

## Dynamic Mechanical Properties of Several Elastomers and Their Potentialities in Vibration Control Applications\*

T. P. YIN and R. PARISER, *Elastomer Chemicals Department, E. I. du Pont de Nemours & Company, Inc., Wilmington, Delaware*

### Synopsis

The time-temperature-dependent mechanical properties of Viton A, Neoprene ILA, Adiprene L-167, and Nordel hydrocarbon elastomer have been measured primarily on the Fitzgerald transducer. The results cover the plastic to rubberlike transition regions which have been reduced to 25°C. whenever possible. The data are then discussed in terms of the relaxation spectra, monomeric friction coefficients and the shift factors,  $\log Q_T$ . Following a brief presentation on the viscoelastic requirements for various vibration control devices, the potentialities of the present elastomers, as well as other common elastomers, are evaluated. It is found that Nordel, Hevea rubber, and Neoprene W are potential vibration isolators, whereas Viton A, Neoprene ILA, and polyisobutylene have desirable vibration damping characteristics. Their effective temperature-frequency regions of application have been calculated.

### INTRODUCTION

It is the purpose of this paper to present the viscoelastic properties of several elastomers obtained from dynamic mechanical studies, as well as to illustrate the use of such characterization for prediction of performance in idealized vibration control devices.

Recent dynamic measurements of several commercial (du Pont) elastomers are first given and discussed in terms of time-temperature dependent relaxation phenomena: these include Viton A fluoroelastomer, Neoprene ILA, Nordel hydrocarbon elastomer, and Adiprene L-167 urethane rubber. Various idealized vibration control devices are then briefly reviewed with emphasis on the viscoelastic requirements of elastomers in such applications, and the potentialities of the present materials are evaluated in this regard. Consideration is also given to Neoprene W<sup>1</sup> and Hypalon 20 synthetic rubber,<sup>2</sup> the dynamic properties of which have been reported earlier, as well as to SBR, polyisobutylene and Hevea rubber.

\* Contribution No. 129.

## EXPERIMENTAL

### Materials

All the samples were prepared from commercial grade polymers and with curing recipes known to give optimum vulcanizate properties. Viton A<sup>3</sup> is a copolymer of hexafluoropropylene and vinylidene fluoride; the system studied was a filled stock having the composition in parts by weight of 100 polymer/18 MT carbon black/15 magnesium oxide/1 ethylenediamine carbamate (Diak No. 1). It was cured at 150°C. for 1 hr. and postcured in open air at 200°C. for another 24 hr. Neoprene ILA<sup>4</sup> is a copolymer of chloroprene and acrylonitrile; a very similar gum recipe to the one selected for Neoprene W studies<sup>1</sup> was used here. It contained 100 weight parts polymer/5 zinc oxide/4 magnesium oxide/2 phenyl- $\alpha$ -naphthylamine (Neozone A rubber antioxidant, du Pont)/0.5 2-mercaptoimidazoline (NA-22), which was cured at 153°C. for 30 min. Nordel<sup>5</sup> is a terpolymer of ethylene, propylene, and a nonconjugated diene. The raw elastomer studied was molded at 150°C. for 5 min. The viscosity of an identically treated sample corresponded to  $\bar{M}_v = 150,000$ . Adiprene L-167<sup>6</sup> is a liquid urethane rubber from the toluene diisocyanate (TDI) and polytetramethylene ether glycol (PTMEG). It was converted to a tough, elastic solid with 0.90 mole of methylene-bis-*o*-chloroaniline (MOCA). None of the above systems are known to contain any appreciable crystallinity in their unstressed states.

### Measurements

The Fitzgerald transducer described previously<sup>1</sup> was used in the present study. The shear strain was small and well within the linear viscoelastic region. Two pairs of sample disks with the following dimensions,  $^{11}/_{16} \times ^3/_{32}$  in. (A) and  $^5/_{16} \times ^3/_{16}$  in. (B) (diameter and thickness, respectively) were normally needed to characterize each material with its complex shear compliance ( $J^* = J' - iJ''$ ) extended over the rubberlike to plastic transi-

TABLE I  
Experimental Conditions for Fitzgerald Transducer Measurements

Elastomer	Sample size	Temperature range covered, °C.	Number of runs
Viton A	A*	80.9 to 50.0	5
	B	50.0 to 10.3	9
Neoprene ILA	B	34.6 to 3.2	7
Nordel	A	24.0 to -12.6	12
	B	-12.6 to -41.5	12
Adiprene L-167	A	115 to 24.0	5

\* In the case of Viton, a discrepancy of 15% was noted between the corresponding values of  $J'$  and  $J''$  from the two sample pairs at the overlapping temperature of 50°C. Assuming the shape factor of the thick sample (B) to be the more reliable one, an empirical correction factor of 1.15 was applied to all the results from sample (A).

tion zone. A brief summary of the experimental conditions is given in Table I.

Only limited data on Adiprene were obtained from the transducer measurements due to the relative insensitivity of this material toward temperature-frequency variations. Hence supplementary studies were made with a  $1 \times 5 \times 1/16$  in. slab on a free-oscillation type torsion pendulum<sup>7</sup> from  $-20$  to  $+150^\circ\text{C}$ . at 2.5–5.2 cycles/sec.

## RESULTS AND DISCUSSION

### Viscoelastic Properties

The transducer results,  $J'$  and  $J''$ , from each material (except Adiprene) over the entire temperature series were reduced to two composite curves at  $T_0 = 25^\circ\text{C}$ . This procedure and the criteria for its applicability are now well known.<sup>8</sup> The reduced shear compliance spectra of Neoprene ILA are presented in Figure 1 for illustration. It should be noted that the corresponding plots for Viton and Nordel contained considerably more experimental points, hence their reduction was executed with even less ambiguity.

