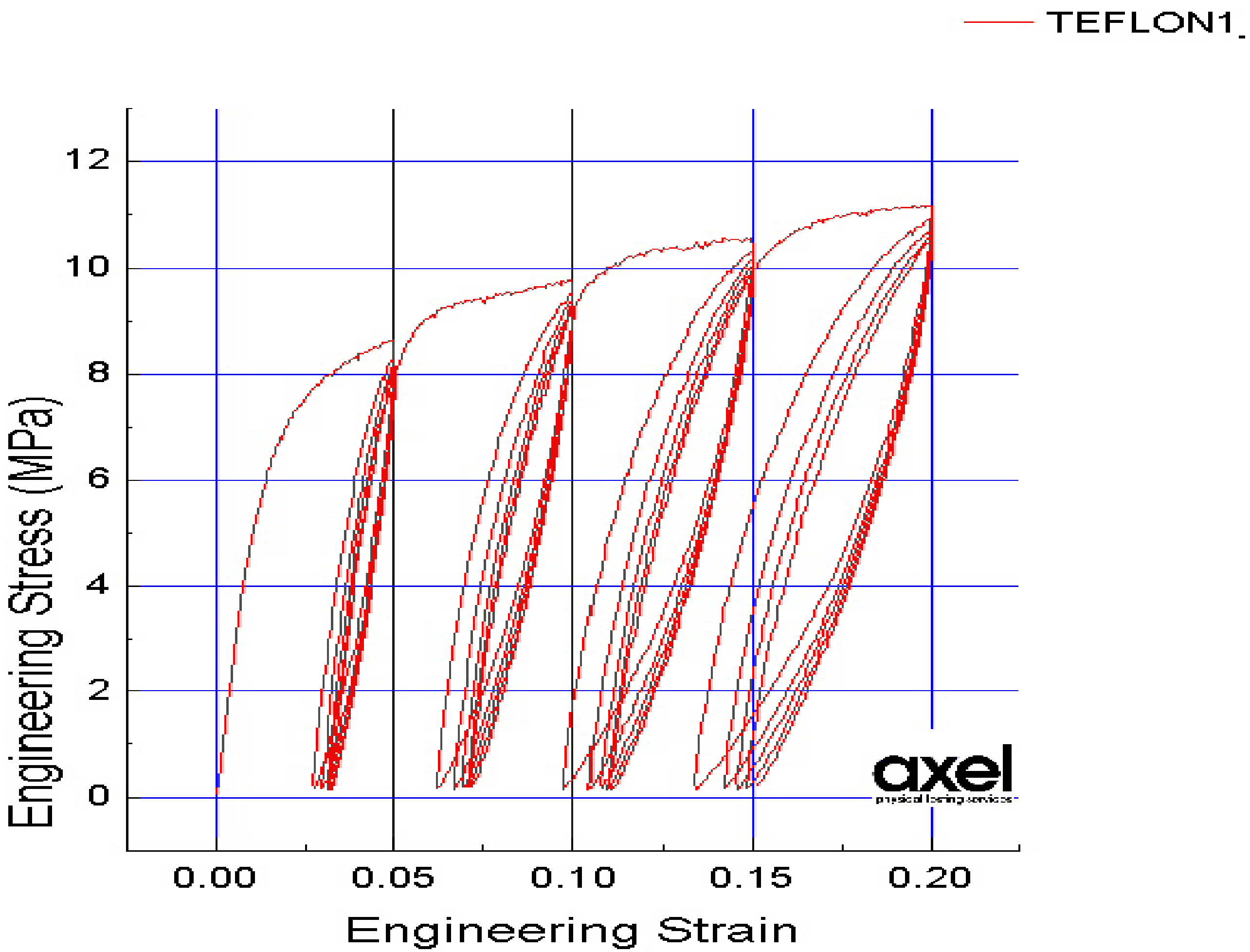


Note: Stress and strain are total quantities.

Static Behavior



Static Behavior

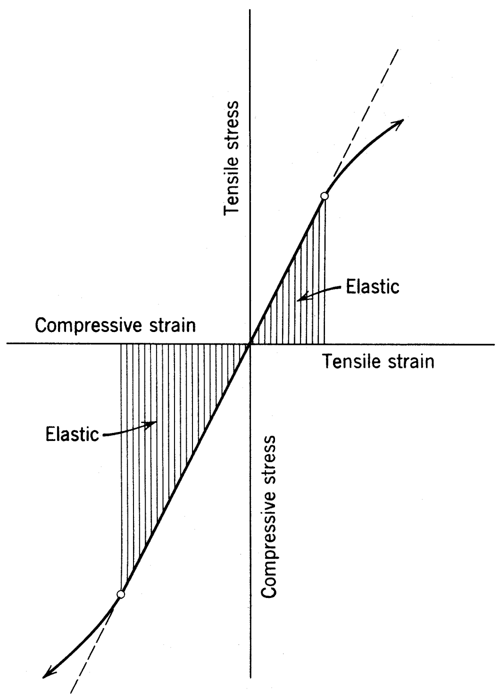


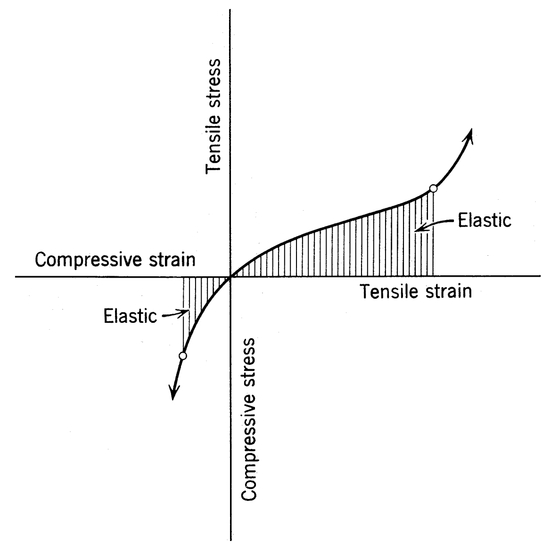
Static Behavior

Comparison of Metal Response to that of Rubber

Crystalline Solid
- Small elastic strain (.2%)
- Plastic yielding
- Tension / Comp. Similar

Rubber
- Large Elastic Strains (600%)
- Complex Damage
- Tension / Comp very different
- Viscoelastic, Hysteresis

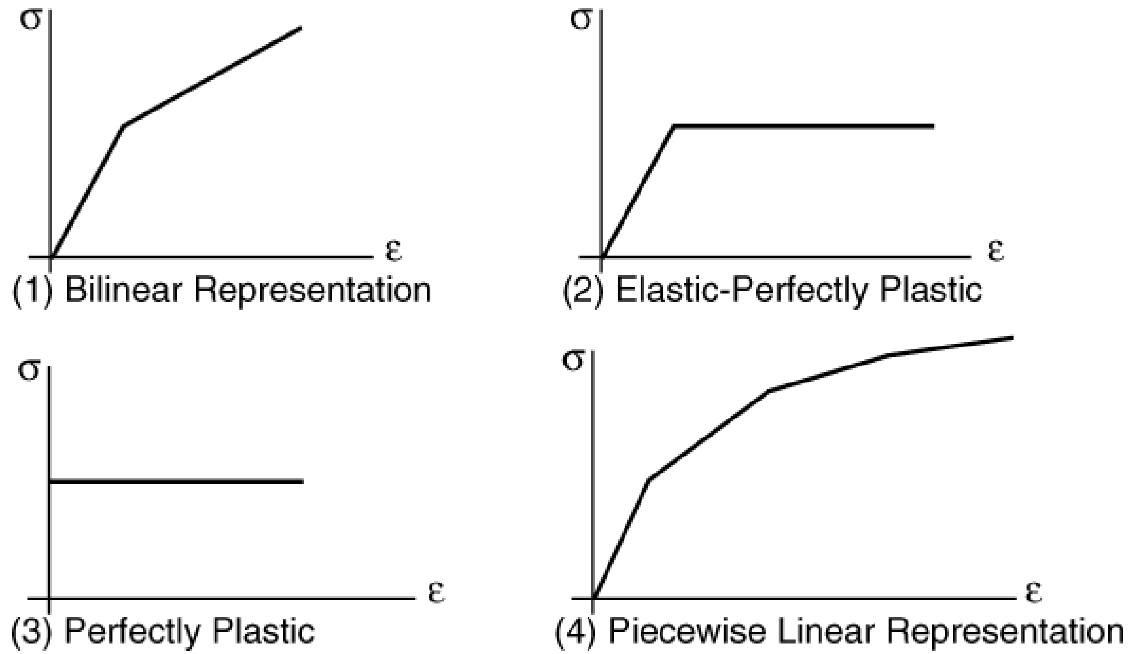


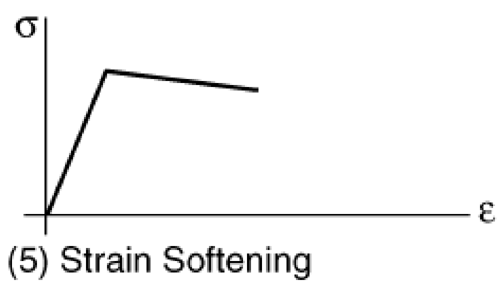


Static Behavior

Simple

Models





Meaningful Parameters:
Young's Modulus, E
Poisson's Ratio, ν

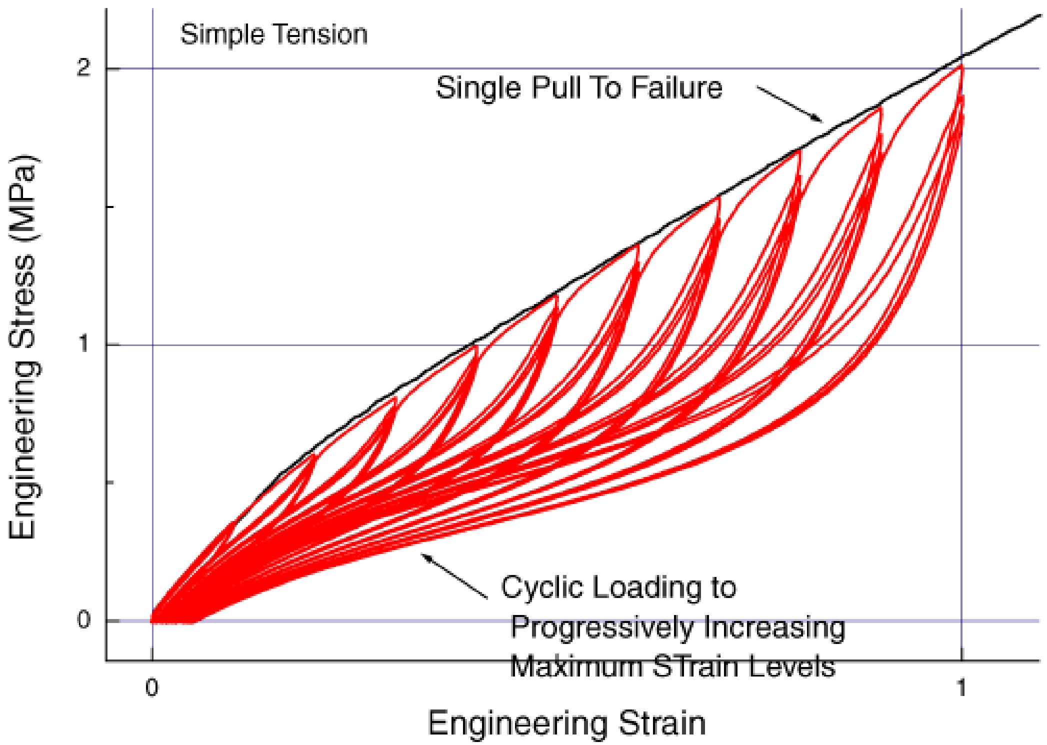
Simplified Stress-Strain Curves (Uniaxial Test)

Static Behavior

Elastomer Behavior, Typical Stress-Strain Response

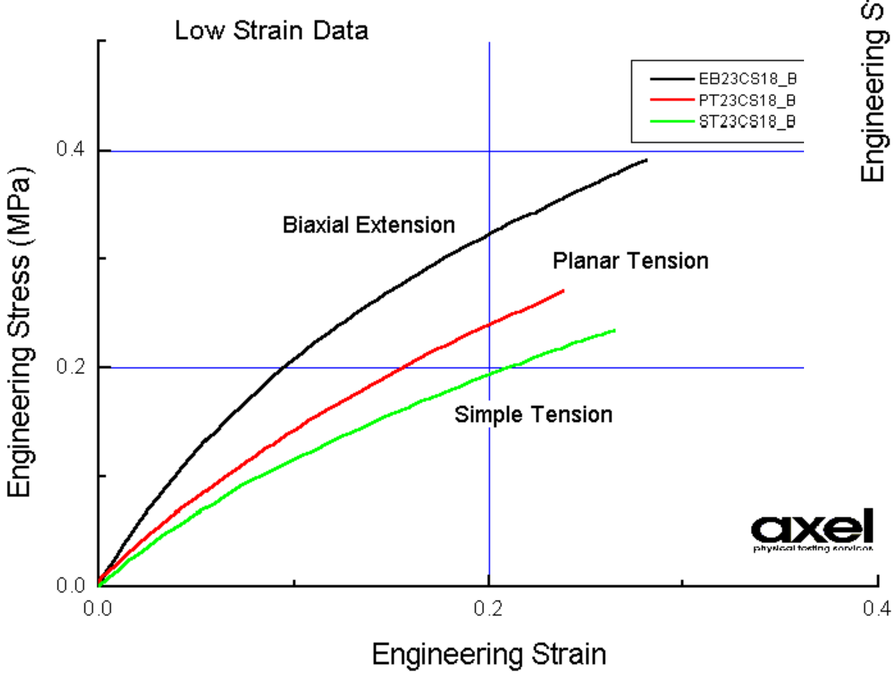
Load, unload cycles show hysteresis and damage

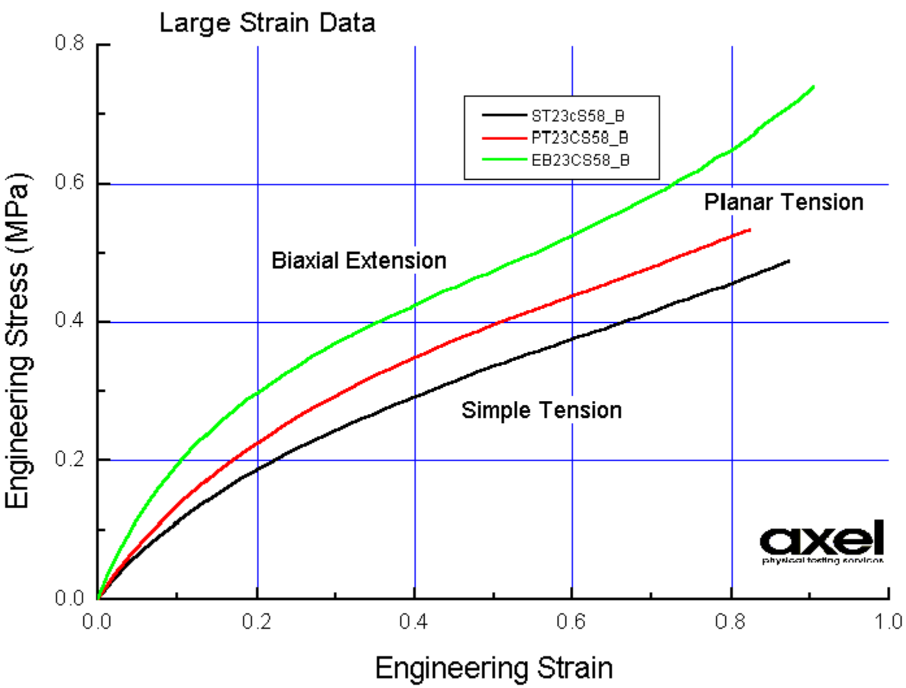
Progressive loads shows progressive damage



Non-physical Parameters:
(i.e., non-measurable) coefficients of nonlinear functions of strain—Must be automatically calibrated (i.e., curve fit) from test data.

Strain States





Static Behavior

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Pure States of Strain or Stress

- Simple Tension
- Pure Shear
- Simple Compression, Biaxial Extension
- Bulk Compression

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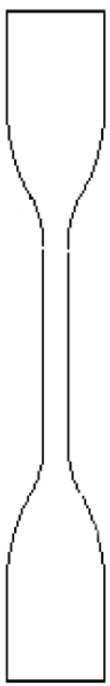
Tensile Testing in the Lab

What is Simple Tension?

