Standard Test Method for Elastic Properties of Elastomeric Yarns (CRE Type Tensile Testing Machines)[1]

This standard is issued under the fixed designation D 2731; 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 determination of elastic properties of "as produced" elastomeric yarns made from rubber, spandex or other elastomers. Elastic properties include force at specified elongations, permanent deformation and stress decay. Other hysteresis related properties can be calculated.

NOTE 1—For a method designed specifically for testing rubber threads, refer to Test Method D 2433.

1.2 This test method is not applicable to covered, wrapped, or core-spun yarns or yarns spun from elastomeric staple.

1.3 This test method is applicable to elastomeric yarns having a range of 40 to 3200 dtex (36 to 2900 denier).

1.4 The values stated in either SI units or U.S. Customary units are to be regarded separately as standard. Within the text, the U.S. Customary units are in parentheses. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other.

1.5 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 76 Specification for Tensile Testing Machines for Textiles[2]

D 123 Terminology Relating to Textiles[2]

D 1776 Practice for Conditioning and Testing Textiles[2]

D 2258 Practice for Sampling Yarn for Testing[2]

D 2433 Test Methods for Rubber Thread[3]

D 2591 Test Method for Linear Density of Elastomeric Yarns (Short-Length Specimens)[2]

D 2653 Test Method for Tensile Properties of Elastomeric Yarns (CRE Type Tensile Testing Machines)[2]

D 4848 Terminology for Force, Deformation and Related Properties of Textiles[4]

D 6717 Test Method for Linear Density of Elastomeric Yarns (Skein Specimens)[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *deformation*, *n*—a change in shape of a material caused by forces of compression, shear, tension, or torsion.

3.1.2 *elastomeric yarn*, *n*—a nontextured yarn which can be stretched repeatedly at room temperature to at least twice its original length and which after removal of the tensile force will immediately and forcibly return to approximately its original length.

3.1.3 *elongation*, *n*—the ratio of the extension of a material to the length of the material prior to stretching.

3.1.4 *force at specified elongation (FASE)*, *n*—the force associated with a specific elongation on the force-extension or force-elongation curve.

3.1.5 *linear density*, *n—for fiber and yarn,*mass per unit length.

3.1.6 *permanent deformation*, *n*—the net long-term change in a dimension of a specimen after deformation and relaxation under specified conditions.

3.1.6.1 *Discussion*—Permanent deformation in elastomeric yarns is frequently referred to as "set". Elastomeric yarns which have been deformed will eventually return to, or nearly to, the original dimension with relaxation.

3.1.7 *stress*, *n*—the resistance to deformation developed within a material subjected to an external force.

3.1.8 *stress decay*, *n*—in mechanics, the reduction in force to hold a material at a fixed deformation over a period of time.

3.1.9 For definitions of other terms related to force and deformation, refer to Terminology D 4848. For definitions of other terms related to textiles used in this standard, refer to Terminology D 123.

4. Summary of Test Method

4.1 A specimen, mounted in a CRE-type tensile machine, is initially subjected to a series of five loading/unloading cycles in which the specimen is extended and relaxed between zero

[1] This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.58 on Yarns.

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 09.02.

[4] *Annual Book of ASTM Standards*, Vol 07.02.

and 75 % of the elongation at first filament break (FFB). During the fifth cycle, the specimen is held at the maximum extension point for 30 s, then unloaded to allow a return to its original gage length position. The specimen is then subjected to a sixth load/unload cycle.

4.2 Force at specified elongations are calculated from the force-elongation curve for the first and fifth loadings and for the fifth unloading. Stress decay is calculated on the fifth cycle. Extension at a specified force is determined on the sixth loading and is used to calculate the permanent deformation.

5. Significance and Use

5.1 This test method is considered satisfactory for acceptance testing of commercial shipments since current estimates of between-laboratory precision are acceptable and the method is used extensively in the trade for acceptance testing.

5.1.1 If there are differences of practical significance between reported test results for two laboratories (or more), comparative tests should be performed to determine if there is a statistical bias between them, using competent statistical assistance. As a minimum, use samples for such comparative tests that are as homogeneous as possible, drawn from the same lot of material as the samples that resulted in disparate results during initial testing, and randomly assigned in equal numbers to each laboratory. The test results from the laboratories involved should be compared using a statistical test for unpaired data, at a probability level chosen prior to the testing series. If bias is found, either its cause must be found and corrected, or future test results for that material must be adjusted in consideration of the known bias.