On the other hand, further analysis of the transducer data on Adiprene

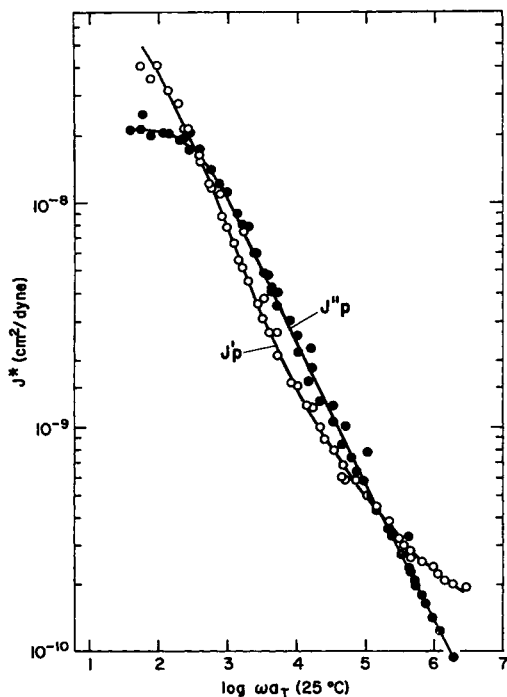


Fig. 1. Real ( $J'_p$ ) and imaginary ( $J''_p$ ) components of reduced complex shear compliance of Neoprene ILA vs. reduced radial frequency at  $25^\circ\text{C}$ .

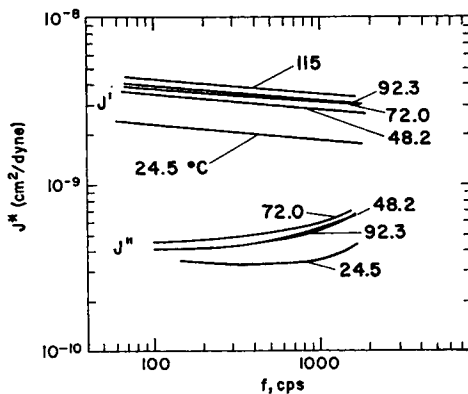


Fig. 2. Real ( $J'$ ) and imaginary ( $J''$ ) components of complex shear compliance of Adiprene L-167 cured with 0.90 mole MOCA vs. frequency.

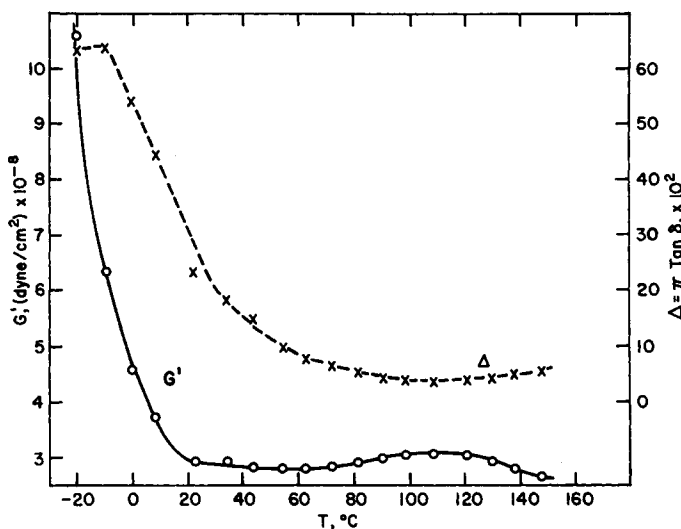


Fig. 3. Torsion pendulum data of Adiprene L-167 cured with 0.90 mole MOCA vs. temperature.

was impossible, since its compliance shown in Figure 2 remained fairly constant over the extended temperature range covered here. Such constancy is unusual; the magnitude of  $10^{-9} < J' < 10^{-8}$  corresponds to the midpoint of a transition zone, hence the system is expected to be sensitive to temperature and frequency variations. This apparent anomaly may be attributed to the 0.90 mole of rigid MOCA present in an otherwise flexible TDI/PTMEG prepolymer. The observed compliance is then the composite response of two segmental consistencies, one soft and one hard, both being remote from their respective transition zones; hence the polymer is insensitive to environmental changes. The torsion pendulum data shown

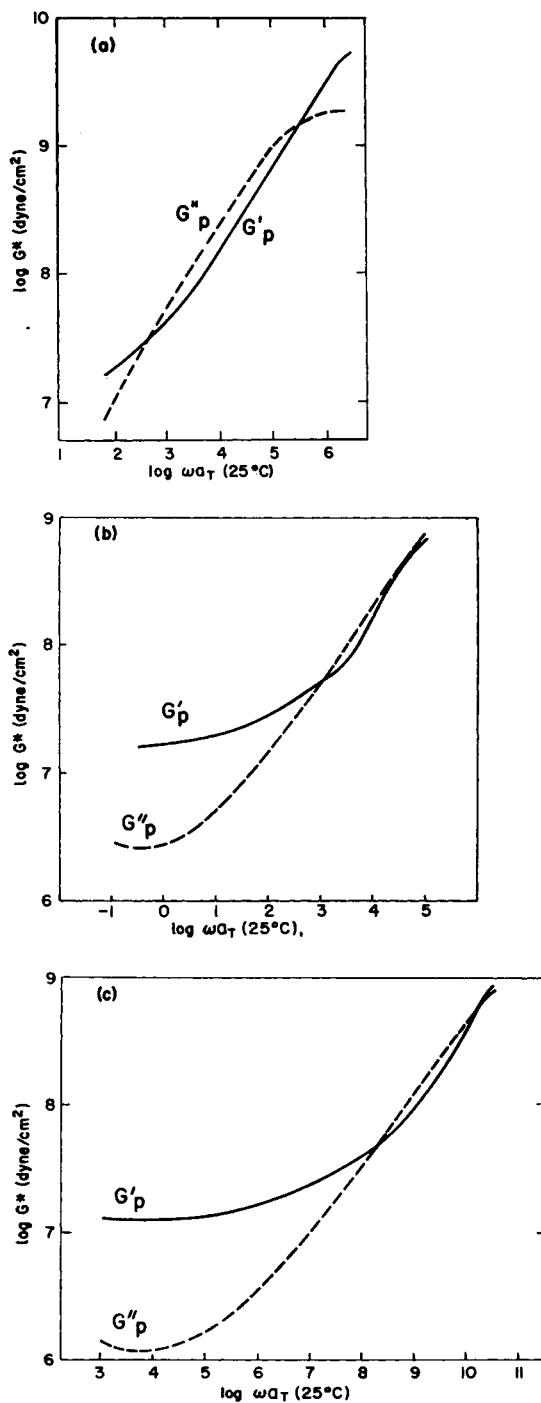


Fig. 4. Real ( $G'_p$ ) and imaginary ( $G''_p$ ) components of reduced complex shear modulus of (a) Neoprene ILA, (b) Viton A, and (c) Nordel vs. reduced radial frequency at 25°C.

