Testing and Analysis

Fitting a Hyperelastic Mullins Model to Describe the Stress Distribution in a Rubber Mount

Objective

A material model is needed to describe the stress distribution in an elastomeric mount during use.

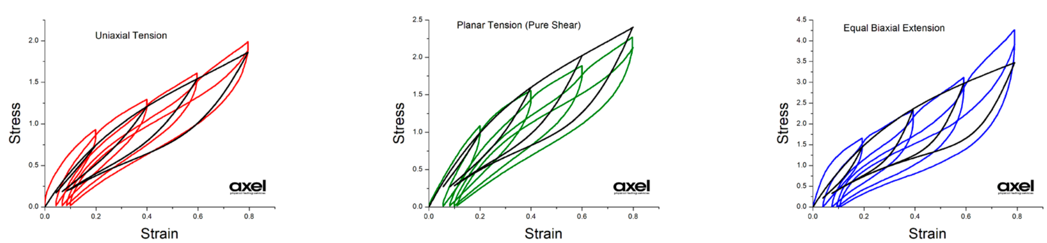
Introduction

At Axel, we fit material models based on the needs of the simulation, the capabilities of the finite element software being used, and the behavior of the material. In this case, the material will be compressed and somewhat confined in a metal housing. A hyperelastic model is selected to capture the incompressible material behavior during use to describe the complex strain field and predict the performance of the part. A Mullins model is used along with the hyperelastic material model to describe the reduction in stiffness from multiple loadings and the reduction in stiffness based on the maximum strain on an element by element basis. This will allow elements in the simulation to soften based on the maximum local strain.

Testing and Modeling Effort

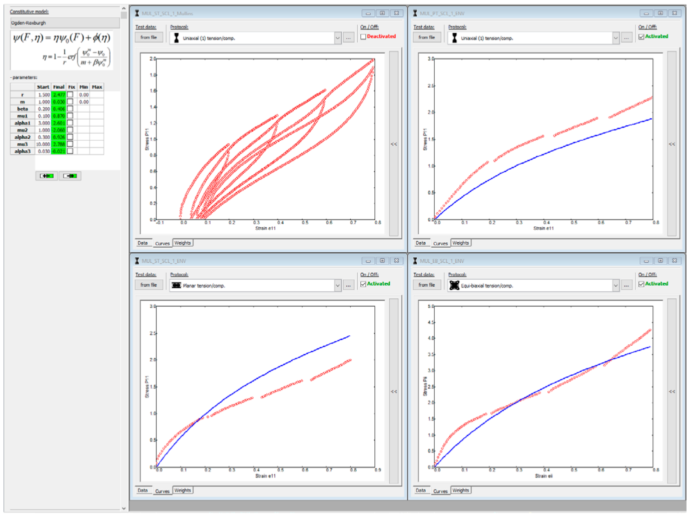
Physical experiments are performed in multiple strain states so that the calibrated hyperelastic model describes the material behavior during its complex deformation. Multiple models are reviewed and the simplest math model with the best fit is selected. Models considered include Mooney-Rivlin, Neo-Hookean, Yeoh, Ogden, Gent, and Arruda-Boyce. The experiments run are the three classic experiments: uniaxial tension, planar tension (pure shear), and equal biaxial extension. Because the bushing will experience significant confinement, a volumetric experiment is performed to capture the bulk behavior. Uniaxial compression is avoided because of adverse friction effects during the experiment.

The experiments were run using a slow cyclic time-strain loading-unloading pattern. The test specimens were stretched from zero stress to 20% strain and unloaded to zero stress 5 times and then strained to 40% strain and unloaded to zero stress 5 times and on to 60% and 100% strain levels in the same way. This loading pattern allows us to observe the effects of Mullins softening on the material stiffness and allows us to observe any plastic strain accumulation. The 20%, 40%, 60%, and 100% strain levels were selected because these strains are typical of the strains in the part during use.

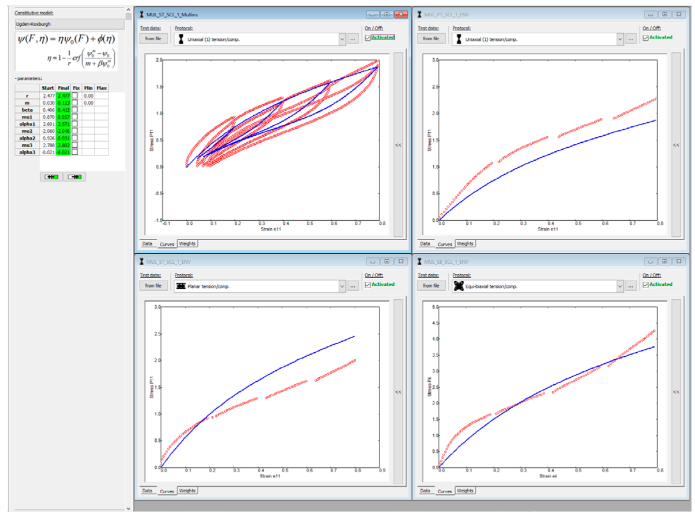


The Hyperelastic Mullins Fit (black curves) is shown compared to experimental data in Uniaxial Tension, Planar Tension, and Equal Biaxial Extension.

