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VIBRATION ISOLATOR PROPERTIES OF A PHASE MIXED POLYURETHANE

J. Lee*, J. Dickens**, J. Fedderly*, G. Lee*, B. Hartmann*

* Naval Surface Warfare Center, 9500 MacArthur Boulevard, 20817-5700, West Bethesda, MD, United States Of America

** Aeronautical and Maritime Research Laboratory, PO Box 4331, 3001, Melbourne, Victoria, Australia

Tel.: 1-301-227-5568 / Fax: 1-301-227-4732 / Email: leejd@nswccd.navy.mil

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ABSTRACT

Preliminary measurements were made of the vibration isolation characteristics of a phase mixed polyurethane in the Vibration Isolation Test Facility over the frequency range from 5 Hz to 2 kHz at room temperature with static loads resulting in strains of 0, 5, and 10 per cent. Qualitative analysis of the complex four-pole parameters shows that the modulus and loss factor both increase with increasing static strain. Dynamic mechanical measurements were also made on the same polymer. Modulus and loss factor both increase with decreasing temperature. These results are in qualitative agreement with the hypothesis that strain dependence and temperature dependence are correlated through the changes in polymer volume.

1 - INTRODUCTION

As part of a program to relate the molecular structure of polymers to their vibration isolation properties, a polyurethane of known, controlled composition was synthesized and evaluated. Based on our earlier studies [1], the first polymer selected to be evaluated was phase-mixed to avoid the complication of the hard segment crystallinity that occurs in phase separated polymers. Vibration isolation properties were determined in the new Vibration Isolation Test Facility [2] as a function of frequency from 5 Hz to 2 kHz at room temperature and various static compressive strains. These measurements were supplemented with measurements of the dynamic mechanical properties as functions of temperature and frequency. It is hypothesized that the static compressive strain will reduce the volume of the polymer and that this volume change occurs entirely in the free volume (unoccupied volume) of the polymer. In other words, covalent bonds are not compressed. The effect of this volume reduction should then be equivalent, to first order, to the volume reduction produced by lowering the polymer temperature. The first step in this program is then to verify that the effect of compressive strain is to produce the same effect as lowering the temperature. Quantitative verification of this idea will require measurements as a function of temperature that produce a known volume change.

2 - POLYMER SYNTHESIS AND CHARACTERIZATION

The polymer was synthesized from an equi-molar blend of poly(tetramethylene ether glycol) of molecular weight 1400 and 2,2-dimethyl-1,3-propanediol reacted with a stoichiometric amount of 4,4'-diphenylmethane diisocyanate in a one-shot synthesis. The resulting polymer had a density of 1.070 g/cm³ and a glass transition temperature, determined in a differential scanning calorimeter, of -39°C. Thus measurements at room temperature are in the rubbery region of the polymer.

Two samples were made, with heights of 10.5 cm and 5.25 cm, both with 16.9 cm diameter. Each sample was cast directly onto an aluminum end plate. After smoothing the free surface of the samples, a matched aluminum end plate was bonded to the free surface with a polyurea adhesive.

Dynamic mechanical properties were determined in a resonance apparatus [3] over the temperature range from -60 to 70°C. At each temperature, typically four resonant peaks were observed in the frequency range from 600 Hz to 8 kHz. The time-temperature superposition principle was then used to shift the

raw data into a master curve (frequency dependent plot) at a reference temperature of 25°C. The results are shown in Figure 1 as the solid symbols. The master curve data was fitted to the Havriliak-Negami equation [4]:

$$(G^* - G_\infty) / (G_0 - G_\infty) = (1 + (i\omega\Gamma)^\alpha)^{-\beta} \quad (1)$$

where G_∞ is the limiting high frequency modulus, G_0 is the limiting low frequency modulus, Γ is the relaxation time and α and β are dimensionless parameters with values between zero and one. Using a non-linear least squares fitting algorithm, the parameters for this polymer were found to be: $G_\infty = 1.87$ GPa, $G_0 = 2.06$ MPa, $\Gamma = 0.38 \mu\text{s}$, $\alpha = 0.767$, and $\beta = 0.048$. The fitted curve is shown as the solid lines in Figure 1.

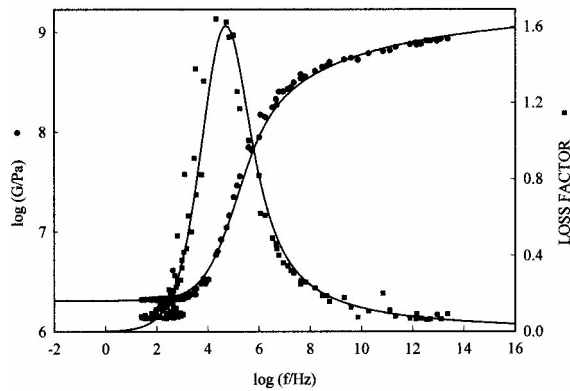


Figure 1: Dynamic mechanical properties of polyurethane polymer.