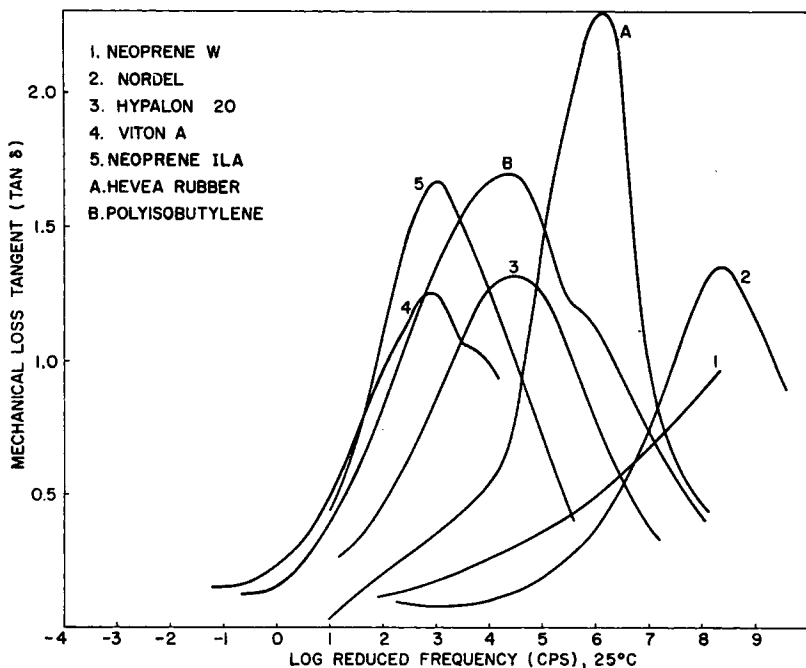


Fig. 5. Mechanical loss tangent vs. reduced frequency at 25°C. for seven elastomers.

in Figure 3 confirm the general features of the transducer result on this material; namely, it exhibits substantially rigidity and low mechanical loss throughout the temperature range usually associated with the transition zone for elastomers with subzero  $T_g$ . Furthermore the two sets of results are in agreement; for example, from the transducer data at 48.2°C. and 100 cycles/sec.,  $J' = 3.5 \times 10^{-9}$  cm.<sup>2</sup>/dyne and  $\tan \delta = 0.12$ ; then  $G' \approx 1/J' = 2.9 \times 10^8$  dyne/cm.<sup>2</sup> and  $\Delta = \pi \tan \delta = 0.37$  as compared to  $G' = 2.8 \times 10^8$  and  $\Delta = 0.13$  at the same temperature and 5 cycles/sec. measured on the pendulum; the discrepancy in  $\Delta$  reflects, at least partially, the different experimental time scales involved.

The shear modulus spectra of Neoprene ILA, Viton and Nordel, all reduced to a common  $T^0 = 25^\circ\text{C}$ ., are presented in Figure 4. They were converted from the respective compliance curves with the reciprocal relationship of  $G_p^* = 1/J_p^* = G'_p + iG''_p$ . It is interesting to note that the uncured Nordel stock shows a fairly respectable pseudo-equilibrium modulus of  $10^{7.1}$  dyne/cm.<sup>2</sup>.

The corresponding mechanical loss tangent curves,  $\tan \delta = G''_p/G'_p$ , are plotted in Figure 5 which also includes other known systems for comparison. Viton exhibits a narrow shoulder adjacent to its loss peak which is analogous to the plateau observed in polyisobutylene.<sup>9</sup> The latter has been attributed to the steric hindrance of the two bulky methyl groups attached to the same carbon atom. A study of the Viton structural model

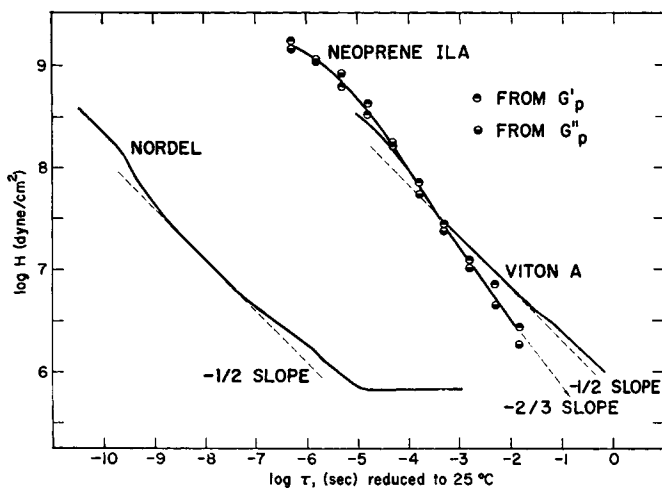


Fig. 6. Relaxation spectra of Neoprene ILA, Viton A, and Nordel vs. reduced time,  $\tau$ , at 25°C.

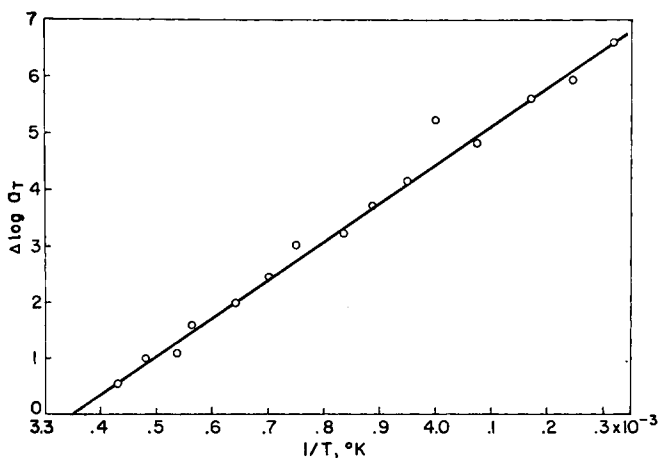


Fig. 7. Empirical shift factors,  $\Delta \log a_T$ , of Nordel vs. reciprocal absolute temperature with  $T_0 = 298^\circ\text{K}$ .

reveals that the  $\text{CF}_3$  group does hinder the rotation of the carbon chain and is probably responsible for this feature.

