Designation: D6601 – 15

Standard Test Method for Rubber Properties—Measurement of Cure and After-Cure Dynamic Properties Using a Rotorless Shear Rheometer[1]

This standard is issued under the fixed designation D6601; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the use of a rotorless oscillating shear rheometer for measuring after cure dynamic properties at predetermined temperature(s) below the cure temperature.

1.2 Specified cure conditions that approximate a "static cure" also are covered to minimize effects on cured rubber compound dynamic properties. This test method is not intended to replace Test Method D5289.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.4 **Warning—**Compounds based on silicone or fluoroelastomers may have high levels of thermal contraction or poor adhesion to the dies when cooled after the cure portion of this test method, causing slippage during strain sweeps. If this occurs, the results will not be reliable.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1349 Practice for Rubber—Standard Conditions for Testing

D4483 Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries

D5289 Test Method for Rubber Property—Vulcanization Using Rotorless Cure Meters

D5992 Guide for Dynamic Testing of Vulcanized Rubber and Rubber-Like Materials Using Vibratory Methods

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *complex shear modulus, G^*, n*—the ratio of peak amplitude shear stress to peak amplitude shear strain; mathematically, $G^* = (G'^2 + G''^2)^{1/2}$.

3.1.2 *complex torque, S^*, n*—the peak amplitude torque response measured by a reaction torque transducer for a sinusoidally applied strain; mathematically, S^* is computed by $S^* = (S'^2 + S''^2)^{1/2}$.

3.1.3 *dynamic cure, n*—any cure condition which oscillates or moves the die.

3.1.4 *elastic torque, S', n*—the peak amplitude torque component, which is in phase with a sinusoidally applied strain.

3.1.5 *loss angle, δ, n*—the phase angle by which the complex torque (S^*) leads a sinusoidally applied strain.

3.1.6 *loss factor, tan δ, n*—the ratio of loss modulus to storage modulus, or the ratio of viscous torque to elastic torque; mathematically, $\tan \delta = G''/G' = S''/S'$.

3.1.7 *loss shear modulus, G'', n*—the component of applied stress that is 90° out-of-phase with the shear strain, divided by the strain.

3.1.8 *static cure, n*—the cure conditions of 0.0° arc strain and 0.0 Hz in frequency, that is, no movement of the dies during the cure test.

3.1.9 *storage shear modulus, G', n*—the component of applied stress that is in phase with the shear strain, divided by the strain.

3.1.10 *viscous torque, S'', n*—the peak amplitude torque component, which is 90° out of phase with a sinusoidally applied strain.

4. Summary of Test Method

4.1 A rubber test specimen is contained in a die cavity that is closed and maintained at an elevated cure temperature. The cavity is formed by two dies, one of which is oscillated through a rotary amplitude. This action produces a sinusoidal torsional strain in the test specimen resulting in a sinusoidal torque, which measures the viscoelastic changes of the test specimen as it cures. The test specimen must be a unvulcanized rubber compound containing curatives. A controlled limited strain is applied during cure to prevent effecting the aftercure properties.

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[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

4.2 After a predetermined cure time, the temperature is reduced and dynamic property measurements can be based on a strain sweep in which the strain amplitude is programmed to change in steps under constant frequency and temperature, a frequency sweep in which the frequency is programmed to change in steps under constant strain amplitude and temperature, or, a temperature sweep in which the temperature is programmed to decrease under constant strain amplitude and frequency conditions.

4.3 For an after-cure strain sweep, the instrument is typically programmed to increase the strain with each subsequent step change. This is done to minimize the influence of prior test conditions on subsequent test steps. Typically two repeat strain sweeps may be programmed consecutively to quantify the Payne Effect,[3] which is the reduction in dynamic storage modulus from strain softening of the rubber vulcanizate.

5. Significance and Use

5.1 This test method is used to determine the vulcanization characteristics of (vulcanizable) rubber compounds under selected test conditions of strain and frequency which do not significantly affect the cured dynamic properties. In the same test, this test method also will measure the dynamic properties of the vulcanizate at temperatures significantly below the cure temperature. These lower temperature measurements are necessary in order to more effectively relate to rubber product service conditions.

