

Testing Brief

Compression or Biaxial Extension?



Figure 1, Compression Experiment

Introduction

When fitting hyperelastic material models in analytical software, it is desirable to fit experimental data in multiple states of strain so that the material model can effectively analyze complex strain states that occur in simulations. The basic strain states of tension, shear and compression should be represented if possible. Both tension information and compression information is required because unlike some metal material models, elastomers behave very differently in compression than in tension. This brief will examine 2 experiments intended to provide compression information.

Discussion

An additional requirement is that the experimental data represent pure states of strain. In other words, the tension experiment should be performed in a state of simple tension only without any shear or compression strains. This can be achieved by making the specimen very long relative to the width or thickness. Likewise, a simple compression experiment needs to be free of shear or tensile strains. To achieve this, the test specimen needs to be compressed between two platens without any friction effects between the platens and the specimen (Figure 1). Naturally, this is impossible so the question becomes, “Are the effects of friction significant?”

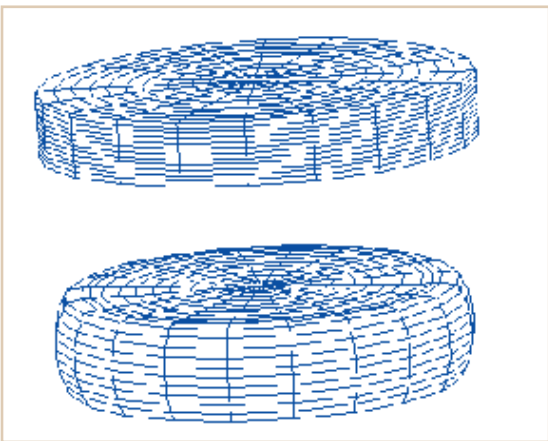


Figure 2, Finite Element Analysis of a Compression Experiment

To better understand this, Jim Day of GM Powertrain analytically examined the effects of friction on the standard ASTM D395, type 1 button which is used in ASTM 575 Standard Test Methods for Rubber Properties in Compression (Figure 2) [1]. A material model was developed and the specimen was analytically strained. The coefficient of friction was altered to see the effect of friction on the resulting stress-strain data. A coefficient of friction value of zero corresponds to a perfect state of simple uniaxial compression. (Figures 3 and 4).

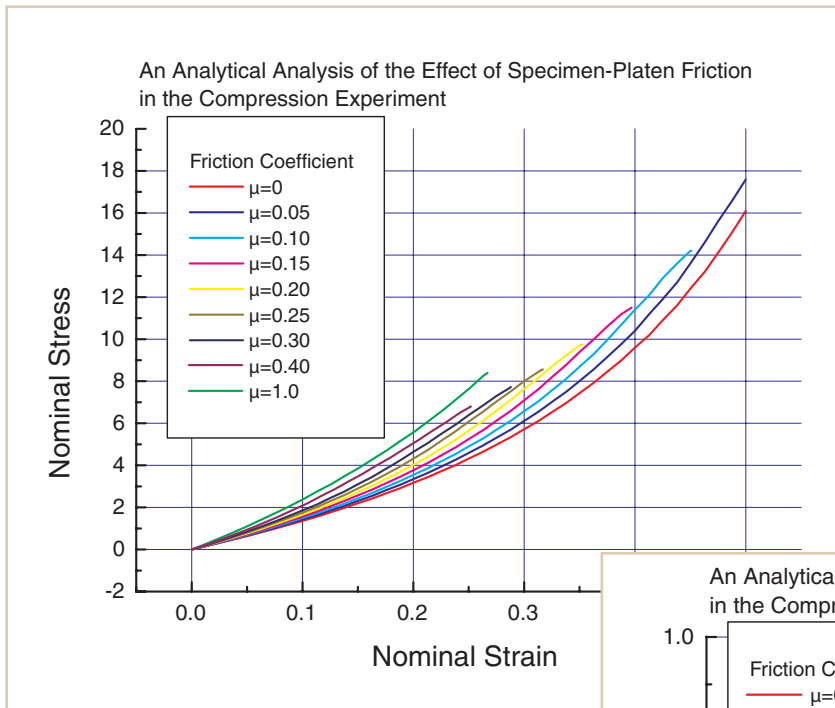


Figure 3, Friction Effects on Stress - Strain Curves.

Friction Effects on Compression

From the analysis, one can conclude that even very small levels of friction significantly affect the measured stiffness. Furthermore, this effect is apparent at both low and high strains. This is particularly troubling because friction values for elastomers are typically a function of normal force and are not well characterized. As such, the experimental compression data cannot be corrected with a significant degree of certainty. Other compression specimen shapes have also been examined with similar results.