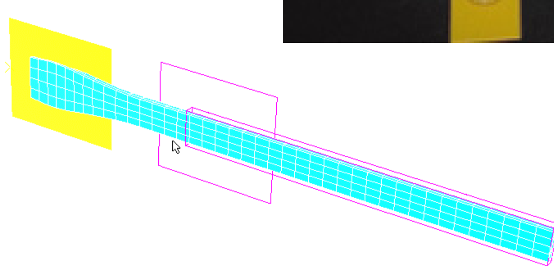
Uniaxial Loading

Free of Lateral

aint



Gage Section:
Length:Width
>10:1



Tensile Testing in the Lab

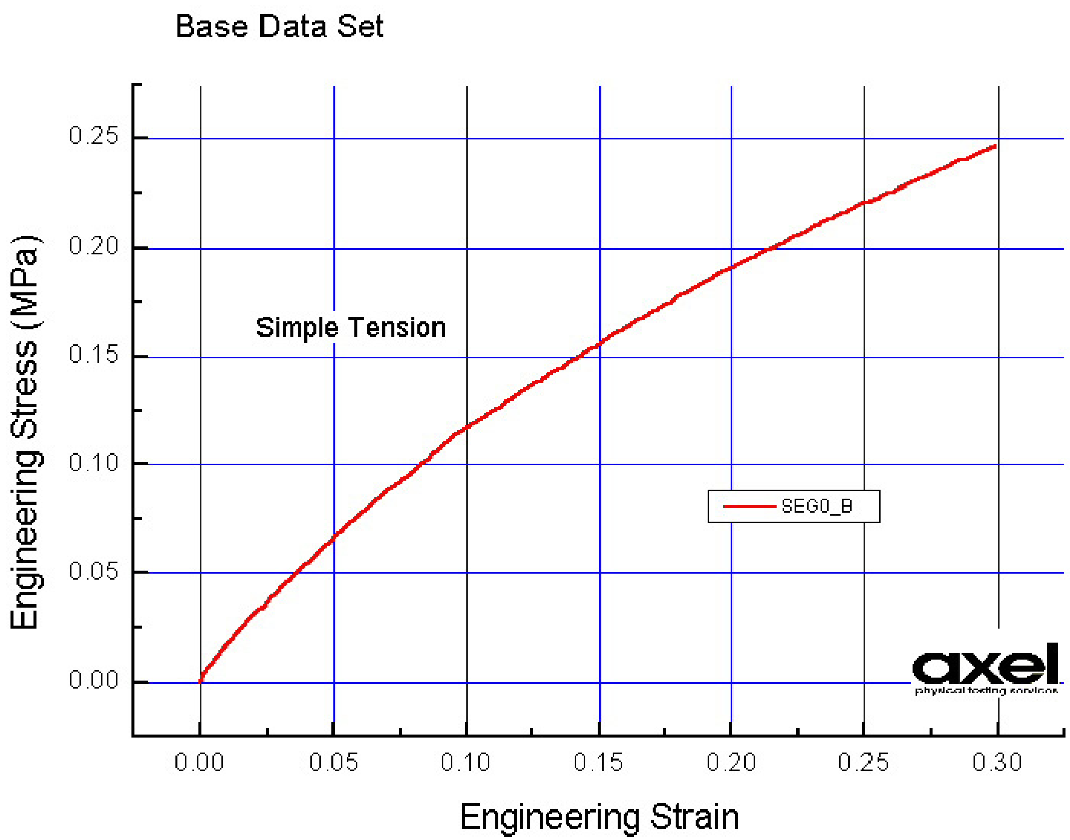
Measure Strain only in the Region where a Uniform State of Strain Exists

No Contact

Tensile Testing in the Lab

Initial Loading

Typical of Data from
Existing Standards

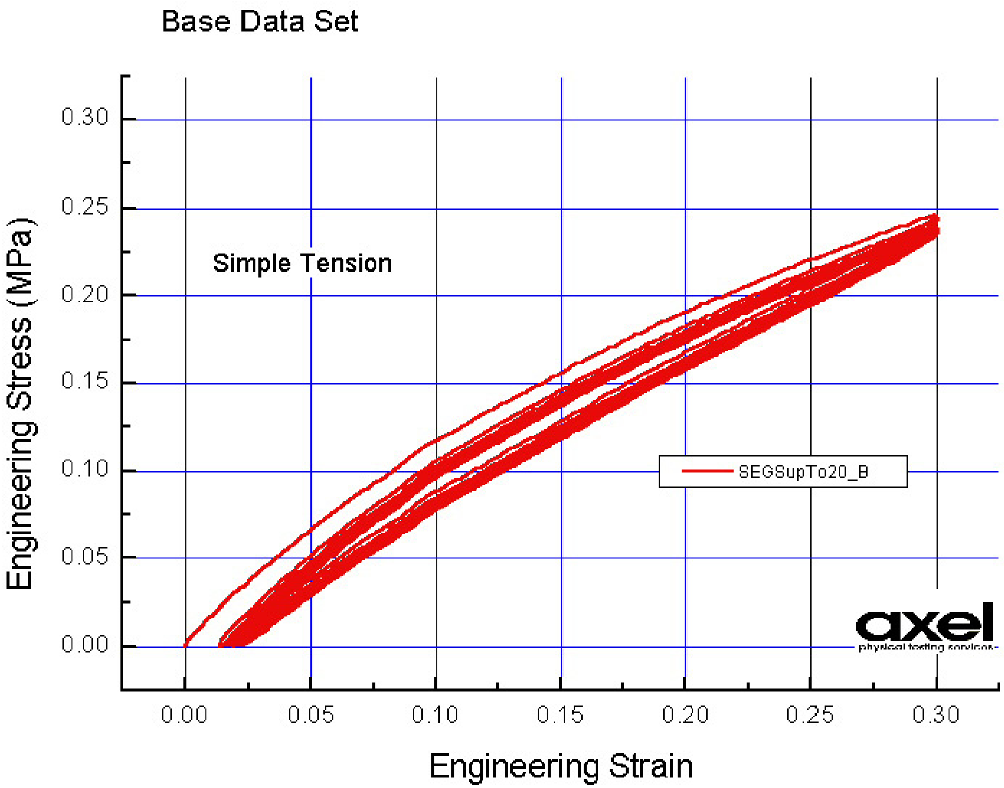


Tensile Testing in the Lab

Mutiple Loadings

Softening

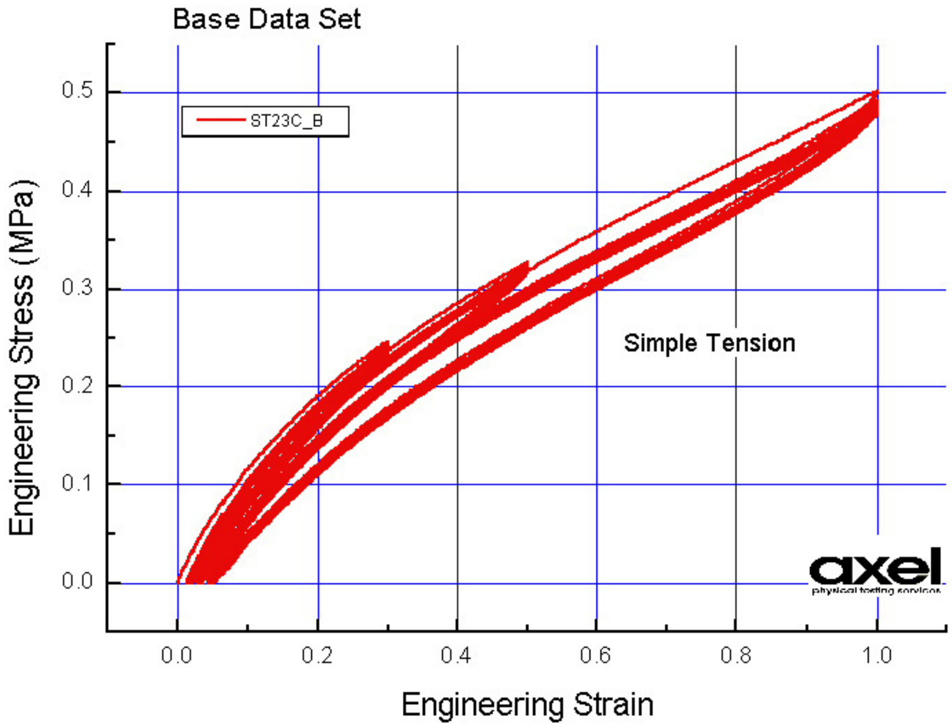
Permanent Strain Effects



Tensile Testing in the Lab

Loading to Larger Strain Levels

- Additional Softening
- Additional Permanent Damage



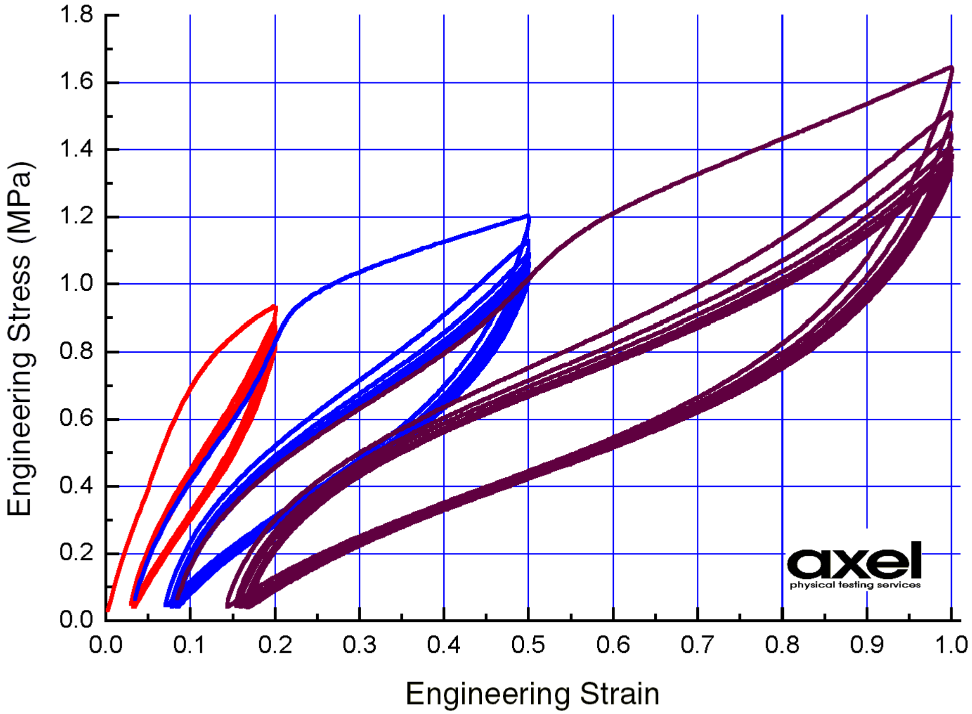
Tensile Testing in the Lab

Some Common Elastomers Exhibit Dramatic Strain Amplitude and Cycling Effects at Moderate Strain Levels

Conclusions:

Test to Realistic Strain Levels

Use Application Specific Loadings to Generate Material Data

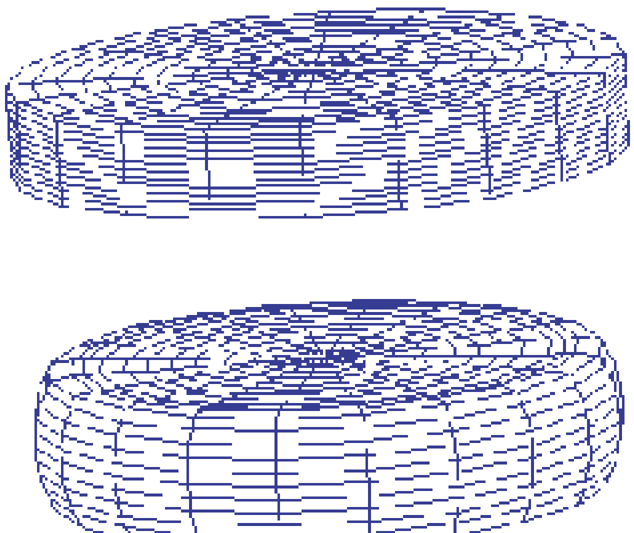


Compression Testing in the Lab

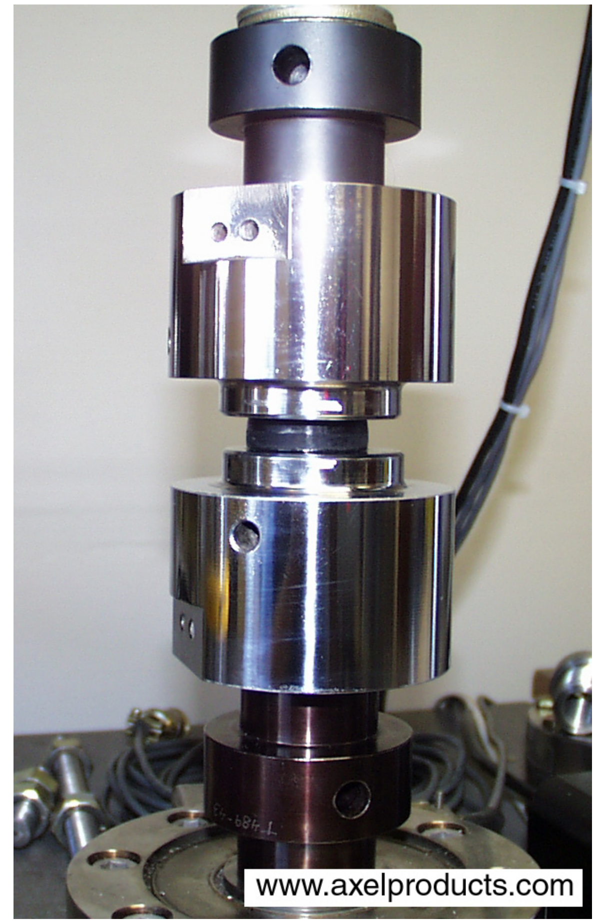
Requirements:

Uniaxial Loading

No Lateral Constraint



Coutesy, Jim Day, GM Powertrain



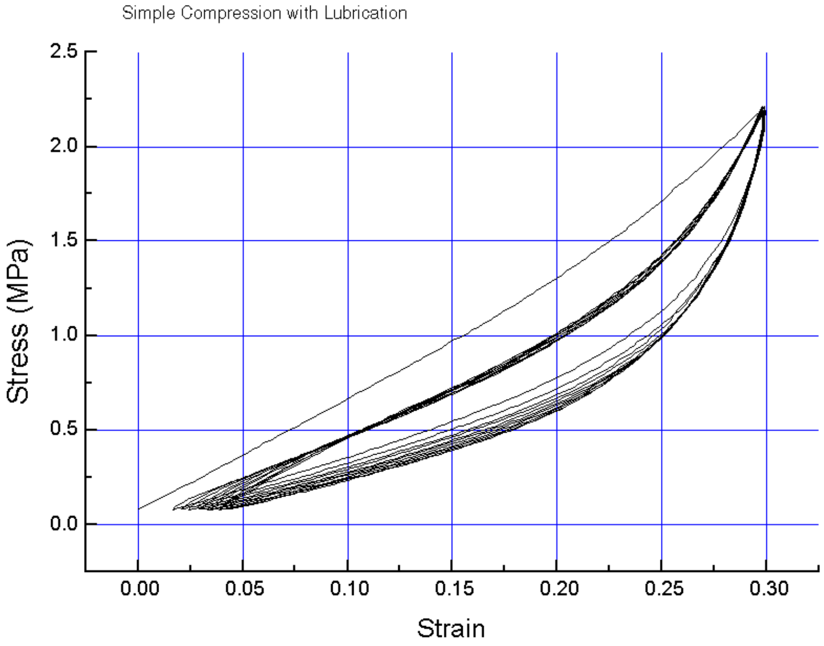
Compression Testing in the Lab

It is Experimentally Difficult to Minimize Lateral Constraint due to Friction at the Specimen Loading Platen Interface

Friction Effects Alter the Stress-strain Curves

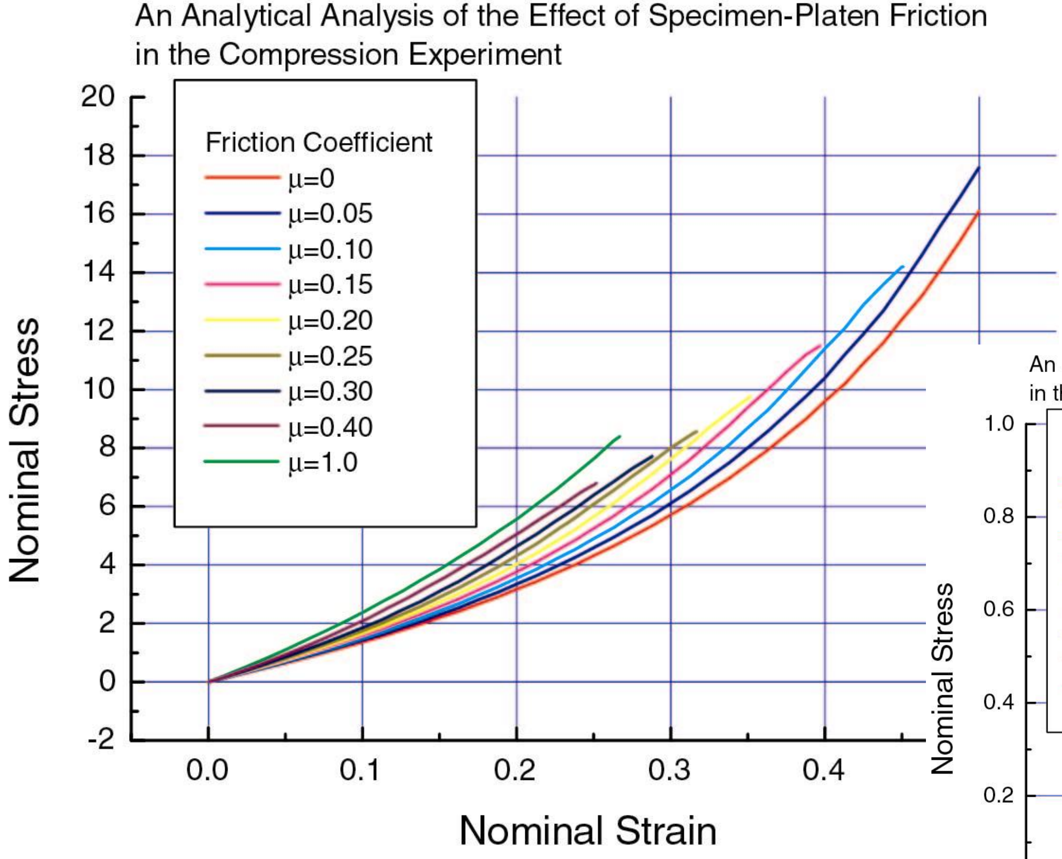
The Friction is Not Known and Cannot be Accurately Corrected