5.2 This test method may be used for quality control in rubber manufacturing processes and for research and development testing of rubber compounds containing curatives. This test method also may be used for evaluating cure and dynamic property differences resulting from the use of different compounding ingredients.

5.3 For additional information regarding the significance of dynamic testing of vulcanized rubber, the reader may wish to reference Guide D5992.

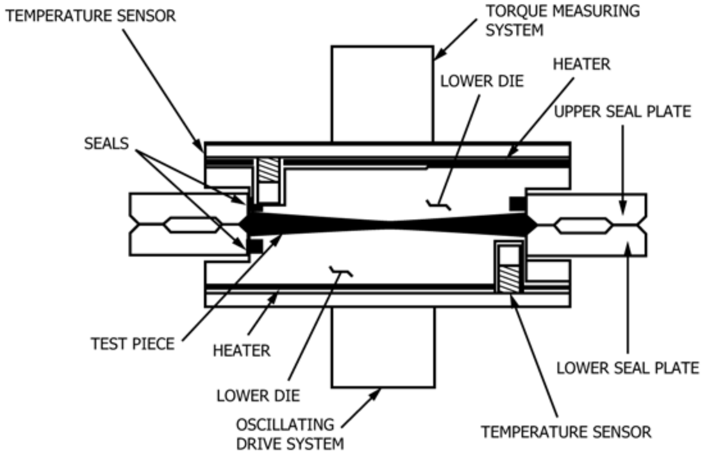
6. Apparatus

6.1 *Torsion Strain Rotorless Oscillating Rheometer with a Sealed Cavity*—This type of rheometer measures the elastic torque S' and viscous torque S'' produced by oscillating angular strain of set amplitude and frequency in a completely closed and sealed test cavity.

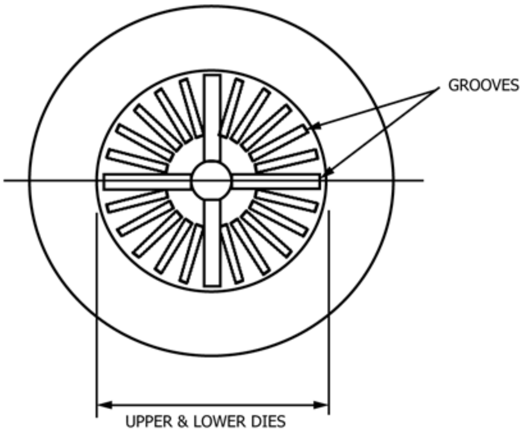
6.2 *Sealed Die Cavity*—The sealed die cavity is formed by two conical surface dies. In the measuring position, the two dies are fixed a specified distance apart so that the cavity is closed and sealed (see Fig. 1).

6.3 *Die Gap*—For the sealed cavity, no gap should exist at the edges of the dies. At the center of the dies, the die gap shall be set at 0.45 ± 0.05 mm.

6.4 *Die Closing Mechanism*—For the sealed cavity, a pneumatic cylinder or other device shall close the dies and hold them closed during the test with a force not less than 11 kN (2500 lbf).



A) MEASURING PRINCIPLE



B) REACTION DIES

FIG. 1 Typical Sealed Torsion Shear Rotorless Curemeter

6.5 *Die Oscillating System*—The die oscillating system consists of a direct drive motor, which imparts a torsional oscillating movement to the lower die in the cavity plane.

6.5.1 The oscillation amplitude can be varied, but a selection of 0.2° arc (±2.8 % shear strain) is preferred for the cure test while strains from ±1 to ±100 % are preferred for the after-cure strain sweeps. The oscillation frequency can be varied between 0.03 Hz and 30 Hz.

6.6 *Torque Measuring System*—The torque measuring system shall measure the resultant shear torque.

6.6.1 The torque measuring device shall be rigidly coupled to the upper die, any deformation between the die and device shall be negligibly small, and the device shall generate a signal, which is proportional to the torque. The total error resulting from zero point error, sensitivity error, linearity, and repeatability errors shall not exceed 1 % of the selected measuring range.