The relaxation spectra are shown in Figure 6. They were computed from  $G'_p$  and  $G''_p$  with appropriate approximations.<sup>10</sup> In the transition zones, the maximum deviation from the two sources is  $<0.20$  log units (16%) as illustrated by the Neoprene ILA system. Agreement in the rubbery region for Nordel is consistently poorer, hence the magnitude of  $\log H$  is less certain above  $\tau = 10^{-5}$  sec. The dashed lines are the slopes of  $-1/2$  and  $-2/3$  as predicted by the theories of Rouse<sup>11a</sup> and Zimm,<sup>11b</sup>

respectively. It is interesting to note that the Neoprene ILA spectrum follows the Zimm slope over an extended time scale, whereas Viton and Nordel agree more closely to the Rouse theory in which hydrodynamic interaction between the moving segmental junctions is neglected. One may speculate that the strong polar nitrile and chlorine groups in Neoprene ILA constitute such an interaction which is also reflected by a relatively high  $\Delta H_a$  of 43.2 kcal./mole.

The temperature-frequency reduction procedures mentioned earlier in this paper provide empirical equations from which some molecular parameters can be derived. Analogous results from Neoprene W<sup>1</sup> and Hypalon 20<sup>2</sup> are included in Table II for comparison. The equations follow either WLF<sup>8</sup> or the Arrhenius form. In the case of Neoprene ILA, one may rationalize its divergence from the WLF equation by noting that the temperature range covered experimentally was rather narrow, hence the Arrhenius form was adequate. On the other hand, it is surprising that the empirical shift factors of Nordel gave a satisfactory linear relationship when plotted against  $1/T$  as shown in Figure 7 with  $\Delta H_a = 31.4$  kcal./mole. When this is correlated with the fact that  $G'_p$  is unusually low ( $<10^9$ ) even at  $-41.5^\circ\text{C}$ . and kilocycle driving frequencies (tail of Fig. 4c), one is led to believe that the apparent  $T_g$  is lower than  $-55^\circ\text{C}$ . observed dilatometrically.

The presently derived reduction equation for Viton A appears different from that of Krigbaum et al.<sup>12</sup> obtained from stress relaxation and birefringence on a  $\gamma$ -ray irradiated gum vulcanizate. This apparent discrepancy may be understandable if one considers that the two equations were derived from different viscoelastic regions: our measurements encompassed the transition zone, whereas the stress relaxation data covered the rubbery region.

The monomeric friction coefficients,  $\zeta_0$ , were calculated from the relaxation spectra<sup>13</sup> and reflect the local flexibilities of the monomeric segments at  $25^\circ\text{C}$ . It is interesting to compare Viton and Hypalon; although they have comparable  $T_g$ , Hypalon is much more flexible than Viton at room temperature. This is undoubtedly due in part to the steric hindrance in the latter. When Neoprene ILA is compared with Neoprene W, the incorporation of the stiff acrylonitrile into polychloroprene results in an expected increase in  $T_g$  and the disappearance of crystallinity; furthermore, it can be noted that the magnitude of  $\log \tau$  at  $\log H = 6.5$  is considerably larger in the case of Neoprene ILA, hence its frictional resistance must be higher than in Neoprene W. The magnitude of  $\zeta_0$  for Nordel is significantly smaller than for other polymers of comparable  $T_g$ ,<sup>14</sup> which reflects an unusually high degree of local flexibility.

### Viscoelastic Requirements of Vibration Control Devices

Elastomers have been used extensively to reduce and control vibrations of rigid and flexible bodies under periodic, as well as transient loadings.



TABLE II  
 Reduction Equations and Related Parameters

Elastomer	Reduction equation ( $T_0 = 298.1^\circ\text{K.}$ ) $-\log \alpha_T =$	Expansion coefficient of free volume $\alpha_f \times 10^4$ ( $\text{deg.}^{-1}$ )	Fractional free volume at $T_0$ $f_0$	$T, ^\circ\text{C.}$		Density $\rho$ at $25^\circ\text{C.}$ , g./cc.	Monomeric friction coefficient $\log \zeta_0$ , dyne- sec./cm.
				Dynamic	Dila- tometric		
Neoprene W	$\frac{10.6(T - T_0)}{93.6 + (T - T_0)}$	4.4	0.023	-17	-46	1.25	-5.74
Neoprene ILA	$\frac{9,470(T - T_0)}{TT_0}$	—	—	—	-8	1.30	*
Viton A	$\frac{11.0(T - T_0)}{128 + (T - T_0)}$	3.1	0.024	-25	-25	1.79	-2.51 <sup>b</sup>
Hypalon 20	$\frac{8.90(T - T_0)}{101 + (T - T_0)}$	4.8	0.025	-25	-28	1.13	-4.33 <sup>b</sup>
Nordel	$\frac{6,870(T - T_0)}{TT_c}$	—	—	(< -55)	-55	0.848	-8.03 <sup>b</sup>

\* Zimm's theory does not characterize the frictional resistance by  $\zeta_0$ .

<sup>b</sup> Calculated with root-mean-square end-to-end distance equal to 7 Å, a mean value for vinyl compounds.

It can be shown that the various vibration mechanisms require elastomers with different viscoelastic properties to achieve effective control.