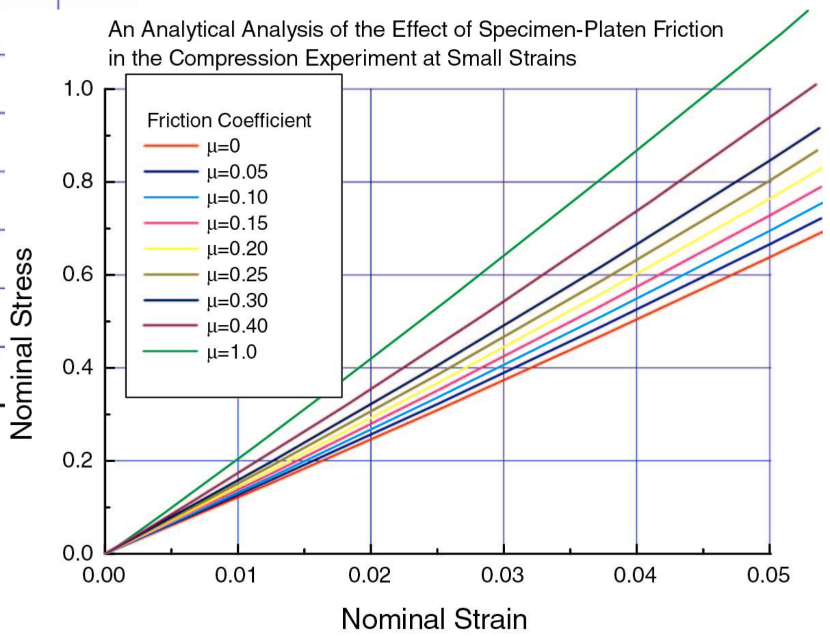
Even Very Small Friction Levels have a Significant Effect at Very Small Strains



Compression Testing in the Lab

Friction Effects on Compression Data





Analysis by Jim Day, GM Powertrain

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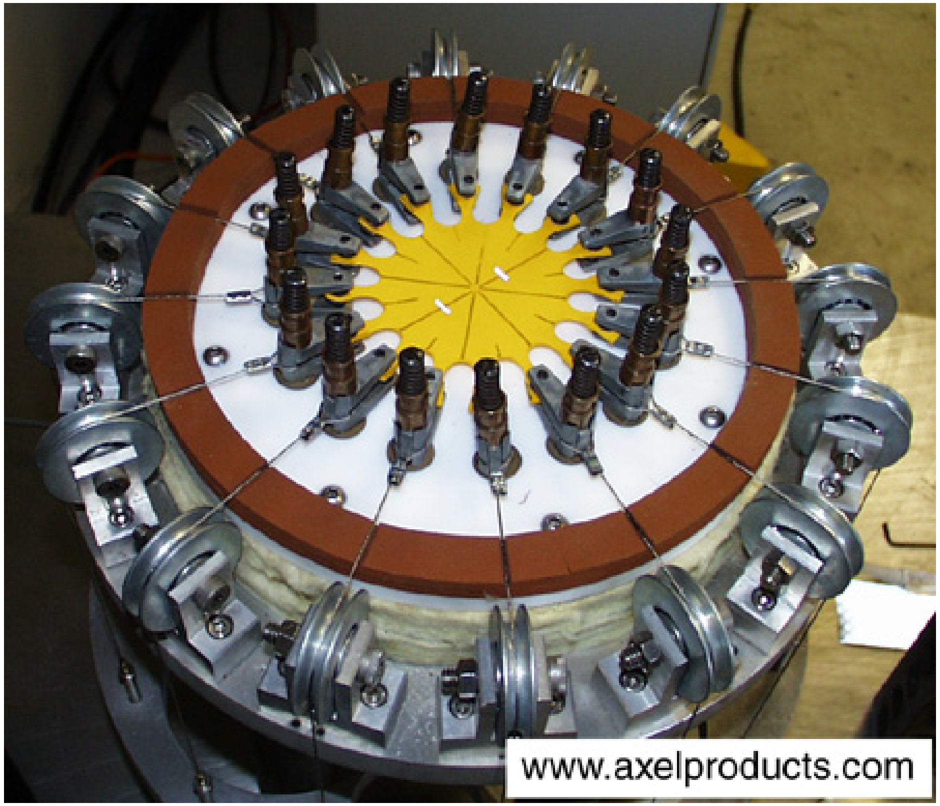
Equal Biaxial Testing

Why?

Same Strain State as Compression

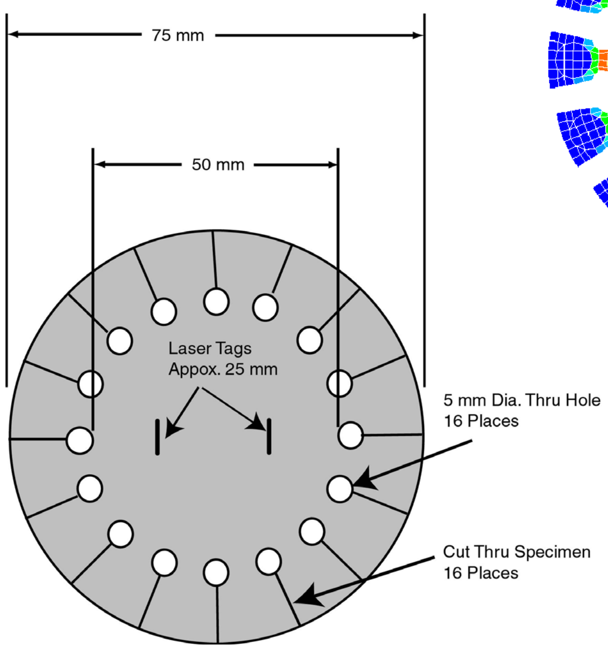
Can Not Do Pure Compression

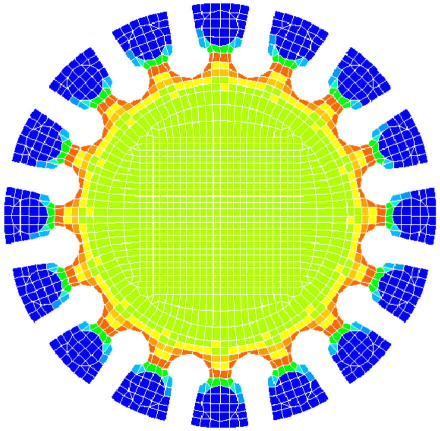
Can Do Pure Biaxial

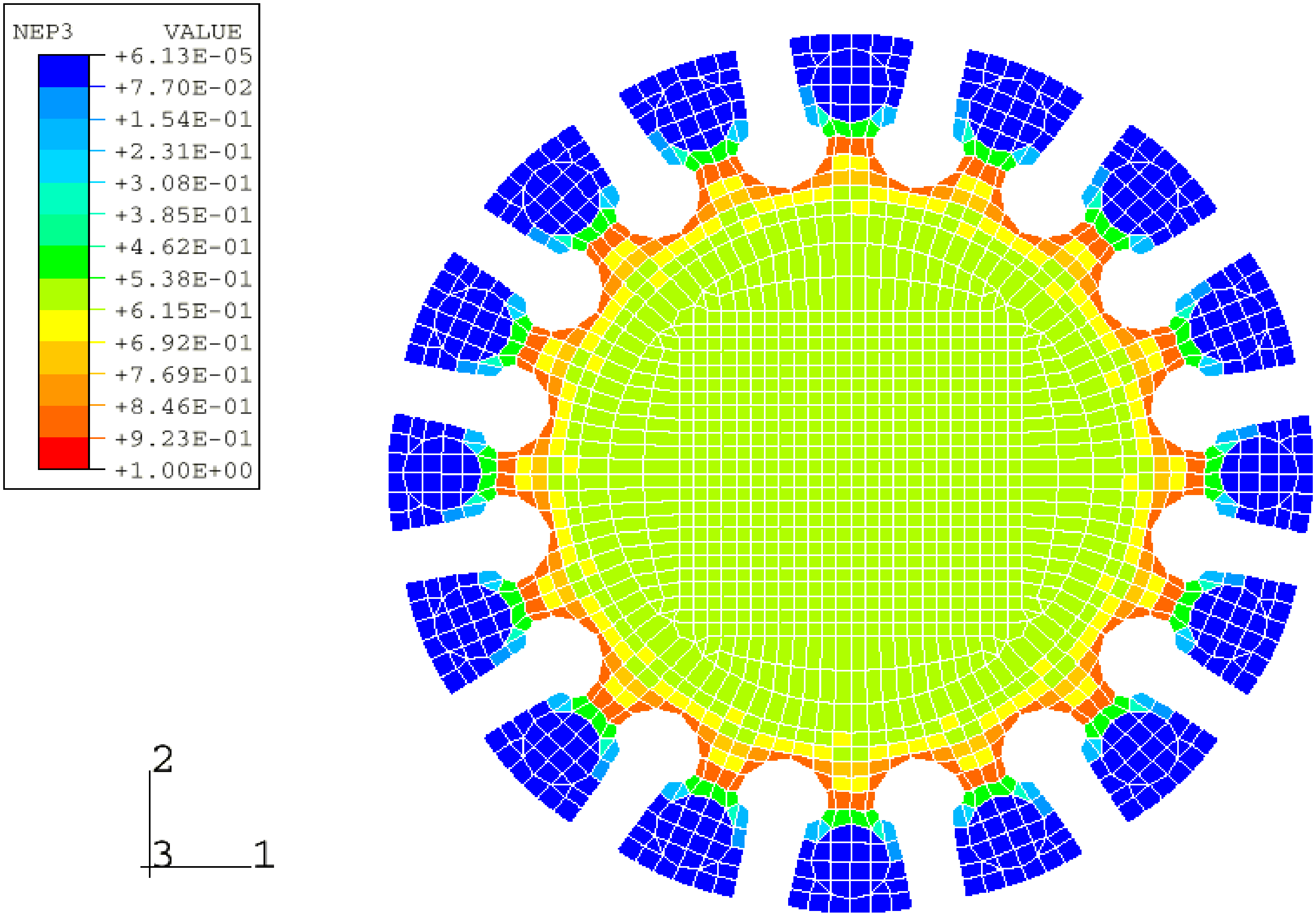


Equal Biaxial Testing

Analysis of the Specimen Justifies
Geometry





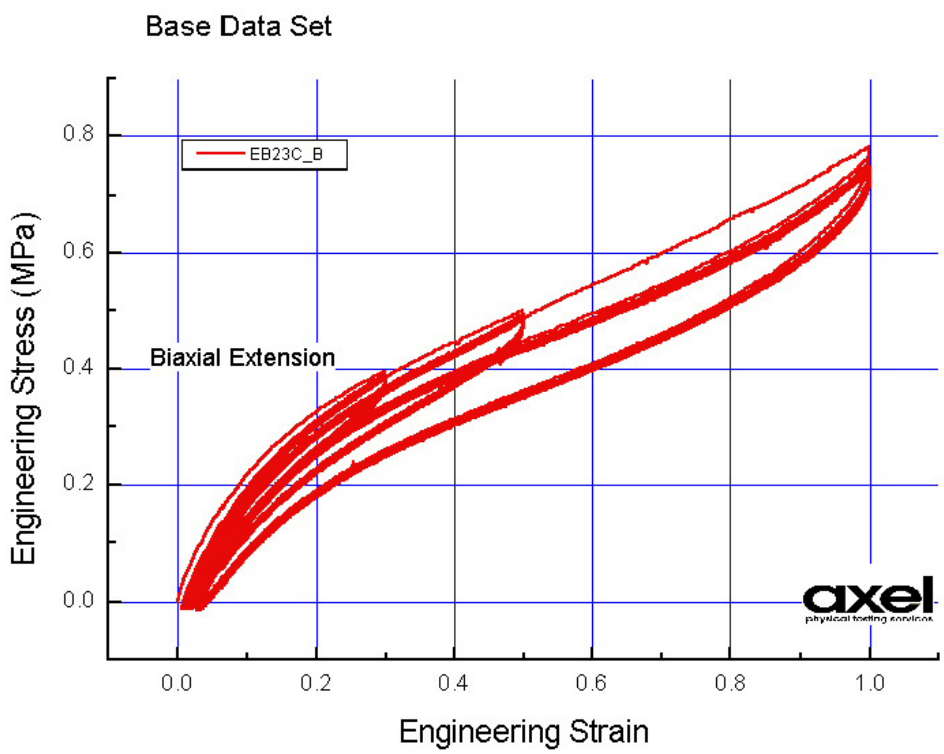

NEP3 VALUE
+6.13E-05
+7.70E-02
+1.54E-01
+2.31E-01
+3.08E-01
+3.85E-01
+4.62E-01
+5.38E-01
+6.15E-01
+6.92E-01
+7.69E-01
+8.46E-01
+9.23E-01
+1.00E+00
2
3
1

Equal Biaxial Testing

Biaxial Extension

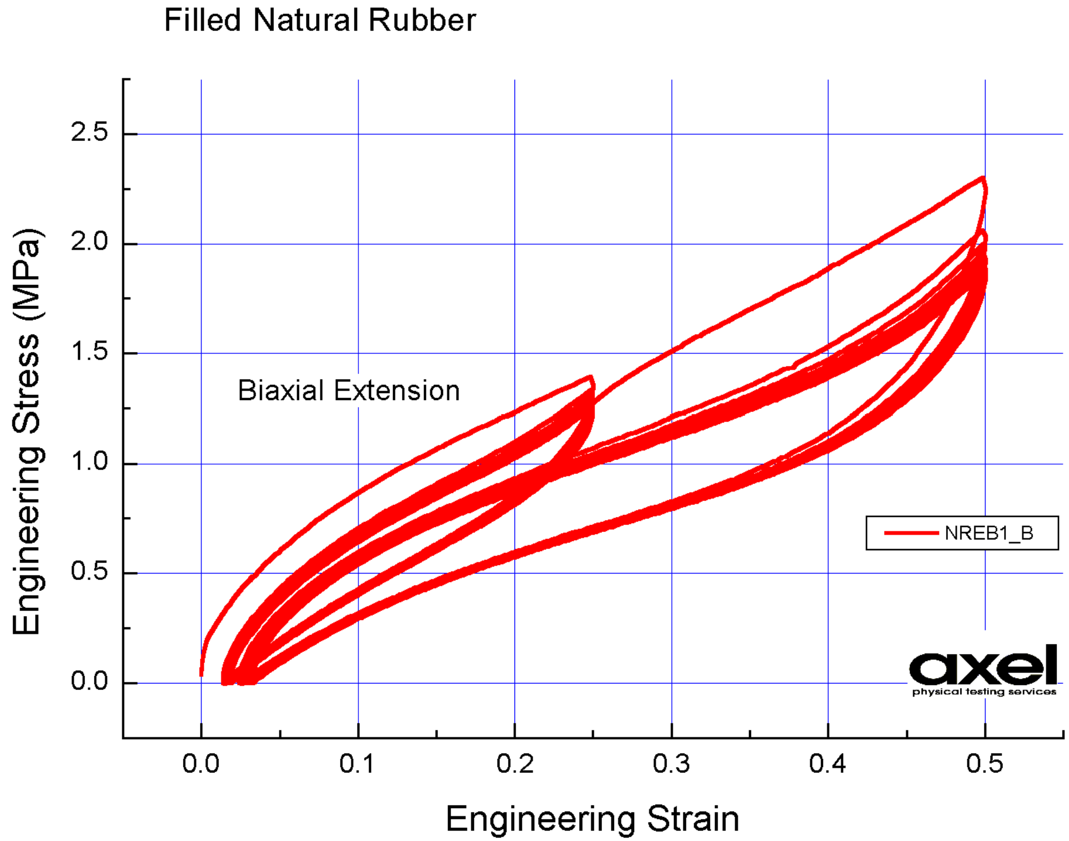
Curves have the same
General Shape as
Simple Tension

