Designation: D8054/D8054M − 16

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

This standard is issued under the fixed designation D8054/D8054M; 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 para-aramid flat yarns.

1.1.1 This standard includes procedures used to measure force at specified elongation (FASE) of para-aramid flat yarns.

1.1.2 This standard includes procedures used to measure linear density of para-aramid flat yarns.

1.1.3 This standard includes procedures to determine modulus of para-aramid flat yarns.

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 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/D1776M Practice for Conditioning and Testing Textiles
D1907/D1907M 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
D6477 Terminology Relating to Tire Cord, Bead Wire, Hose Reinforcing Wire, and Fabrics
D6587 Test Method for Yarn Number Using Automatic Tester
D7269 Test Methods for Tensile Testing of Aramid Yarns
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

3. Terminology

3.1 *Definitions:*

3.1.1 *flat yarn, n*—continuous filament yarns which, when removed from processing package are fully drawn, without twist and untextured.

3.1.1.1 *Discussion*—Flat yarn is either extruded in this form or it could be made as a slit cut structure with no additional processing modifying the extension direction of the individual elements (for example, filaments) in the yarn.

3.2 The following terms are relevant to this standard: modulus, elongation, force at specified elongation (FASE), force-elongation curve.

3.3 For definitions of terms related to industrial fibers and metallic reinforcements, see Terminology D6477.

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

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

4. Summary of Test Methods

4.1 Using various test methods and protocols identified in the procedures, this standard determines the tensile strength, force at specified elonation (FASE), linear density and modulus of para-aramid flat yarns.

5. Significance and Use

5.1 For application areas such as optical fiber and cable reinforcements, aramid is usually used in a linear – not twisted – form. For designing constructions like this, it is essential to use data based on a specimen without twist applied.

5.1.1 The modulus and FASE of twisted yarns demonstrate reduced values when compared to p-aramid flat yarns.

5.1.2 Use Test Method D7269 for testing of twisted p-aramid yarns.

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[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 July 1, 2016. Published November 2016. DOI: 10.1520/D8054_D8054M-16.

[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.

5.2 The levels of tensile properties obtained when testing aramid yarns 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.

5.3 The FASE is used to describe the absolute resistance of the p-aramid flat yarn to an imposed deformation.

5.4 The initial modulus of the yarn is the value most commonly used when a specified force is applied to the yarn.

5.5 Shape, size, and internal construction of the end-product can have appreciable effect on product performance. It is not possible, therefore, to evaluate the performance of end product in terms of the reinforcing material alone.

5.6 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.

6.2 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 or specimen failure, or both, in the clamping zone. (see Appendix X1; Figure X1.1). It is recommended to use pneumatic clamps which can be operated using a foot pedal.

6.3 The compliance of the total testing system (tensile tester, load cell, and clamping system) shall be less than 0.2 µm [10^{-6} in.] per newton.

6.4 *Gauge Length*—The gauge length is the total length between the jaw faces (see Fig. X1.1).

NOTE 1—The selected testing equipment (tester, clamp, gauge length) is known to have an influence on the properties measured. A method for eliminating the influences introduced by the selected testing equipment is given in Test Methods D7269, Appendix X1.

7. Sampling

7.1 *Yarn*—For acceptance testing, sample each lot as directed in Practice D2258. Take the number of specimens for testing specified for the specific property measurement to be made.

7.1.1 *Number of Samples and Specimens*—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. 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 yarn.

7.1.2 *Preparation of Samples*—Remove and discard a minimum of 25 m [75 yd] from the outside of the package before taking the sample or any specimens. Use care in handling the sample. Special care should be used to prevent over handling and disruption of the filament alignment in the yarn bundle. Discard any sample subjected to any change of twist, kinking, or making any bend with a diameter less than 10 times the yarn thickness (or diameter).

8. Conditioning

8.1 Without pre-drying, bring the bobbin with yarn to equilibrium in the atmosphere for testing as directed in Practice D1776/D1776M for aramid.

9. Linear Density

9.1 This test method is used to determine the linear density of flat yarn for use in the calculation of tensile properties such as modulus.

9.1.1 Determine linear density as directed in Option 1 of Test Method D1907/D1907M or use an Automated Tester as directed in Test Method D6587. For both test methods, condition the yarn as specified in Section 8.

