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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 Force	11
Breaking Tenacity	12
Breaking Toughness	17
Elongation at Break	13
Force at Specified Elongation (FASE)	14
Linear Density	10
Modulus	15
Stress at Break	12
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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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
D2258 Practice for Sampling Yarn for Testing
D3800 Test Method for Density of High-Modulus Fibers
D4848 Terminology Related to Force, Deformation and Related Properties of Textiles
D6587 Test Method for Yarn Number Using Automatic Tester
E23 Test Methods for Notched Bar Impact Testing of Metallic Materials

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).

3.2 The following terms are relevant to this standard: aramid, breaking force, breaking tenacity, breaking toughness, chord modulus, elongation, force at specified elongation (FASE), industrial yarn, initial modulus, moisture equilibrium for testing, standard atmosphere for testing textiles, work-to-break.

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

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

[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.

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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. 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 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, gauge 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 force* 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 tensile testing equipment can be either manually operated or can be an automated device. The specifications and methods of calibration and verification of these machines shall conform to Specification D76. The tester shall be equipped with an electronic data acquisition and data evaluation system.

6.1.1 *Clamps:*

6.1.1.1 *Manually Operated System*—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 and Fig. 2). Clamps with a wrap angle of 180° are required for yarns with a linear density up to 3500 decitex [3000 denier]. For linear densities above 3500 decitex [3000 denier], clamps with a wrap angle of 270° are recommended to prevent slippage. See Note 1.

6.1.1.2 *Automated Device*—Use the clamping system supplied. See Note 1.

6.1.1.3 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.

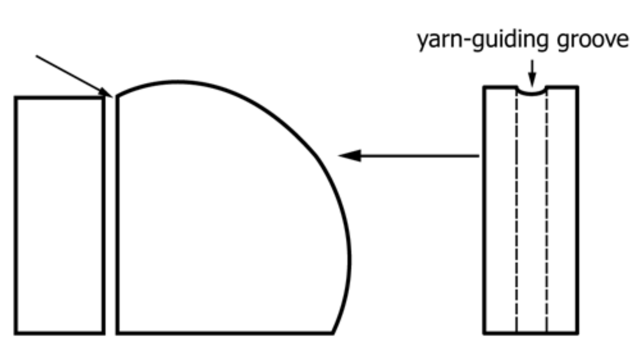


FIG. 1 Example Bollard Type Clamps

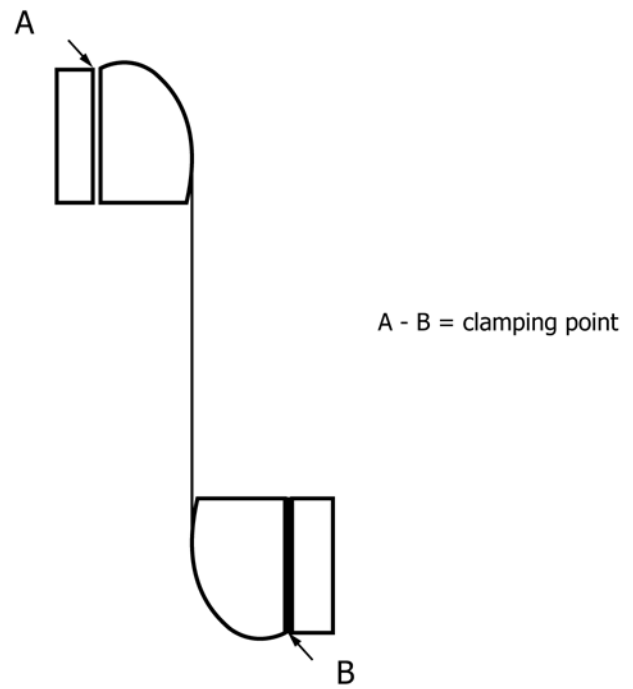


FIG. 2 Gauge Length in Bollard Type Jaws

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).

NOTE 1—The selected testing equipment (tester, clamp, gauge length) is known to have an influence on the properties measured (see Section 19, Table 8). A method for eliminating the influences introduced by the selected testing equipment is given in Appendix X1.

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; 120 % 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 [27 yd] from the outside of the package before taking the sample or any specimens.

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 and cord to moisture equilibrium for testing in the atmosphere for testing aramids as directed in Practice D1776. Report the option used.