Allows for Matched
Loading Conditions



Equal Biaxial Testing

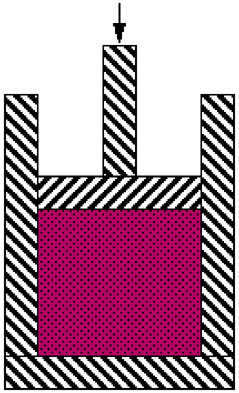
Some Common Elastomers Exhibit Dramatic Strain Amplitude and Cycling Effects at Moderate Strain Levels

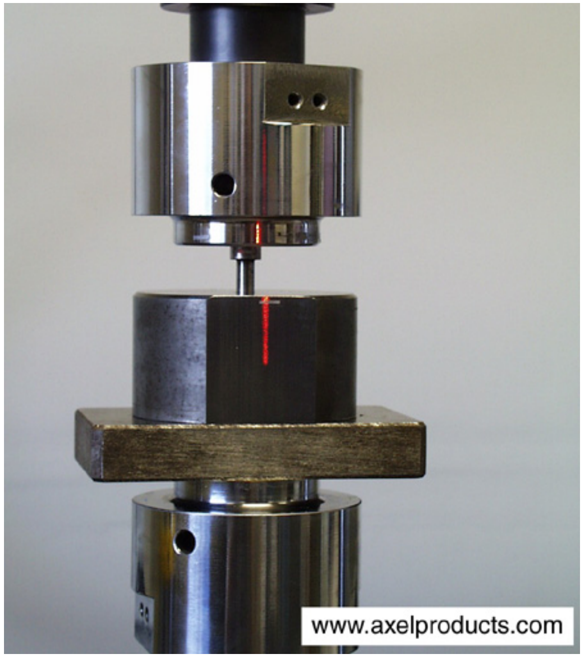


Volumetric Compression Testing

Direct Measure of the Stress Required to Change the Volume of an Elastomer

Requires Resolute Displacement Measurement at the Fixture

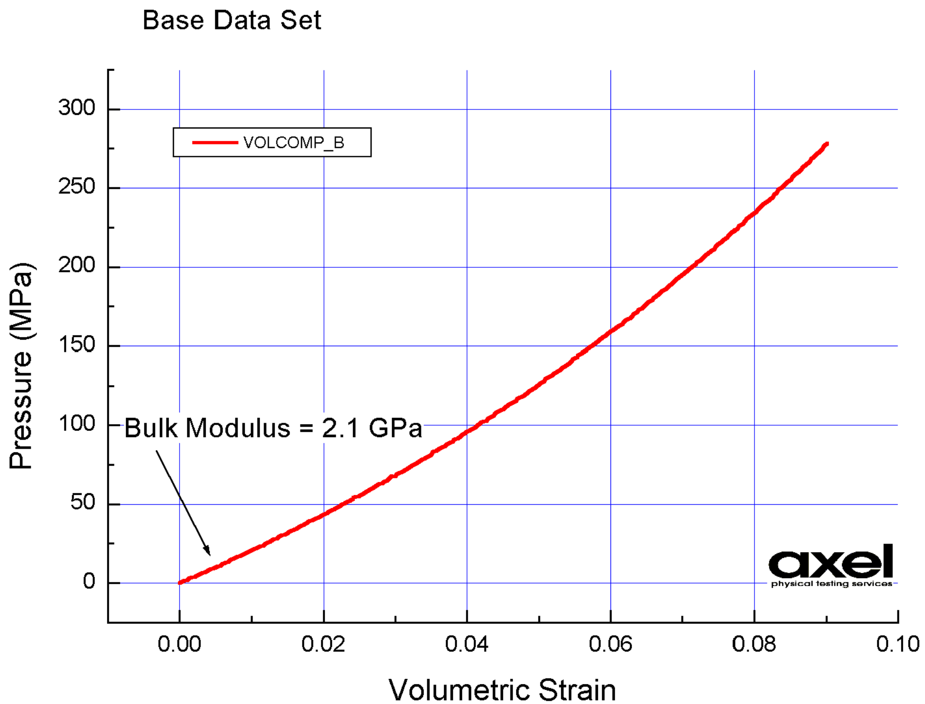




Volumetric Compression Testing

Initial Slope = Bulk Modulus

Typically, only highly constrained applications require an accura measure of the entire Pressure Volume relationship.



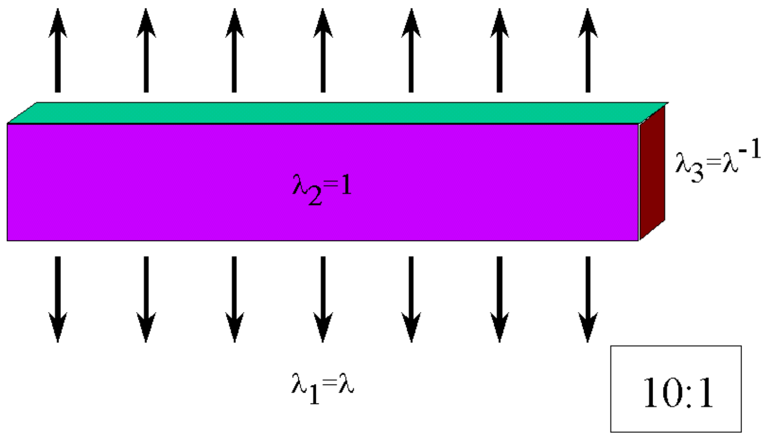
Planar Tension Testing

What is Planar Tension?

Uniaxial Loading

Perfect Lateral Constraint

All Thinning Occurs in One Direction



Planar Tension Testing

Strain Measurement is Particularly Critical

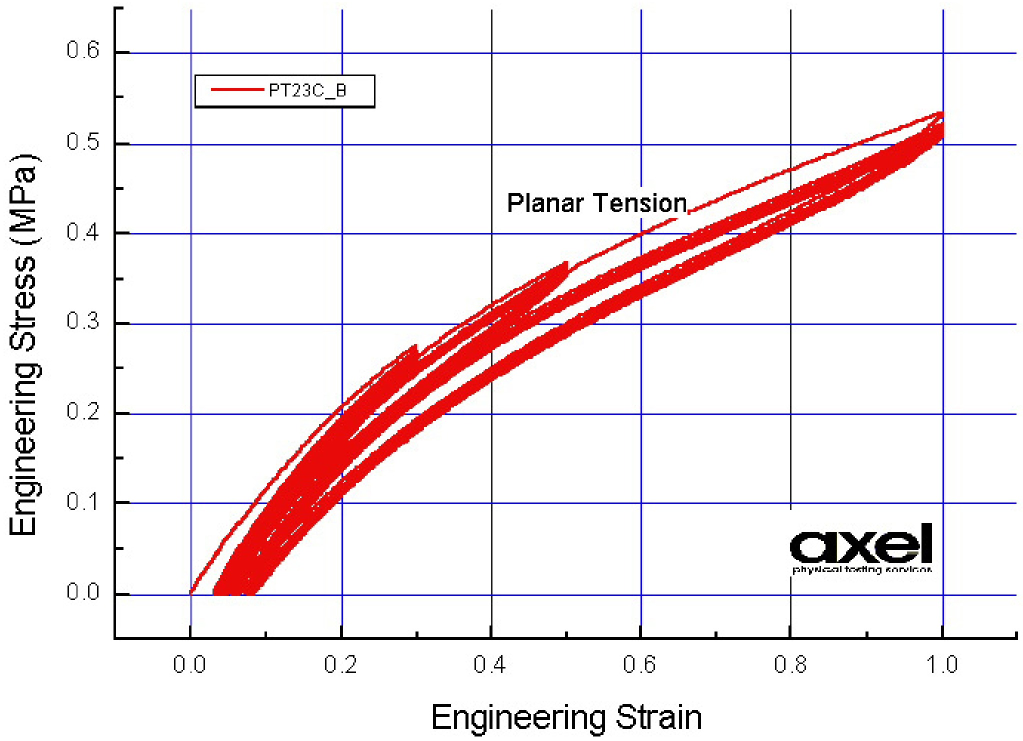
- Some Material Flows from the Grips
- The Effective Height is Smaller than Starting Height so >10:1 Width:Height is Needed

Planar Tension Testing

Similar Stress-strain Shape to
Simple Tension and
Biaxial Extension

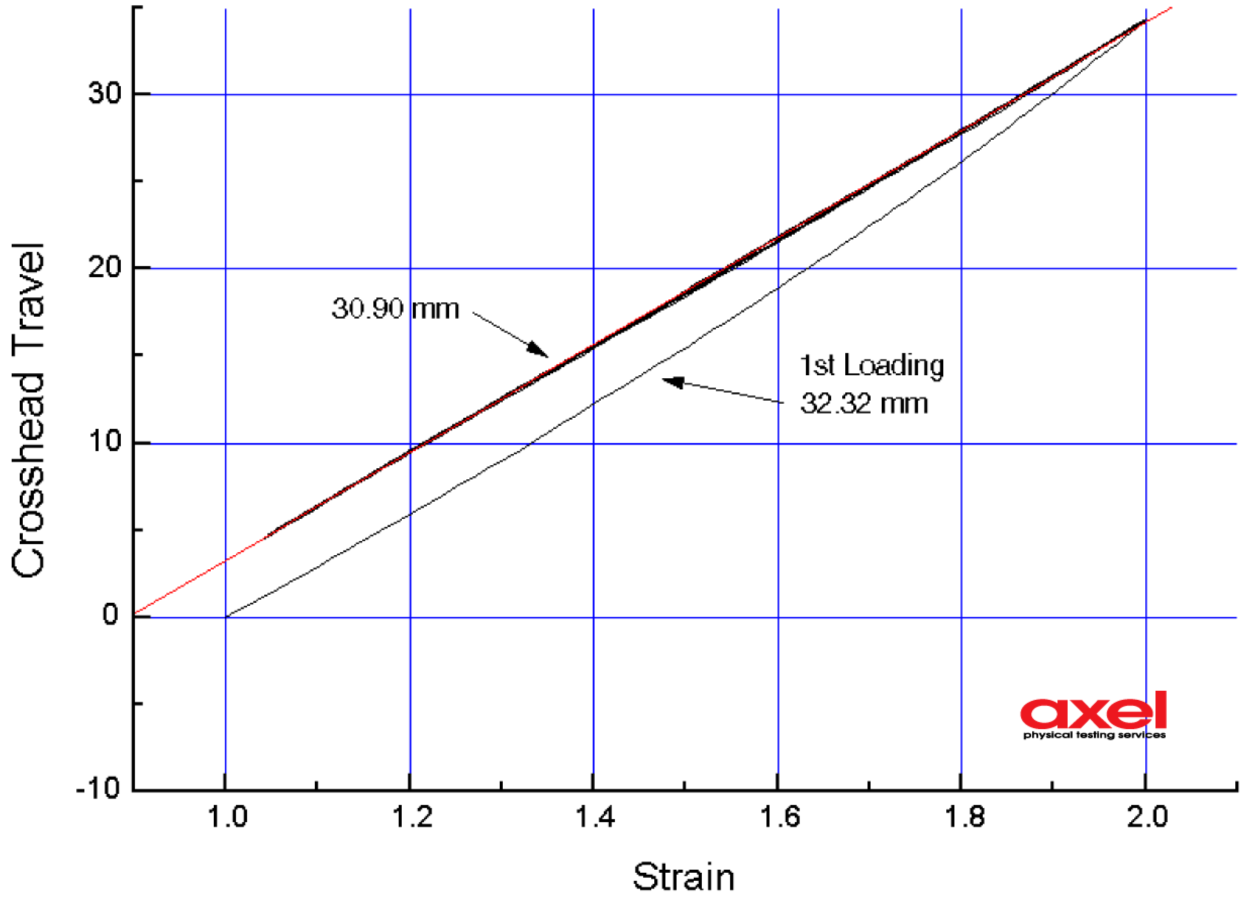
Match Loadings between
Strain States

Base Data Set

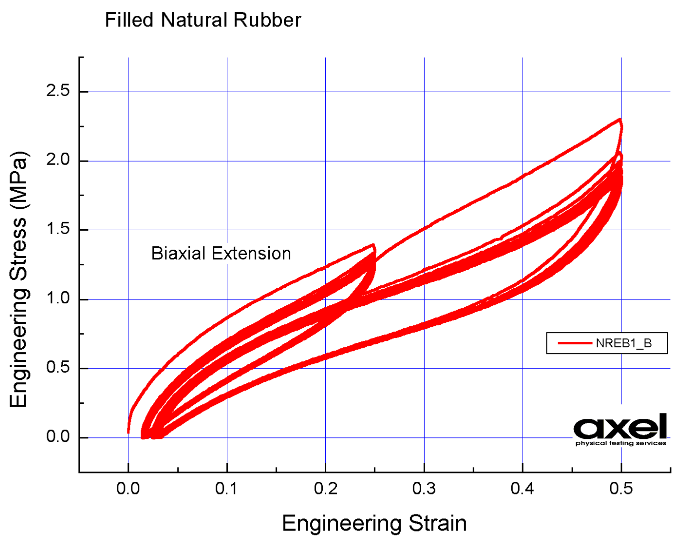


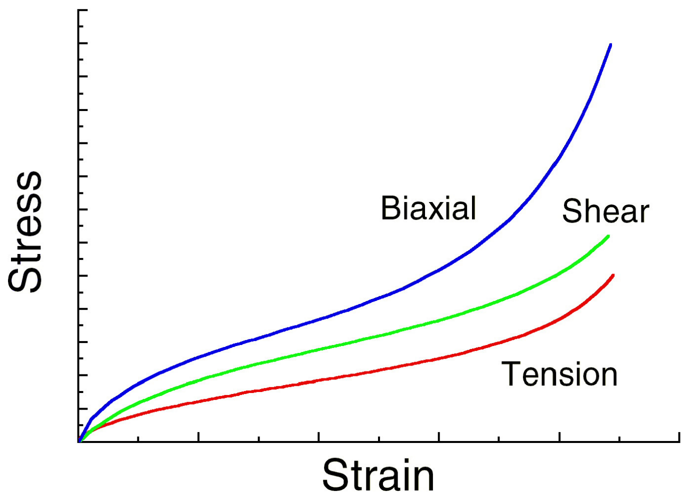
Planar Tension Testing

A Small but Significant amount of Material will Flow From the Planar Tension Grips.