6.6.2 The torque recording device shall be used to record the signal from the torque measuring device and shall have a

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[3] A.R. Payne, *J. Polymer Sci.*, 6, 57 (1962).

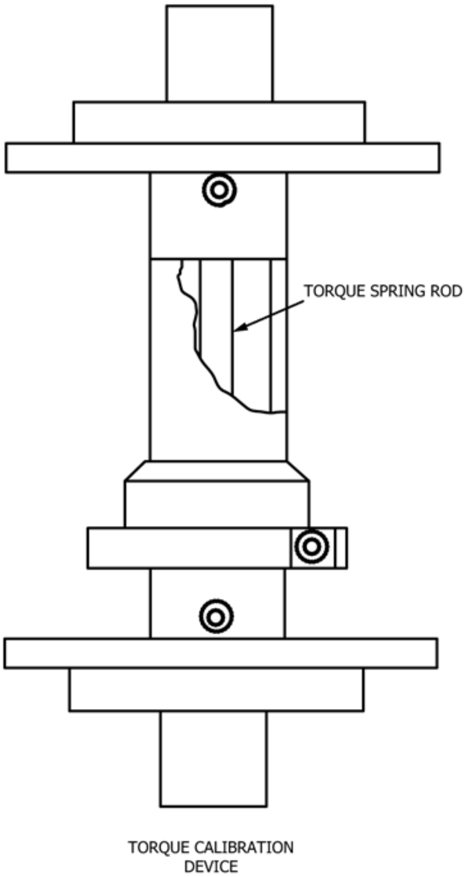

FIG. 2 Typical Torque Standard Calibration Device for Torsion Shear Curemeters

TABLE 1 Test Conditions for Cure Test[A]

NOTE 1—Cure properties should be measured in accordance with Test Method D5289.

Cure Condition No.	Temperature, °C	Frequency, Hz	Strain, ± ° Arc.
1	140	1.67	0.2
2	160	1.67	0.2
3	180	1.67	0.2
4	140	0	0
5	160	0	0
6	180	0	0

[A] Please note that cure conditions of 0.2° arc strain and 1.67 Hz frequency may influence post cure properties

response time for full scale deflection of the torque scale of 1 s or less. The torque shall be recorded with an accuracy of ± 0.5 % of the range. Torque recording devices may include analog chart recorders, printers, plotters, or computers.

6.6.3 A reference torque device is required to calibrate the torque measurement system. A torque standard may be used to calibrate the torque measuring system at the selected angular displacement by clamping a steel torsion rod to the oscillating and the torque measuring dies of the torsion shear rheometer (see Fig. 2). The reference values for angular displacement and corresponding torque shall be established by the manufacturer for each torque standard.

6.7 *Reference Test Temperature*—The standard reference test temperature for cure shall be either 140°C, 160°C, or 180°C while dynamic property measurements after-cure (dynamic property measurements made after completion of the cure test) should be made at either 100°C or 60°C. Tests may be carried out at other temperatures, if required. Other temperatures should be selected in accordance with Practice D1349 when practical.

6.8 *Temperature Control System*—This system shall permit the reference temperature to be varied between 40°C and 220°C with an accuracy of ±0.3°C or better.

6.8.1 The dies shall heat to the set point temperature in 1.0 min or less from closure of the test cavity. Once the initial heating up time has been completed, die temperature shall not vary by more than ±0.3°C for the remainder of a cure test at a set temperature. When the set temperature is changed in a programmed temperature sweep or strain sweep, dynamic property measurements should not be recorded until the die temperatures are within ±0.3°C of the new set temperature for at least 30 s.

6.8.2 Temperature distribution within the test piece shall be as uniform as possible. Within the deformation zone, a tolerance of ±1°C of the average test piece temperature shall not be exceeded.

6.8.3 Die temperature is determined by a temperature sensor used for control. The difference between the die temperature and the average test piece temperature shall not be more than 2°C. Temperature measurement accuracy shall be ±0.3°C for the die temperature sensor.