When a rigid body vibrates steadily under a periodic force, it may be desirable to prevent the transmission of this force onto its surroundings. This can be accomplished with the insertion of an elastomeric isolator as illustrated by the one-dimensional model (Fig. 8), and is commonly known

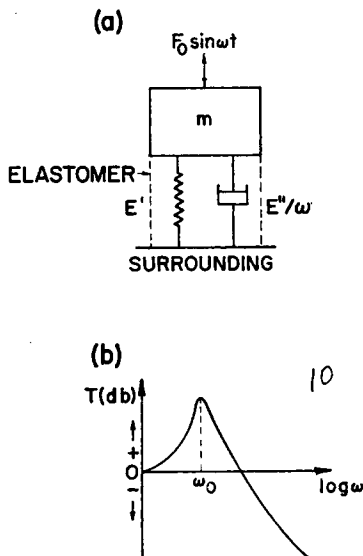


Fig. 8. (a) Forced vibration with the elastomeric isolator represented as a spring-dashpot pair; (b) schematic transmissibility curve illustrating the explicit dependence of  $T$  vs. the driving frequency.

as *vibration isolation*. The equation of motion for such a vibrating system is well known.<sup>15</sup> The defined transmissibility  $T$  is the fraction of force transmitted and can be represented as<sup>16</sup>

$$T(\omega) = \left( \frac{F_{tr}}{F_0} \right) = \left\{ \frac{(1 + \tan^2 \delta)}{[1 - (\omega^2 m / E' k)]^2 + \tan^2 \delta} \right\}^{1/2} \quad (1)$$

$T$  is expressed in terms of the viscoelastic parameters  $\tan \delta$  and the elastic Young's modulus  $E'$  ( $E' \doteq 3G'$  for rubbery materials), whereas  $k$  is a constant determined solely by the mount geometry.  $T$  is also seen to be an explicit function of frequency, that is, in addition to whatever the inherent frequency dependence of  $E'$  and  $\tan \delta = E''/E'$  may be. Four illustrative examples have been computed (Fig. 9), from which the following generalized conclusions can be reached:

(1) Only vibrations beyond the resonance frequency,  $\omega_0 = (E'k/m)^{1/2}$ , of a system can be isolated. In order to ensure a small  $\omega_0$ , an elastomer with low  $E'$  should be chosen for the mount of a given geometry (of course, in practice, space and load-bearing considerations will set a lower limit to  $E'$ ).

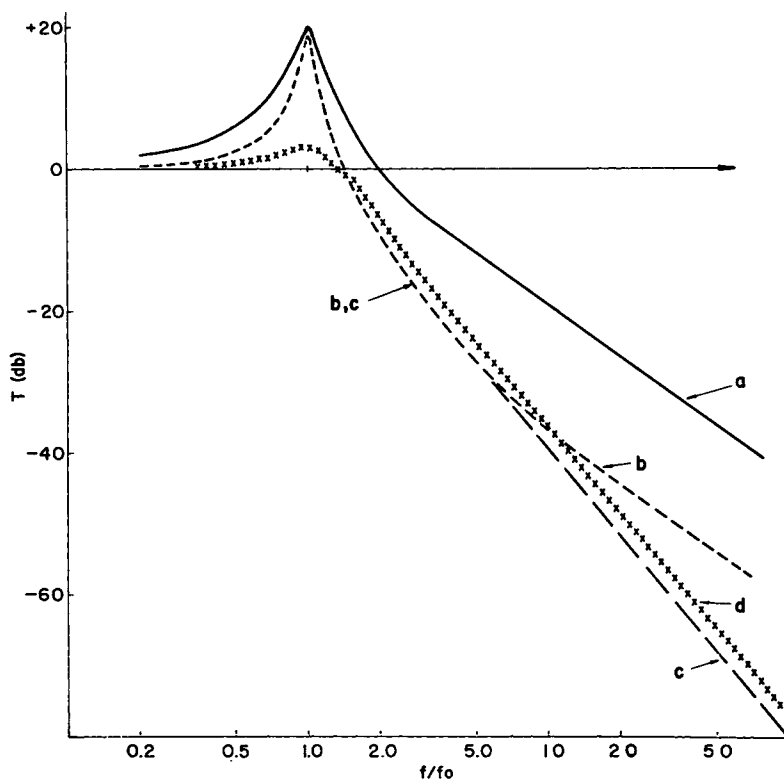


Fig. 9. Four illustrative  $T$  curves vs. normalized frequency ( $\omega/\omega_0$ ) where  $T$  (db) =  $20 \log$  (fraction of force transmitted): (a)  $\tan \delta = 0.1$ ,  $E' \sim \omega$ ; (b)  $E'$  constant,  $\tan \delta \sim \omega$  and = 0.1 at resonance frequency  $\omega_0$ ; (c)  $E'$  constant,  $\tan \delta = 0.1$ ; (d)  $E'$  constant,  $\tan \delta = 1.0$ .

(2) Elastomers with minimum increase of  $E'$  with respect to frequency give maximum rate of attenuation in transmissibility beyond resonance.

(3) Highly lossy elastomers suppress amplification at resonance but have a detrimental effect on isolation at higher frequencies.

If the rigid body vibrates as a result of a sudden impulse, an elastomeric dampener can be used to increase the decay rate of such a transient vibration; this may be termed *vibration damping*. The viscoelastic requirement of the dampener is simply high loss tangent as shown by the well known logarithmic decrement eq. (2) in which  $\Delta$  is defined as the natural log ratio of the successive vibration amplitudes.

$$\Delta = 2\pi \tan \delta / 1 + (1 - \tan^2 \delta)^{1/2} \quad (2)$$

On the other hand, if the vibrating component is structurally flexible, such as a panel sheet, it will be subject to bending waves under dynamic loading forces. A damping layer can be applied to reduce the amplitude

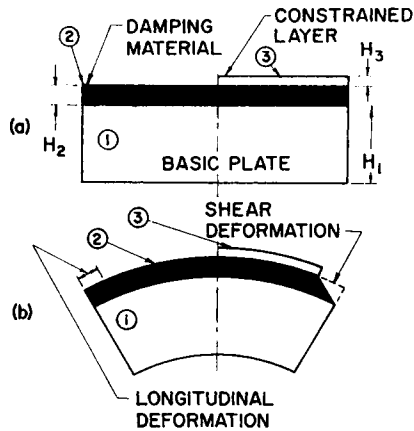


Fig. 10. (a) Free (left) and constrained (right) damping layer arrangements; (b) composite panel under bending wave motions.