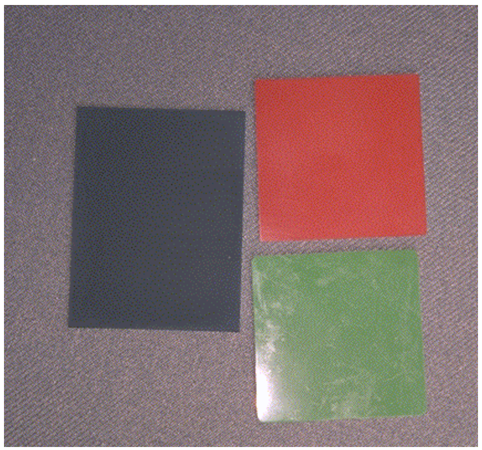


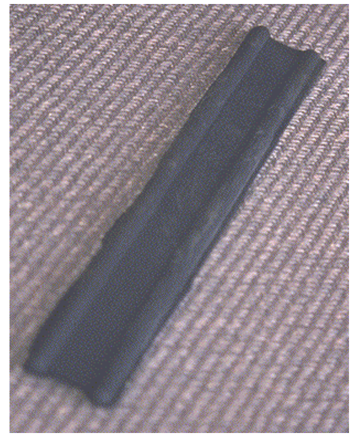
Data Reduction in the Lab

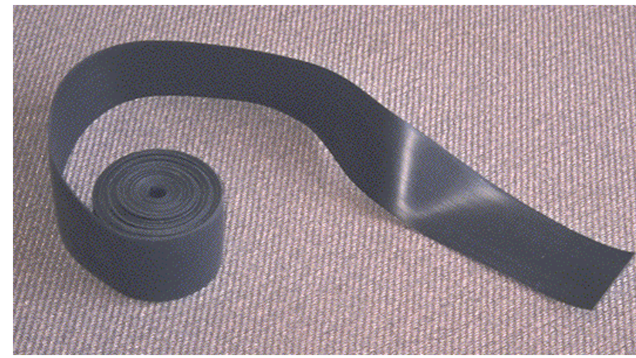


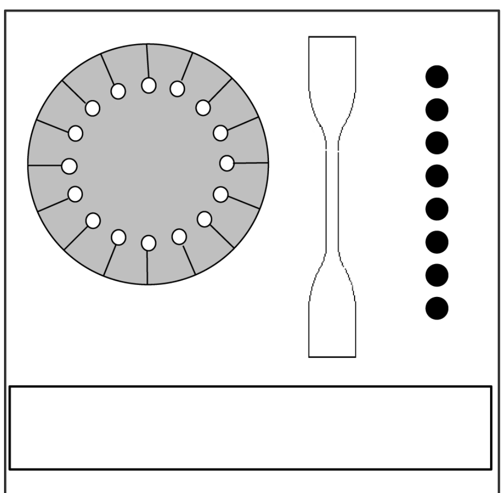


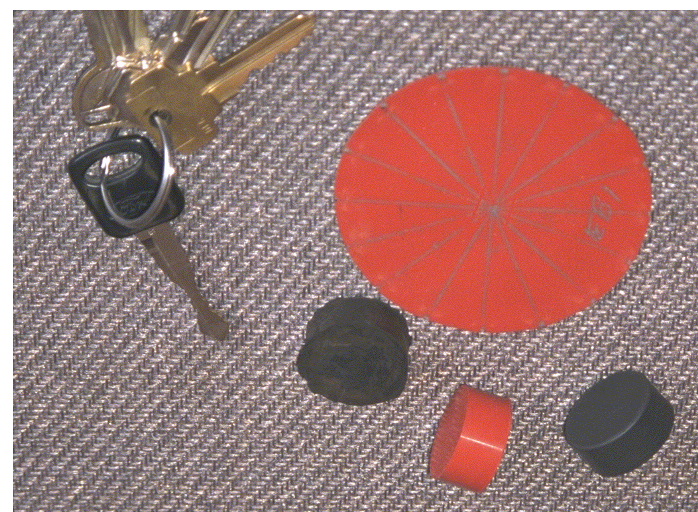
Testing the Correct Material







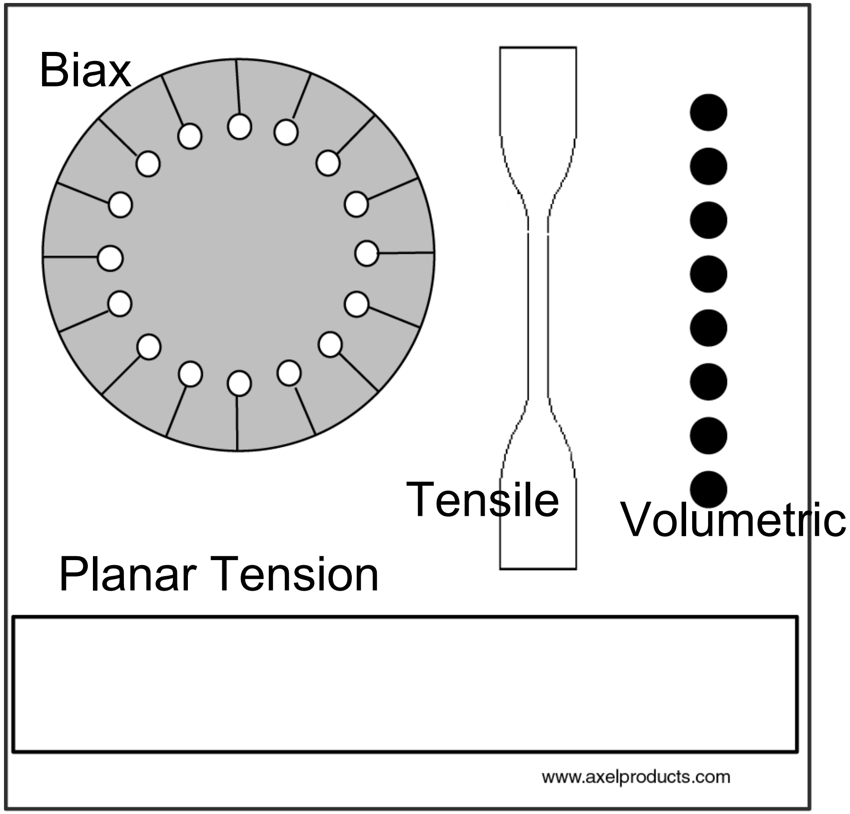




Testing the Correct Material

Consistent within The Experimental Data Set

Cut All Specimens from the Same Slab



Testing the Correct Material

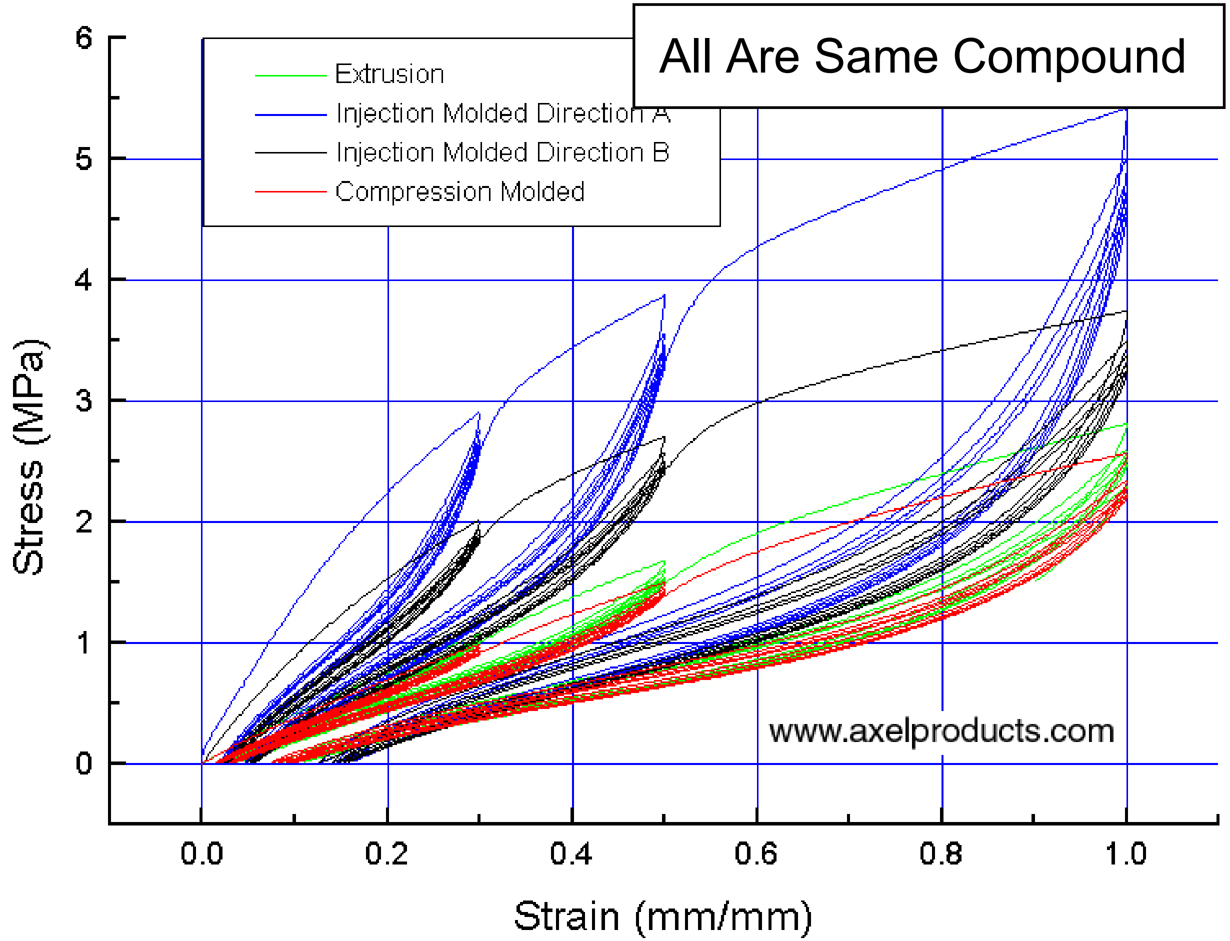
Verify that The Tested Material is the Same as the Part

Processing

Color

Cure

History …



Testing at Non-ambient Temperatures

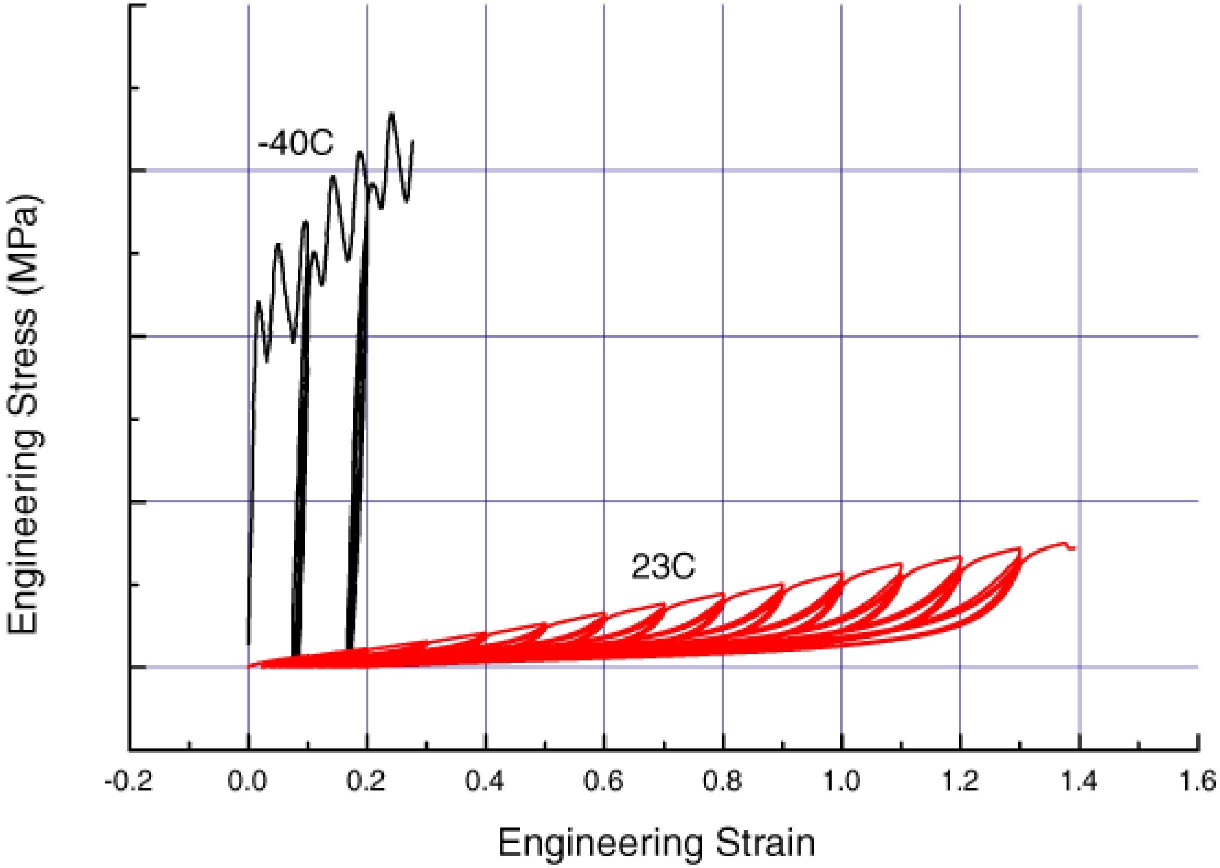
Testing at the Application Temperature

Measure Strain at the Right Location

Perform Realistic Loadings

Testing at Non-ambient Temperatures

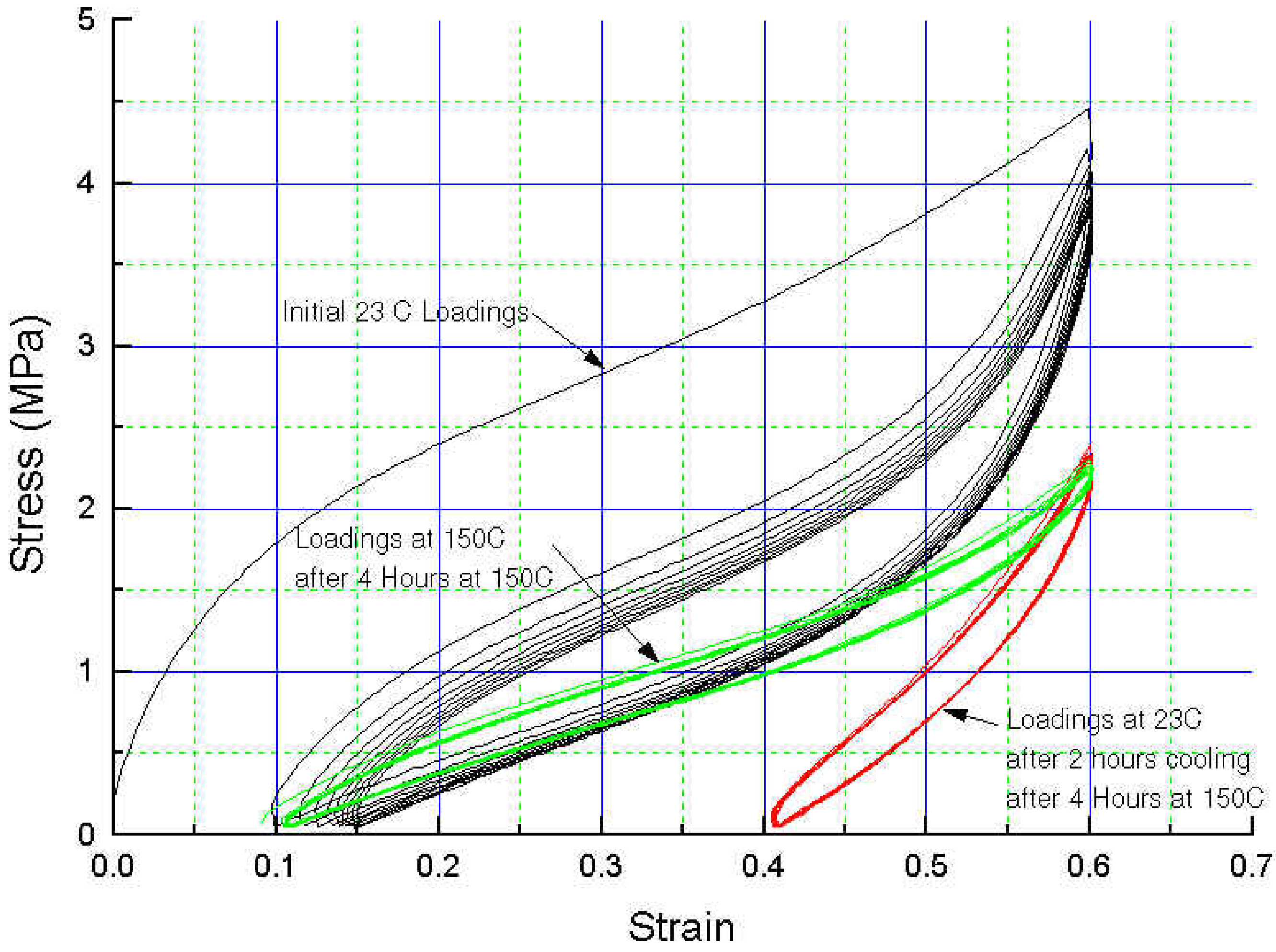
Elastomers Properties Can Change by Orders of Magnitude in the Application Temperature Range.