6.8.4 The upper and lower dies shall each be jacketed with forced air cooling devices in order to rapidly decrease the temperature of the upper and lower dies after the cure test is completed.

7. Test Specimen

7.1 A test specimen taken from a sample shall be between 5 and 6 cm^3 for the sealed cavity oscillating rheometer. The specimen volume should exceed the test cavity volume by a small amount, to be determined by preliminary tests. Typically, specimen volume should be 130 to 150 % of the test cavity volume. Once a target mass for a desired volume has been established, specimen masses should be controlled to within ±0.5 g for best repeatability. The initial test specimen shape should fit well within the perimeter of the test cavity.

7.2 *Compounded Rubber Specimens*—Test specimens shall be taken from a rubber compound as required by the mixing method or other sampling instructions. Only rubber compounds with curatives may be tested.

7.2.1 The rubber compound shall be in the form of a sheet, at room temperature, and as free of air as possible.

8. Procedure

8.1 Select from one of six different cure conditions shown in Table 1.

8.2 Select from one of eight different after-cure dynamic testing conditions shown in Table 2.

8.3 Program a test configuration which incorporates these conditions and store on the instrument computer operating system.

TABLE 2 Test Conditions for After-Cure Strain Sweeps

Dynamic Property Condition No.	First Strain Sweep Temperature °C	First Strain Sweep Frequency, Hz	First Strain Sweep Strain[A] , ± %	Second Strain Sweep Temperature °C	Second Strain Sweep Frequency, Hz	Second Strain Sweep Strain[A] , ± %
1	100	1	1,2,5,10,20	100	1	1,2,5,10,20
2	100	10	1,2,5,10,20	100	10	1,2,5,10,20
3	60	1	1,2,5,10,20	60	1	1,2,5,10,20
4	60	10	1,2,5,10,20	60	10	1,2,5,10,20

[A] If a specially soft compound with a Shore A Durometer below 40 is tested, additional strain conditions of 50 and 100 % may be added to the strain sweeps.

8.4 Load the test configuration to run the test.

8.5 Enter specimen identification.

8.6 Wait until both dies are at the initial test temperature. Open the test cavity and visually check both upper and lower dies for cleanliness. Clean the dies, if necessary. Place the test specimen on the center of the lower die and close the dies within 20 s.

9. Report

9.1 Report the following information.

9.1.1 A full description of the sample, or test specimen(s), or both, including their origin.

9.1.2 Type and model of oscillating rheometer.

9.1.3 The frequency, strain, temperature and time for the cure test (if no strain, indicate "static cure").

9.1.4 Minimum torque (M_L) as dNm, maximum torque (M_H) as dNm, time to scorch as indicated by time to one unit rise (in dNm units) from minimum torque (t_{S1}) in minutes and decimal fraction of a minute, and time to 10 %, 50 %, and 90 % state of cure in minutes and decimal fraction of a minute.

NOTE 1—For static cure, no cure properties are reported since no measurements are possible.

9.1.5 The temperature, frequency and different strains applied in an after-cure strain sweep.

9.1.6 The storage shear modulus G' in kPa and the percent strain for each step in the programmed strain sweep.

9.1.7 The loss shear modulus G'' in kPa and the percent strain for each step in the programmed strain sweep.

9.1.8 The tangent delta (tan δ) and the percent strain for each step in the programmed strain sweep.

9.1.9 If two consecutive strain sweeps are programmed, the results from both of these strain sweeps should be recorded (reference the Payne Effect discussed in 4.3).

10. Precision and Bias

10.1 These precision statements have been prepared in accordance with Practice D4483. Refer to this practice for terminology and other statistical details.

10.2 The results in this precision and bias section give an estimate of the precision of this test method with the materials used in the interlaboratory program described below. The precision parameters should not be used for acceptance or rejection testing of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols of the test method.

10.3 A type 1 interlaboratory precision program was conducted. Both repeatability and reproducibility represent short term (daily) testing conditions. The testing was performed using one operator in each laboratory performing the test twice on each material on each of two days (total of four tests). A test result is the value obtained from a single determination. Acceptable difference values were not measured.