From Figure 1, for frequencies of 2 kHz and less, the shear modulus and loss factor ($\tan\delta$) both increase with increasing frequency at room temperature. Using the time-temperature superposition principle, this is equivalent to increasing modulus and loss factor with decreasing temperature.

3 - VIBRATION ISOLATION MEASUREMENTS

Measurements were made in the Vibration Isolation Test Facility on the 10.5 cm height sample. The shape factor of the sample was 0.29. Static loads were applied to the sample that gave strains of 0, 5, and 10 per cent in the height of the sample. A dynamic strain, of maximum of 0.1 per cent, was superimposed on the static strain. Dynamic measurements were made over the range from 5 Hz to 2 kHz, at room temperature. Measurements were made of the input force and velocity, F_1^* and V_1^* , and the output force and velocity, F_2^* and V_2^* . These measurements were then analyzed to determine the transfer function from input to output. The transfer function in this case is a two by two matrix of complex quantities known as four-pole parameters [5], α_{11}^* , α_{12}^* , α_{21}^* , and α_{22}^* . Plots of the complex four-pole parameters are shown in Figure 2.

From α_{21}^* , the measured magnitudes of the compression complex normal moduli of the polyurethane element at 10 Hz were 8.3, 9.7, and 10.9 MPa for static strains of 0, 5, and 10 per cent respectively. Using the -3 dB bandwidth method on the first trough of α_{11}^* , yielded $\tan\delta$ of 0.20, 0.21, and 0.22 at frequencies of 146, 154, and 161 Hz for static strains of 0, 5, and 10 per cent respectively. This behavior of increasing magnitude of the complex normal modulus and $\tan\delta$ with increasing static strain also occurs for natural rubber vulcanizes with carbon black filler [2]. In comparing the modulus and loss factor determined from the four-pole parameters with the values on Figure 1, recall that the plate modulus is determined from the four-pole parameters while the shear modulus is plotted in Figure 1. With this understanding, there is reasonable agreement between the two.

4 - DISCUSSION

The four-pole results presented here demonstrate that the effect of static strain on the vibration isolation properties of polymers is to increase the modulus and loss factor of the polymer. The dynamic mechanical data show that the modulus and loss factor increase with decreasing temperature. Both these results are in qualitative agreement with the hypothesis that volume changes dominate complex modulus and not how the volume is changed. In short, uniaxial strain produces the same effect as lowering the temperature.

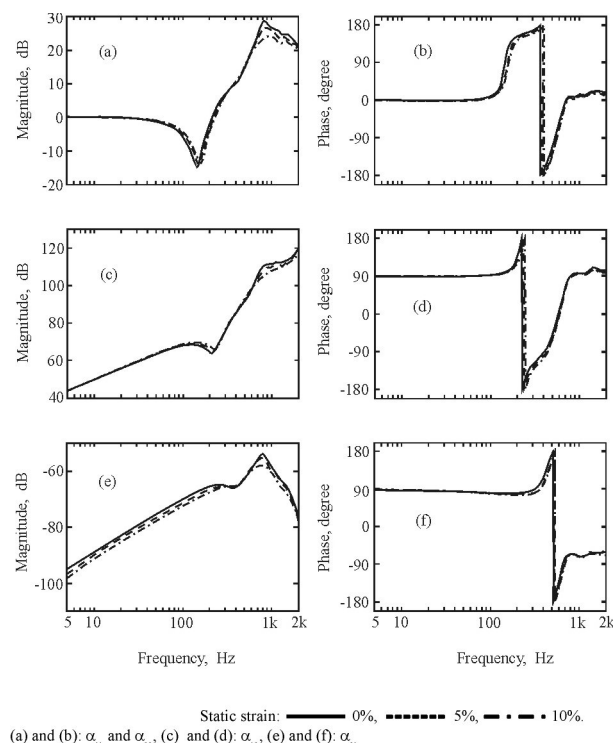


Figure 2: Four pole parameters.

The idea that volume changes dominate various polymer properties is not new. What is new here is the application of that idea to uniaxial strain and temperature rather than hydrostatic pressure and temperature as was done previously and the application to dynamic modulus rather than static modulus [6]. What has been demonstrated here so far is suggestive rather than convincing and will require quantitative results. To validate the hypothesis here will require quantitative evaluations, presently underway.

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