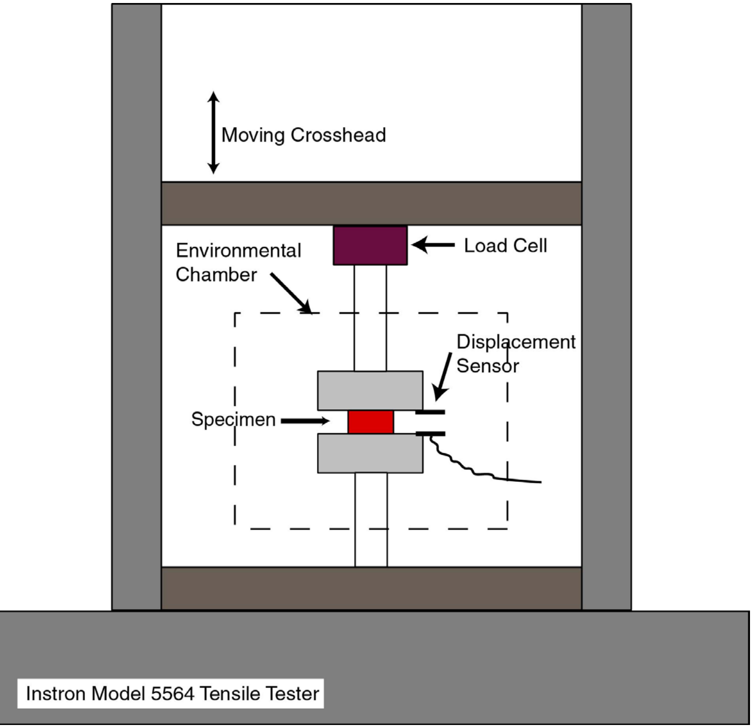
Measuring Thermal Constants

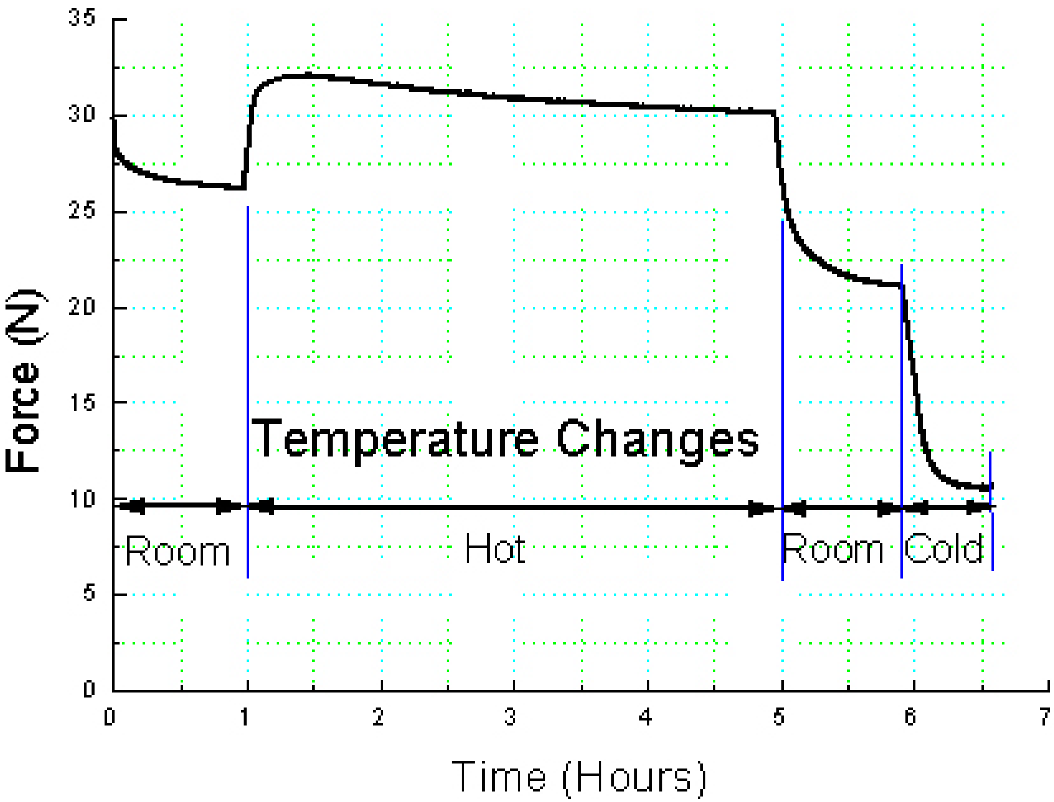
- Thermal Conductivity
- Thermal Diffusivity
- Specific Heat

Thermal Effects

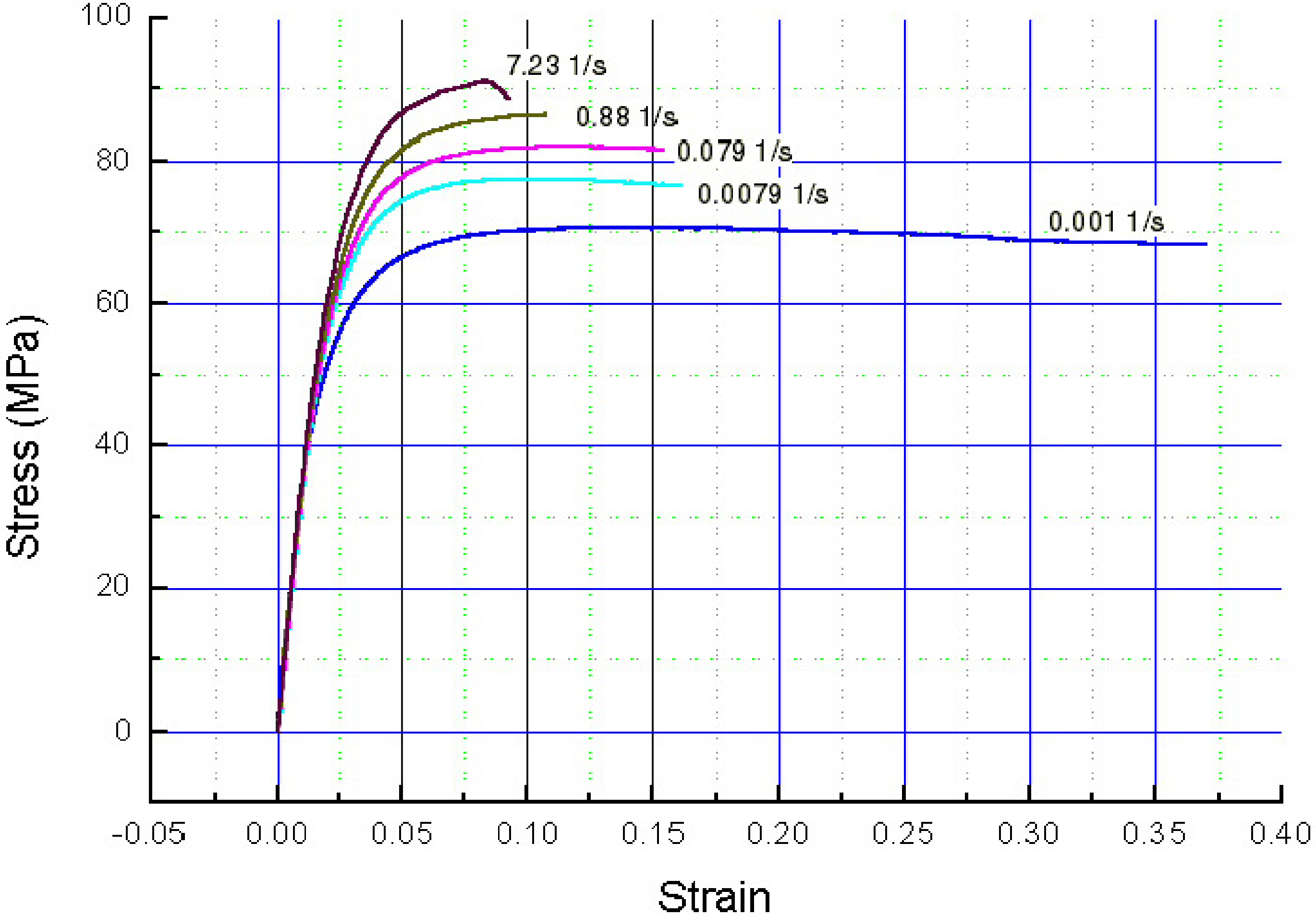


Thermal Effects

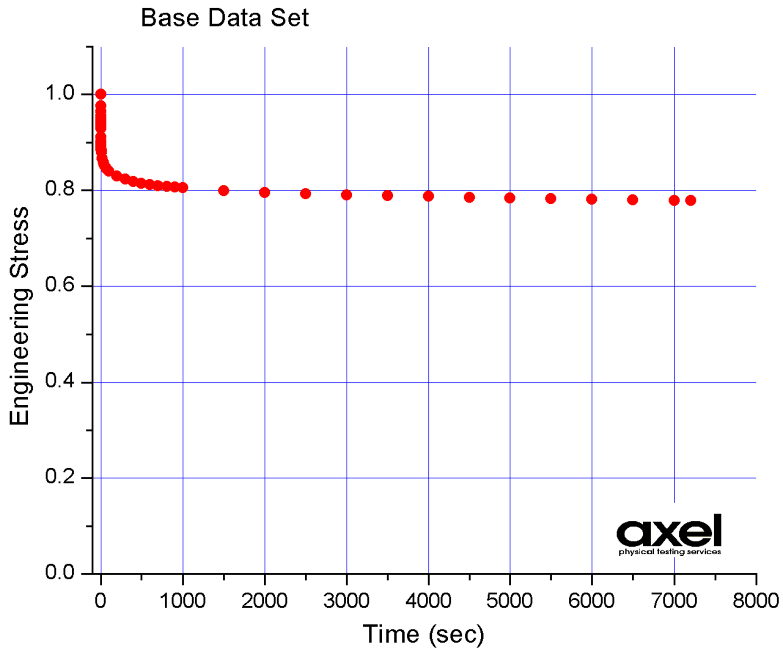




Rate of Loading



Viscoelastic Behavior – Testing



Viscoelastic Behavior

Can be Assumed to Reasonably Follow Linear Viscoelastic Behavior in Many Cases

Is not the same as aging!

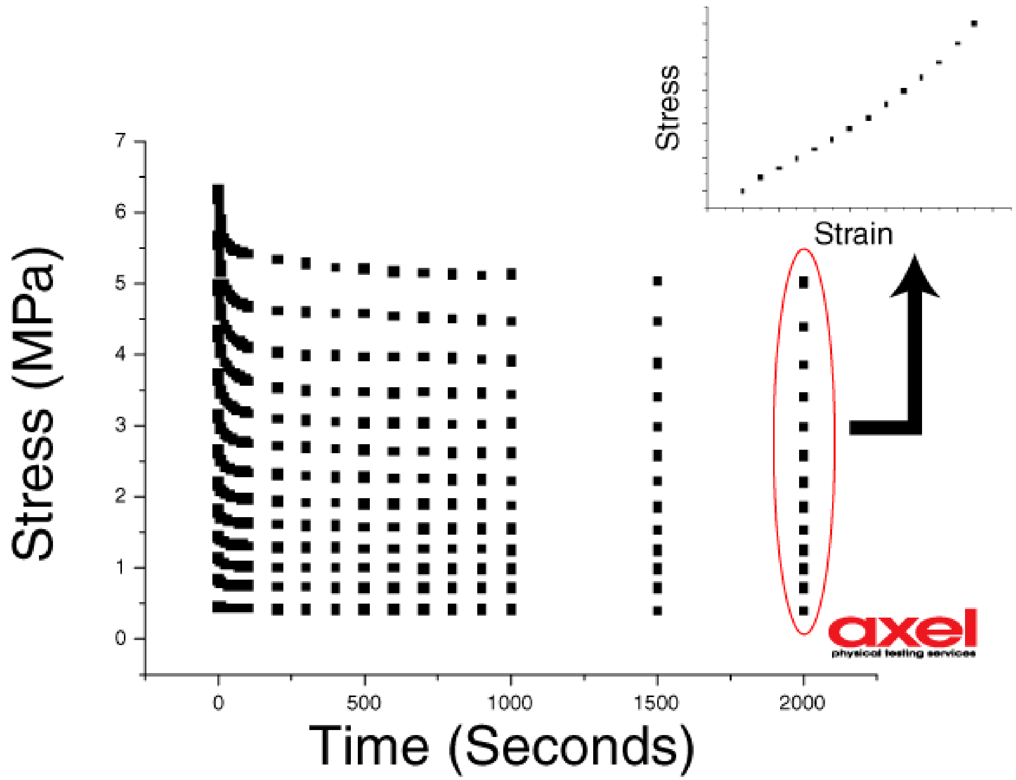
Describes the short term reversible behavior of elastomers.

Tensile, shear and biax have similar viscoelastic properties!

Viscoelastic Behavior – Testing

A totally "relaxed" Stress-strain Curve can Be Constructed

Decades of data in time are equally valuable for fitting purposes.