10.4 The results of the precision calculations for this test are given. The materials are arranged in ascending "mean level" order. The relative reproducibility is more independent of the mean level so the relative repeatability, (r), and reproducibility, (R), are the preferred parameters.

10.5 *Repeatability*—The pooled relative repeatability, (r), of this test has been established and may be used as an estimate of repeatability, as appropriate. The difference between two single test results (or determinations) found on identical test material under the repeatability conditions prescribed for this test will exceed the repeatability on an average of not more than once in 20 cases in the normal and correct operation of the method. Two single test results that differ by more than the appropriate value must be suspected of being from different populations and some appropriate action taken.

NOTE 2—Appropriate action may be an investigation of the test method procedure or apparatus for faulty operation or the declaration of a significant difference in the two materials, samples, and so forth, which generated the two test results.

10.6 *Reproducibility*—The pooled relative reproducibility, (R), of this test has been established. The difference between two single and independent test results found by two operators working under the prescribed reproducibility conditions in different laboratories on identical test material will exceed the reproducibility on an average of not more than once in 20 cases in the normal and correct operation of the method. Two single test results produced in different laboratories that differ by more than the appropriate value must be suspected of being from different populations and some appropriate investigative or technical/commercial action taken.

10.7 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (true) test property value. Reference values do not exist for this test method since the value or level of the test property is exclusively defined by the test method. Bias, therefore, cannot be determined.

10.8 *Precision Type*—All precision statements given in this section are Type 1 Precision in accordance with Practice

TABLE 3 Precision Parameters for Test Method D6601 – G' @ 1 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Compound	1819.7	26.1	73.8	4.1	65.2	184.6	10.1
NBR Compound	1137.4	22.6	63.9	5.6	25.7	72.8	6.4
High Damping Tread Compound	512.6	12.5	35.4	6.9	17.0	48.0	9.4
Average	1156.5						
Pooled Values		21.2	59.9	5.2	41.7	117.9	10.2

D4483. These data were all calculated from the parameters of seven (7) separate laboratories independently performing Test Method D6601. All participating laboratories cured these compounds at 180°C, ± 2.8 % strain, 1.67 Hz, for 12 min followed by performing two identical strain sweeps (back to back) at 100ºC and 1.0 Hz. See Tables 3-32.

11. Keywords

11.1 dynamic properties; loss modulus; rotorless oscillating shear rheometer; storage modulus

TABLE 4 Precision Parameters for Test Method D6601 – G' @ 2 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1561.2	32.2	91.1	5.8	61.8	174.8	11.2
NBR Compound	1098.2	17.8	50.3	4.6	24.9	70.5	6.4
High Damping Tread Compound	459.4	11.2	31.6	6.9	20.6	58.3	12.7
Average	1039.6						
Pooled Values		22.2	62.8	6.0	40.3	113.9	11.0

TABLE 5 Precision Parameters for Test Method D6601 – G' @ 5 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1239.7	27.3	77.3	6.2	46.7	132.2	10.7
NBR Compound	1048.1	17.6	49.9	4.8	16.4	46.4	4.4
High Damping Tread Compound	386.3	6.5	18.5	4.8	15.3	43.4	11.2
Average	891.4						
Pooled Values		19.1	54.2	6.1	29.9	84.7	9.5

TABLE 6 Precision Parameters for Test Method D6601 – G' @ 10 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1047.7	30.3	85.7	8.2	44.9	126.9	12.1
NBR Compound	1001.0	15.5	43.7	4.4	16.8	47.6	4.8
High Damping Tread Compound	336.3	4.8	13.4	4.0	14.6	41.3	12.3
Average	795.0						
Pooled Values		19.8	56.1	7.1	28.9	81.8	10.3

TABLE 7 Precision Parameters for Test Method D6601 – G' @ 20 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	877.7	29.1	82.3	9.4	48.8	138.1	15.7
NBR Compound	929.5	13.5	38.2	4.1	26.1	73.9	8.0
High Damping Tread Compound	292.6	4.1	11.5	3.9	7.9	22.3	7.6
Average	699.9						
Pooled Values		18.7	52.8	7.5	32.3	91.4	13.1