8.1.1 The moisture equilibrium of conditioned aramids 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 flat multifilament yarns. Therefore, a defined amount of twist must be inserted prior to testing. Machine twisting by means of a ring twister is recommended. The ring twisters can be equipped with a guiding eyelet with either a variable or a fixed distance to the traveller (the latter resulting in a more uniform twist tension). The twist tension should be approximately 10 mN/tex [0.10 gf/den]. If used, anti-balloon rings must be of a material that will not damage the yarn. A manual or mechanical twister can also be used in the absence of a ring twister, provided the RPM is calibrated and verified with a tolerance of 20 ± 0.1 revolutions at a frequency based on use. For meta-aramid, the inserted twist is 120 tpm [3.0 tpi]. For para-aramid yarns the amount of twist to be inserted depends upon the linear density and is approximately:

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

NOTE 2—The twist level per range is based on the equation $\text{twist}[\text{Tpm}] = \frac{1055 \pm 55}{\sqrt{LD[\text{tex}]}}$.

9.2 Inserting twist for tensile testing has the following effects on the test results:

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

9.2.2 Increases elongation at break, and

9.2.3 Reduces modulus.

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 at break.

10.2 *Procedure:*

10.2.1 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 test methods, condition the yarn as specified in Section 8.

10.2.2 If scoured oven-dried linear density is needed, use Test Method D1907, Option 5.

10.3 Report the method used and the average linear density of the sample.

11. Breaking Force of Conditioned Yarns and Cords

11.1 *Scope*—This test method is used to determine the breaking force of yarns and cords after conditioning in the atmosphere for testing aramids as defined in Practice D1776. Make all tests on the conditioned yarns and cords in the atmosphere for testing aramids as directed in Practice D1776.

11.2 *Number of Specimens*—Perform five tests per specimen.

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 of the load cell used. 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 load cell amplifier. Adjust the distance between the clamps measured from nip to nip of the jaws of the clamps (Fig. 2) on the testing machine. For meta-aramids, use 250 ± 1 mm [10.00 ± 0.05 in.]. For para-aramids, the gauge length is 500 ± 2 mm [20.0 ± 0.1 in.]. For bollard type clamps with a wrap angle of 270° a gauge length of 635 ± 2 mm [0.0 ± 0.1 in.] is recommended. Remove the test material from the specimen or sample and handle it to prevent any change in twist prior to closing the jaws of the clamps. Do not touch that portion of the material 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:

Slack Start procedure (preferred procedure, see 11.3.1) or
Pretension–start procedure (see 11.3.2)

11.3.1 *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 (BF) (maximum force) in Newton [pounds-force]. Discard tests that do not break within the free length between the clamps. 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 gauge length of the specimen will be slightly greater as specified in 11.3.

11.3.2 *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 6.1.3. When the specimen breaks (ruptures), read the breaking force BF (maximum force), in Newton [pounds-force]. Discard tests that do not break within the free length between the clamps. 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. The following notes provide useful information in obtaining more consistent results in tensile testing:

NOTE 3—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 gauges. 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 4—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 5—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.

11.3.3 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]

11.4 Calculate the average and standard deviation of breaking force from the individual breaking forces.

NOTE 6—The preferred term to use is BF (Breaking Force), however the use of BS (Breaking Strength) for the average value is permitted.

11.5 Report results as stated in Section 18.

11.6 *Precision and Bias:*

11.6.1 *Precision*—See Section 19.

11.6.2 *Bias*—See 19.3.

12. Breaking Tenacity and Stress at Break 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-Newton per tex (mN/tex) [grams-force per denier (gf/den)] from the breaking force and the linear density using Eq 1 and 2:

$$BT_n = \frac{BF_n \cdot 1000}{LD_t} \quad (1)$$

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

where:

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

12.2.1 Calculate the average and standard deviation of the breaking tenacity of the sample.

12.3 Report results as stated in Section 18.

12.4 *Precision and Bias:*

12.4.1 *Precision*—See Section 19.

12.4.2 *Bias*—See Section 19.3.

12.5 *Stress or Break:*

12.5.1 *Scope*—This test method is used to determine the breaking force per cross-section area of yarns and cords after conditioning in the atmosphere for testing aramids.

12.5.2 Calculate the specific stress at break using Eq 3:

$$SB = BT_n \cdot \frac{Rho}{1000} \quad (3)$$

where additonally:

SB = stress at break in MPa, and
Rho = density in kg/m^3.

12.5.2.1 The density is either:

(1) determined according to Test Method D3800, Procedure A—Buoyancy (Archimedes) Method; test temperature as in Section 8.

(2) the value determined by the supplier (Test Method D3800, see *(1)*).

(3) the nominal value for para-aramids fo 1440 kg/m^3.