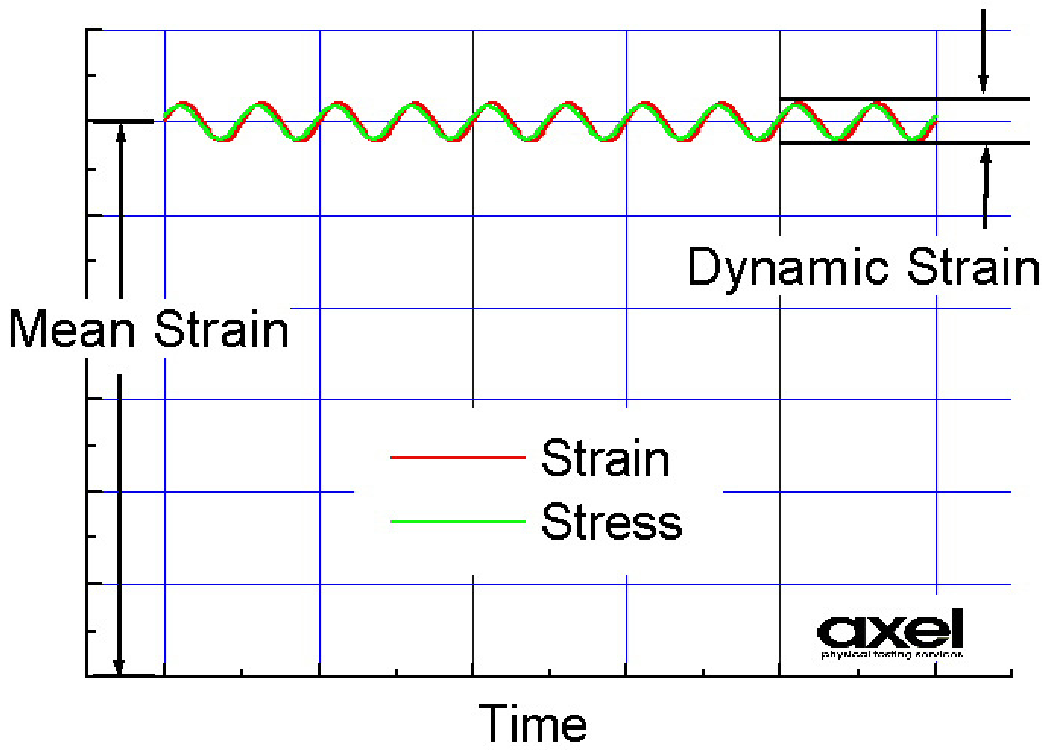


Dynamic Behavior - Testing

Types of Dynamic Behavior

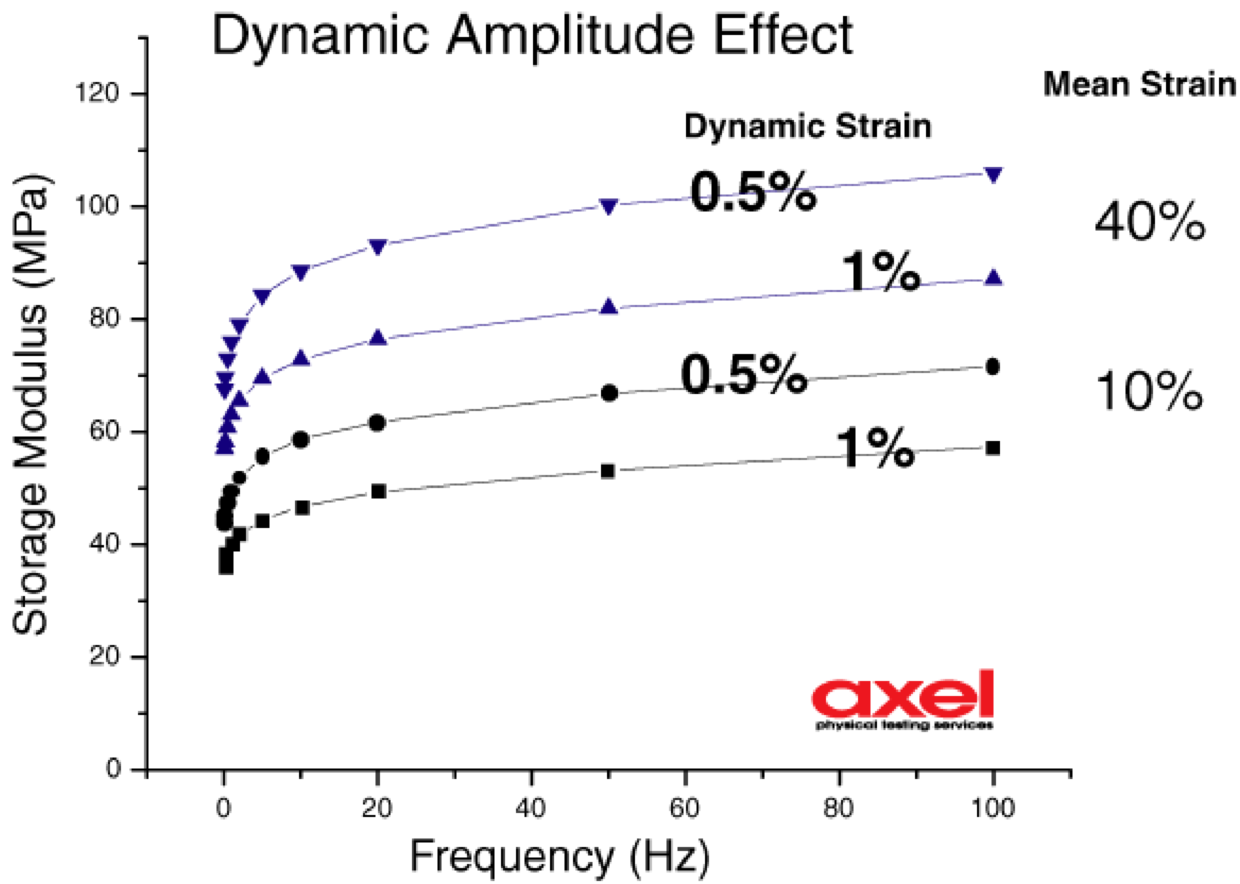
Large strains at high velocity

Small sinusoidal strains superimposed on large mean strains

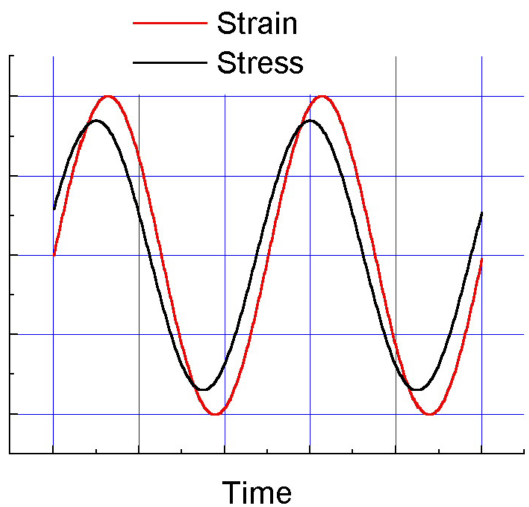


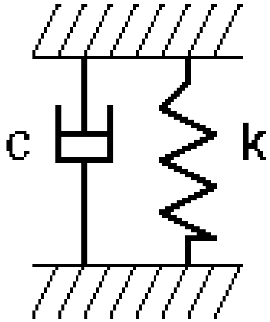
Dynamic Behavior - Testing

Mean Strain and Amplitude
Effects are Significant



Low Speed Testing





No inertia effect

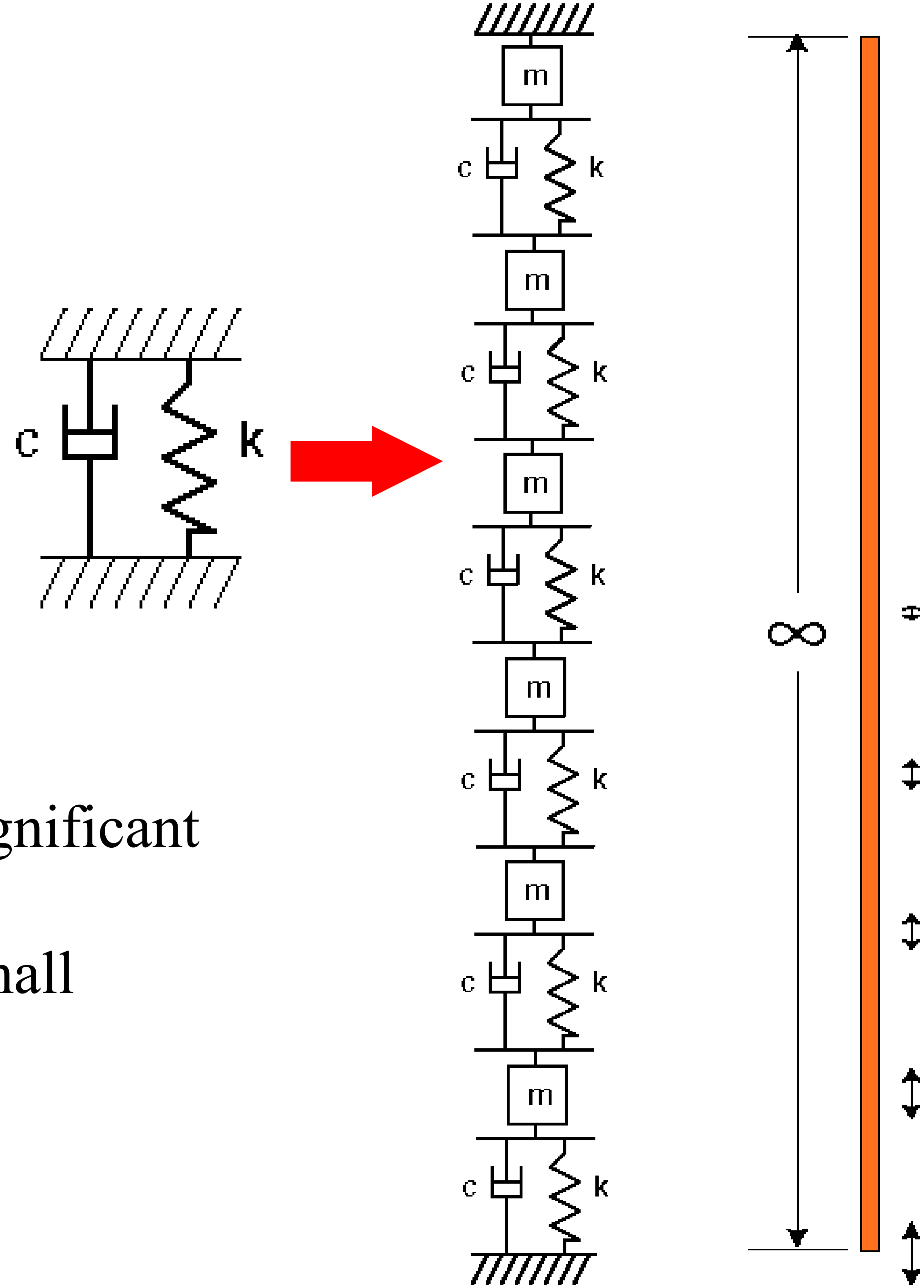
Long Wave Length vs Measurement

Dynamic Modulus = Peak Stress/ Peak Strain

Storage Modulus = E*cosδ

Loss Modulus = E*sinδ

High Speed Dynamics



Wave Propagation

Inertial effect is Significant

Wave Length is Small

100 - 10,000 Hz.

Wave Propagation

$$E^{*} = \rho c^{2}$$

Measure:

