Designation: D7269/D7269M – 11

Standard Test Methods for Tensile Testing of Aramid Yarns[1]

This standard is issued under the fixed designation D7269/D7269M; 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 These test methods cover the tensile testing of aramid yarns, cords twisted from such yarns, and fabrics woven from such cords. The yarn or cord may be wound on cones, tubes, bobbins, spools, or beams; may be woven into fabric; or may be in some other form. The methods include testing procedure only and include no specifications or tolerances.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 This standard includes the following test methods:

	Section
Breaking Strength (Force)	11
Breaking Tenacity	12
Breaking Toughness	17
Elongation at Break	13
Force at Specified Elongation (FASE)	14
Linear Density	10
Modulus	15
Work-to-Break	16

1.4 *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:*[2]

D76 Specification for Tensile Testing Machines for Textiles
D123 Terminology Relating to Textiles
D1776 Practice for Conditioning and Testing Textiles
D1907 Test Method for Linear Density of Yarn (Yarn Number) by the Skein Method
D1909 Standard Tables of Commercial Moisture Regains and Commercial Allowances for Textile Fibers
D2258 Practice for Sampling Yarn for Testing
D4848 Terminology Related to Force, Deformation and Related Properties of Textiles
D6587 Test Method for Yarn Number Using Automatic Tester

3. Terminology

3.1 *Definitions:*

3.1.1 *slippage, n—with tensile testing*, insufficient quality of clamping, resulting in movement of the test material through the total clamping surface. This can be visualized by the movement of markers at the clamp exit, or by sudden changes in the strain-modulus curves (1st derivative of the strain-stress curve).

3.1.2 *zero twist, n*—twistless, devoid of twist.

3.2 The following terms are relevant to this standard: industrial yarn, moisture equilibrium for testing, aramid, zero twist, standard atmosphere for testing textiles.

3.3 For definitions of terms related to force and deformation in textiles, refer to Terminology D4848.

3.4 The following terms are relevant to this standard: breaking force, breaking strength, breaking tenacity, breaking toughness, chord modulus *in a stress-strain curve*, elongation, force at specified elongation (FASE), initial modulus, tensile strength, and work-to-break.

3.5 For definitions of other terms related to textiles, refer to Terminology D123.

4. Summary of Test Method

4.1 These test methods are used to determine the tensile properties of aramid yarns or cords.

4.2 A conditioned or oven-dried specimen of aramid yarn or cord is clamped in a tensile testing machine and then stretched or loaded until broken. Breaking force, elongation, and force at specified elongation (FASE) are determined directly. Modulus and work-to-break are calculated from the force-elongation curve. The output of a constant-rate-of-extension (CRE) tensile testing machine can be connected with electronic recording and

[1] These test methods are under the jurisdiction of ASTM Committee D13 on Textiles and are the direct responsibility of Subcommittee D13.19 on Industrial Fibers and Metallic Reinforcements.

Current edition approved May 1, 2011. Published June 2011. Originally approved in 2006. Last previous edition approved in 2010 as D7269/D7269M–10. DOI: 10.1520/D7269_D7269M-11.

[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.

computing equipment, which may be programmed to calculate and print the test results of tensile properties of interest.

5. Significance and Use

5.1 The levels of tensile properties obtained when testing aramid yarns and cords are dependent on the age and history of the specimen and on the specific conditions used during the test. Among these conditions are rate of stretching, type of clamps, gage length of specimen, temperature and humidity of the atmosphere, rate of airflow across the specimen, and temperature and moisture content of the specimen. Testing conditions accordingly are specified precisely to obtain reproducible test results on a specific sample.

5.2 Because the force-bearing ability of a reinforced product is related to the strength of the yarn or cord used as a reinforcing material, *breaking strength* is used in engineering calculations when designing various types of textile reinforced products. When needed to compare intrinsic strength characteristics of yarns or cords of different sizes or different types of fiber, breaking tenacity is very useful because, for a given type of fiber, breaking force is approximately proportional to linear density.

5.3 *Elongation* of yarn or cord is taken into consideration in the design and engineering of reinforced products because of its effect on uniformity of the finished product and its dimensional stability during service.

5.4 The *FASE* is used to monitor changes in characteristics of the textile material during the various stages involved in the processing and incorporation of yarn or cord into a product.

5.5 *Modulus* is a measure of the resistance of yarn or cord to extension as a force is applied. It is useful for estimating the response of a textile reinforced structure to the application of varying forces and rates of stretching. Although modulus may be determined at any specified force, initial modulus is the value most commonly used.

5.6 *Work-to-break* is dependent on the relationship of force to elongation. It is a measure of the ability of a textile structure to absorb mechanical energy. *Breaking toughness* is work-to-break per unit mass.

5.7 It should be emphasized that, although the preceding parameters are related to the performance of a textile-reinforced product, the actual configuration of the product is significant. Shape, size, and internal construction also can have appreciable effect on product performance. It is not possible, therefore, to evaluate the performance of a textile reinforced product in terms of the reinforcing material alone.

5.8 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, test samples should be used that are as homogeneous as possible, that are drawn from the material from which the disparate test results were obtained, and that are randomly assigned in equal numbers to each laboratory for testing. Other materials with established test values may be used for this purpose. The test results from the two laboratories should be compared using a statistical test for unpaired data, at a probability level chosen prior to the testing series. If a bias is found, either its cause must be found and corrected, or future test results must be adjusted in consideration of the known bias.

6. Apparatus

6.1 *Tensile Testing Machine*—A single-strand tensile testing machine of the constant rate of extension (CRE) type. The specifications and methods of calibration and verification of these machines shall conform to Specification D76. The testing machine shall be equipped with an autographic recorder (rectilinear coordinates preferred). It is permissible to use tensile testing machines that have a means for calculating and displaying the required results without the use of an autographic recorder. It is also permissible to use automated tensile testing equipment.