TABLE 8 Precision Parameters for Test Method D6601 – G" @ 1 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	343.1	6.3	17.8	5.2	11.7	33.1	9.6
NBR Compound	140.5	5.2	14.7	10.5	6.1	17.2	12.3
High Damping Tread Compound	109.9	3.4	9.6	8.7	3.6	10.2	9.3
Average	197.8						
Pooled Values		5.1	14.4	7.3	7.9	22.3	11.3

TABLE 9 Precision Parameters for Test Method D6601 – G" @ 2 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	325.0	9.5	26.8	8.3	13.7	38.7	11.9
NBR Compound	142.6	3.4	9.7	6.8	8.7	24.7	17.3
High Damping Tread Compound	106.5	1.5	4.2	4.0	2.2	6.1	5.8
Average	191.4						
Pooled Values		5.9	16.6	8.7	9.4	26.7	14.0

TABLE 10 Precision Parameters for Test Method D6601 – G" @ 5 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	272.9	5.1	14.4	5.3	10.4	29.6	10.8
NBR Compound	146.1	4.4	12.4	8.5	7.7	21.8	14.9
High Damping Tread Compound	94.3	1.9	5.4	5.7	3.9	10.9	11.6
Average	171.1						
Pooled Values		4.0	11.4	6.7	7.8	22.1	12.9

TABLE 11 Precision Parameters for Test Method D6601 – G" @ 10 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	222.9	4.8	13.5	6.0	8.4	23.7	10.6
NBR Compound	141.9	5.2	14.8	10.4	7.1	20.0	14.1
High Damping Tread Compound	82.3	1.7	4.8	5.9	3.3	9.4	11.5
Average	149.0						
Pooled Values		4.2	11.9	8.0	6.6	18.7	12.6

TABLE 12 Precision Parameters for Test Method D6601 – G” @ 20 % Strain 1st Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	181.5	4.5	12.8	7.1	7.1	20.2	11.1
NBR Compound	136.9	4.7	13.2	9.6	5.5	15.5	11.3
High Damping Tread Compound	70.5	1.4	3.9	5.6	2.9	8.3	11.8
Average	129.6						
Pooled Values		3.8	10.9	8.4	5.5	15.5	11.9

TABLE 13 Precision Parameters for Test Method D6601 – tan delta @ 1 % Strain 1st Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Compound	0.1861	0.0036	0.0101	5.5	0.0114	0.0322	17.3
NBR Compound	0.1234	0.0025	0.0070	5.7	0.0045	0.0126	10.2
High Damping Compound	0.2087	0.0034	0.0095	4.6	0.0077	0.0217	10.4
Average	0.1727						
Pooled Values		0.0032	0.0090	5.2	0.0083	0.0236	13.7

TABLE 14 Precision Parameters for Test Method D6601 – tan delta @ 2 % Strain 1st Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2087	0.0070	0.0198	9.5	0.0129	0.0364	17.4 6
NBR Compound	0.1298	0.0039	0.0110	8.5	0.0070	0.0199	15.3
High Damping Compound	0.2269	0.0051	0.0144	6.3	0.0126	0.0357	15.7
Average	0.1885						
Pooled Values		0.0055	0.0155	8.2	0.0112	0.0316	16.8

TABLE 15 Precision Parameters for Test Method D6601 – tan delta @ 5 % Strain 1st Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2205	0.0059	0.0166	7.5	0.0099	0.0281	12.8
NBR Compound	0.1404	0.0037	0.0105	7.5	0.0063	0.0178	12.6
High Damping Compound	0.2420	0.0041	0.0115	4.8	0.0051	0.0145	6.0
Average	0.2009						
Pooled Values		0.0046	0.0131	6.5	0.0074	0.0210	10.4

