Testing for dynamic modulus and its relationship to static modulus

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Materials go through a history of applied forces and resulting strains during their productive lifetime. This history is very significant in the case of viscoelastic materials, such as elastomers. One way to characterize and predict the behavior of an elastomer such as rubber is to study its dynamic modulus and its relationship to the static modulus of the same specimen.

As Dr. Felix Yerzley explained, the mechanical oscillograph (ref. 1) has been widely used in the vibration isolation industry over many decades with great success. Traditionally, the Yerzley mechanical oscillograph (AYO-IV of www.tavdico.com) has been widely used to analyze the relationship between the dynamic modulus and the static modulus. As per the ASTM D945-16 (ref. 2) test method, this test machine utilizes simple harmonic motion with varying moments of inertia by adding weights to a beam, which induces compression forces onto a sample between two parallel plates. The same mode is also used on shear samples, which are prepared as dual samples of rubber components in between three parallel steel plates as per ASTM D945-16, Part B: Measurements in Shear Methods A and B (ref. 3).

Current evaluation of this relationship in compression mode has been studied for two hardness ranges, namely 40 and 70 durometer A , as well as a 50 durometer A hardness dual-component sample (as per ASTM D945-16) in shear tests. All these samples are made of natural rubber compounds.

Table 1 - typical output of AYO-IV for a shear sample

Test ID: TK SHR RT C 3 4D	
Test date: 11/05/19	
Test time: 10:24:31	
Specimen height	0.500 inches
Specimen area	0.884 square inches
Sampling rate	200 samples/second
Test duration	6 seconds
Weights forward	2.00
Weights middle	0.00
Weights rear	0.00
Parameters specified by ASTM D945	
Yerzley resilience	80.847%
Resilience-SAE J16	87.238%
Yerzley hysteresis	19.153%
Point modulus	89.879 pounds/square inch
Natural frequency	2.395 cycles/second
Dynamic modulus	85.041 pounds/square inch
Moment of inertia	0.14162 slug - square foot
Impact energy	7.584 inch - pound/cubic inch
Tangent of delta	0.0789
Delta	4.51°
Final deflection	22.213%
Dynamic/static modulus	0.946
Logarithmic decrement BCD	0.12397
Logarithmic decrement CDE	0.14925

Table 1 notes a typical output one might get as a result of testing an elastomer compound in the shear mode.

Figure 1 shows the typical graphical representation of the results of testing in the shear mode.

We then, in a different study, decided to take a closer look at the results of testing in the compression mode at different temperatures. A series of tests was carried out on a compound of natural rubber at different filler levels and at specific temperatures: 4°C, 23°C (RT) and 66°C. These tests were conducted at the final deflection values close to each other at around 20% (ref. 4). Table 2 notes a typical output one might get as a result of testing an elastomer compound in the compression mode.

Figure 2 provides a graphical representation of the results for the natural rubber compounds tested at various temperatures listed in table 2.

The following observations were made:

- An increase in temperature yields increasing resilience and decreasing hysteresis, point and dynamic moduli, natural frequency, impact energy, tan delta and delta (loss angle).
- An increase in temperature yields a small increase in the ratio of dynamic/static modulus between 4°C and 23°C, but shows a decline at 66°C.
- The moment of inertia and frequency decreased, yielding the decreasing trend of dynamic modulus. The dynamic modulus is equal to (If2), where (I) is the moment of inertia and (f2) is the frequency squared. Thus, the frequency impacts the dynamic modulus by a power of two.

$$\text{Dynamic modulus} = If^2 \qquad (1)$$

- Furthermore, a comparison of the results of the tests for the dynamic modulus in compression mode versus the shear mode (2,642 psi versus 85 psi in tables 2 and 1) yields a ratio of 31 fold. Obviously, incompressible rubber resists forces under compression mode much better than those under shear mode.