6.1.1 *Clamps*—Bollard type clamps, in which the specimen is gripped between plane-faced jaws and then makes a partial turn (wrap angle) around a curved extension (or other type of snubbing device) of one jaw before passing to the other similar clamp (see Fig. 1). Clamps with a wrap angle of 3.14 rad [180°] are recommended for yarns with a linear density up to 10 000 decitex [9000 denier]. For linear densities above 10 000 decitex [9000 denier], clamps with a wrap angle of 4.71 rad [270°] are required to prevent slippage.

6.1.1.1 Clamps shall grip the test specimen without spurious slippage or damage to the test specimen which can result in jaw breaks. The clamps shall maintain constant gripping conditions during the test by means of pneumatic or hydraulic clamps. The surface of the jaws in contact with the specimen shall be of a material and configuration that minimizes slippage and/or specimen failure in the clamping zone.

6.1.2 *Gauge Length*—The gauge length shall be the total length of yarn measured between the clamping point A of the first clamp and the point B of the second clamp in the starting position (see Fig. 2).

6.1.3 Use a crosshead travel rate in mm/min [in./min] of 50 % of the nominal gauge length in millimeters [inches] of the specimen for para-aramids; 100 % of the nominal gauge length in millimeters [inches] of the specimen for meta-aramids.

7. Sampling

7.1 Remove and discard a minimum of 25 m [75 yd] from the outside of the package before taking the sample or any specimens.

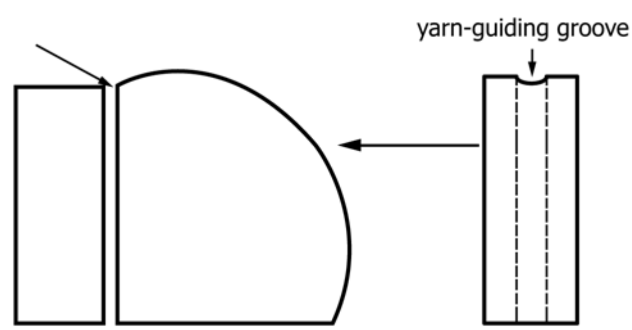


FIG. 1 Principle of Bollard Type Clamps

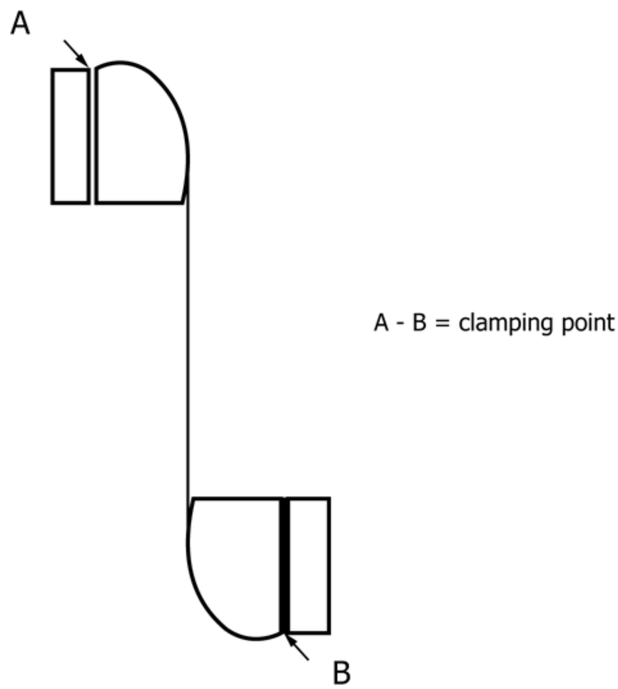


FIG. 2 Principle of Specimen Fixing in Bollard Type Jaws

7.2 *Yarn:*

7.2.1 *Packages*—For acceptance testing, sample each lot as directed in Practice D2258. Place each laboratory sampling unit in a moisture-proof polyethylene bag or other moisture-proof container to protect the samples from atmospheric changes until ready to condition the samples in the atmosphere for testing aramids. Take the number of specimens for testing specified for the specific property measurement to be made.

7.2.2 *Beams*—For acceptance testing, sample by winding yarns on a tube or spool by means of a winder using a tension of 5 ± 1 mN/tex [0.05 ± 0.01 gf/den]. Take the yarn from the outside beam layers unless there is a question or disagreement regarding the shipment; in this case, take the sample only after removing yarn from the beam to a radial depth of 6 mm [¼ in.] or more to minimize the effects of handling and atmospheric changes that may have occurred during shipment or storage. Place each laboratory sampling unit in a moisture-proof polyethylene bag or other moisture-proof container to protect the samples from atmospheric changes until ready to condition the samples in the atmosphere for testing aramids. Take the number of specimens for testing specified for the specific property measurement to be made.

7.3 *Cord:*

7.3.1 *Number of Samples and Specimens*—The size of an acceptance sampling lot of tire cord shall be not more than one truck or rail car load or as determined by agreement between the purchaser and the supplier. Take samples at random from each of a number of cones, tubes, bobbins, or spools within a lot to be as representative as possible within practical limitations. Make only one observation on an individual package for each physical property determination. Take the number of samples, therefore, that will be sufficient to cover the total number of specimens required for the determination of all physical properties of the tire cord. The recommended number of specimens is included in the appropriate sections of specific test methods covered in this standard. Where such is not specified, the number of specimens is as agreed upon between buyer and supplier.

7.3.2 *Preparation of Samples*—If specimens are not taken directly from the original package, preferably wind the sample on a tube or spool by means of a winder using a tension of 5 ± 1 mN/tex [0.05 ± 0.01 gf/den]. If the sample is collected as a loosely wound package, or in the form of a skein, some shrinkage invariably will occur, in which case, report that the observed results were determined on a relaxed sample. Use care in handling the sample. Discard any sample subjected to any change of twist, kinking, or making any bend with a diameter less than 10 times the yarn/cord thickness (or diameter). Place the sample in a moisture-proof polyethylene bag or other moisture-proof container to protect it from atmospheric changes until ready to condition the sample in the test atmosphere for aramids.

