

Viscoelastic Material Characterization

Successful design of passive damping treatments using viscoelastic materials (VEM) such as elastomers depends upon several factors. One important factor is accurate knowledge of the way in which the properties of viscoelastic materials vary with temperature and frequency. These materials are generally more difficult to characterize than are structural materials such as metals.

This occurs for two basic reasons.

1. When an elastomer is dynamically loaded, even at levels well within its linear range, it converts a much larger fraction of the input energy into heat than does a metal. It is therefore necessary to measure both the energy storage property (stiffness) and energy dissipation property (damping).
2. Both stiffness and damping of elastomers tend to vary significantly with frequency and temperature. Generally, the more dissipative a material, the greater the variation.

Both problems are accommodated by describing the mechanical properties of the material in terms of a frequency and temperature-dependent complex modulus

G^* .¹ The stress-to-strain ratio for the material is treated as a complex quantity. Complex arithmetic provides a convenient means for keeping track of the phase angle by which an imposed cyclic stress leads the resulting cyclic strain. The complex shear modulus, for example, is usually expressed in the form

$$G^*(f, T) = G_0(f, T)[1.0 + j\eta(f, T)]$$

The real and imaginary parts of the modulus are then $G_0(f, T)$ and $G_0(f, T)\eta(f, T)$, respectively. The two frequency-temperature functions on the right in the equation are commonly called the storage modulus and loss modulus. Fourier transform theory and the correspondence principle of viscoelasticity allow complex moduli to be used for calculating response to arbitrary dynamic inputs. Material properties are most often specified and measured in terms of their complex shear modulus because it allows greater flexibility in choosing the size and shape of the test specimen.

Most VEMs can be assumed to be thermorheologically simple, which can be characterized using frequency-temperature equivalence.² A temperature shift curve, α_T or alpha_t, which is a function of temperature only, is constructed for each particular set of complex modulus data. The real part, G_R , the imaginary part, G_I , and the material loss factor, $\eta = G_I / G_R$, of the complex modulus data are plotted as a function of the reduced frequency, f_R , where f_R is the product of the experimental frequency, f_E , and α_T ($f_R = f_E \alpha_T$). Historically, the temperature shift function for a particular damping material has been defined empirically by the experimental complex modulus data. The value of α_T at each experimental temperature is selected such that it simultaneously shifts horizontally the three complex modulus data points G_R , G_I , and η to define curves and minimize scatter. With the use of computers, it is convenient to fit the

empirical temperature shift function with a suitable analytical function of parametric nature.

Once the master curves for G_R , G_I , and η versus f_R are created, a reduced temperature nomogram, or international plot, may be created by placing the experimental frequency on the right hand scale and then using the frequency-temperature equivalence principle to superimpose lines of constant temperature on the plot. A damping designer may then read modulus and loss factor values off this plot for any particular frequency and temperature of interest (Figure 1).

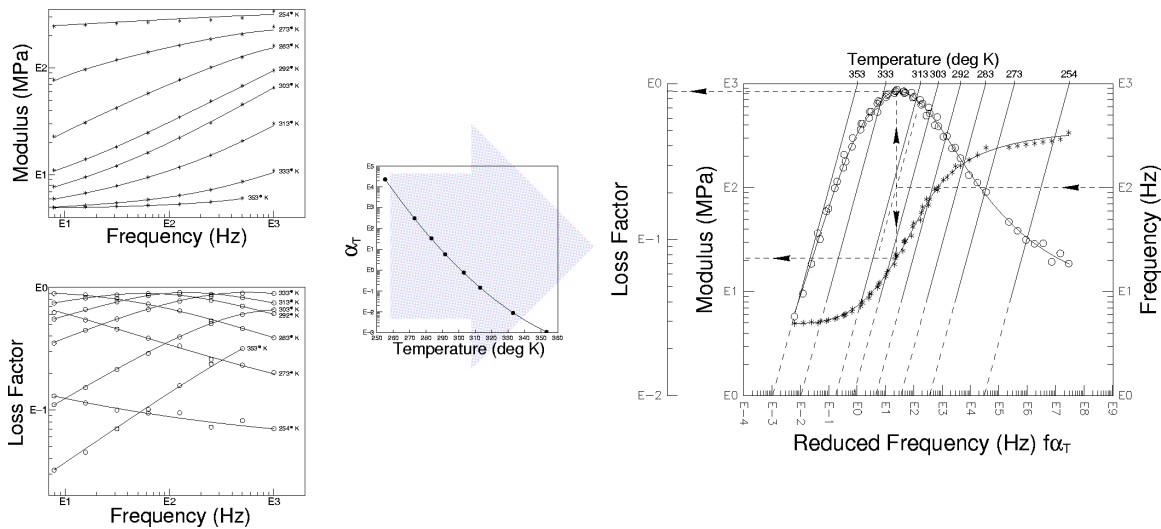


Figure 1: VEM data reduction

The use of this international plot to read values of modulus and loss factor is demonstrated in the figure. To get modulus and loss factor values corresponding to 100 Hz and 311K (100°F), one reads the 100 Hz frequency on the right-hand scale and proceeds horizontally to the 311K temperature line. Then proceed vertically to intersect the curves along a line of reduced frequency. Finally, proceed horizontally from these intersections to the left-hand scale to read the values of 20.5 MPa (2970 psi) for the real modulus and 0.89 for the loss factor.

The main difficulty in performing characterization lies in correctly choosing parameters for the master curve equations so that they accurately represent the VEM. Interactive computer graphics have greatly improved the process of choosing and adjusting the correct parametric values.

CSA Engineering has much experience with characterizing viscoelastic materials and has written a state-of-the-art computer program that implements frequency-temperature equivalence through the Collocation process³ to interactively characterize viscoelastic materials.

¹A.D. Nashif, D.I.G. Jones, J.P. Henderson, *Vibration Damping*, John Wiley and Sons, New York, 1985.

²J.D. Ferry, *Viscoelastic Properties of Polymers*, John Wiley and Sons, 3rd ed., 1980.

³ L. Rogers, "An Accurate Temperature Shift Function and a New Approach to Modeling Complex Modulus," Proceedings of the 60th Shock and Vibration Symposium, Virginia Beach, VA, Vol. 3, pp. 197-215, November 14-16, 1989