5.2 Force at Specified Elongation (FASE) is a measure of the tensile force required to extend a textile material within specified limits. This characteristic of elastomeric yarn indicates the resistance that will have to be overcome by the wearer while putting on a garment made of the material and is also an indication of the garment's resistance to deformation caused by normal body movements during wear. The elongations used for these measurements are typically 100 %, 200 % and 300 %.

5.3 Permanent Deformation (set) is a measure of the increase in length of an elastomeric yarn resulting from cyclic stretching and relaxation. The characteristic is a visible indication of the realignment of intermolecular bonds within the elastic material. As with stress decay, the amount of set increases with yarn extension; however, for any particular extension, little or no additional set takes place after five cycles of exercising. Generally, the characteristic set of the yarn is developed during fabric preparation and the fabric itself shows a negligible amount of set.

5.4 Stress decay increases with yarn extension, but at any specified extension the stress decay takes place in the first 30 s with insignificant decay after 5 min. This characteristic is caused by the gradual realignment of intermolecular bonds within the elastic material, and helps to explain the changes in yarn properties that accompany cyclic stretching and relaxing. The realignment of the bonds is a reversible effect. Following complete relaxation of the yarn, the molecules tend to assume their original configuration with just about complete elimination of the previously observed strain.

5.5 This test method was developed using elastomeric yarns in the "as-produced" condition, but may be used for treated elastomeric yarns provided the treatment is specified. The method does not cover the removal of finish for the determination of elastic properties of "finish-free" elastomeric yarns.

6. Apparatus

6.1 *Specimen Boards*, with short pile or plush surfaces of black or contrasting color, for storing specimens during conditioning.

6.2 *Tensile Testing Machine*, CRE-type, conforming to Specification D 76 with respect to force indication, working range, capacity and verification of recorded elongation, capable of cycling, and designed for operation at a pulling speed of 500 mm/min (20 in./min).

6.3 *Clamping Assembly*, pneumatically operated, with jaws as described in Test Method D 2653.

6.4 *Computer or Microprocessor*, interfaced, with automatic data gathering system, optional.

6.5 *Tensioning Weights*, with various masses from 10 mg to 3 g to pretension the specimen to 30 to 50 mN/tex (0.3 to 0.5 mgf/d) before testing.

6.6 *Air Supply*, capable of providing 415 kPa (60 psi) to the pneumatic clamps.

7. Sampling, Test Specimens, and Test Units

7.1 *Lot Sample*—As a lot sample for acceptance testing, take a random number of shipping units directed in an applicable material specification or other agreement between the purchaser and the supplier, such as an agreement to use Practice D 2258. Consider shipping cases or other shipping units to be the primary sampling units.

NOTE 2—An adequate specification or other agreement between the purchaser and the supplier requires taking into account the variability between shipping units, between packages or ends within a shipping unit, and between specimens from a single package to provide a sampling with a meaningful producer's risk, consumer's risk, acceptable quality level and limiting quality level.

7.2 *Laboratory Sample*—As a laboratory sample for acceptance testing, take at random from each shipping unit in the lot sample the number of packages directed in an applicable material specification or other agreement between the purchaser and the supplier, such as an agreement to use Practice D 2258. Preferably, take the same number of packages from each of the shipping units selected. If differing numbers of packages are to be taken from the shipping units, determine at random which shipping units are to have each number of packages for testing.

7.3 *Test Specimens*—From each package or end in the laboratory sample, take six specimens as directed in 7.3.1.

7.3.1 Remove the outer layer of yarn from the package. Avoid any damaged areas in selecting segments for testing. Carefully unwind yarn from the package with as low as tension as possible to avoid stretching. As test specimens, cut approximately 125 mm (5 in.) long segments of yarn from each package, taking them at intervals of at least 1 m (1 yd). Three of the six specimens are used as spare to allow for unacceptable breaks, such as caused by slippage or breaking in the clamps.