9.1.2 If scoured oven-dried linear density is needed, use Test Method D1907/D1907M, Option 5.

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

10. Sample Preparation

10.1 *Sample Preparation*—Take test specimens directly from the original package. Rewound and skein specimen will likely result in lower values. Remove the surface layer and discard.

10.2 *Specimen Preparation*—Mount the sample onto a frame using the "Rolling take off" method. Examples of suitable frames are shown in Fig. 1. Take off test specimen tangentially from the bobbin directly without touching any of the measured part of the yarn and without applying any twist.

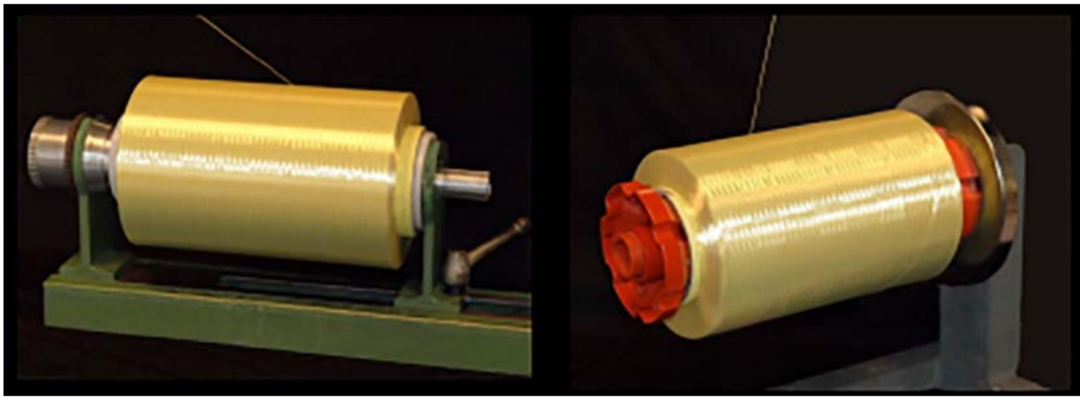

FIG. 1 Examples of Frames/Holders for "Rolling Take Off" Sampling

10.3 Holding the yarn firmly at the free end and using the "rolling take off" method, remove about 1 m for the specimen. Do not use yarn within 50 mm of either end of the sample ball. Do not let test specimen sag or loop.

10.4 Clamp the specimen in the clamps ensuring that when clamped the tension does not exceed 20 mN/tex.

10.5 During testing, monitor the sample for slippage and splayed yarn due to excessive catenary.

10.6 If slippage is monitored, reject by deletion, clean clamps and repeat.

NOTE 2—Test specimen should be taken off freely with no great drag on the specimen which would increase tension, but still with enough tension applied by hand to remove and keep removed any catenary present. This is particularly important when the specimen is made up of more than one threadline as it requires more tension by hand to ensure that the catenary is all removed. As long as the mounted specimen does not give a reading greater than 20 mN/tex, the test will be valid.

11. Determination of the Modulus of FASE Values of Aramid Flat Yarn

This test method describes two options for the determination of the modulus and FASE values of aramid flat yarn:

Option 1: Measurement of the FASE and modulus of flat yarns (see 11.1).

Option 2: Compute the flat yarn FASE and modulus from twisted yarn test-results (see 11.2).

11.1 *Option 1: Tensile Testing of Flat Yarns:*

11.1.1 *General:*

11.1.1.1 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 of this 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]

11.1.1.2 *Tensile Tester*—Select a load 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 load cell amplifier.

11.1.1.3 *Gauge Length*—Adjust the distance between the clamps on the testing machine so that the nominal gauge length of the specimen, measured between the jaw faces of the clamps, is 500 ± 2 mm [20.00 ± 0.01 in.]. Make all tests on the conditioned yarns in the atmosphere for aramid yarn. Remove the specimen from the sample and handle it to prevent any change in configuration prior to closing the jaws of the clamps on the specimen. Avoid any damage to the yarn.

11.1.1.4 *Test Speed*—Use a crosshead travel rate of 250 ± 1 mm/min [10.00 ± 0.05 in./min]. This is 50 % of the nominal gauge length of the specimen.

11.1.1.5 *Slack Start*—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 11.1.1.4 and stretch the specimen until it ruptures. 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. The gauge length is defined as the length at a pretension level of 20 mN/tex. The slack start procedure has the effect that the nominal gauge length of the specimen is not exactly 500 mm [20 in.] as specified in 11.1.1.3, but always will be slightly increased due to slack in the specimen after closing the clamps.