Figure 1 - typical graphical output of AYO-IV for a shear sample

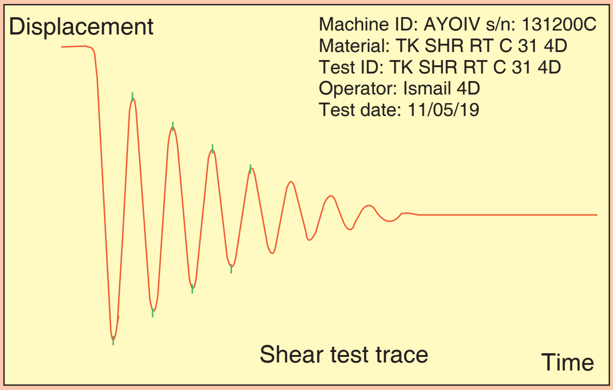

Table 2 - AYO-IV compression test results of a 70A durometer rubber component tested at three different temperatures

Temperature, °C	*4*	*23*	*66*
Yerzley resilience, %	35,393	39,567	52,230
Resilience, SAE J16, %	46,179	48,022	59,183
Yerzley hysteresis, %	64,607	60,433	47,770
Point modulus, psi	1,068,639	949,545	616,239
Natural frequency, Hz	5,634	5,714	4,494
Dynamic modulus, psi	2,771,422	2,641,935	1,246,019
Moment of inertia, slug - square foot	0.41711	0.38650	0.29467
Impact energy, inch pound/cubic inch	54,480	51,847	42,069
Tangent of delta, unitless	0.4011	0.3694	0.2620
Delta, degrees	21.86	20.27	14.68
Final deflection, %	20.482	21.166	22.584
Dynamic/static modulus unitless	2,593	2,782	2,022
Logarithmic decrement BCD, unitless	0.63010	0.58022	0.41154
Logarithmic decrement CDE; unitless	0.93895	0.91464	0.65196

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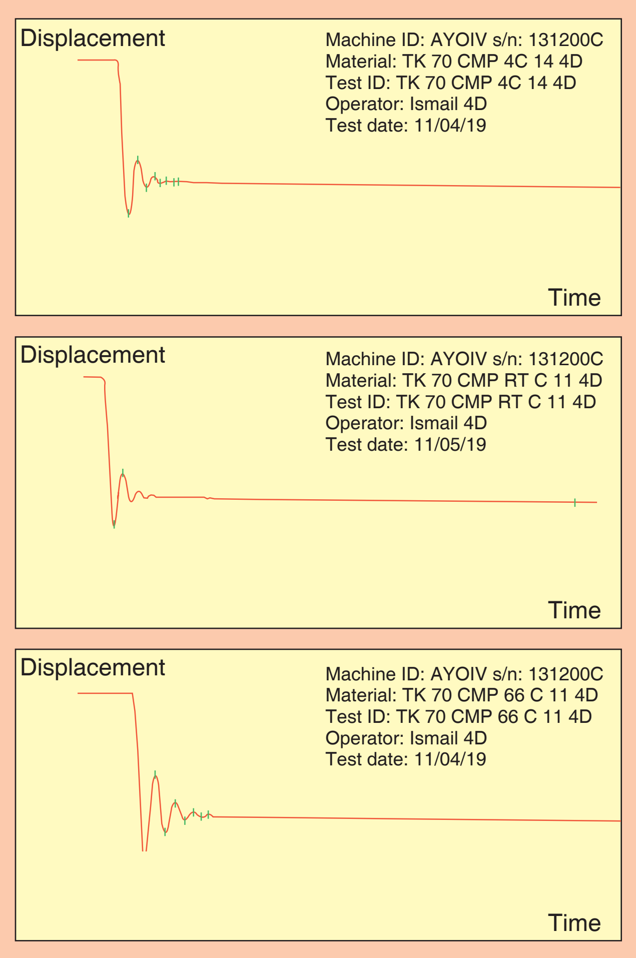

We have found there are a number of other applications where our technology can or has been used. Table 3 provides formulations with varying filler types and ratios as a framework for testing carried out in PI-based elastomer compounds for improved flame retardant compound development.

In his investigations, David John Kind (ref. 5) arrived at the following conclusions: Yerzley static modulus increases broadly in line with hardness, as expected. The reduction in polymer increases the DM/SM ratio, broadly increasing with filler loading, but varying by filler type.

When rubber is used in a dynamic application such as an engine mounting, it is useful to be able to evaluate the effect of additives within a material test for dynamic behavior. Table 3 notes PI-based compounds where various loading levels of different fillers were used. And table 4 shows the resulting physical and dynamic properties obtained upon testing.