We approach this by separating the hyperelastic and Mullins softening parts of the material model. An "envelope" curve is first constructed from the data set to represent what would be similar to a first-time loading. The uniaxial tension, planar tension, and equal biaxial extension data are first fitted to a suitable hyper-elastic model. The complete data sets are then prepared for the Mullins fitting. We do this by extracting the first and last loadings to each strain level. This is preferred over trying to fit the entire data set because the number of data points is large and because the Mullins can only describe the final condition. Therefore, having the 2nd, 3rd, and 4th loading-unloading curves in the fitting process doesn't help. Finally, the Mullins terms are fitted by using the all of the data in one operation.



Using Hyperfit software to first fit envelope data.



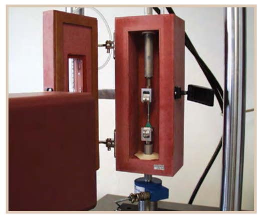
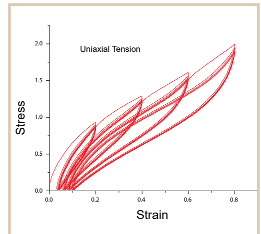
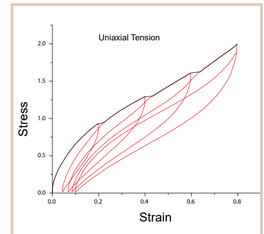
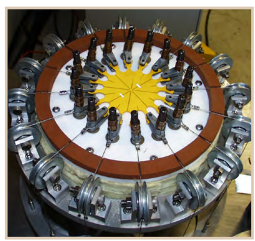
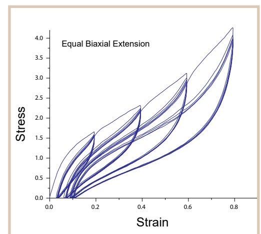
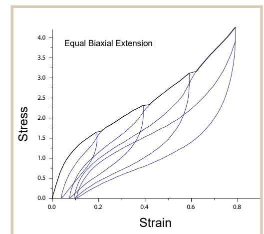
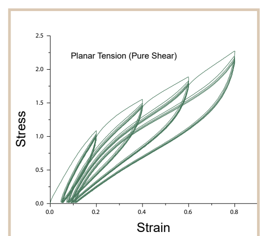
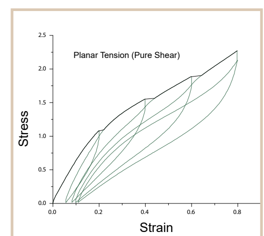
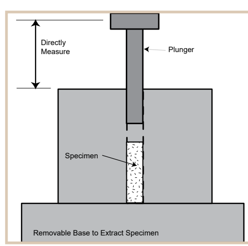
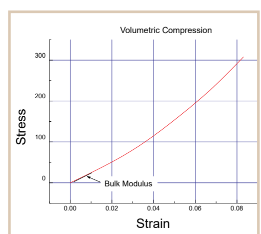
Using Hyperfit software to fit Mullins parameters.

We used a commercial fitting tool, Hyperfit, to do the fitting operation. The same data handling tasks would be applicable using other fitting tools.

The last step is to run single element models to verify that the material model performs as expected in the simulation software under the loading conditions of the experiments. This step must happen. In this case, we ran Abaqus single element simulations in uniaxial tension, planar tension, and equal biaxial extension and compared these results to the experimental data. Any time fitting tools external to the simulation software are used verification must take place because simple or extreme errors may appear.

Test Plan Summary:
Uniaxial Tension Test, Slow Cyclic Loading, 23C
Planar Tension Test, Slow Cyclic Loading, 23C
Uniaxial Tension Test, Slow Cyclic Loading, 23C
Volumetric Compression, 23C

Analysis Tools Summary:
Axel Internal Data Handling Tools
Hyperfit fitting utility
Simulia Abaqus for Single Element Verification

	Typical Specimen	Test	Raw Data	Mullins Curves
Uniaxial Tensile				
Equal Biaxial Extension				
Planar Tension				
Volumetric Compression				

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Axel Products provides physical testing services for engineers and analysts. The focus is on the characterization of nonlinear materials such as elastomers and plastics.

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