12.5.3 Calculate the average and standard deviation of the stress at break of the sample.

12.5.4 Report results as stated in Section 18.

12.5.5 *Precision and Bias:*

12.5.5.1 *Precision*—See Section 19.

12.5.5.2 *Bias*—See 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 by electronic means. The general equation for elongation at break is given in Eq 4:

$$EB = \left(\frac{E_{bf}}{L_o}\right) \cdot 100\ \% \quad (4)$$

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 4.

13.2.2 *Slack Start*—Calculate the gauge length (L_o) to include the slack using Eq 5:

$$L_o = L_s + DP \quad (5)$$

where:

L_o = length of the specimen, under specified pretension, measured from nip-to-nip of the holding clamps, mm [in.],

[3] Jones, R. E. and Desson, M. J., "Adiabatic Effects on Tensile Testing," *Journal of the I.R.I*, June 1967.

L_s = gauge 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 6:

$$EB = \frac{E_{bf}}{L_s + DP} \cdot 100\ \% \tag{6}$$

where:

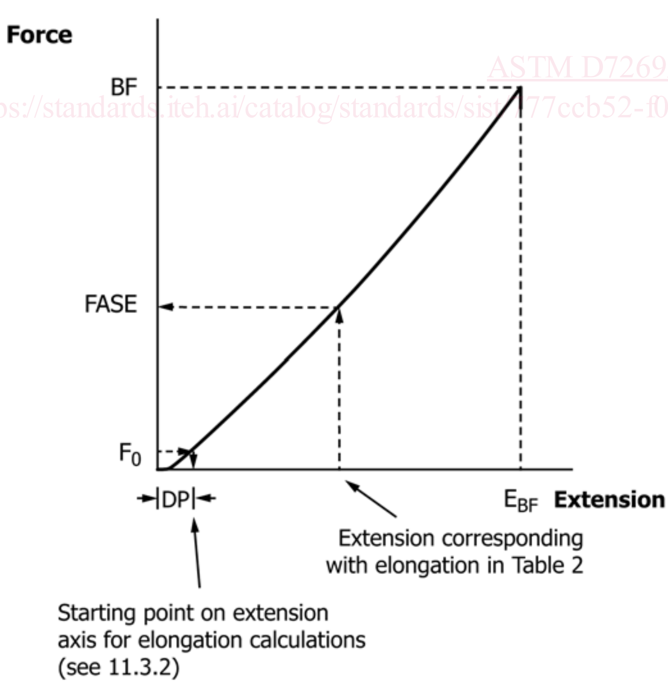
EB = elongation at break, %,
E_{bf} = extension of specimen at the breaking force, mm [in.],
L_s = gauge length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), mm [in.], and
DP = displacement of crosshead to reach the specified pretension of the specimen (see Fig.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

13.2.3 Calculate the average and standard deviation of the elongation at break of the sample.

13.2.4 For calculating the FASE (Section 14), Chord Modulus (Section 15), and Work-to-Break (Section 16), it is required to calculate the elongation at any force from the corresponding extension.

13.3 Report results as stated in Section 18.

13.4 *Precision and Bias:*



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

13.4.1 *Precision*—See Section 19.
13.4.2 *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 by electronic means with an on-line computer at the specified value of elongation listed in Table 1.

NOTE 7—The preferred term to use is FASE (Force at Specified Elongation), however the use of LASE (Load at Specified Elongation) is permitted.

14.2.1 Ensure 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 7 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.

$$E_x = E_s \cdot \frac{(L_s + DP)}{100} \tag{7}$$

where:

E_x = extension, mm [in.],
E_s = specified elongation, %,
L_s = gauge 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 Calculate the average and standard deviation of the FASE of the sample.

14.4 Report results as stated in Section 18.

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:*

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.

TABLE 1 Elongation Values for Determination of FASE

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

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 2. 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.

NOTE 8—The chord interval for m-aramid can be within ±0.01 N/tex (±0.1 gf/den) of the specified limits in Table 2.

15.1.2.1 Calculate the chord modulus of a specimen using Eq 8:

$$CM = 100 \cdot \frac{T_b - T_a}{E_b - E_a} \quad (8)$$

where:

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

15.1.3 Calculate the average and standard deviation of the chord modulus of the sample.

15.1.4 Report results as stated in Section 18.

15.1.5 *Precision and Bias:*

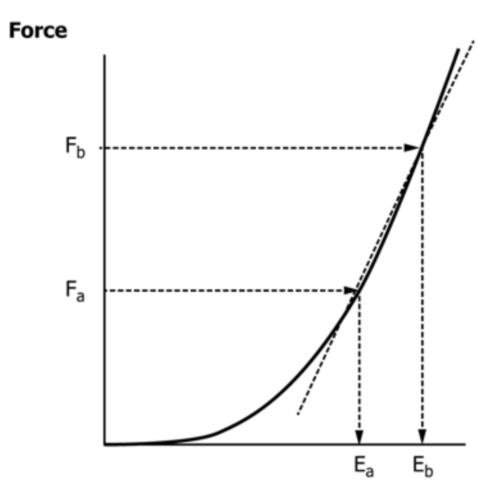
15.1.5.1 *Precision*—See Section 19.