7.4 Determine the tex (denier) of the yarn for each laboratory sample using Test Method D 2591 or Test Method D 6717.

7.5 Determine the elongation at first filament bread (FFB) for each laboratory sample as directed in Test Method D 2653.

8. Preparation of Apparatus and Calibration

8.1 Prepare and verify the calibration of the tensile testing machine as directed in the manufacturer's instructions.

8.2 Set up and adjust the CRE-type tensile testing machine as follows:

8.2.1 Examine the acrylic clamp jaw face for wear and replace as needed. Position the jaw faces horizontally in the clamps.

8.2.2 Set the distance between the jaw faces (gage length) to 50 ± 1 mm (2 ± 0.05 in.).

NOTE 3—A convenient technique for checking the gage length is to place a piece of carbon paper and white paper in the clamps and close the clamps. The distance between the marks made on the white paper by the carbon paper represents the set gage length.

8.2.3 Use a force measuring system such that the cycling force will be between 30 and 80 % of full scale capacity.

8.2.4 Set the Cycling Limits as follows:

8.2.4.1 Set Minimum Extension to nominal gage length (zero extension).

8.2.4.2 Set Maximum Extension equivalent to 75 % of the elongation at first filament break of the elastomeric yarn (see 10.2) or 300 % of gauge length.

8.2.5 Set the crosshead speed to 500 mm/min (20 in./min) or 1000 % extension per min.

8.2.6 Set the extension measuring system as follows:

8.2.6.1 When using a chart recorder, set the chart speed to 500 mm/min (20 in./min).

8.2.6.2 When using an interfaced computer or microprocessor, set parameters to obtain selected properties using supplier's directions and Specification D 76.

8.2.7 Set the air pressure for pneumatic clamps to 415 kPa (60 psi). At this pressure, the clamping force is approximately 450 N (100 lb).

9. Conditioning

9.1 No preconditioning is required for currently produced rubber yarns and other elastomeric yarns.

9.2 Condition the specimens relaxed on specimen boards in the standard atmosphere for testing textiles as directed in Practice D 1776, which is 21 ± 1°C (70 ± 2°F) and 65 ± 2 % relative humidity for a minimum of 4 h.

10. Procedure

10.1 Test the relaxed specimens in the standard atmosphere for testing textiles.

NOTE 4—The force measuring system should be zeroed prior to running any specimens and periodically during the course of the test, particularly if drift is observed in the zero value of the force measuring system.

10.2 Select the appropriate pretensioning weight based on the linear density of the yarn that will provide a 30 to 50 mN/tex (0.3 to 0.5 mgf/d) tension to the yarn.

10.3 Attach the selected tensioning weight (10.2) to the specimen such that when the specimen is placed in the lower clamp, the tensioning weight will hang freely.

10.4 Position a specimen centrally between the top clamp faces and close the clamp. Ensure that the tension weight is hanging freely below the bottom clamp.

10.5 Close the lower clamp and remove the tensioning weight.

10.6 Start the test apparatus and cycle the specimen five times between the limits established in 8.2.4.

NOTE 5—If using a chart recorder, only the first loading cycle and complete fifth cycle need be recorded on the chart.

10.7 On the fifth cycle, stop the crosshead at the maximum extension limit and hold for 30 s. At the end of holding at the maximum extension limit, return the crosshead to gage length.

10.8 Immediately, start the crosshead and record the loading portion of a sixth cycle.

10.9 Return the crosshead to the zero position, remove the spectrum and continue testing until all specimens have been tested for each laboratory sampling unit and for the lot.

11. Calculation or Interpretation of Results

11.1 *Force at Specified Elongation (FASE)*—Determine the FASE as follows:

11.1.1 From the tensile hysteresis chart for each specimen, read and record the force at 100, 200 and 300 % elongation on the first loading cycle, the force at 300 % elongation on the fifth loading cycle, prior to holding for 30 s, and the force at 100 and 200 % elongation of the fifth unloading cycle to the nearest cN (0.1 gf).

11.1.2 Calculate the average FASE for each of the elongations and applicable cycles determined in 11.1.1 for each laboratory sampling unit and for the lot to the nearest cN (0.1 gf).

11.2 *Stress Decay*—Determine the percent stress decay as follows:

11.2.1 From the chart and on the fifth loading cycle, read and record the force at maximum extension and the force after holding at maximum extension for 30-s for each specimen.

