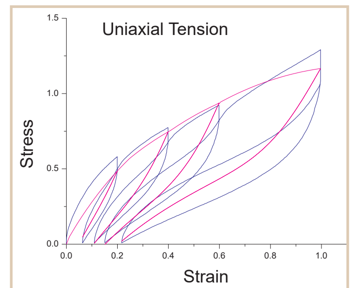
Testing and Analysis

Capturing Set and Plastic Behavior in Thermoplastic Elastomers and Elastomers used Near Tg

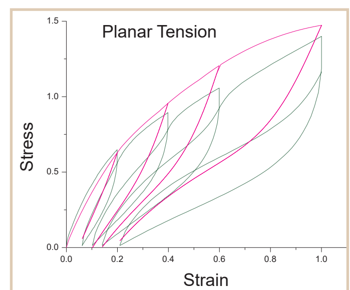
Objective
A material model is needed to describe the stress distribution and the set in an elastomeric part during use.

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. In addition, the application requires that we predict the plastic set in the part as well. In this case, the material does have significant set during in-use operations and the simulation software Abaqus supports the combination of plastic and hyperelastic material descriptions.



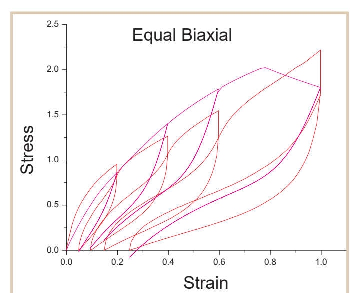
Uniaxial Tension Data with fit (magenta).

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. The experiments run are the three classic experiments: uniaxial tension, planar tension (pure shear), and equal biaxial extension. Because the part 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.



Planar Tension Data with fit (magenta).

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 also 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.



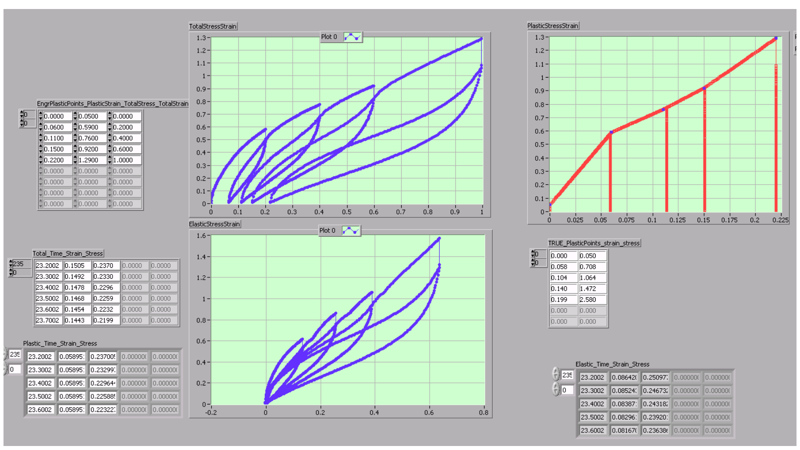
Equal Biaxial Extension Data with fit (magenta).

We approach this by separating the plastic, the hyperelastic, and Mullins softening parts of the material model. The plastic behavior is first extracted by using the loading-unloading data to identify the plastic strain resulting from the total stress at each of the 20%, 40%, 60%, and 100% strain maximums. A first pass isotropic plastic material model can be identified and the remaining elastic behavior can be separated. At Axel, we have an in-house software tool to do this. The tools to perform this operation also exist in CAE and are well documented in the Simulia Learning Community material modeling page.

After the plastic behavior is separated, hyperelastic and Mullins models may be constructed for the modified data sets. To do this, 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. 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.

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. This is a complex material model and verification is critical.



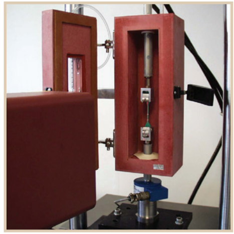
Using the math from Simulia Support Note QA00000041611, the plastic (upper right) and elastic (lower left) are separated from the total data set (upper left).

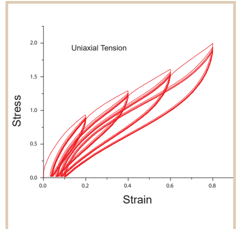
Test Plan Summary:
Uniaxial Tension Test, Slow Cyclic Loading, 23C
Planar Tension Test, Slow Cyclic Loading, 23C
Uniaxial Tension Test, Slow Cyclic Loading, 23C
Volumetric Compression, 23C

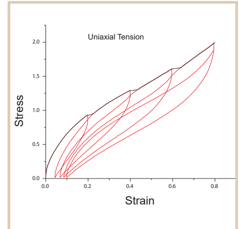
Analysis Tools Summary:
Axel Internal Data Handling Tools
Hyperfit fitting utility
Simulia Abaqus for Single Element Verification

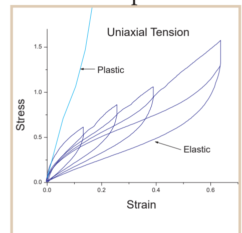
Typical Specimen | Test | Test Data | Mullins Curves | Hyperelastic-Plastic Separation

Uniaxial Tensile

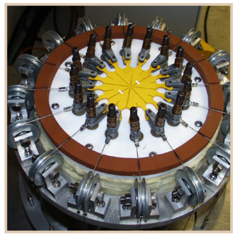


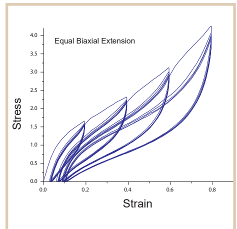


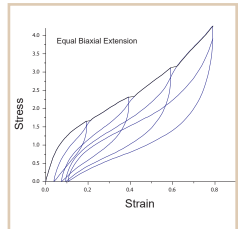


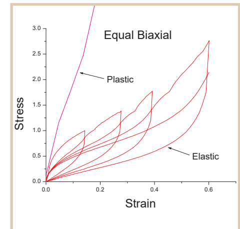


Equal Biaxial Extension

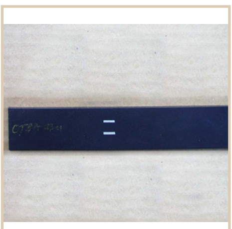


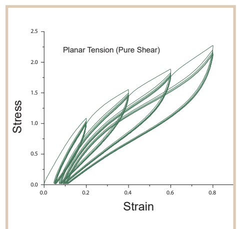


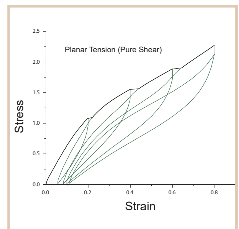


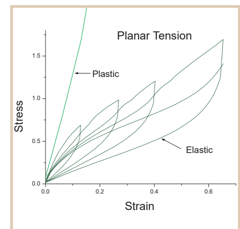


Planar Tension

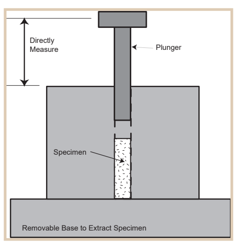


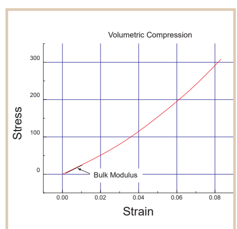






Volumetric Compression





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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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