- Density ρ
- Wave Speed c
- Wave Decay

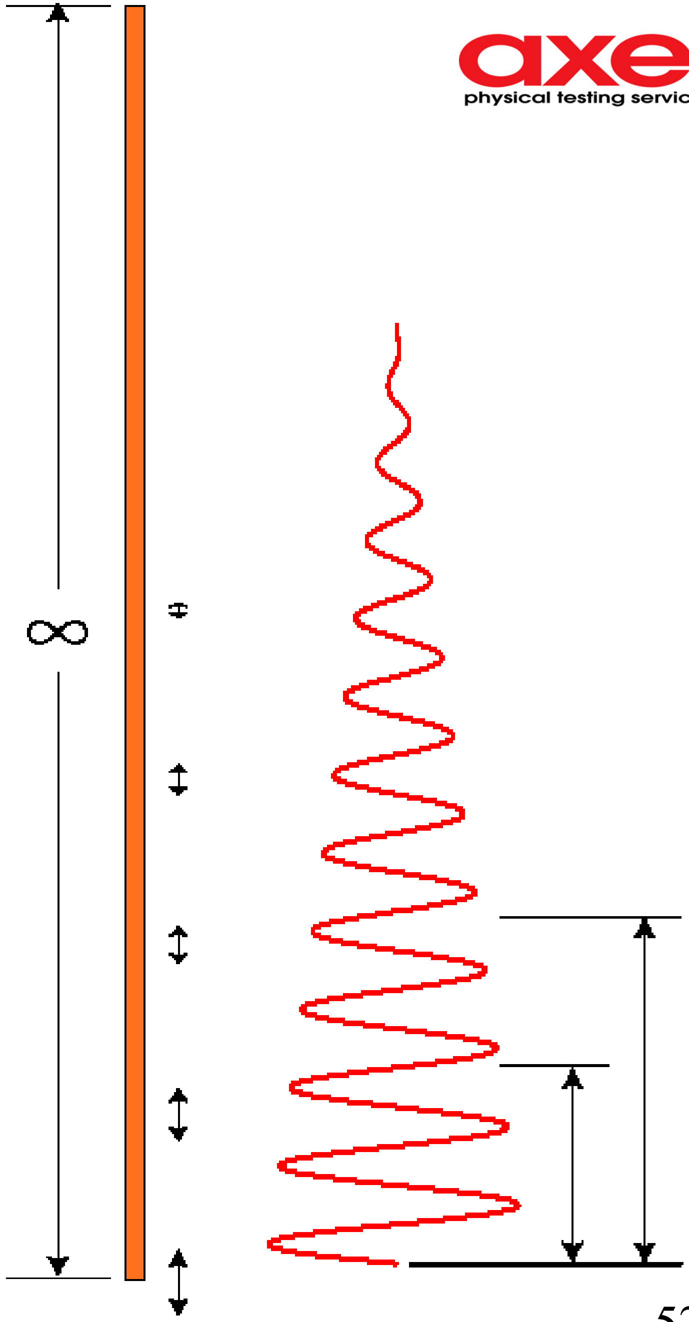
$c = f\lambda$

c speed of longitudinal wave

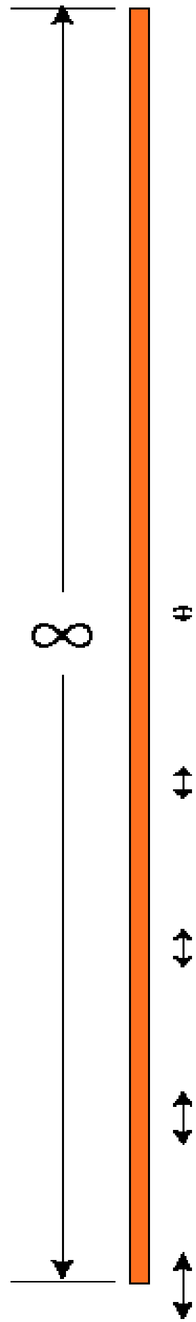
f excitation frequency

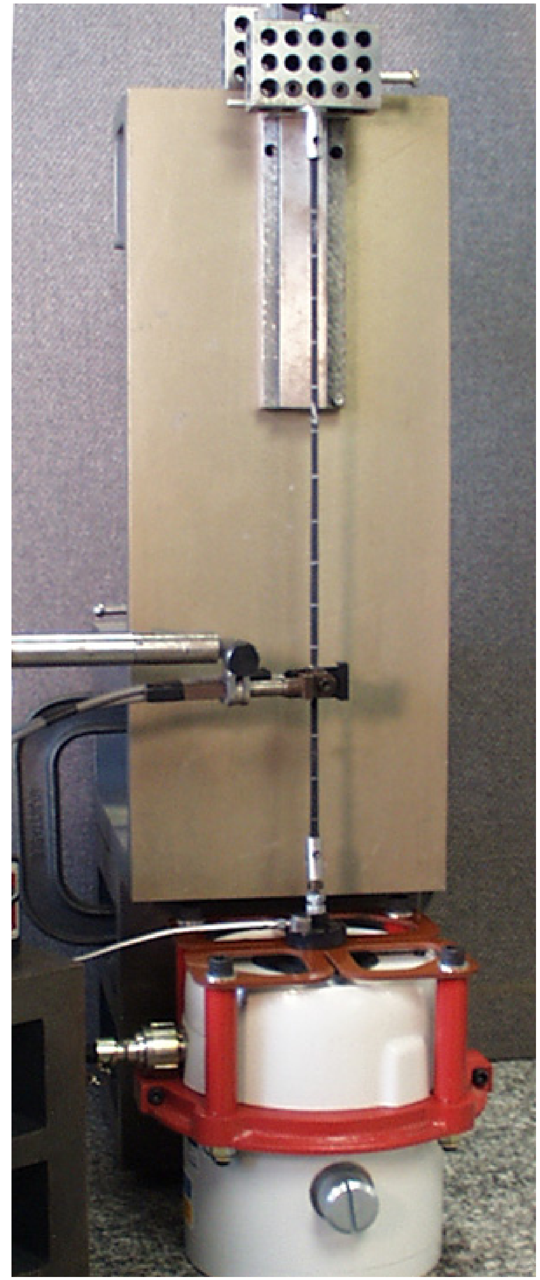
λ wave length

E* Dynamic Modulus

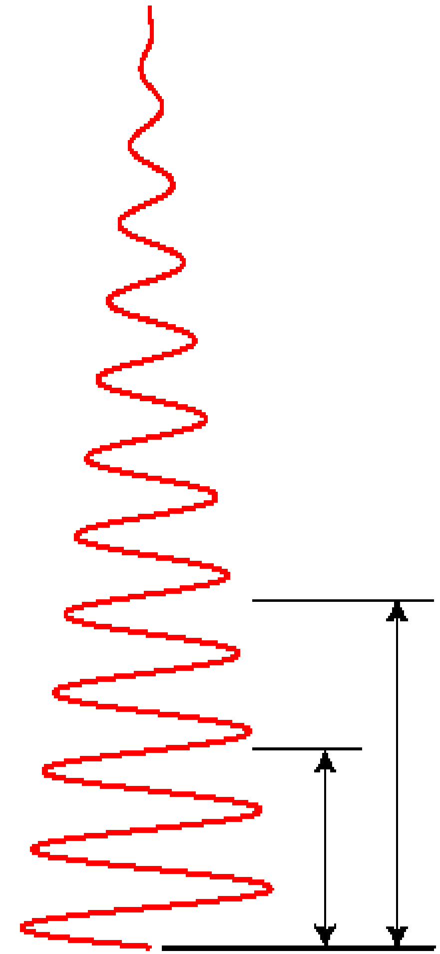


Wave Propagation

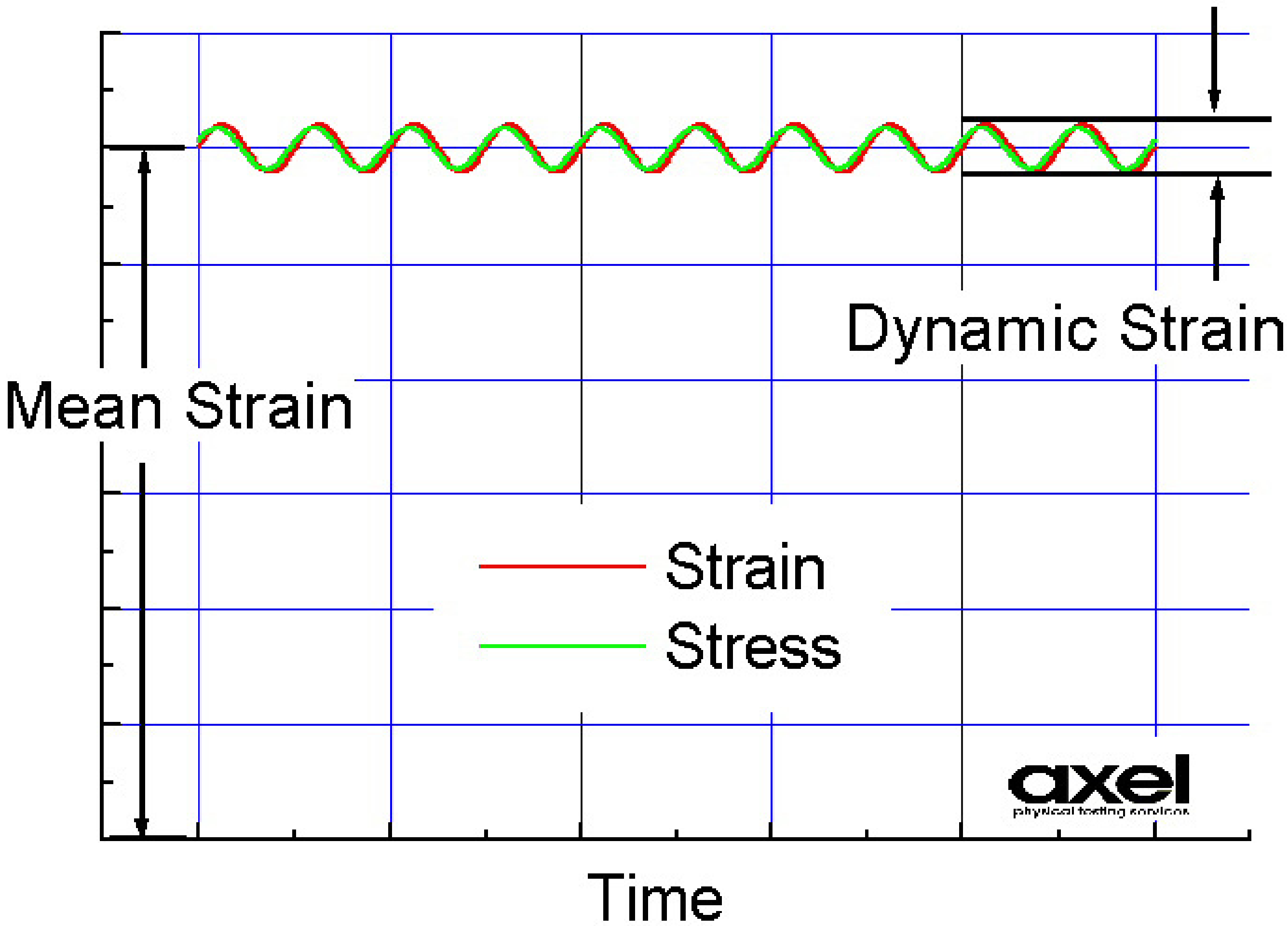




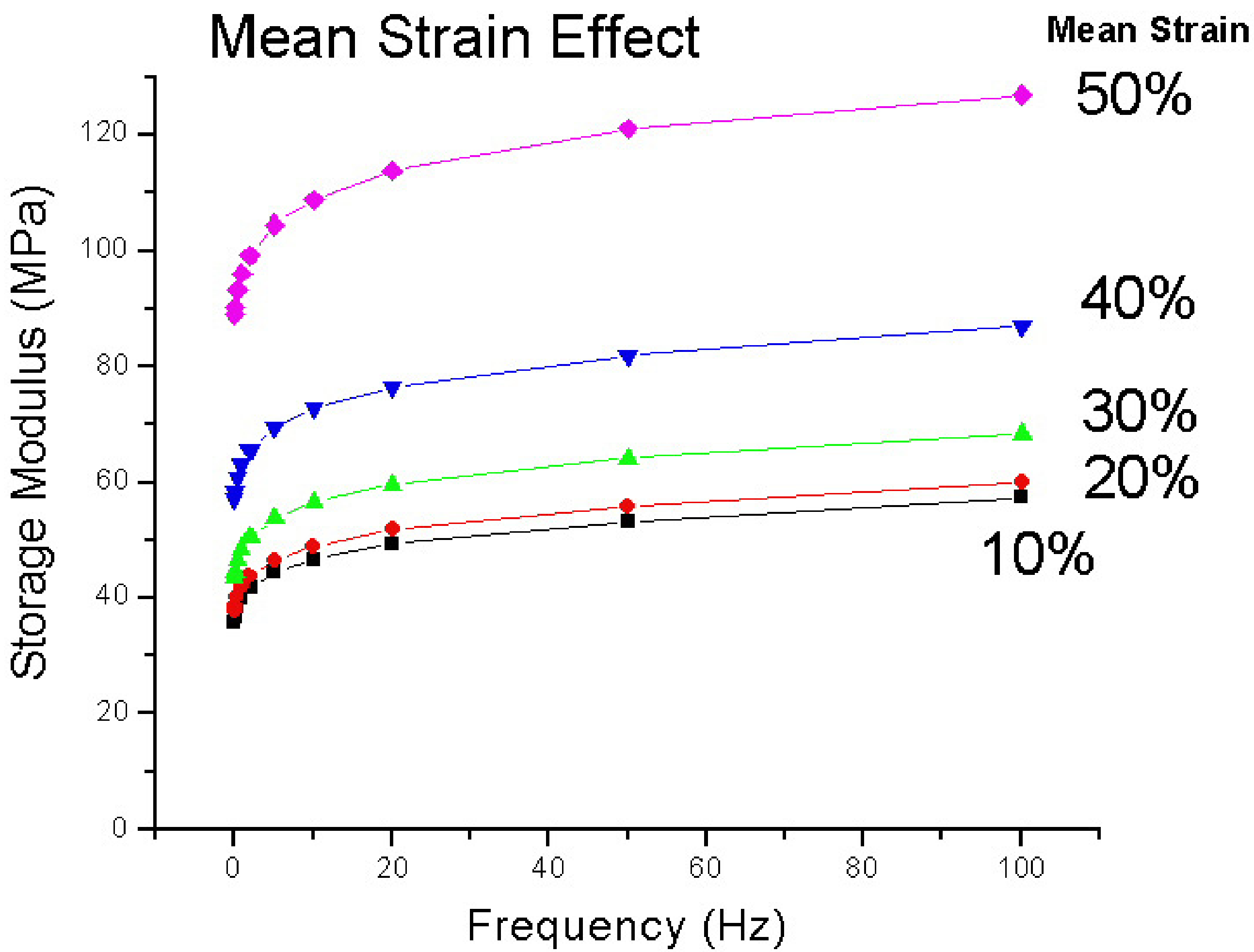
axel
physical testing services



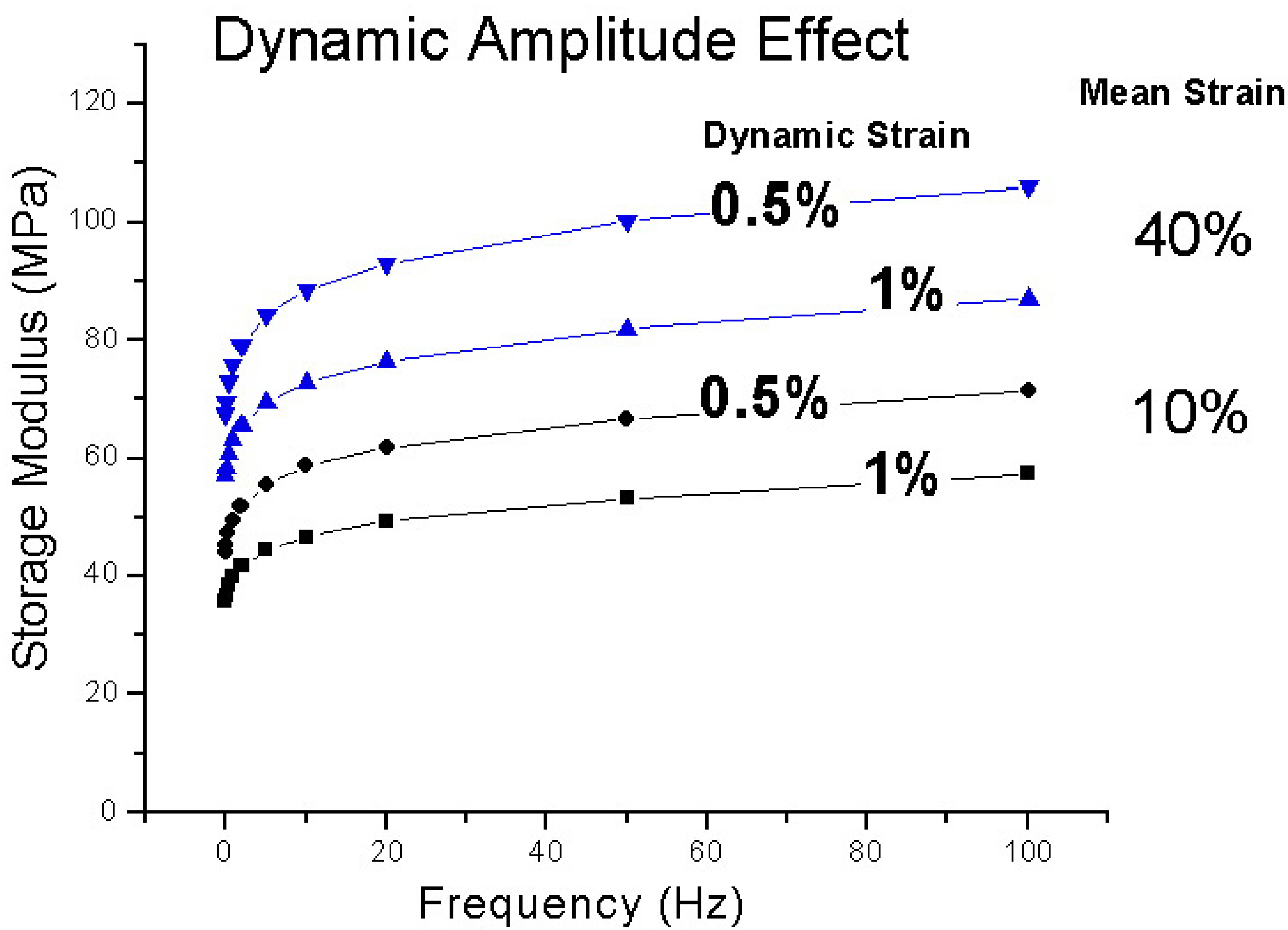
Dynamic Vibrations



Dynamic Vibrations



Dynamic Vibrations



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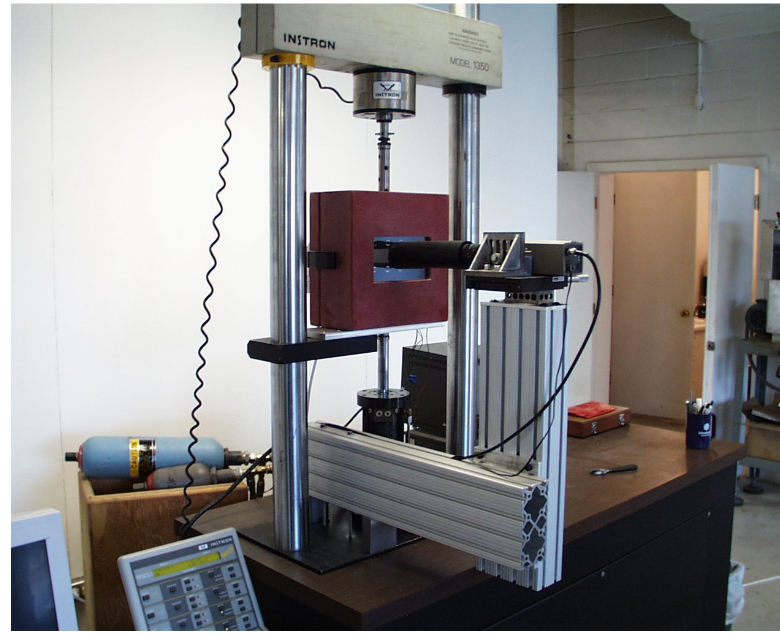
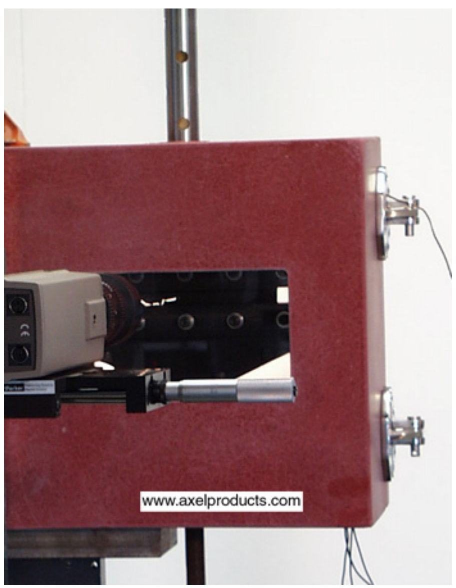
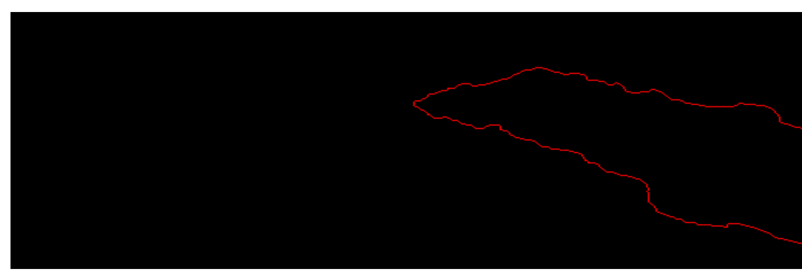
Fatigue Crack Growth

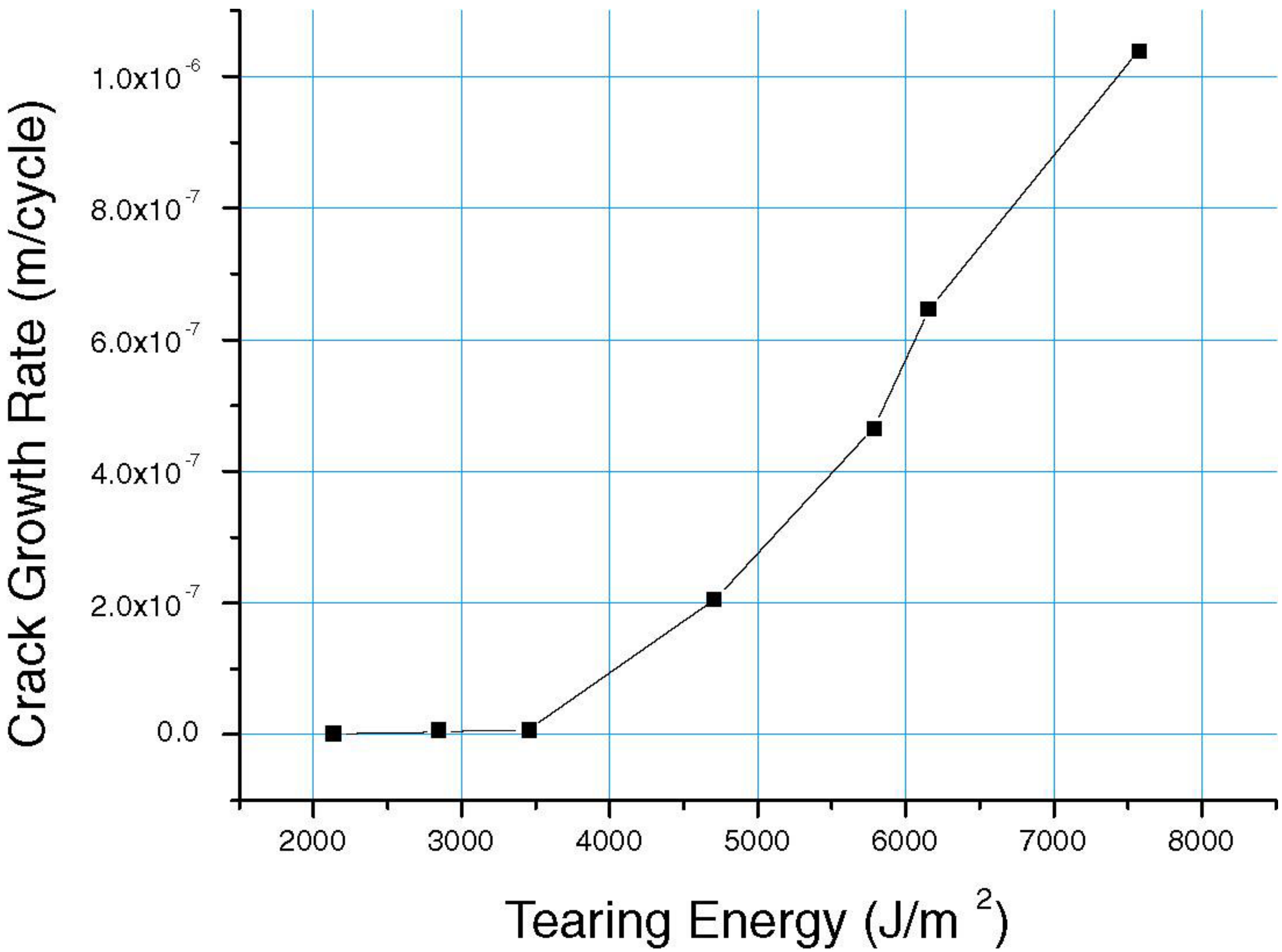
Provides Great Potential.
Not well understood.







Fatigue Crack Growth



Model Verification Experiments

Attributes of a Good Model Verification Experiment

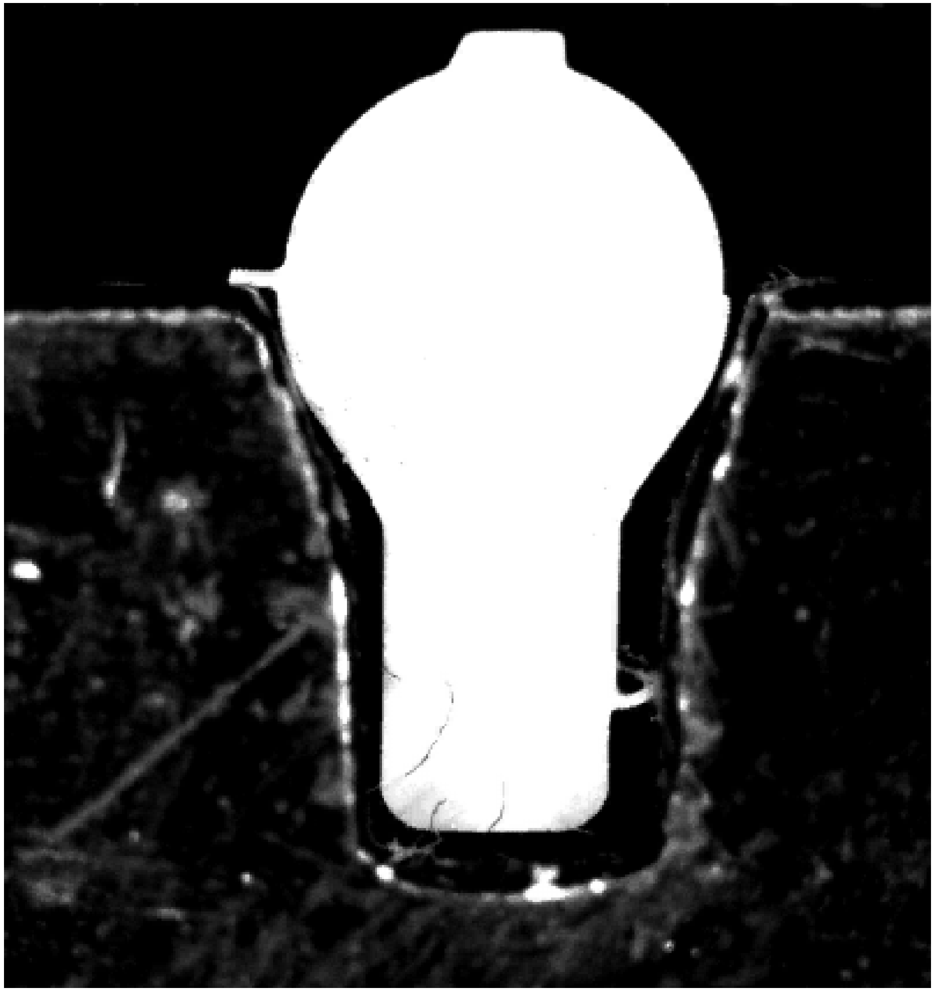
The geometry is realistic.

All Relevant Constraints are Measurable.

The Analytical Model is Well Understood

Model Verification Experiments

The Contribution of the Flashing on the Part was Unexpected, Initially Not Modeled, But Very Significant to the Actual Load Deflection



Thermal Aging