8. Conditioning

8.1 Bring all specimens of yarn, cord, and fabric to moisture equilibrium for testing in the atmosphere for testing industrial yarns for at least 14 h as directed in Practice D1776.

8.1.1 Standard aramid yarn shall be pre-conditioned at 45 ± 5°C [113 ± 40°F] for 3 to 6 h, then condition per 8.1.

8.1.2 The moisture equilibrium of conditioned aramid yarns and tire cords made from such yarns can be affected by heat and humidity conditions to which the samples have been previously exposed.

9. Sample Preparation

9.1 Because of the difficulty of securing the same tension in all the filaments and because of slippage in the clamps, variable results may be obtained when testing zero-twist multifilament yarns unless a small amount of twist is inserted prior to testing. Machine twisting by means of a ring twister using steel insert travelers is recommended. The twist tension should be approximately 10 mN/tex [0.10 gf/den]. If used, anti-balloon rings must be chromium plated. For aramid yarns the amount of twist to be inserted depends upon the linear density and shall be approximately:

Linear density dtex	Twist tpm
180-240	230
240-380	190
380-500	160
500-650	140
650-775	125
775-1050	110
1050-1400	95
1400-2100	80
2100-4500	60
4500-7000	45
7000-9500	35
9500->	30

9.2 Inserting some twist in zero-twist yarns for tensile testing has the following effects on the test results:

9.2.1 Modestly increases breaking force; too much twist reduces breaking force,

9.2.2 Increases elongation at break, and

9.2.3 Reduces modulus (the slope of the force-elongation curve).

9.3 Manner of inserting the twist into the yarn, manually or with a twisting machine, can influence the test results.

10. Linear Density

10.1 *Scope*—This test method is used to determine the linear density of yarn or cord for use in the calculation of tensile properties such as modulus and tenacity.

10.2 *Number of Specimens*—Test five specimens of yarn or cord. This number is based on the assumption that the applicable coefficient of variation is 1.0 % and the allowable variation is 0.8 % of average with a probability level of 95 %.

10.3 *Procedure*—Determine linear density as directed in Option 1 of Test Method D1907 or use an Automated Tester as directed in Test Method D6587. For both methods, condition the yarn as specified in Section 8.

10.3.1 If oven-dried and finish-free linear density is needed, use Option 5 or Option 6 with an allowance for moisture regain (see Test Method D1909 for commercial moisture regain values).

11. Breaking Strength (Force) of Conditioned Yarns and Cords

11.1 *Scope*—This test method is used to determine the breaking strength (force) of yarns and cords after conditioning in the atmosphere for testing aramids.

11.2 *Number of Specimens*—Test ten specimens. This number is based on the data for cords in Table 1 which shows precision to be expected at the probability level of 95 % based on ten breaks from a single test spool of cord.

11.3 *Procedure*—Select a loading cell and the settings of the tensile tester such that the estimated breaking force of the specimen will fall in the range from 10 to 90 % of the full-scale force effective at the time of the specimen break. This selection of the full scale force may be done manually by the operator before the start of the test or by electronic means or computer control during the test by automatically adjusting the amplification of the loading cell amplifier. Adjust the distance between the clamps on the testing machine so that the nominal gage length of the specimen, measured from nip to nip of the jaws of the clamps, is 500 ± 2 mm [20 ± 0.10 in.] (alternate 250 ± 1 mm [10 ± 0.05 in.]). Make all tests on the conditioned yarns and cords in the atmosphere for testing aramids (Notes 1 and 2 provide useful information in obtaining more consistent results in tensile testing). Remove the specimen from the sample and handle it to prevent any change in twist prior to closing the jaws of the clamps on the specimen.. Do not touch that portion of the specimen that will be between the clamps with bare hands. Depending on the equipment being used and the availability of on-line computer control and data processing, either can be used:

Pretension-start procedure (see 11.3.1) or
Slack start procedure (see 11.3.2)

TABLE 1 Critical Differences, Expressed as Percent of Observed Average (Except as Noted)^{A,B}

Property Measured	Number of Observations in Each Average	Critical Differences	
		Single-Operator Precision	Between-Laboratory Precision
Table 1a 1500⁄2 High-Modulus Aramid Cord (4 × 4 twist):			
Breaking strength, lbf	10	1.06	6.68
Elongation at Break, %	10	2.26	20.80
Modulus, gf/den	10	3.22	19.69
Work-to-break, in.·lbf/in.	10	3.89	48.99
Thickness of cords, mils	10	0.77^C	10.73^C
Twist, tpi:			
Cord	10	0.09^C	0.34^C
Singles	10	0.09^C	0.24^C
Table 1b 1500⁄2 High-Modulus Aramid Cord (7.5 × 7.5 twist):			
Breaking strength, lbf	10	2.11	9.79
Elongation at break, %	10	2.18	26.70
Modulus, gf/den	10	2.13	35.43
Work-to-break, in.·lbf/in.	10	8.41	43.77
Thickness of cords, mils	10	0.77^C	8.49^C
Twist, tpi:			
Cord	10	0.09^C	0.40^C
Singles	10	0.09^C	0.56^C
Load at specified elongation (LASE) without Rosin (reported at 2 % E), lbf	10	1.12	13.00
Table 1c 1500⁄1 High-Modulus Aramid Yarn:			
Breaking strength, lbf	10	1.33	9.46
Elongation at break, %	10	2.55	23.39
Modulus, gf/den	10	4.43	14.68

^{A} The critical differences were calculated using t = 1.960 which is based on infinite degrees of freedom.
^{B} To convert the values of the critical difference expressed as a percent of the grand average to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as a decimal fraction.
^{C} Properties noted in this table have critical differences in the units shown rather than as a percent of the grand average.