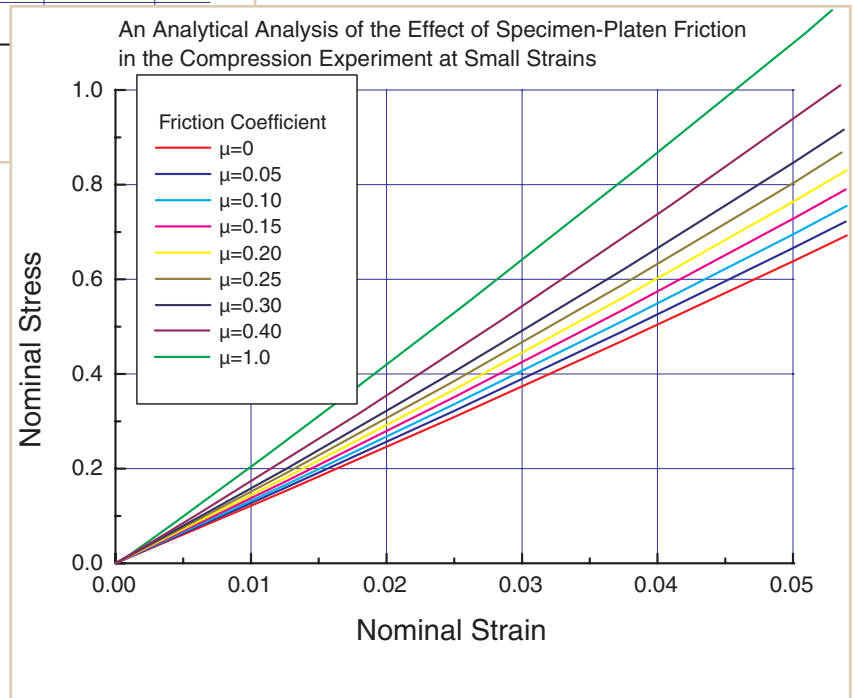


Figure 4, Friction Effects on Stress - Strain Curves at Low Strains.

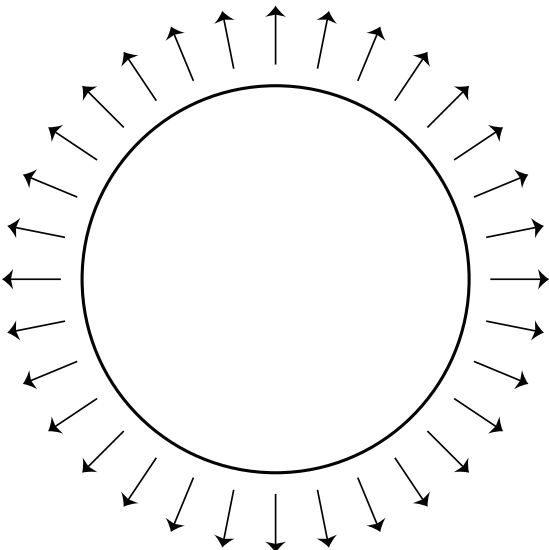


Figure 5, Biaxial Extension by Radial Stretching.

Equal Biaxial Extension

Another experiment that also provides compression information is the equal biaxial extension experiment. This may not seem obvious at first glance. However, as an elastomer is radially strained in all directions in a single plane as shown in Figure 5, the free surfaces come together. For incompressible materials, the state of strain in the material is the same as that in simple compression and free from friction. The measured experimental parameters are radial strain and the radial stress.

As an academic exercise, these biaxial strains and biaxial stresses can be converted directly to compression strains and compression stresses as follows:

$$\sigma_c = \sigma_b (1 + \epsilon_b)^3$$

$$\epsilon_c = 1/(\epsilon_b + 1)^2 - 1$$

Where:

σ_c is Nominal Engineering Compression Stress

σ_b is Nominal Biaxial Extension Stress

ϵ_c is Nominal Engineering Compression Strain

ϵ_b is Nominal Biaxial Extension Strain

It typically isn't necessary to do this conversion because most curve fitters accept equal biaxial extension data directly.



Figure 6, Equal Biaxial Experiment

As with the compression experiment, analysis of the equal biaxial extension specimen is necessary to examine its suitability. The specific specimen shape used at Axel Products, Inc. was also examined by Jim Day of GM Powertrain and is shown to provide a very pure state of strain in the specimen (Figure 6) [1].

An additional advantage to using equal biaxial extension in place of simple compression is that the biaxial extension specimen can be cut from the same sheet of material as the simple tension and pure shear specimens whereas most compression specimens need to be molded separately. By cutting all specimens from the same sheet, consistent material properties and therefore a consistent data set can be developed.

Conclusion

Although it may seem odd, the biaxial extension experiment is preferable to the simple compression experiment for the measurement of pure compression when used to develop analytical material models.

References

[1] J. R. Day, and K.A. Miller, "Equibiaxial Stretching of Elastomeric Sheets, An Analytical Verification of Experimental Technique" ABAQUS 2000 User's Conference Proceedings, Newport, Rhode Island, May 30-June 2, 2000.

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