Material property tests of Smooth-on Vytaflex60 liquid rubber

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During the fall semester of the 2005-2006 academic year, I decided to try to produce some scale models of structural systems out of rubber. I had in mind to use these models to demonstrate structural behavior to undergraduate students, thinking that seeing models deform under load would be far more convincing than the standard line diagrams of deformed shapes that we typically use in engineering classes.

Peter Chomowicz, Professor of Environmental Design at the Maryland Institute College of Art, agreed to help me build the models, provided I could design them to demonstrate the proper structural response. One of the main difficulties in designing the models was a lack of information on the material properties of the liquid rubber we would use to form the models. Smooth-on, the supplier of the rubber, called Vytaflex60 in their product line, was able to provide quantities such as the density, 0.0376 lb/cu.in., the rupture strain 480%, and the shore A hardness, or durometer, 60. They could not provide the elastic modulus, the critical material property necessary for design of the structural models.

Though I did not look that hard, I could not find any literature pointing to a direct relationship between shore A hardness and elastic modulus. The only test result I was able to find, at www.moldeddimensions.com/stressstrain.htm, indicated that a urethane rubber with a shoreA hardness of 65 had a modulus, for elongation up to about 200% of 200 psi. Faced with a lack of material property data and facing some difficulties in designing the models to demonstrate very specific types of behavior, Peter and I decided to forge ahead and build a small arch bridge, spanning 20 inches, out of vytaflex60. I would then perform material tests on the rubber, and use this first model to evaluate the accuracy of the calculation methods I was using in my design. Figure 1 shows this model, along with a scale factor. The model was designed using an elastic modulus of 200 psi and a weight density of 0.0376 lb/cu.in. To make the model, Peter built a beautiful mold, and demolded the bridge after a day of curing. From excess material, he also cut two material samples that I would test to determine the elastic properties of Vytaflex60.

On March 17th, Ben Schafer, also of Johns Hopkins Civil Engineering, and I performed two tension tests on the material sample shown in Figure 2 in

Figure 1: Rubber bridge model with scale factor.

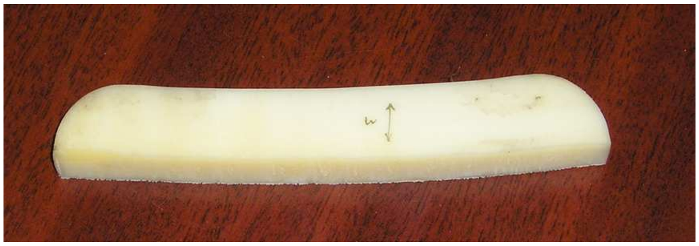

Figure 2: Tensile coupon.

the test setup shown in Figure 3. We measured the width and thickness of the sample at four locations, and also measured the gauge length of the sample three times (See Table 1). The average cross section geometry gives a cross section area of 0.481 in^2. We also measured gauge length between the test machine grips, assuming no slip in the grips and that the elongation during the test was uniformly distributed along the gauge length. This measurement is necessary to determine the state of strain in the sample during the test. We tested constant cross section test sample at two strain rates, 1/3 in/min and 3 1/3 in/min. MATLAB postprocessing software converted test machine output voltages to elongation and load. This test procedure does not conform to standard material testing protocols, particularly with respect to sample geometry.

The results of the two tension tests (Figure 4) show the nonlinear elastic

Figure 3: Test setup.

Table 1: Test specimen geometry.

Measurement number	Thickness (in)	Width (in)	Gauge length (in)
1	0.555	0.834	2.508
2	0.572	0.845	2.521
3	0.581	0.852	2.504
4	0.577	0.831	
average	0.571	0.840	2.511