TABLE 16 Precision Parameters for Test Method D6601 – tan delta @ 10 % Strain 1st Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2131	0.0070	0.0199	9.3	0.0084	0.0237	11.1
NBR Compound	0.1429	0.0032	0.0090	6.3	0.0061	0.0173	12.1
High Damping Tread Compound	0.2451	0.0039	0.0110	4.5	0.0060	0.0170	6.9
Average	0.2004						
Pooled Values		0.0050	0.0141	7.0	0.0069	0.0196	9.8

TABLE 17 Precision Parameters for Test Method D6601 – tan delta @ 20 % Strain 1st Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2076	0.0081	0.0230	11.1	0.0108	0.0306	14.7
NBR Compound	0.1473	0.0032	0.0090	6.1	0.0059	0.0166	11.3
High Damping Tread Compound	0.2464	0.0033	0.0094	3.8	0.0036	0.0101	4.1
Average	0.2004						
Pooled Values		0.0054	0.0153	7.6	0.0074	0.0209	10.4

TABLE 18 Precision Parameters for Test Method D6601 – G’ @ 1 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1558.4	29.1	82.4	5.3	62.1	175.8	11.3
NBR Based Compound	1111.4	21.0	59.4	5.3	25.9	73.4	6.6
High Damping Tread Compound	440.0	9.8	27.6	6.3	25.8	73.1	16.6
Average	1036.6						
Pooled Values		21.5	60.8	5.9	41.6	117.8	11.4

TABLE 19 Precision Parameters for Test Method D6601 – G’ @ 2 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1368.1	31.1	88.0	6.4	60.7	171.7	12.5
NBR Based Compound	1083.4	13.6	38.5	3.6	14.0	39.6	3.7
High Damping Tread Compound	410.4	8.4	23.9	5.8	22.2	62.8	15.3
Average	954.0						
Pooled Values		20.2	57.2	6.0	38.2	108.0	11.3

TABLE 20 Precision Parameters for Test Method D6601 – G' @ 5 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	1119.9	32.1	90.7	8.1	48.6	137.5	12.3
NBR Based Compound	1019.8	13.9	39.3	3.9	21.3	60.3	5.9
High Damping Tread Compound	355.4	4.4	12.5	3.5	16.5	46.7	13.1
Average	831.7						
Pooled Values		20.3	57.5	6.9	32.1	90.8	10.9

TABLE 21 Precision Parameters for Test Method D6601 – G' @ 10 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	985.0	29.2	82.8	8.4	46.9	132.7	13.5
NBR Based Compound	978.4	12.8	36.1	3.7	22.4	63.5	6.5
High Damping Tread Compound	325.6	3.8	10.7	3.3	9.0	25.6	7.9
Average	763.0						
Pooled Values		18.6	52.5	6.9	30.5	86.2	11.3

TABLE 22 Precision Parameters for Test Method D6601 – G' @ 20 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	870.2	28.5	80.8	9.3	47.8	135.4	15.6
NBR Based Compound	927.5	12.9	36.5	3.9	25.6	72.6	7.8
High Damping Tread Compound	291.3	4.0	11.3	3.9	7.6	21.6	7.4
Average	696.3						
Pooled Values		18.2	51.6	7.4	31.6	89.6	12.9

TABLE 23 Precision Parameters for Test Method D6601 – G" @ 1 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	327.2	10.9	30.7	9.4	27.3	77.3	23.6
NBR Based Compound	139.4	3.5	9.9	7.1	7.6	21.5	15.4
High Damping Tread Compound	100.3	2.3	6.5	6.5	2.5	7.1	7.1
Average	189.0						
Pooled Values		6.7	19.0	10.1	16.4	46.5	24.6

TABLE 24 Precision Parameters for Test Method D6601 – G” @ 2 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	313.3	8.1	22.8	7.3	15.6	44.1	14.1
NBR Based Compound	144.9	3.3	9.2	6.4	8.0	22.5	15.5
High Damping Tread Compound	98.0	2.3	6.5	6.6	2.5	6.9	7.1
Average	185.4						
Pooled Values		5.2	14.7	7.9	10.2	28.9	15.6