11.2.2 Calculate the average percent stress decay for each specimen to the nearest 0.1 %, using Eq 1

$$D = 100\ (F_L^{\,5} - F_U^{\,5}/F_L^{\,5} \qquad (1)$$

where:

D = stress decay, %,
$F_L^{\,5}$ = loading force at maximum extension on fifth cycle, cN (gf), and
$F_U^{\,5}$ = unloading force after 30-s hold on fifth cycle (start of unload cycle), cN (gf).

NOTE 6—Stress in yarns is expressed as force per unit area or force per linear density. However, the units of force are used in Eq 1 because the area or linear density in units of stress effectively cancel one another in the equation.

11.2.3 Calculate the average percent stress decay for each laboratory sampling unit and for the lot.

11.3 *Permanent Deformation (Set)*—Determine the percent permanent deformation as follows:

11.3.1 Determine the force corresponding to 0.05 mN/tex (0.5 mgf/den) for each specimen using the tex (denier) values obtained in 7.4.

11.3.2 For each specimen, read and record the extension on the sixth loading cycle that corresponds to the force calculated in 11.3.1.

11.3.3 Calculate the percent permanent deformation for each specimen to the nearest 0.1 % using Eq 2.

$$S = 100 \times E^6/L \quad (2)$$

where:

S = permanent deformation (set), %,
E^6 = extension on the sixth loading cycle at 0.05 mN/tex (0.5 mgf/d) tension, mm (in.), and
L = gage length, mm (in.).

11.3.4 Calculate the average percent permanent deformation for each laboratory sampling unit and for the lot.

11.4 *Coefficient of Variation and Standard Deviation–Coefficient of Variation and Standard Deviation*—Calculate coefficient of variation and standard deviation for each laboratory sampling unit and for the lot, if requested.

11.5 *Computer Processed Data*—When data are automatically computer processed, calculations are generically contained in the associated software and the results displayed or printed or both. In any event, it is recommended that computer-processed data be verified against known property values and its software described in the report.

12. Report

12.1 State that the samples were tested as directed in Test Method D 2731. Describe the material or product sampled and the method of sampling used.

12.2 Report the following information for each laboratory sampling unit and for the lot:

12.2.1 Force at the specified elongations for the specified,

12.2.2 Stress decay for the fifth cycle,

12.2.3 Permanent deformation (set) for the sixth loading cycle, (Indicate whether a delay was used following the fifth cycle.),

12.2.4 Number of specimens tested,

12.2.5 Coefficient of variation, or standard deviation, or both, for each of the properties, if calculated,

12.2.6 Elongation at first filament break, as determined using Test Method D 2653,

12.2.7 Make and model of the tensile testing machine and the capacity used,

12.2.8 Option for the clamping system used,

12.2.9 For computer-processed data, identify the program (software) used, and

12.2.10 Any modification of the test method.

13. Precision and Bias

13.1 An interlaboratory study was performed in November 2000 to estimate variability of the test method. The study included four laboratories. Two or three operators from each laboratory each measured three specimens for three different denier elastomeric yams on two different dates. ANOVA was used to determine variance components. Tables 1-8 show the average value in units of measurement and the components of variance as the squares of the standard deviation.

13.2 Method repeatability is defined as the "maximum difference" that can "reasonably" be expected between two test results obtained on the same material when the test results are obtained in the same laboratory. Repeatability standard deviation, s_r, is taken to be the square root of the "specimen" variance component, and represents within-operator precision. Method reproducibility is defined as the "maximum difference" that can "reasonably" be expected between two test results obtained on the same material when the test results are

TABLE 1 Response = Force @ 100% Elongation, g—First Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	3.28481	0.00743	0.00674	0.03671	0.44972
210	13.16106	0.24885	0.00871	0.15565	0.05226
840	49.65320	1.10535	0.36198	0.93832	0.32075

TABLE 2 Response = Force @ 200% Elongation, g—First Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	7.63509	0.09014	0.01285	0.03674	0.09172
210	24.29116	0.14391	0.01255	0.21850	0.15837
840	93.42214	3.10279	0.11338	2.30822	1.35456

TABLE 3 Response = Force @ 300% Elongation, g—First Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	16.45989	0.19301	0.05868	0.20825	0.21949
210	43.23460	0.46967	0.15480	0.40020	0.26016
840	168.37890	13.57769	0.00000	6.24039	14.76829

