Modeling Rubber and Viscoelasticity with Abaqus

Abaqus 2017
Course objectives
Upon completion of this course you will be able to:

- Use experimental test data to calculate material constants
- Check the stability of the Abaqus material model at extreme strains
- Obtain the best possible material constants from the available test data
- Select elements for modeling rubber and foams
- Design an appropriate finite element mesh
- Model viscoelastic behavior in both the time and frequency domain
- Use a user subroutine to define the hyperelastic behavior

Targeted audience
Simulation Analysts

Prerequisites
This course is recommended for engineers with experience using Abaqus

2 days
Day 1

- Lecture 1  Rubber Physics
- Lecture 2  Introduction to Hyperelasticity Models
- Lecture 3  Mechanical Testing
  - Workshop 1  Axial Deflection of a Rubber Bushing
- Lecture 4  Defining Rubber Elasticity Models in Abaqus
- Lecture 5  Modeling Issues and Tips
  - Workshop 2  Bead Seal Compression
Day 2

- Lecture 6  Viscoelastic Material Behavior
- Lecture 7  Time-Domain Viscoelasticity
  - Workshop 3  Bead Seal Relaxation
- Lecture 8  Frequency-Domain Viscoelasticity
  - Workshop 4  Bead Seal Vibration
- Lecture 9  Permanent Set in Solid Elastomers
- Lecture 10  Anisotropic Hyperelasticity
### Additional Material

- **Appendix 1**  Finite Deformations
- **Appendix 2**  Rubber Elasticity Models: Mathematical Forms
- **Appendix 3**  Linear Viscoelasticity Theory
- **Appendix 4**  Harmonic Viscoelasticity Theory
- **Appendix 5**  Suggested Reading
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- SIMULIA is the Dassault Systèmes brand for Realistic Simulation solutions

- Portfolio of established, best-in-class products
  - Abaqus, Isight, Tosca, fe-safe, Simpack

* Included in extended licensing pool
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<table>
<thead>
<tr>
<th>App</th>
<th>Features</th>
<th>Tools</th>
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| **Abaqus**| • Routine and Advanced Simulation  
• Linear and Nonlinear, Static and Dynamic  
• Thermal, Electrical, Acoustics  
• Extended Physics through Co-simulation  
• Model Preparation and Visualization | Realistic Human Simulation  
High Speed Crash & Impact  
Noise & Vibration |
| **Isight**| • Process Integration  
• Design Optimization  
• Parametric Optimization  
• Six Sigma and Design of Experiments | Material Calibration  
Workflow Automation  
Design Exploration |
| **Tosca** | • Non-Parametric Optimization  
• Structural and Fluid Flow Optimization  
• Topology, Sizing, Shape, Bead Optimization | Conceptual/Detailed Design  
Weight, Stiffness, Stress  
Pressure Loss Reduction |
| **fe-safe**| • Durability Simulation  
• Low Cycle and High Cycle Fatigue  
• Weld, High Temperature, Non-metallics | Safety Factors  
Creep-Fatigue Interaction  
Weld Fatigue |
| **Simpack**| • 3D Multibody Dynamics Simulation  
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Lesson content:

- Motivation
- Solid Rubber
  - Molecular structure
  - Material processing
  - Glass transition temperature
  - Nearly incompressible behavior
  - Typical stress–strain response
  - Hysteresis and damping
  - Damage
  - Anisotropy
- Thermoplastic Elastomers
  - Physical description
  - Advantages and disadvantages
- Rubber Foam
  - Physical description
  - Cellular structure
  - Typical stress–strain response
  - Poisson’s effect
- The Nonlinear Elastic Assumption

Lesson 1: Rubber Physics
30 minutes
Lesson 2: Introduction to Hyperelasticity Models

Lesson content:
- Introduction
- Models for Nearly Incompressible Hyperelasticity
- Model for Foam Rubber Hyperelasticity (Hyperfoam)
Lesson 3: Mechanical Testing