It can be seen that dilution of the polymer with fillers will tend to increase the modulus, and particularly increase the dynamic stiffness. This can lead to increased transmissibility of vibration. In addition, the resilience will typically drop, indicating a higher damping characteristic. This can lead to greater heat build-up in the product, leading to a reduced service life through physical or chemical degradation.

In addition, it can be noted that hardness values indicate that the silica and calcium carbonate do not provide the same level of modulus increase afforded by the carbon black. The static modulus values confirm the effect of filler on the hardness values measured, with the inorganic fillers leading to reduced material modulus. The DM/SM ratio was seen to vary considerably with different filler combinations, and the formulations with half loadings tended to lower levels of DM/SM ratios than the 100% mixes. This may be attributed to the fact that mixtures tended to disrupt the formation of significant filler-filler structures within the matrix, which can lead to a higher dynamic response in rubber compounds. The use of carbon black and silica yields comparable resilience values; whereas the use of calcium carbonate gives an extremely high resilience. The use of silica was seen to produce an increase in Yerzley creep, with a

Table 3 - polyisoprene formulations varied by filler type with equal total pphr

Ingredient (values in pphr)	*B*	*SB*	*S*	*CB*	*C*
Synthetic polyisoprene	100	100	100	100	100
Carbon black N550	40	20	-	20	-
Precipitated amorphous silica	-	20	40	-	-
Calcium carbonate	-	-	-	20	40
Naphthenic process oil	2	2	2	2	2
Zinc oxide	5	5	5	5	5
Stearic acid	2	2	2	2	2
Antioxidant TMQ	2	2	2	2	2
Antiozonant wax	2	2	2	2	2
Sulfur	0.25	0.25	0.25	0.25	0.25
MBS	2.1	2.1	2.1	2.1	2.1
TMTD	1.25	1.25	1.25	1.25	1.25
Total	156.6	156.6	156.6	156.6	156.6

Table 4 - physical properties for varied filler formulations of polyisoprene formulations

Formulation code	*B*	*SB*	*S*	*CB*	*C*
Tensile stress/strain properties					
Tensile strength, MPa	23.1	21.1	20.4	21.4	15.6
Elongation at break, %	509	504	595	554	659
Hardness, IRHD	56	49	46	47	41
Specific gravity	1.08	1.09	1.10	1.11	1.14
Yerzley properties					
Static modulus (SM), MPa	0.72	0.55	0.51	0.52	0.38
Dynamic modulus (DM), MPa	1.13	0.75	0.83	0.66	0.51
DM/SM ratio	1.57	1.36	1.63	1.27	1.34
Angle loss, %	5.8	4.8	5.6	3.3	3.1
Phase angle, %	8.1	5.5	5.2	3.1	1.1
Resilience, %	72	73	72	83	87
Creep, %	4.4	6.3	8.9	4.0	3.9

doubling of the value for 100% silica in comparison with carbon black or calcium carbonate.

Another study by M.N. Myslivets et al. (ref. 6) is described as follows, where he looked at vibration isolators based on various natural and synthetic based rubbers, including polysoprene and polybutadiene. There is a correlation between the logarithmic decrement and the hysteresis losses. The increase in hysteresis losses leads to an increase in the heat build-up within the vibration isolating material, which often has a negative effect on the life of the vibration isolator.

Consequently, during the operation of vibration isolators manufactured from the investigated materials, the maximum amplitude at resonance will be achieved in a period from 10 to 15 years, after which the heat build-up will be minimal.

From the results of investigations of the development of residual compressive deformation, it can be seen that during the operation of the vibration isolator, constant displacement of the resonance zone will occur with time, and here the direction of this displacement will depend not only on the shape of the working element of the rubber mass, but also on the type of deformation. Thus, before carrying out studies to determine the service lives of vibration isolators, it is necessary to rank its main characteristics on the basis of its service conditions. In the design of vibration isolators, account must be taken of the fact that, with time, the correlation relationship between the characteristics (for example, between the dynamic and static moduli) can change in one or other direction.

Conclusion

The relationship between dynamic and static moduli in compression and shear tests yields predictive results showing how the end product will behave in a vibration isolation (damping) function in real life. The AYO-IV Yerzley mechanical oscillograph is a true companion of rubber compounders, as well as molders. One can utilize this well-proven, user-friendly testing machine as a true companion in the design, compounding and forming of rubber products to obtain the most durable and functional end product.

References

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