15.1.5.2 *Bias*—See 19.3.

15.2 *Specific Chord Modulus:*

15.2.1 *Scope*—This test method is used to determine the chord modulus per cross-section area of yarns and cords after conditioning in the atmosphere for testing aramids.

15.2.2 Calculate the specific chord modulus using Eq 9:



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 2 Lower and Upper Limit of the Chord Modulus Interval

Type of Fiber	Lower Limit, T_a		Upper Limit, T_b	
	N/tex	[gf/den]	N/tex	[gf/den]
p-Aramid	0.30	[3.5]	0.40	[4.5]
m-Aramid	0.035	[0.4]	0.125	[1.4]

$$CMA = CM \cdot \frac{Rho}{1000} \quad (9)$$

where additionally:

CMA = specific chord modulus in GPa,
Rho = average density in kg/m^3.

The density is either:

(1) determined according to Test Method D3800; test temperature as in Section 8.

(2) the value determined by the supplier (Test Method D3800; test temperature as in Section 8).

(3) the nominal value for para-aramids of 1440 kg/m^3.

15.2.3 Calculate the average and standard deviation of the chord modulus of the sample,

15.2.4 Report results as stated in Section 18.

15.2.5 *Precision and Bias:*

15.2.5.1 *Precision*—See Section 19.

15.2.5.2 *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, the work-to-break and specific work-to-break can be calculated using Eq 10 and Eq 11 or Eq 12 and Eq 13:

$$WB_j = \sum_{k=0}^{n-1} \frac{F_{k+1} + F_k}{2} \cdot \frac{E_{k+1} - E_k}{1000} \quad (10)$$

$$WB_{sj} = \frac{1000 \cdot WB_j}{L_0} \quad (11)$$

or:

$$WB_i = \sum_{k=0}^{n-1} \frac{F_{k+1} + F_k}{2} \cdot (K_{k+1} - E_k) \quad (12)$$

$$WB_{si} = \frac{1000 \cdot WB_i}{L_0} \quad (13)$$

where:

WB_j = work-to-break, J,
WB_i = work-to-break, lbf,
F_o = force at pretension level, N [lbf],
F_a = force at first data pair, N [lbf],
F_k = force at *k*th data pair, N [lbf],
E_a = extension at first data pair, mm [in.],
E_k = extension at *k*th data pair, mm [in.],
WB_{sj} = specific work-to-break, J/m,
WB_{si} = specific work-to-break, lbf/in., and
L_o = gauge length of specimen, mm [in.].

16.2.1 Calculate the average and standard deviation of the work-to-break of the sample.

16.3 Report results as stated in Section 18.

16.4 *Precision and Bias:*

16.4.1 *Precision*—See Section 19.

16.4.2 *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*—The information of Section 16 is used to calculate the breaking toughness of the yarn or chord sample (Eq 14 and Eq 15).

$$BT_j = \frac{WB_{sj} \cdot 10^3}{L_0 \cdot LD_t} \tag{14}$$

$$BT_i = \frac{WB_{si}}{L_0 \cdot LD_d} \tag{15}$$

where:

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

17.3 Calculate the average and standard deviation of the breaking toughness of the sample.

17.4 Report results as stated in Section 18.

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 average value and the standard deviation of each property measured or calculated for each sample. These numbers can be rounded as given in Test Methods E23, section 6.4.2 and 7.4.

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. Flat 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 Force (BF)	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 3-5 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.

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

TABLE 3 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

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

TABLE 4 Standard Deviations by Material, Device

NOTE 1—For unknown reasons, one of the participating laboratories (Spruance) found a too low breaking force of 350 N using the Instrons. The correct breaking force is 410 N. This led to high standard deviation for the Instron breaking force.