Lesson content:

- Modes of Deformation
  - Uniaxial tension
  - Planar tension
  - Uniaxial compression
  - Equibiaxial tension
  - Confined compression
- Loading History
  - Testing at temperature
- Test Specimens
- Test Data Guidelines
- Testing for Time-Dependent Properties
- Workshop Preliminaries
- Workshop 1: Axial Deflection of a Rubber Bushing (IA)
- Workshop 1: Axial Deflection of a Rubber Bushing (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Curve-Fitting for Hyperelasticity of Nearly Incompressible Materials
- Material Stability
- Curve-fitting in Abaqus/CAE
- Choosing a Hyperelastic Model
- Augmenting Data
- Defining Hyperelastic Models
- Mullins Effect
- Hyperfoam Model
- UHYPER

Lesson 4: Defining Rubber Elasticity Models in Abaqus

1.5 hours
Lesson 5: Modeling Issues and Tips

Lesson content:

- Contact
- Element Selection
- Meshing Considerations
- Constraints and Reinforcements
- Instability
- Output Variables
- Using Abaqus/Explicit for Rubber Analyses
- Special Features
- Example: Column Shifter Boot
- Example: Weather Seal
- Workshop 2: Bead Seal Compression (IA)
- Workshop 2: Bead Seal Compression (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.
Lesson content:

- Introduction
- Effects of Viscoelasticity
  - Creep
  - Stress relaxation
  - Damping and hysteresis
- Linear Viscoelasticity
- Finite-strain Nonlinear Viscoelasticity
- Temperature Dependence
Lesson 7: Time-Domain Viscoelasticity

Lesson content:

- Classical Linear Viscoelasticity
- Prony Series Representation
- Finite-Strain Linear Viscoelasticity
- Relaxation and Creep Test Data
- Prony Series Data
- Automatic Material Evaluation
- Time-Temperature Correspondence
- Usage Hints
- Finite-Strain Nonlinear Viscoelasticity
- Structural Relaxation in Glass
- Workshop 3: Bead Seal Relaxation (IA)
- Workshop 3: Bead Seal Relaxation (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.

2.5 hours
Lesson content:

- Frequency-Domain Response
- Storage and Loss Moduli
- Classical Isotropic Linear Viscoelasticity
- Isotropic Finite-Strain Viscoelasticity
- Procedures
- Workshop 4: Bead Seal Vibration (IA)
- Workshop 4: Bead Seal Vibration (KW)

Both interactive (IA) and keywords (KW) versions of the workshop are provided. Complete only one.

1.75 hours
Lesson 9: Permanent Set in Solid Elastomers

Lesson content:

- Motivation
- Defining Permanent Set
- Example
- Summary
Lesson 10: Anisotropic Hyperelasticity

Lesson content:

- Motivation
- Models Available in Abaqus
- Examples
Appendix 1: Finite Deformations

Appendix content:

- Motions and Displacements
- Extension of a Material Line Element
- The Deformation Gradient
- Strain for Large Deformations
- Decomposition of a Deformation
- Principal Stretches and Principal Axes of Deformation
- Strain Invariants
- Deformation Example – Simple Shear
- Summary

45 minutes
Appendix content:

- Energy Functions for Solid Rubbers (Isotropic)
  - Polynomial Model
  - Mooney-Rivlin Model
  - Reduced Polynomial Model
  - Neo-Hookean Model
  - Yeoh Model
  - Ogden Model
  - Marlow Model
  - Arruda-Boyce Model
  - Van der Waals Model
- Foam Rubber Model
- Mullins Effect
Appendix 3: Linear Viscoelasticity Theory

Appendix content:

- Classical Linear Viscoelasticity
Appendix 4: Harmonic Viscoelasticity Theory

Appendix content:

- Classical Linear Viscoelasticity
- Harmonic Excitation
Appendix 5: Suggested Reading

Appendix content:

- Suggested Reading

15 minutes