TABLE 4 Response = Force @ 300% Elongation, g—Fifth Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	10.87589	1.59158	0.02591	0.10952	0.09793
210	32.86173	6.08133	0.09505	0.24877	0.68235
840	121.60650	88.56520	0.00000	5.27203	5.27521

TABLE 5 Response = Force @ 200% Elongation, g—Unload Fifth Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	1.18616	0.01220	0.00000	0.00751	0.00098
210	5.76695	0.17327	0.04808	0.07196	0.03294
840	20.79409	0.51027	0.48479	0.37089	0.18660

TABLE 6 Response = Force @ 100% Elongation, g—Unload Fifth Cycle

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	0.70981	0.00878	0.00000	0.00635	0.00280
210	3.78586	0.05282	0.05514	0.06385	0.01646
840	13.74894	0.04508	0.47160	0.28061	0.13148

TABLE 7 Response = Stress Decay, %

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	29.60175	1.92296	0.11895	0.00000	6.02033
210	25.27127	0.79193	0.03074	0.06246	0.27545
840	23.36364	0.87851	0.25327	0.00000	0.31771

TABLE 8 Response = Permanent Deformation, %

Denier	Average	V(lab)	V(operator)	V(date)	V(specimen)
40	20.48123	7.83721	0.00000	8.82367	4.77576
210	22.53286	13.29625	0.42718	5.44726	2.14382
840	20.30788	15.00142	0.76486	1.90290	0.26144

TABLE 9 Response = Force@ 100% Elongation, g—First Cycle—Loading

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.67061	1.85884	0.70753	1.96117
210	0.22861	0.63368	0.68226	1.89112
840	0.56635	1.56985	1.65118	4.57685

TABLE 10 Response = Force @ 200% Elongation, g—First Cycle—Loading

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.30284	0.83944	0.48108	1.33348
210	0.39795	1.10306	0.73029	2.02427
840	1.16386	3.22605	2.62278	7.26996

TABLE 11 Response = Force @ 300% Elongation, g—First Cycle—Loading

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.46849	1.29860	0.82428	2.28478
210	1.12257	3.11160	1.51156	4.18984
840	3.84295	10.65212	5.88102	16.30135

TABLE 12 Response = Force @ 300% Elongation, g—Fifth Cycle—Loading

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.31294	0.86742	1.35090	3.74451
210	0.82605	2.28968	2.66599	7.38975
840	2.29678	6.36636	9.95552	27.59530

TABLE 13 Response = Force @ 200% Elongation, g—Unload Fifth Cycle

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.03134	0.08686	0.14384	0.39870
210	0.18150	0.50308	0.57119	1.58326
840	0.43197	1.19737	1.24601	3.45377

obtained from different laboratories.[5] s_R, the total standard deviation, is formed by taking the square root of the sum of intra- and inter-laboratory variance components. Tables 9-16 show these values.

NOTE 7—Because the interlaboratory test included less than the recommended five laboratories, estimates of precision data in Tables 1-16 may be either underestimated or overestimated to a considerable extent and should be used with special caution.

TABLE 14 Response = Force @ 100% Elongation, g—Unload Fifth Cycle

Denier	s_r	Repeatability	S_R	Reproducibility
40	0.05290	0.14662	0.13386	0.37104
210	0.12828	0.35559	0.43390	1.20271
840	0.36261	1.00510	0.96373	2.67133

TABLE 15 Response = Stress Decay, %

Denier	s_r	Repeatability	S_R	Reproducibility
40	2.45364	6.80113	2.83941	7.87044
210	0.52483	1.45476	1.07730	2.98613
840	0.56366	1.56238	1.20395	3.33717

TABLE 16 Response = Permanent Deformation, %

Denier	s_r	Repeatability	S_R	Reproducibility
40	2.18535	6.05749	4.62997	12.83363
210	1.46418	4.05850	4.61676	12.79702
840	0.51131	1.41729	4.23446	11.73731

13.3 *Bias*—The procedure of this test method produces a test value that can be defined only in terms of a test method. There is no independent, referee method by which bias may be determined. This test method has no known bias.

14. Keywords

14.1 elastic properties; elastomeric yarn; force at specified elongation; permanent deformation; stress decay

[5] John Mandel and Theodore W. Lashof, 1987. The Nature of Repeatability and Reproducibility. Jour. Quality Technology, 19 (1).