of a steady-state bending wave or to increase the decay rate of a transient bending wave by increasing the energy dissipation capacity of the composite panel. This is known as *structural damping*. Two typical applications are shown in Figure 10. Under the action of bending waves, the damping layer on the left will be subjected primarily to longitudinal deformations while the constrained layer on the right will be subjected chiefly to shear deformations. Approximate solutions of the corresponding wave equations have been obtained. Oberst<sup>17</sup> has given the following relationship for the free layer treatment

$$(\tan \delta)_E = \frac{(\tan \delta) eh (3 + 6h + 4h^2)}{1 + eh (3 + 6h + 4h^2)} \quad (3)$$

$(\tan \delta)_E$  is the effective damping of the composite panel expressed in terms of the loss tangent of the damping layer,  $(\tan \delta)$ , the ratios of the elastic components of the Young's moduli for the damping layer and the base plate,  $e = E'_2/E'_1$ , and their relative thickness,  $h = H_2/H_1$ . It is seen that attainment of high effective damping requires: (1)  $\tan \delta$  of the viscoelastic coating must be high and (2) its elastic modulus,  $E'_2$ , must be comparable in magnitude with  $E'_1$ .

These two concurrent requirements are difficult to meet, since polymers exhibit maximum mechanical loss only in the transition region where  $E'_2$  has not yet attained its highest value and is therefore usually considerably smaller than  $E'_1$ . One possible solution to this problem is by proper compounding of an inherently lossy polymer with high modulus fillers. It is known that fillers can substantially increase the modulus of an elastomer without comparable reduction of mechanical loss.<sup>18</sup>

The corresponding solution developed by Kerwin<sup>19</sup> for a constrained damping layer system is considerably more complex.  $(\tan \delta)_E$  depends upon the properties of the multiple layers as well as their thickness ratios.<sup>20</sup>

It suffices to summarize here only the requirements of the viscoelastic layer for an ideal case: (1) the elastic modulus,  $G'$ , should vary proportionally with frequency; and (2) the loss tangent should be high. These two requisites are approximately compatible for polymers in the transition region. Thus each material has a potentially useful temperature (and frequency) region for constrained damping application.

### Potentialities of the Various Elastomers in Vibration Control Applications

On the basis of the foregoing discussion, it may be possible to predict the performance of elastomers in vibration control applications from their inherent viscoelastic properties. Although most of the present data refer to gum stocks or raw polymers which are unlikely to be used in any practical applications, such effects as cure, fillers, amplitude of deformation and

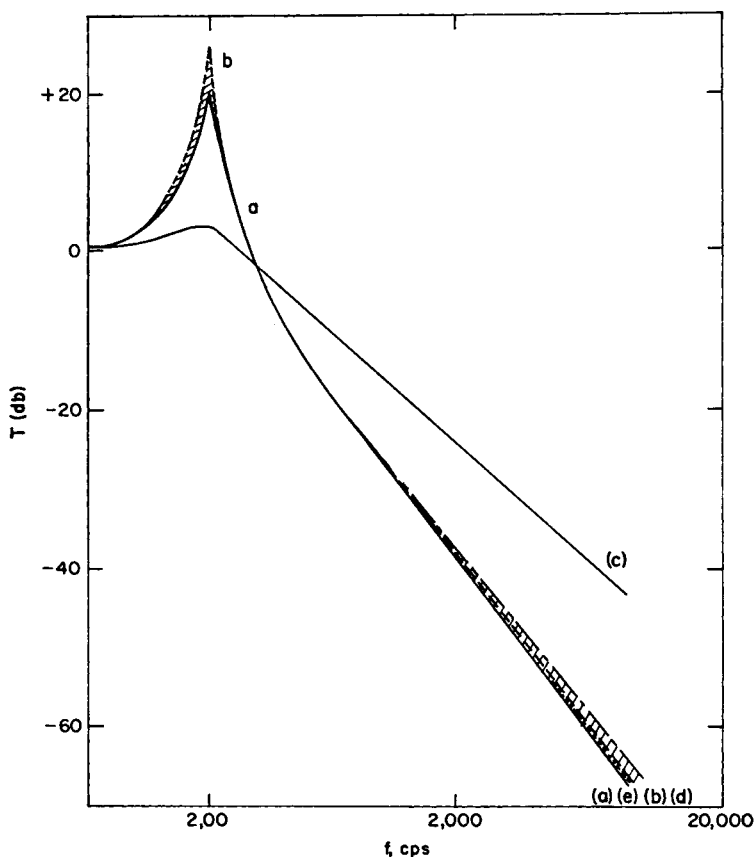


Fig. 11. Computed  $T$  curves for (a) Nordel; (b) Hevea rubber; (c) PIB; (d) SBR, (e) Neoprene W at 25°C. (77°F.) with resonance frequencies arbitrarily chosen as 200 cycles/sec. With the exception of PIB, the other elastomers display similar spectra as indicated by the envelope. Their relative efficiencies range as (d), (b), (e), and (a) in increasing order.

