Testing Elastombers and Plastics for Marc Material Models

Presented by:
Kurt Miller
Axel Products, Inc.
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.

- Testing Elastomers for Hyperelastic Models (CEM)
We Measure Structural Properties

Stress – Strain–Time-Temperature
Test Combinations

- Softening
- Viscoelasticity
- Vibrations
- Rate, Set
- Set, Creep
- Fatigue
- All things Hot and Cold
- Directional
- Plastic + Unload
Nonlinear Elasticity with Permanent Set

- Parallel Rheological Framework - Behavior Supported
- Nonlinear Elasticity
- Viscoelastic
- Plasticity
- Damage

This Slide is Borrowed from MSC
Amplitude Dependent Harmonic Models

- Phenomenological models
  - Thixotropic (Lion)
    - Process dependent relaxation times (viscosities)
  - Triboelastic
    - Cyclic plasticity
  - Direct
    - Kraus/Ulmer
  - Combined thixotropic and triboelastic
- General models
  - Tabular
  - User defined

This Slide is Borrowed from MSC
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
Isolate Behaviors

- Separate Elastic & Plastic
- Go to the Application Temperature
- Observe Failure
- Grow the Defect
- Go Very Slow
- Go Very Fast

You Can’t Model Everything!
Rubber Bands
Rubber
A Spring and a Dashpot?
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.

\[
\frac{K}{G} = \frac{2(1 + \nu)}{3(1 - 2\nu)}
\]
What Does Incompressible Mean?

Constrained vs Unconstrained Compression

VOLUMETRIC COMPRESSION

SIMPLE COMPRESSION

Soft Elastomer

Axel Products, Inc.  www.axelproducts.com   734-994-8308
Incompressibility

Not a spring and dashpot
Rubber
Hyperelastic Surface
Hyperelastic Material Models

1. There are many in Marc.
2. They capture incompressibility.
3. You don’t know which is best until you try to fit real data.
4. Use the simplest math that works.
Loading Conditions

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

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

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

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
Harmonic Vibrations

1. Types of Dynamic Behavior
2. Large strains at high velocity
3. Small sinusoidal strains superimposed on large mean strains
Vibrations

No inertia effect
Long Wave Length vs Measurement

Dynamic Modulus = Peak Stress/ Peak Strain
Storage Modulus = E*\cos\delta
Loss Modulus = E*\sin\delta
Vibrations

Data at 30% Mean Strain
Vibrations

Mean Strain Effect

Mean Strain
50%
40%
30%
20%
10%

Storage Modulus (MPa)

Frequency (Hz)
Vibrations

Dynamic Amplitude Effect

- Dynamic Strain 0.5%
- Dynamic Strain 1%
- Mean Strain 40%
- Mean Strain 10%

Storage Modulus (MPa)
Frequency (Hz)
Amplitude Dependent Harmonic Models

- Phenomenological models
  - Thixotropic (Lion)
    - Process dependent relaxation times (viscosities)
  - Triboelastic
    - Cyclic plasticity
  - Direct
    - Kraus/Ulmer
  - Combined thixotropic and triboelastic
- General models
  - Tabular
  - User defined

This Slide is Borrowed from MSC
Payne Effect - Introduction

- Payne effect or Fletcher-Gent effect
  - Many filled rubbers show a pronounced effect of amplitude on storage ($G'$) and loss ($G''$) modulus when subjected to harmonic loads.
  - Frequency dependent damping, incorporating the effect of the excitation magnitude
- Marc Implementation
  - With Marc Harmonic approach the complete analysis can be done as one job, stepping through the preload, stepping through the harmonic frequency and stepping through the harmonic excitation magnitude

\[
G' \quad \text{log}(\Delta \varepsilon) \\
G'' \quad \text{log}(\Delta \varepsilon)
\]
Cold and Hot

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

Plastic is NOT incompressible.
Plastic

Note: Stress and strain are total quantities.
Plastic
(small deformation plasticity)
Plastic

Tensile Test

Stress

Strain

Region of Interest
Plastic

- Modulus is Unclear
- Yield is Unclear
- Load = Unload?
- Set
Thermoplastic Elastomers

![Graph showing Thermoplastic Elastomer behavior](graph.png)

Axel Products, Inc.  www.axelproducts.com   734-994-8308
Teflon

Stress (MPa)

Strain

Loading and Unloading

Single Pull

Axel Products, Inc.  www.axelproducts.com   734-994-8308
Nonlinear Elasticity with Permanent Set

- Parallel Rheological Framework - Behavior Supported
- Nonlinear Elasticity
- Viscoelastic
- Plasticity
- Damage

This Slide is Borrowed from MSC
Parallel Rheological Framework (PRF)

- Primary Network (0)
  - Mooney
  - Ogden
  - Gent
  - Arruda-Boyce
  - Foam
  - Isotropic

- Viscoelastic (1 to n) – Visco Hype
  - Arruda-Boyce

- Plasticity (n+1 to m) – Perm Set
  - Ogden
  - Arruda-Boyce
  - Isotropic

This Slide is Borrowed from MSC
Simple Shear

1. Additional Strain State
2. Using DIC Strain Measuring
Long Term Creep

![Graph showing creep strain over time for different stress levels](image)
Plastic

Long Term Creep Experiments
- Often Required for Metal Replacement Applications
- Structural Applications May Require a Range of Stress Levels and Temperatures
Plastic Rates
Structural Properties
Structural Properties
Structural Properties
Fracture in Plastic
Soft Edge - Initial Crack

This Slide is Borrowed from MSC
This Slide is Borrowed from MSC

Soft Edge - Crack Propagation

Axel Products, Inc.  www.axelproducts.com   734-994-8308
Focused Mesh at Crack Tip after Crack Propagation
In Summary

– Marc has Great Material Models
– Understand the General Behavior of Material
– Capture Only what is Needed

Thank you!
... Kurt

• kurt@axelproducts.com