11.1.2 *Tenacity:*

11.1.2.1 This test method is used to determine the tenacity of yarns after conditioning in the atmosphere for testing aramid at any force level. The calculation of tenacity is required to determine the modulus (11.1.4).

11.1.2.2 *Tenacity*—Tenacity is defined by dividing the load (force) by the linear density using Eq 1.

$$T_F = \frac{F}{LD} \quad (1)$$

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

where:

F = force, N [gf],
LD = linear density, tex [den], and
T_F = tenacity, N/tex [gf/den].

11.1.2.3 *Reporting*—This parameter is used for determining the modulus and is not reported.

11.1.3 *Elongation of Flat Yarns:*

11.1.3.1 This test method is used to determine the elongation of yarns after conditioning in the atmosphere for testing aramid at any forced level. The calculation of elongation from clamp displacement is required in order to determine Modulus and FASE.

11.1.3.2 *Pretension*—The pretension for aramid yarns corresponds with 20 ± 1 mN/tex [0.20 ± 0.01 gf/den].

11.1.3.3 *Slack Start*—Calculate the specimen length (L_0) including the slack using Eq 2:

$$L_0 = L_s + DP \tag{2}$$

where:

L_0 = gauge length of the specimen, under specified pretension, measured from nip-to-nip of the holding clamlps, mm [in.],
L_s = length after clamping specimens (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. 2).

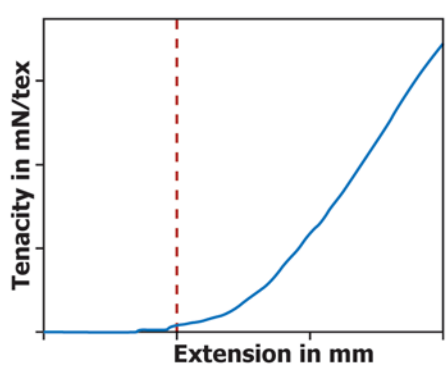

FIG. 2 Force-Extension Curve

11.1.3.4 *Elongation*—The general equation for elongation is given in Eq 3:

$$E_F = \frac{l_f}{L_0} \cdot 100\% \tag{3}$$

where:

E_F = elongation at force F, %,
l_F = extension of specimen at force F, mm [in.],
L_0 = length of the specimen, under specified pretension, measured from nip-to-nip of the holding clamps, mm [in.].

11.1.3.5 *Reporting*—This parameter is used for determining the modulus and FASE and is not reported.

11.1.4 *Modulus of Yarns:*

11.1.4.1 This test method is used to determine the modulus of yarns after conditioning in the atmosphere for testing aramid.

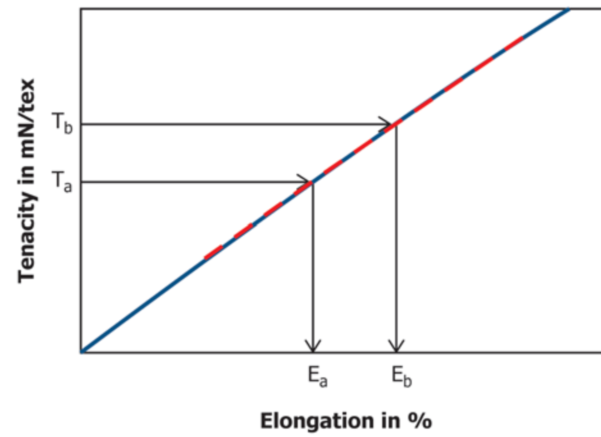

FIG. 3 Tenacity-Elongation Curve for the Determination of Modulus

where:

T_a = tenacity Lower Limit as specified in Table 1
T_b = tenacity Upper Limit as specified in Table 1
E_a = elongation point corresponding to Upper Limit Force in Table 1
E_b = elongation point corresponding to Upper Limit Force in Table 1

11.1.4.2 *Procedure: Modulus Yarns*—Determine the modulus of each conditioned specimen from the tenacity-elongation curve (see Fig. 3). Determine the modulus between the points as specified in Fig. 3 and Table 1. Locate the points E_{a1} and E_{b1} on the ordinate at the forces F_{a1} and F_{b1} equivalent to the lower and the upper tenacity limit in N/tex [gf/den] as given in Table 1. 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.