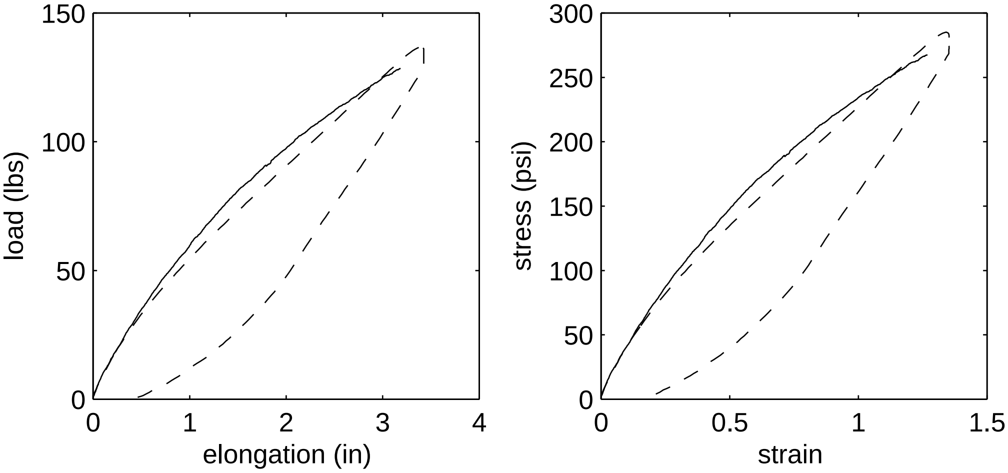

Figure 4: Test results. Left frame shows load-displacement response, and right frame stress-strain response. The solid line represents the test conducted at 1/3 in/min load rate, and the dashed line the test conducted at 3 1/3 in/min

behavior that is typical of rubbers. The response appears essentially invariant to load rate, although the maximum load rate used in this test, 3 1/3 in./min, is not high. The stress strain curve of the right panel of Figure 4 shows that the Vytaflex60 does not have a unique elastic modulus, but rather that the material stiffness varies with the state of strain. The material softens as the strain increases. Our test, ending at an applied strain of approximately 1.25, did not stretch the material far enough for us to observe the hardening that occurs in hyperelastic materials at extremely large strains.

Although current structural analysis software can account for materials with nonlinear-elastic response, I would much rather design my structural demonstration models using linear elastic analysis, even if I have to approximate the nonlinear material response by a linear model. In order to implement an approximate linear material model, I must select, from the test data, a single elastic modulus for the material. Figure 5 shows, for the 1/3 in/min test, the secant and tangent moduli as a function of applied strain. The curves are truncated at the left end because the data for very small displacements are noisy. The tangent modulus is calculated by finding the best linear fit to 50 adjacent measurement points which serves to smooth the otherwise noisy tangent modulus curve. This corresponds to averaging over a strain range of approximately 0.1.

An alternative to estimating secant and tangent moduli directly from the data is to fit a model to the stress-strain data and then compute the tangent and secant moduli from that model. A popular choice for modeling material nonlinearity is a power law (Ramberg-Osgood) of the form $\epsilon = a\sigma^n$, in which ϵ is the strain, σ is the stress, and a and n are parameters. The stress-strain data obtained from our experiment are not well modeled by a power law over the

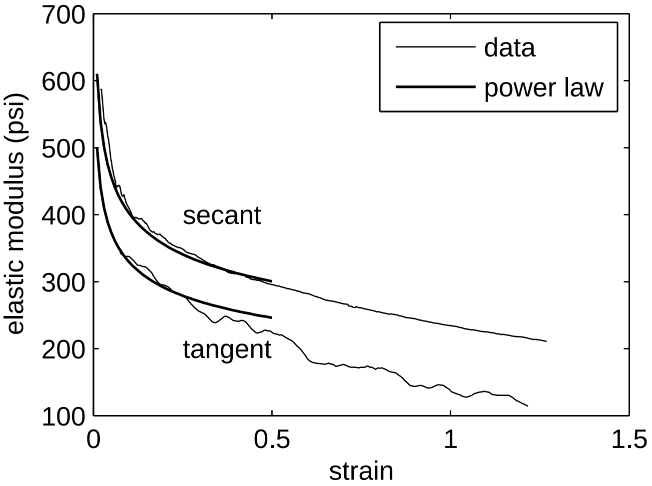

Figure 5: Tangent and secant moduli derived from test results.

full range of the experiment. Over the strain range $[0, 0.5]$, however, very good agreement is given by a power law with parameters $a = 0.001099$ and $n = 1.221$. The tangent and secant moduli obtained from this power law are also shown in Figure 5

I am now left with the question of how to use this data in the design of structural demonstration models. The first conclusion is that the value of 200 psi used for the elastic modulus in the design of the initial model is certainly too low. Although the deformations developed in the model bridge are large, on the order of an inch, the maximum strains in the material remain quite small, on the order of 0.1 at a maximum. I therefore look to the small strain regime of the test results, and, preferring the secant modulus as a linear elastic substitute for the nonlinear material behavior, choose a value of 500 psi for the rubber. The rubber is approximately 60,000 times less stiff than standard structural steel in the small strain regime. It remains now to be seen whether this value will give a good prediction of the response of the model bridge.