11.3.1 *Pretension-Start Procedure*—Use a tensioning device that applies a pretension corresponding to 20 ± 1 mN/tex [0.20 ± 0.01 gf/den] for aramid fibers. This device may be a weight, a spring, or an air-actuated mechanism. Thread one end of the specimen between the jaws of the clamp connected to the loading cell and close it. Place the other end through the jaw of the second clamp and fix a pretension weight to the unclamped end or pull the end of the specimen until the specified pretension is applied. Close the second clamp and operate the testing machine at the rate specified in 9.1.3. When the specimen breaks (ruptures), read the breaking force [maximum force) in Newtons [pounds-force] from the force-elongation [or force-extension] curve on the chart, from the dial, from the display, or by electronic means. Discard specimens that break in the jaws or within 10 mm [⅛ in.] of the nip of the jaws. If the clamps are of the air-actuated type, adjust the air pressure so that specimens will not slip in the jaws, but keep air pressure below the level that will cause specimens to break at the edge of the jaws.

NOTE 1—When arbitration of test data is involved, use care in the application of the pretension force that may be specified because the actual pretension in the specimen commonly is different from the amount applied externally because of losses due to friction in the clamp. Check the pretension before starting the testing machine. The actual pretension can be measured by strain gages. Other tension-measuring instruments with sufficient accuracy may be used, provided that the specimen is threaded through the instrument prior to being placed in the second clamp. This procedure is necessary because many instruments require appreciable displacement of the specimen.

NOTE 2—When arbitration is not involved, one of the following approximations of the specified pretension may be used. Either exert a force of 120 % of the nominal pretension to the unclamped end of the specimen prior to closing the second grip, or apply one of the forces listed as follows for the specified groups of yarn and cord sizes to secure the necessary pretension.

Linear Density of Specimen	Amount of Force N	[gf]
Below 400 tex [3600 denier]	1	[100]
400 to 600 tex [3600 to 5400 denier]	2	[200]
600 to 800 tex [5400 to 7200 denier]	3	[300]
Above 800 tex [7200 denier]	4	[400]

NOTE 3—When using a CRE-type tensile machine, a third technique is to close the upper clamp, then apply pretension by pulling on the specimen until the recorder pen moves approximately ½ chart division from the zero line on the chart when using a force scale that is the same as that used for determining the breaking force.

11.3.2 *Slack Start Procedure*—Thread one end of the specimen between the jaws of one of the clamps and close it. Place the other end of the specimen through the jaws of the second clamp and keep the specimen just slack (zero tension) and close the clamp, taking care that the thread is positioned in the centerline of the jaws of the clamp. Operate the testing machine at the rate as specified in 6.1.3 and stretch the specimen until it ruptures. When the specimen breaks, read the breaking force (maximum force) in Newtons [pounds-force] from the force-elongation curve, from the dial, from the display, or by electronic means. Discard specimens that break in the jaws or within 10 mm [⅛ in.] of the nip of the jaws. If the clamps are of the air-actuated type, adjust the air pressure to prevent specimens slipping in the jaws, but keep the air pressure below the level that will cause specimens to break at the edge of the jaws. This slack start procedure has the effect that the nominal gage length of the specimen is not exactly 500 [or 250] mm [20 (or 10) in.] as specified in 11.3, but always will be somewhat more due to slack in the specimen after closing the clamps.

11.3.3 The velocity of conditioned air flowing across a specimen while determining tensile properties can have a measurable effect on the breaking force and elongation at break because of the Gough-Joule effect. The magnitude ofthis effect depends on the type of fiber, air velocity, and sample history. Interlaboratory testing of nylon, polyester, and rayon cords indicates that air velocities of less than 250 mm/s [50 ft/min] across the specimen will not significantly bias the comparison of cord properties between laboratories.[3]

11.3.4 As diameters and strengths of cords increase, clamps with larger snubbing surfaces and greater holding power or capacity may be required to prevent slippage of cords in testing machine clamps or an excessive number of jaw breaks. The levels of cord size and strength at which such higher capacity clamps are required must be determined by experiment because they will vary with the type of fiber and construction. Some clamps with larger snubbing surfaces and greater holding power or capacity may be too large to allow a 250 or 500-mm [10 or 20-in.] gage length. In those cases, use the appropriate gage length for the clamp in use. If slippage of cords cannot be prevented with the highest capacity clamps available to the user, it has been found useful to apply powdered rosin to the two portions of the cord that will be held between the snubbing surfaces. Use of rosin has been found particularly useful in testing organic cords that have been adhesive treated.

11.4 *Calculation*—Calculate the average breaking force from the observed breaking forces of specimens read from the testing machine chart or dial to the nearest 0.5 N [0.1 lbf].

11.5 *Report:*

11.5.1 State that the specimens were tested as directed in Section 11 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

11.5.2 Report the option or procedure used; the number of specimens tested; the amount of twist, if any, inserted into the yarn for the tensile testing; and the breaking force for the sample as the breaking strength.

11.6 *Precision and Bias:*

11.6.1 *Precision*—See Section 19.

11.6.2 *Bias*—See 19.3.

12. Breaking Tenacity of Conditioned Yarns and Cords

12.1 *Scope*—This test method is used to determine the breaking tenacity of yarns and cords after conditioning in the atmosphere for testing aramids.

12.2 *Calculation*—Calculate the breaking tenacity of the sample in terms of milli-Newtons per tex (mN/tex) [grams-force per denier (gf/den)] from the breaking strength and the linear density using Eq 1 and 2:

$$BT_n = \frac{BF_n \cdot 1000}{LD_t} \tag{1}$$

[3] Jones, R. E. and Desson, M. J., "Adiabatic Effects on Tensile Testing," *Journal of the I.R.I.*

$$BT_g = \frac{BF_l \cdot 454}{LD_d} \quad (2)$$

where:

BT_n = breaking tenacity, mN/tex,
BT_g = breaking tenacity, gf/den,
BF_n = average breaking force, N,
BF_l = average breaking force, lbf,
LD_t = measured linear density, tex, and
LD_d = measured linear density, denier.

12.3 *Report:*

12.3.1 State that the specimens were tested as directed in Section 12 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

12.3.2 Report the option or procedure used, the number of specimens tested, and the breaking tenacity for the sample.

12.4 *Precision and Bias:*

12.4.1 *Precision*—See Section 19.