TABLE 25 Precision Parameters for Test Method D6601 – G” @ 5 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	269.8	4.8	13.7	5.1	9.4	26.5	9.8
NBR Based Compound	151.5	5.3	15.0	9.9	5.2	14.6	9.7
High Damping Tread Compound	91.3	2.3	6.6	7.2	4.1	11.7	12.8
Average	170.9						
Pooled Values		4.4	12.3	7.2	6.6	18.7	11.0

TABLE 26 Precision Parameters for Test Method D6601 – G” @ 10 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	221.1	4.9	13.9	6.3	7.9	22.2	10.1
NBR Based Compound	144.3	4.3	12.3	8.5	6.9	19.5	13.5
High Damping Tread Compound	80.8	1.5	4.2	5.2	3.6	10.2	12.6
Average	148.7						
Pooled Values		3.9	11.0	7.4	6.4	18.0	12.1

TABLE 27 Precision Parameters for Test Method D6601 – G” @ 20 % Strain 2nd Sweep

NOTE 1—Units: kPa

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	178.9	4.7	13.4	7.5	7.0	19.9	11.1
NBR Based Compound	134.9	4.7	13.2	9.8	4.0	11.4	8.5
High Damping Tread Compound	69.6	1.3	3.8	5.4	2.9	8.2	11.8
Average	127.8						
Pooled Values		3.9	11.1	8.7	5.0	14.0	11.0

TABLE 28 Precision Parameters for Test Method D6601 – tan delta @ 1 % Strain 2nd Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2100	0.0063	0.0179	8.5	0.0147	0.0417	19.9
NBR Based Compound	0.1254	0.0029	0.0083	6.6	0.0064	0.0180	14.4
High Damping Tread Compound	0.2224	0.0047	0.0134	6.0	0.0174	0.0493	22.2
Average	0.1859						
Pooled Values		0.0049	0.0138	7.4	0.0137	0.0387	20.8

TABLE 29 Precision Parameters for Test Method D6601 – tan delta @ 2 % Strain 2nd Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2294	0.0091	0.0257	11.2	0.0144	0.0409	17.8
NBR Based Compound	0.1347	0.0019	0.0054	4.0	0.0062	0.0176	13.1
High Damping Tread Compound	0.2284	0.0066	0.0187	8.2	0.0068	0.0191	8.4
Average	0.1975						
Pooled Values		0.0066	0.0186	9.4	0.0099	0.0280	14.2

TABLE 30 Precision Parameters for Test Method D6601 – tan delta @ 5 % Strain 2nd Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2413	0.0067	0.0191	7.9	0.0102	0.0288	11.9
NBR Based Compound	0.1463	0.0029	0.0082	5.6	0.0054	0.0152	10.4
High Damping Tread Compound	0.2578	0.0068	0.0194	7.5	0.0089	0.0252	9.8
Average	0.2151						
Pooled Values		0.0058	0.0164	7.6	0.0084	0.0238	11.1

TABLE 31 Precision Parameters for Test Method D6601 – tan delta @ 10 % Strain 2nd Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2274	0.0075	0.0212	9.3	0.0076	0.0216	9.5
NBR Based Compound	0.1475	0.0025	0.0072	4.9	0.0059	0.0166	11.3
High Damping Tread Compound	0.2529	0.0042	0.0118	4.7	0.0067	0.0188	7.5
Average	0.2093						
Pooled Values		0.0052	0.0146	7.0	0.0068	0.0191	9.1

TABLE 32 Precision Parameters for Test Method D6601 – tan delta @ 20 % Strain 2nd Sweep

NOTE 1—Units: Dimensionless

Material	Mean Level	Sr	r	(r)	SR	R	(R)
SBR Sulfur-Cured Compound	0.2063	0.0083	0.0236	11.4	0.0116	0.0329	16.0
NBR Based Compound	0.1472	0.0031	0.0086	5.9	0.0064	0.0182	12.4
High Damping Tread Compound	0.2454	0.0033	0.0093	3.8	0.0030	0.0086	3.5
Average	0.1996						
Pooled Values		0.0055	0.0155	7.8	0.0079	0.0223	11.2

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