TABLE 1 Lower and Upper Limit of the Modulus Intervals

Type of Fiber	Lower Limit, Ta		Upper Limit, Tb	
	N/tex	[gf/den]	N/tex	[gf/den]
aramid	0.30	[3.4]	0.40	[4.5]

11.1.4.3 Calculate the modulus *CM* of a specimen using Eq 4:

$$CM = 100 \cdot \frac{T_b - T_a}{E_b - E_a} \tag{4}$$

where:

CM = 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 = elongaton corresponding to T_b, %, and
E_a = elongation corresponding to T_a, %.

The modulus can also be reported per cross-sectional area:

$$CMA = CM \cdot \frac{Rho}{1000} \quad (5)$$

where:

CMA = modulus, GPa, and
Rho = density in kg/m^3.

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; Procedure A—Buoyancy (Archimedes) Method; test temperature as in Section 8.).

(3) The nominal value of 1440 kg/m^3 for p-aramids.

The density must be reported.

11.1.4.4 Calculate the average and standard deviation of the modulus and specific modulus.

11.1.4.5 Report results as stated in Section 12.

11.1.4.6 *Precision and Bias*—See Section 13.

11.1.5 *Force at Specified Elongation (FASE) of Conditioned Yarns:*

11.1.5.1 This test method is used to determine the force at specified elongation (FASE) of yarns conditioning in the atmosphere for aramid.

11.1.5.2 *Procedure*—Determine the force at specified elongation (FASE) of each conditioned specimen from the force-elongation curve (see Fig. 4) or by electronic means or with an on-line computer at the specified value of elongation listed in Table 2.

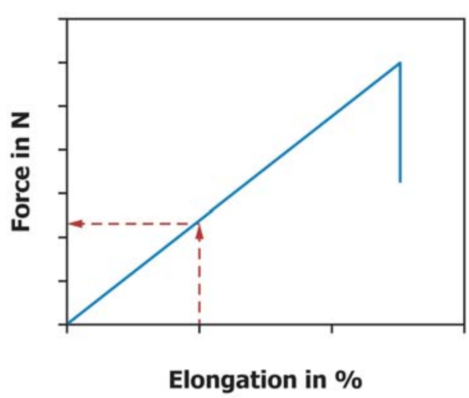

FIG. 4 Force-Elongation Curve

TABLE 2 Elongation Values for Determination of FASE

Type of Fiber	Elongation in %
aramid Flat Yarn	0.3
	0.5
	1.0

NOTE 3—The preferred term to use is FASE (Force at Specified Elongation), however the use of LASE (Load at Specified Elongation) is also permitted.

11.1.5.3 Calculate the average and standard deviation of the FASE values.

11.1.5.4 Report results as stated in Section 12.

11.1.5.5 *Precision and Bias*—See Section 13.

11.2 *Option 2: Computed Flat Yarn FASE and Modulus from Twisted Yarn Test-Results:*

11.2.1 *General:*

11.2.1.1 With the procedure for determination of properties for quality control and test reports (Test Methods D7269) it is required to twist the yarn prior to testing. Option 2 describes a method for computing the modulus and FASE from these data.

11.2.1.2 *Physical Background*—See Appendix X2 for the physical background of the procedure.

11.2.2 *Modulus:*

11.2.2.1 This test method is used to determine the modulus of yarns after conditioning in the atmosphere for testing aramid.

11.2.2.2 *Modulus*—The equation for calculating the modulus from twisted data is given by Eq 6:

$$M_S = \frac{1}{\frac{1}{M_{\text{twisted, standard}}} - c_M} \quad (6)$$

where:

$M_{\text{twisted, standard}}$ = modulus of the twisted yarn, GPa (See Test Methods D7269; conversion to GPa using Eq 5),
c_M = experimentally determined constant, GPa^{-1}. This constant has to be determined for every yarn type (yarn + finish), and
M_S = modulus of the flat yarn, GPa.

11.2.2.3 *Constant*—The constant is experimentally determined by measuring the modulus of twisted and flat yarns from a representative selection of samples. This is done by:

(a) Per sample, measure the modulus of twisted material using Test Methods D7269.

(b) Per sample, measure the modulus using the method described in 11.1.

(c) Calculate the constant using Eq 7:

$$C_M = \frac{1}{M_{\text{twisted, standard}}} - \frac{1}{M_S} \quad (7)$$

(d) Calculate the average constant.

NOTE 4—The number of samples to be selected: the validation procedure will be discussed and defined with ASTM-ILS.