12.4.2 *Bias*—See Section 19.3.

13. Elongation at Break of Conditioned Yarns and Cords

13.1 *Scope*—This test method is used to determine the elongation at break of yarns and cords after conditioning in the atmosphere for testing aramids.

13.2 *Procedure*—Determine the elongation at break of each conditioned specimen when determining its breaking force (see Section 11). Read the extension at the breaking force from the autographic recorder or by electronic means. The general equation for elongation at break is given in Eq 3:

$$EB = \left(\frac{E_{bf}}{L_o}\right) \cdot 100\ \% \quad (3)$$

where:

EB = elongation at break, %,
E_{bf} = extension of specimen at the breaking force, mm [in.], and
L_o = length of the specimen, under specified pretension measured from nip-to-nip of the holding clamps, mm [in.].

13.2.1 *Pretension Start*—Use Eq 3.

13.2.2 *Slack Start*—Calculate the gage length (L_o) to include the slack using Eq 4:

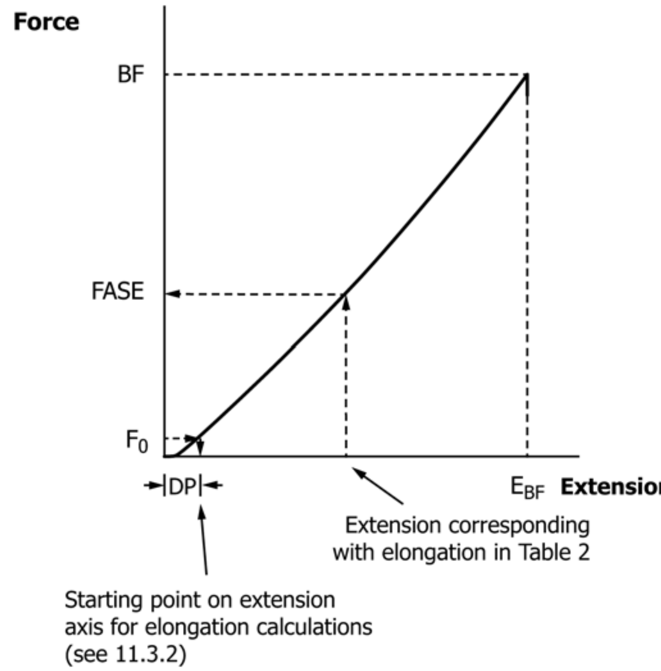
$$L_o = L_s + DP \quad (4)$$

where:

L_o = length of the specimen, under specified pretension, measured from nip-to-nip of the holding clamps, mm [in.],
L_s = gage length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), mm [in.], and
DP = displacement of crosshead to reach the specified pretension of the specimen (see Fig. 3), mm [in.].

13.2.2.1 The pretension for aramid corresponds with 20 ± 1 mN/tex [0.20 ± 0.01 gf/den].

13.2.2.2 The general equation for elongation at break for the slack start procedure is given in Eq 5:



NOTE 1—
F_0 = Pretension force
DP = Slack
BF = Breaking force
E_{BF} = Extension at breaking force
FASE = Force at specified elongation

FIG. 3 Force-Extension Curve

$$EB = \frac{E_{bf}}{L_s + DP} \cdot 100\ \% \quad (5)$$

where:

EB = elongation at break, %,
E_{bf} = extension of specimen at the breaking force, mm [in.],
L_s = gage length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), mm [in.], and
DP = displacement of crosshead to reach the specified pretension of the specinen (see Fig. 1), mm [in.].

13.2.3 Elongation also may be determined from the force-elongation curve at any force.

13.3 *Calculation*—Calculate the average elongation of the sample to the nearest 0.1 %.

13.4 *Report:*

13.4.1 State that the specimens were tested as directed in Section 13 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

13.4.2 Report the option or procedure used, the number of specimens tested, and the elongation for the sample.

13.5 *Precision and Bias:*

13.5.1 *Precision*—See Section 19.

13.5.2 *Bias*—See 19.3.

14. Force at Specified Elongation (FASE) of Conditioned Yarns and Cords

14.1 *Scope*—This test method is used to determine the force at specified elongation (FASE) of yarns and cords after conditioning in the atmosphere for testing aramids.

14.2 *Procedure*—Determine the force at specified elongation (FASE) of each conditioned specimen when determining its breaking force (see Section 11 and Fig. 3). Read the force directly from the force-extension curve (see Fig. 3) or by electronic means or with an on-line computer at the specified value of elongation listed in Table 2.

14.2.1 Assure that the displacement (DP) of the crosshead to remove slack is taken into account when using slack start procedure. Follow same general procedure as for elongation at break (see 13.2 and Fig. 3).

14.2.2 Use Eq 6 in the case of slack start procedure to locate extension corresponding to specified elongation. Extension is measured from the pretension point (see Fig. 3), where the slack is removed from the specimen.

$$E_x = E_s \cdot \frac{(L_s + DP)}{100} \quad (6)$$

where:

E_x = extension, mm [in.],
E_s = specified elongation, %,
L_s = gage length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), mm [in.], and
DP = displacement of crosshead to reach the specified pretension of the specimen (see Fig. 3), mm [in.].

14.2.2.1 Read force, N [lbf], corresponding to above extension from the ordinate of the force-extension curve.

14.3 *Calculation*—Calculate the average FASE of the sample to the nearest 0.5 N [0.1 lbf].

14.4 *Report:*

14.4.1 State that the specimens were tested as directed in Section 14 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

14.4.2 Report the option or procedure used, the number of specimens tested, and the FASE for the sample.

14.5 *Precision and Bias:*

14.5.1 *Precision*—See Section 19.

14.5.2 *Bias*—See 19.3.