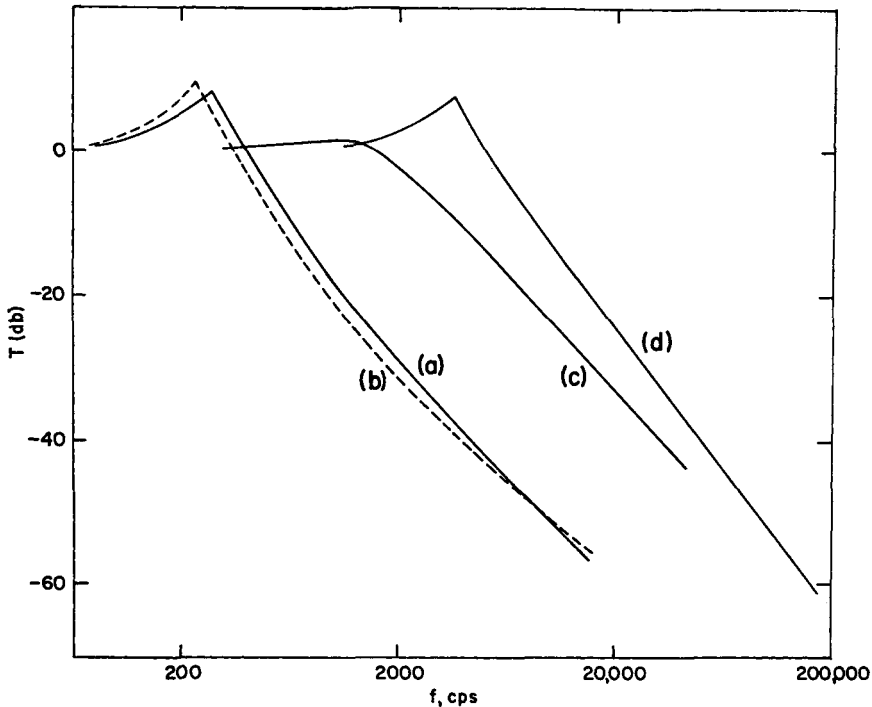


Fig. 12. Performance at  $-18^{\circ}\text{C}$ . ( $0^{\circ}\text{F}$ ) predicted for the same systems as in Fig. 11.

degree of static stress do not influence *radically* the basic dynamic characteristics of the materials.<sup>18\*</sup> Specific formulations can usually be developed for individual end use once the appropriate elastomer is chosen.

For illustrative purposes on vibration isolation applications, the transmissibility curves (Fig. 11) for Neoprene W,<sup>1</sup> Nordel, Hevea,<sup>22</sup> polyisobutylene,<sup>9</sup> and SBR<sup>23</sup> have been computed at  $25^{\circ}\text{C}$ . ( $77^{\circ}\text{F}$ .) from the reduced dynamic data according to eq. (1). The resonance frequencies have been arbitrarily chosen as 200 cycles/sec. for all the systems. This involves only a minor adjustment of the  $m/k$  ratios, since the corresponding  $E'$ ( $G'$ ) values are very similar. It is apparent that, except for polyisobutylene, all the systems have similar isolation characteristics. However, if these isolators are compared at  $-18^{\circ}\text{C}$ . ( $0^{\circ}\text{F}$ .), their performance will be modified to various extents as shown in Figure 12. The resonance frequencies are now displaced from the original positions to the present locations. This is due to the different temperature effects on  $E'$  for the various elastomers. It is seen that efficient isolation can still be expected from Hevea rubber and Nordel. The latter should retain such characteristics at even lower temperatures, since its dynamic properties remain relatively

\* This general statement is also supported by the recent work of P. Mason<sup>21</sup> on the strain dependence of rubber viscoelasticity at moderate carbon black fillings and moderate static elongations.

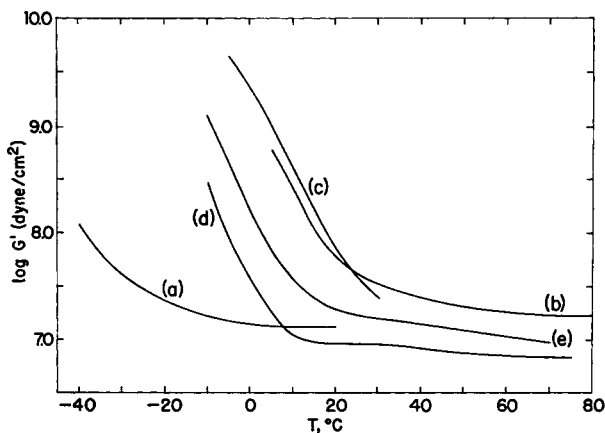


Fig. 13. Elastic shear modulus ( $G'$ ) at 100 cycles/sec. vs. temperature for: (a) Nordel; (b) Viton A; (c) Neoprene ILA; (d) Neoprene W; (e) Hypalon 20.

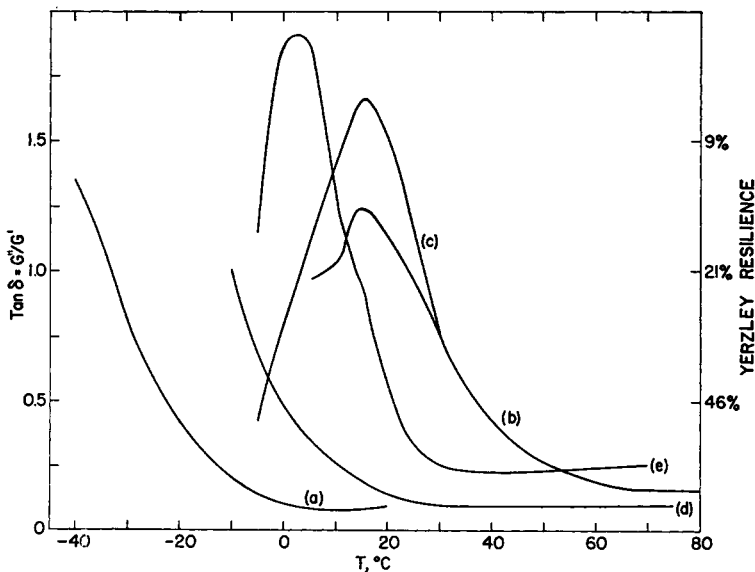


Fig. 14. Mechanical loss tangent ( $\tan \delta$ ) at 100 cycles/sec. vs. temperature for the same systems as in Fig. 13.

more constant than those of Hevea rubber (see Fig. 5). The corresponding curve for Neoprene W is missing, since its dynamic properties are not easily accessible at this temperature due to its partial crystallization.<sup>1</sup> Transmissibility curves can similarly be calculated for other resonance frequencies and temperatures from the viscoelastic properties of the elastomer as presented here.

It is relatively simple to choose a suitable vibration damping elastomer

for attenuating the transient vibrations of a rigid body, since high loss tangent in the temperature and frequency region of interest is the only criterion to be considered. On the other hand, it is necessary to optimize by computation the effective structural damping of a composite panel, either homogeneously coated or in a constrained structure.