Material	Device	N Rows	Std Dev(BF(N))	Std Dev(EB(%))	Std Dev(MOD(CN/Tex))	Std Dev(FASE 0.3%)	Std Dev(FASE 0.5%)	Std Dev(FAS
Kevlar® 1420d	Instron	377	7	0.05	411.43	0.84	0.99	1.71
Kevlar® 1420d	Sigma500	200	9.7	0.11	156.42	0.99	1.35	2.53
Kevlar® 1420d	Statimat	200	19.56	0.11	159.75	2.46	3.94	5.98
Kevlar® 1420d	Statimat PT	200	9.13	0.08	274.67	2.6	3.99	5.04
Kevlar® 1420d	Uster	100	5.81	0.04	34.68	0.37	0.5	0.63
Kevlar® 2840d	Instron	386	11.27	0.05	74.66	1.27	1.65	4.75
Kevlar® 2840d	Sigma500	200	13.73	0.07	136.52	1.52	1.87	2.85
Kevlar® 2840d	Statimat	200	15.98	0.09	148.52	5.11	8.74	12.28
Kevlar® 2840d	Statimat PT	200	12.88	0.07	259.52	4.24	7.43	9.03
Kevlar® 2840d	Uster	100	13.84	0.06	46.73	0.74	1.06	1.6
Kevlar® 600d	Instron	400	2.59	0.06	104.15	0.36	0.35	0.59
Kevlar® 600d	Sigma500	200	5.64	0.17	255.77	0.34	0.53	1.19
Kevlar® 600d	Statimat	200	4.48	0.09	87.14	0.31	0.34	0.33
Kevlar® 600d	Statimat PT	200	2.92	0.09	226.6	0.75	0.89	1.23
Kevlar® 600d	Uster	100	2.1	0.05	30.92	0.09	0.13	0.2
Nomex® 1600d	Instron	400	1.22	1.28	32.77	0.2	0.26	0.48
Nomex® 1600d	Sigma500	200	1.84	0.81	6.11	0.11	0.14	0.23
Nomex® 1600d	Statimat	200	0.94	1.01	4.7	0.4	0.52	0.66
Nomex® 1600d	Statimat PT	200	1.01	1.16	5.01	1.71	1.85	2.04
Nomex® 1600d	Uster	100	0.61	0.97	2.4	0.05	0.08	0.14
Nomex® 200d	Instron	400	0.33	2.26	9.57	0.04	0.04	0.24
Nomex® 200d	Sigma500	200	0.82	1.4	25.22	0.06	0.11	0.25
Nomex® 200d	Statimat	200	0.29	1.73	20.67	0.27	0.27	0.25
Nomex® 200d	Statimat PT	198	0.44	1.69	27.25	0.26	0.28	0.29
Nomex® 200d	Uster	100	1.15	1.25	83.32	0.04	0.1	0.24
Technora® 1500d	Instron	400	29.92	0.3	51.27	0.59	0.71	1.81
Technora® 1500d	Sigma500	200	11.69	0.19	81.1	0.71	0.89	1.18
Technora® 1500d	Statimat	300	15.7	0.44	176.29	3.82	5.82	12.07
Technora® 1500d	Statimat PT	200	13.33	0.22	126.91	2.17	2.77	3.49
Technora® 1500d	Uster	100	6.51	0.06	30.44	0.27	0.36	0.49
Twaron® 1550d	Instron	400	4.92	0.04	74.96	1.06	1.1	2.09
Twaron® 1550d	Sigma500	200	5.09	0.07	136.37	0.76	0.8	1.22
Twaron® 1550d	Statimat	300	33.03	0.87	18241.11	3.07	6.28	15.4
Twaron® 1550d	Statimat PT	200	7.98	0.08	535.28	4.28	5.53	7.16
Twaron® 1550d	Uster	100	6.21	0.05	35.1	0.44	0.57	0.77
Twaron® 3100d	Instron	400	14.68	0.09	62.28	2	2.98	4.53
Twaron® 3100d	Sigma500	200	20.03	0.09	59.91	2.5	3.73	5
Twaron® 3100d	Statimat	300	22.54	0.15	177.78	4.06	8.01	10.76
Twaron® 3100d	Statimat PT	199	16.06	0.15	138.4	3.08	5.56	6.11
Twaron® 3100d	Uster	100	16.23	0.06	48.13	1.84	2.63	3.63
Twaron® 500d	Instron	395	2.02	0.05	105.82	0.47	0.5	0.76
Twaron® 500d	Sigma500	200	4.04	0.17	2145.6	0.75	0.68	0.47
Twaron® 500d	Statimat	300	13.3	0.31	27421.87	0.4	0.45	0.36
Twaron® 500d	Statimat PT	200	2.54	0.08	220.87	0.75	0.81	1.13
Twaron® 500d	Uster	100	1.48	0.03	55.17	0.13	0.18	0.24