15. Modulus of Conditioned Yarns and Cords

15.1 *Initial Modulus:*

TABLE 2 Elongation Values for Determination of FASE

Type of Fiber	Greige	Adhesive Processed Cord
Aramid	0.3 0.5 1.0	1.0

15.1.1 *Scope*—This test method is used to determine the chord modulus of yarns and cords after conditioning in the atmosphere for testing aramids.

15.1.2 *Procedure: Chord-Modulus Yarns and Cords*—Determine the chord modulus of each conditioned specimen from the force-elongation curve (see Fig. 4). Determine the chord modulus between the points A and B as specified in Table 3. Locate the points A and B on the ordinate at the forces equivalent to A mN/tex [gf/den] and B mN/tex [gf/den] respectively. Draw from each of these two points respectively a line perpendicular to the ordinate to the intersection with the force-elongation curve. From these intersection points determine the related elongation values by drawing perpendicular lines to the abscissa.

15.1.2.1 Calculate the chord modulus of a specimen using Eq 7:

$$M_c = 100 \cdot \frac{T_b - T_a}{E_b - E_a} \quad (7)$$

where:

M_c = chord modulus, mN/tex [gf/den],
T_b = upper limit in mN/tex [gf/den],
T_a = lower limit in mN/tex [gf/den],
E_b = elongation corresponding to T_b, %, and
E_a = elongation corresponding to T_a, %.

15.1.3 *Calculation*—Calculate the average initial modulus or the average chord modulus, or both, of the sample to the nearest 10 mN/tex [0.1 gf/den].

15.1.4 *Report:*

15.1.4.1 State that the specimens were tested as directed in Section 15 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

15.1.4.2 Report the option or procedure used for measuring the linear density, the number of specimens tested, and the initial modulus or the chord modulus, or both, for the sample.

15.1.5 *Precision and Bias:*

15.1.5.1 *Precision*—See Section 19.

15.1.5.2 *Bias*—See 19.3.

16. Work-to-Break of Yarns and Cords

16.1 *Scope*—This test method is used to determine the work-to-break of yarns and cords.

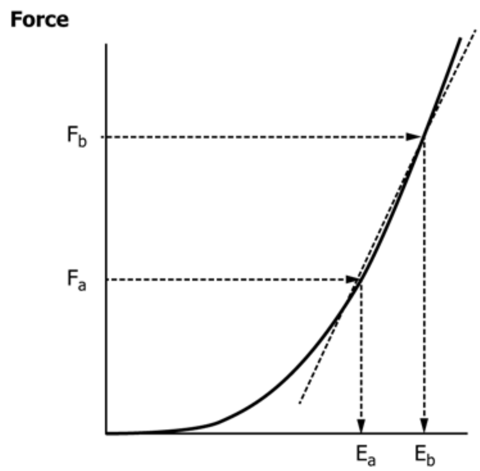
16.2 *Procedure*—Using the force-elongation curves obtained as directed in Section 11, draw a line from the point of the breaking force of each specimen perpendicular to the elongation axis. Measure the area bounded by the curve, the perpendicular, and the elongation axis. This area may be estimated by counting squares, measured with a planimeter, or determined by electronic means.

16.3 *Calculation:*

16.3.1 Calculate the work-to-break for each specimen using Eq 8 and 9:

$$WB_j = A \cdot F_{sf} \cdot E_{sf\%} \cdot 10^{-5} \cdot L_o \quad (8)$$

$$WB_i = A \cdot F_{sf} \cdot E_{sf\%} \cdot 10^{-2} \cdot L_o \quad (9)$$



NOTE 1—
F_a = Force corresponding to specified Lower Limit in Table 2.
F_b = Force corresponding to specified Upper Limit in Table 2.
E_a = Elongation point corresponding to Lower Limit Force
E_b = Elongation point corresponding to Upper Limit Force

FIG. 4 Force-Elongation Curve for the Determination of Chord Modulus

TABLE 3 Lower and Upper Limit of the Chord Modulus Interval

Type of Fiber	Lower Limit, T_a		Upper Limit, T_b	
	mN/tex	[gf/den]	mN/tex	[gf/den]
Aramid	300	[3.0]	400	[4.0]

where:

WB_j = work-to-break, J,
WB_i = work-to-break, in.·lbf,
A = area under force-elongation curve, mm^2 [in.^{2}],
F_{sf} = force scale factor, N/mm [lbf/in.] of chart,
$E_{sf\%}$ = elongation scale factor, %, of specimen elongation per mm [in.] of autographic chart, and
L_o = gage length of specimen, mm [in.].

16.3.2 Calculate specific work-to-break using Eq 10 and 11:

$$WB_{sj} = A \cdot F_{sf} \cdot E_{sf\%} \cdot 10^{-2} \quad (10)$$

$$WB_{si} = A \cdot F_{sf} \cdot E_{sf\%} \cdot 10^{-2} \quad (11)$$

where:

WB_{sj} = specific work-to-break, J/m,
WB_{si} = specific work-to-break, in.·lbf/in.,
A = area under force-elongation curve, mm^2 [in.^{2}],
F_{sf} = force scale factor, N/mm [lbf/in.] of chart, and
$E_{sf\%}$ = elongation scale factor, %, of specimen elongation per mm [in.] of autographic chart.

16.3.3 The equations used to calculate work-to-break and specific work-to-break electronically are given in Eq 12-14:

$$WB_j = \sum_{i=0}^{n-1} \frac{F_{i+1} + F_i}{2} \cdot \frac{E_{i+1} - E_i}{1000} \quad (12)$$

$$WB_{sj} = \frac{1000 \cdot WB_j}{L_0} \quad (13)$$

$$WB_{si} = \frac{WB_i}{L_o} \quad (14)$$

where:

WB_j = work-to-break, J,
WB_i = work-to-break, in.·lbf,
F_o = force at pretension level, N [lbf],
F_a = force at first data pair, N [lbf],
F_i = force at ith data pair, N [lbf],
E_a = extension at first data pair, mm [in.],
E_i = extension at ith data pair, mm [in.],
WB_{sj} = specific work-to-break, in. · J/m,
WB_{si} = specific work-to-break, in.· lbf/in., and
L_o = gage length of specimen, mm [in.].