Figures 13 and 14 show  $G'$  and  $\tan \delta$  plotted as functions of temperature at an arbitrarily chosen 100 cycles/sec. Such a presentation is convenient to use if the vibrating frequency range is narrow but the environment temperature is of greater range. Table III summarizes the temperature ranges of potential vibration dampeners; this range is defined by  $\tan \delta \geq 0.5$  throughout the frequency range of 10–1000 cycles/sec.

TABLE III  
Temperature Range for Effective Damping with  $\tan \delta \geq 0.5$  throughout Frequency  
 $10 \leq f \leq 1000$  cycles/sec.

Polymer	Temperature range (°C.)
Hypalon 20	-5 to 13
Viton A	4 <sup>a</sup> to 25
Neoprene ILA	4 to 25
Hevea Rubber	-45 to -23
SBR	-33 to -14
PIB	-47 to 17

<sup>a</sup> Extrapolated.

It is apparent that Neoprene ILA and Viton A are attractive dampeners near room temperature for audiofrequency vibrations, whereas PIB has outstanding low temperature damping properties. On the other hand, Nordel and Hevea are calculated to be especially effective isolators.

### References

1. Yin, T. P., and R. Pariser, *J. Appl. Polymer Sci.*, **7**, 667 (1963).
2. Kurath, S. F., E. Passaglia, and R. Pariser, *J. Appl. Polymer Sci.*, **1**, 150 (1959).
3. Dixon, S., D. R. Rexford, and J. S. Rugg, *Ind. Eng. Chem.*, **49**, 1687 (1957); J. F. Smith and G. T. Perkins, *J. Appl. Polymer Sci.*, **5**, 460 (1961).
4. *Du Pont Trade Bulletin* BL-380, (1962).
5. Gladding, E. K., B. S. Fisher, and J. W. Collette, *Rubber Chem. Technol.*, **35**, 1114 (1962).
6. Athey, R. J., *Ind. Eng. Chem.*, **52**, 611 (1960).
7. McCrum, N. G., *J. Polymer Sci.*, **34**, 355 (1959).
8. Ferry, J. D., *Viscoelastic Properties of Polymers*, Wiley, New York, 1961, pp. 211–15.
9. Ferry, J. D., L. D. Grandine, Jr., and E. R. Fitzgerald, *J. Appl. Phys.*, **24**, 911 (1953).
10. Williams, M. L., and J. D. Ferry, *J. Colloid Sci.*, **11**, 169 (1953).
11. (a) Rouse, P. E., Jr., *J. Chem. Phys.*, **21**, 1272 (1953); (b) B. H. Zimm, *J. Chem. Phys.*, **24**, 269 (1956); see also ref. 8, pp. 154–166.
12. Krigbaum, W. R., M. Kaneko, and A. Roig, *J. Polymer Sci.*, **A1**, 1 (1963).
13. Ferry, J. D., and R. F. Landel, *Kolloid-Z.*, **148**, 1 (1956).
14. Ref. 8, p. 258.



15. Myklestad, N. O., *Fundamentals of Vibration Analysis*, McGraw-Hill, New York, 1956, pp. 83-90.
16. Snowdon, J. C., *Rubber Chem. Technol.*, **32**, 1209 (1959).
17. Oberst, H., *Acustica*, **2**, No. 4, AB-181 (1952).
18. Chesapeake Instrument Corporation Report No. 187, 1962, to the Office of Naval Research under Contract No. 2678 (00).
19. Kerwin, E. M., Jr., *J. Acoust. Soc. Am.*, **31**, 952 (1959).
20. Ross, D., E. E. Ungar, and E. M. Kerwin, Jr., *Colloquium on Structural Damping*, December, 1959, Am. Soc. Mech. Engrs., New York, 1960.
21. Mason, P., *Rubber Chem. Technol.*, **35**, 918, 927 (1962).
22. Payne, A. R., in *Rheology of Elastomers*, P. Mason and N. Wookey, Eds., Pergamon Press, London, 1958, p. 86.
23. Tobolsky, A. V., *Properties and Structure of Polymers*, Wiley, New York, 1960, pp. 146-147.

### Résumé

On a mesuré initialement les propriétés mécaniques dépendantes du temps et de la température des VITON A, Neoprène ILA, Adiprène L-167 et de l'élastomère hydrocarboné Nordel, au moyen de l'appareil de Fitzgerald. Les résultats couvrent les régions de transition de l'état vitreux à l'état caoutchouteux qui ont été réduites à 25°C quand cela était possible. Les résultats sont ensuite discutés en friction monomérique et facteurs de glissement  $\log Q_T$ . Faisant suite à une brève présentation des conditions requises pour l'élaboration de diverses techniques de mesure de vibrations, on évalue les potentialités des présents élastomères ainsi que celles d'autres élastomères courants. Il s'avère que le NORDEL, le caoutchouc de l'Hévée et le Néoprène W sont des isolateurs potentiels de vibration, tandis que le VITON A, le Néoprène ILA et le polyisobutylène ont des caractéristiques désirées d'amortissement de vibrations. On a calculé leurs régions température-fréquence d'application efficace.

### Zusammenfassung

Die zeit- und temperaturabhängigen mechanischen Eigenschaften von VITON A, Neopren ILA, ADIPREN L-167 und NORDEL Kohlenwasserstoff-Elastomerem wurde in erster Linie mit dem Umwandler von Fitzgerald gemessen. Die Ergebnisse erstrecken sich von plastischen bis zu gummiähnlichen Umwandlungsbereichen, die nach Möglichkeit auf 25°C reduziert wurden. Die Ergebnisse werden dann in bezug auf die Relaxationsspektren, Monomerreibungskoeffizienten und Shiftfaktoren,  $\log Q_T$ , diskutiert. Mit einer kurzen Darstellung der viscoelastischen Erfordernisse für verschiedene Vibrationskontrollanlagen werden die Möglichkeiten der vorliegenden sowie anderer häufiger Elastomerer untersucht. Es wird gefunden, dass NORDEL, Heveagummi, und Neopren W potentielle Vibrationsisolatoren sind, während VITON A, Neopren ILA und Polyisobutylen gute vibrationsdämpfende Eigenschaften haben. Ihre für die Anwendung brauchbaren Temperatur-Frequenzbereiche wurden berechnet.

Received June 28, 1963

Revised November 10, 1963