16.4 *Report:*

16.4.1 State that the specimens were tested as directed in Section 16 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

16.4.2 Report the option or procedure used, the number of specimens tested, and the work-to-break for the sample.

16.5 *Precision and Bias:*

16.5.1 *Precision*—See Section 19.

16.5.2 *Bias*—See 19.3.

17. Breaking Toughness of Yarns and Cords

17.1 *Scope*—This test method is used to determine the breaking toughness of yarns and cords.

17.2 *Procedure*—Calculate linear density of the specimen using Test Method D1907. Use the information developed in Section 16 to calculate the breaking toughness of a yarn or cord sample.

17.3 *Calculation:*

17.3.1 Calculate the breaking toughness of each specimen using Eq 15, Eq 16 or Eq 17 and Eq 18:

$$BT_j = \left(A \cdot F_{sf} \cdot E_{sf\%}\right) \cdot \frac{10}{LD_t} \quad (15)$$

$$BT_i = \left(A \cdot F_{sf} \cdot E_{sf\%}\right) \cdot \frac{10^{-2}}{LD_d} \quad (16)$$

or

$$BT_j = \frac{WB_{sj} \cdot 10^3}{LD_t} \quad (17)$$

$$BT_i = \frac{WB_{si}}{LD_d} \quad (18)$$

where:

BT_j = breaking toughness, J/g,
BT_i = breaking toughness, in.· lbf/in.· den,
A = area under the force-elongation curve, mm^2 [$in.^2$],
F_{sf} = force scale factor, N/mm [lbf/in.],
$E_{sf\%}$ = elongation scale factor, % of specimen elongation per mm [in.] of autographic chart,
LD_t = measured linear density of specimen, tex,
LD_d = measured linear density of specimen, denier,
WB_{sj} = specific work-to-break of specimen, J/m, and
WB_{si} = specific work-to-break of specimen, in.·lbf/in.·den.

17.3.2 The equations used to calculate breaking toughness electronically are given in Eq 19 and Eq 20:

$$BT_j = \frac{WB_{sj} \cdot 10^3}{L_o \cdot LD_t} \quad (19)$$

$$BT_i = \frac{WB_{si}}{L_o \cdot LD_d} \quad (20)$$

where:

BT_j = breaking toughness, J/g,
BT_i = breaking toughness, in.·lbf/in.·den,
WB_{sj} = specific work-to-break of specimen, J/m,
WB_{si} = specific work-to-break of specimen, in.·lbf/in.·den,
L_o = gage length of specimen, mm [in.],
LD_t = measured linear density of specimen, tex, and
LD_d = measured linear density of specimen, denier.

17.4 *Report:*

17.4.1 State that the specimens were tested as directed in Section 17 of Test Methods D7269. Describe the material or product sampled and the method of sampling used.

17.4.2 Report the option or procedure used, the number of specimens tested, and the breaking toughness for the sample.

17.5 *Precision and Bias:*

17.5.1 *Precision*—The precision of breaking toughness is derived from work-to-break and linear density (see Section 16).

17.5.2 *Bias*—See 19.3.

18. Reports, General

18.1 State that all specimens were tensile tested as directed in Test Methods D7269, Sections 11 – 17. Describe the material or product sampled and the methods of sampling used.

18.2 Report the following information:

18.2.1 Test procedure used (pretension or slack start),

18.2.2 Type of clamp used,

18.2.3 The amount of twist, if any, inserted into the yarn especially for the purpose of tensile testing the yarn,

18.2.4 Number of specimens tested per sample, and

18.2.5 The value of each property measured or calculated for each sample.

19. Precision and Bias of Certain Cord Tests

19.1 *Interlaboratory Test Design*—An interlaboratory ("round robin") study was performed by ASTM D13 task group members to quantify performance of new automated tensile testing devices. Three brands of automated tensile test devices were included: Sigma500, Statimat, and Uster. Two laboratories represented each brand of tester (Uster one lab only). Yarn was supplied in pre-twisted state for testing. Untwisted yarn was also provided to Statimat labs, so testing could be performed both on pre-twisted yarn, and on yarn automatically twisted by the test machine. Two laboratories also tested the materials using traditional (Instron) methods for reference. Each of those laboratories used two operators.

19.1.1 —The study included the following nine materials:

Kevlar®: 600 denier
Kevlar®: 1420 denier
Kevlar®: 2840 denier
Nomex®: 200 denier
Nomex®: 1600 denier
Technora®: 1500 denier
Twaron®: 500 denier
Twaron®: 1550 denier
Twaron®: 3100 denier

The number of test determinations required for a test result is specified in each individual test method. For the purpose of this study, each laboratory made one hundred (100) determinations (breaks) for each material. The following properties (and associated measurement units) were recorded:

Property	Units
Break Strength (BS)	N
Elongation at break (EB)	%
Modulus between 300 mN/tex and 400 mN/tex (MOD)	CN/tex
FASE @ 0.3%	N
FASE @ 0.5%	N
FASE @ 1.0%	N

Nominal linear density was used for modulus calculation.

19.2 *Interlaboratory Test Data*—Means, standard deviations and %CV for the materials and devices are shown in Tables 4-6 and Fig. 5.

19.3 *Interlaboratory Test–Precision and Bias*—Biases observed between the various test instrument types presently require separate precision statements. A method to eliminate the bias is presented in Appendix 1.

19.3.1 A simple one-way ANOVA was performed on each (material, instrument) set of data. In most cases two laboratories participated for each instrument type. Each data set therefore contains 200 observations, one hundred replicates taken at each laboratory. Two variance components were calculated from each data set: laboratory to laboratory, and within-laboratory. Those variance components represent long-term and short-term variability, respectively. The variance components are tabled below, along with calculated repeatability and reproducibility for the precision and bias statement. In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Bias for each instrument type was calculated using the Instron for that reference, although the data sets are too small to draw convincing conclusions.

TABLE 4 Mean Values by Material, Device

NOTE 1—For unknown reasons, one of the participating laboratories (Spruance) found a too low breaking force of 250 N using the Instrons.

Material	Device	N Rows	Mean(BF(N))	Mean(EB(%))	Mean(MOD(CN/Tex))	Mean(FASE 0.3%)	Mean(FASE 0.5%)	Mean(FASE 1.0%)
Kevlar® 1420d	Instron	377	335.06	2.52	8510.18	33.24	58.88	122.52
Kevlar® 1420d	Sigma500	200	325.02	2.61	8015.75	23.28	47.77	111.23
Kevlar® 1420d	Statimat	200	312.31	2.44	8186.23	29.3	53.36	113.94
Kevlar® 1420d	Statimat PT	200	333.76	2.6	7878.17	31.5	55.69	116.67
Kevlar® 1420d	Uster	100	324.74	2.53	7770.89	31.23	55.68	117.18
Kevlar® 2840d	Instron	386	613.52	2.49	7686.97	60.59	108.26	227.07
Kevlar® 2840d	Sigma500	200	596.6	2.61	7337.89	42.34	86.6	203.32
Kevlar® 2840d	Statimat	200	588	2.59	6604.97	50.57	89.26	198.95
Kevlar® 2840d	Statimat PT	200	612.34	2.67	6546.6	50.91	90.04	199.83
Kevlar® 2840d	Uster	100	595.59	2.48	7272.97	57.77	102.92	218.71
Kevlar® 600d	Instron	400	166	3.98	5522.15	12.23	19.9	37.41
Kevlar® 600d	Sigma500	200	163.11	4.04	5642.8	9.98	17.86	36.56
Kevlar® 600d	Statimat	200	160.95	3.86	5572.75	11.51	19.18	37.53
Kevlar® 600d	Statimat PT	200	166.34	3.94	5605.72	11.84	19.72	38.28
Kevlar® 600d	Uster	100	161.05	3.95	5217.43	11.29	18.7	36.01
Nomex® 1600d	Instron	400	74.91	27.64	93.43	8.62	12.12	20.1
Nomex® 1600d	Sigma500	200	74.64	26.88	76.69	5.02	8.65	17.57
Nomex® 1600d	Statimat	200	74.68	23.73	85.33	8.93	12.61	21.12
Nomex® 1600d	Statimat PT	200	74.73	23.34	87.24	7.67	11.49	20.45
Nomex® 1600d	Uster	100	73.43	30.15	65.01	8.52	11.92	19.71
Nomex® 200d	Instron	400	9.92	25.26	101.74	1.18	1.67	2.68
Nomex® 200d	Sigma500	200	9.75	26.39	96.48	0.76	1.22	2.31
Nomex® 200d	Statimat	200	10.35	19.74	142.14	1.31	1.87	3.1
Nomex® 200d	Statimat PT	198	10.4	19.62	147.24	1.31	1.88	3.11
Nomex® 200d	Uster	100	9.95	28.48	98.93	1.15	1.63	2.71
Technora® 1500d	Instron	400	380.43	4.1	5643.36	27.38	46.74	90.24
Technora® 1500d	Sigma500	200	380.16	4.36	5547.08	18.78	37.1	82.75
Technora® 1500d	Statimat	300	332.06	3.37	5322.14	27.24	46.63	94.08
Technora® 1500d	Statimat PT	200	403.46	4.4	5340.93	26.79	45.05	87.96
Technora® 1500d	Uster	100	388.68	4.3	5277.02	26.03	44.42	86.76
Twaron® 1550d	Instron	400	369.65	2.8	7371.76	34.4	59.63	122.03
Twaron® 1550d	Sigma500	200	367.62	2.98	7212.17	24	48.17	110.8
Twaron® 1550d	Statimat	300	345.82	3.15	19503.39	29.26	50.64	104.73
Twaron® 1550d	Statimat PT	200	369.28	2.86	6757.17	34.03	57.63	118.27
Twaron® 1550d	Uster	100	357.53	2.82	6867.98	31.7	55.35	115.5
Twaron® 3100d	Instron	400	752.78	3.99	4830.35	43.9	76.52	160.84
Twaron® 3100d	Sigma500	200	730.88	4.19	4775.27	29.6	59.78	142.06
Twaron® 3100d	Statimat	300	688.38	3.89	4535.53	39.62	66.08	144.17
Twaron® 3100d	Statimat PT	199	750.77	4.1	4644.51	42.09	70.35	148.89
Twaron® 3100d	Uster	100	728.47	3.84	4697.42	45.01	76.8	158.72
Twaron® 500d	Instron	395	134.69	3.41	6378.45	10.97	18.13	35.18
Twaron® 500d	Sigma500	200	131.09	3.45	4445.16	8.67	15.87	33.77
Twaron® 500d	Statimat	300	113.9	2.95	25688.31	10.75	17.92	35.61
Twaron® 500d	Statimat PT	200	134.05	3.38	6415.34	10.95	18.3	36.22
Twaron® 500d	Uster	100	132.48	3.43	6042.51	10.13	16.99	33.88

19.3.2 *Repeatability* and *reproducibility* deal with the variability of test results obtained under specified laboratory conditions. Repeatability concerns the variability between independent test results obtained within a single laboratory in the shortest practical period. Those results are obtained by a single operator with a specific set of test apparatus using test specimens (or test units) taken at random from a single quantity of homogeneous material obtained or prepared for the interlaboratory study (ILS). Two single test results, obtained in the same laboratory under normal test method procedures, that differ by more than this calculated value must be considered as derived from different or non-identical sample populations. Reproducibility deals with the variability between single test results obtained in different laboratories, each of which has applied the test method to test specimens (or test units) taken at random from a single quantity of homogeneous material obtained or prepared for the ILS. Two single test results, obtained in two different laboratories under normal test method procedures, that differ by more than this tabulated *R* must be considered to have come from different or non-identical sample populations.

20. Keywords

20.1 aramid; cord; fabric; linear density; tensile properties/tests