11.2.3 *FASE:*

11.2.3.1 *Scope*—This test method is used to determine the FASE of yarns after conditioning in the atmosphere for testing aramid.

11.2.3.2 *FASE*—The equation for calculating the FASE of flat yarn from twisted data is given in Eq 8:

$$FASE_S = \frac{1}{\frac{1}{FASE_{\text{twisted, standard}}} - \frac{c_F}{LD}} \quad (8)$$

where:

$FASE_{\text{twisted, standard}}$ = FASE of the twisted yarn, N (see Test Methods D7269),

c_F = experimentally determined constant, tex/N. This constant has to be determined for every yarn type (yarn + finish) and FASE level,
$FASE_S$ = FASE of the flat yarn, N, and
LD = linear density, tex.

11.2.3.3 *Constant*—The constant is experimentally determined by measuring the modulus of twisted and flat yarns from a representative selection of samples. This is done by:

(a) Per sample, measure the FASE of twisted material using Test Methods D7269.

(b) Per sample, measure the FASE of flat yarn using the method described in 11.1.

(c) Calculate per FASE level the constant using Eq 9:

$$C_F = \frac{LD}{FASE_{\text{twisted, standard}}} - \frac{LD}{FASE_S} \tag{9}$$

(d) Calculate the average constant.

NOTE 5—The number of samples to be selected: the validation procedure will be discussed and defined with ASTM-ILS.

NOTE 6—The preferred term to use is FASE (Force at Specified Elongation), however the use of LASE (Load at Specified Elongation) is also permitted.

12. Reports, General

12.1 State that all specimens were tensile tested as directed in Test Method D8054, Section 11. Describe the material or product sampled and the methods of sampling used.

12.2 Report the following information:

12.2.1 Test procedure used,

12.2.2 Laboratory conditions,

12.2.3 Type of clamp used,

12.2.4 Number of specimens tested per sample, and

12.2.5 The value of each property measured or calculated.

13. Precision and Bias of Certain Yarn Tests

13.1 *Precision and Bias*—The precision of this test method is based on an intralaboratory study of ASTM WK45529 – New Test Methods for Determination of Modulus and Force at Specified Elongation of Flat Aramid Yarns, conducted in 2015. A single laboratory participated in this study, testing two different types of yarns. Every "test result" represents an individual determination. The laboratory was asked to report ten replicate test results for each yarn type. Except for the use of only one laboratory, Practice E691 was followed for the design and analysis of the data; the details are given in an ASTM Research Report.[4]

13.1.1 *Repeatability (r)*—The difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same apparatus under constant operating conditions on identical test material within short intervals of time would in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

13.1.1.1 Repeatability can be interpreted as maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

13.1.1.2 Repeatability limits are listed in Tables 3 and 4.

TABLE 3 A-3140 dtex

	Average $\bar{x}$	Repeatability Standard Deviation S_r	Repeatability Limit r
CM (N per tex)	85.65	0.30	0.85
FASE 0.3 (N)	75.39	0.80	2.25
FASE 0.5 (N)	129.22	0.92	2.59
FASE 1.0 (N)	260.11	1.23	3.47
FASE 2.0 (N)	–	–	–

TABLE 4 B-1610 dtex (N)

	Average $\bar{x}$	Repeatability Standard Deviation S_r	Repeatability Limit r
CM (N per tex)	86.59	0.20	0.57
FASE 0.3 (N)	41.79	0.32	0.90
FASE 0.5 (N)	69.66	0.33	0.92
FASE 1.0 (N)	138.13	0.36	0.99
FASE 2.0 (N)	281.31	0.62	1.74

13.1.2 *Reproducibility (R)*—The difference between two single and independent results obtained by different operators applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

13.1.2.1 Reproducibility can be interpreted as maximum difference between two results, obtained under reproducibility conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

13.1.2.2 Reproducibility limits cannot be calculated from a single laboratory's results.

13.1.3 The above terms (repeatability limit and reproducibility limit) are used as specified in Practice E177.

13.1.4 Any judgment in accordance with 9.1.1 would normally have an approximate 95 % probability of being correct, however the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting replicate results essentially guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit as a general guide, and the associated probability of 95 % as only a rough indicator of what can be expected.

13.2 *Bias*—At the time of this study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement on bias is being made.

13.3 The precision statement was determined through statistical examination of 90 test results, from a single laboratory.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-1143. Contact ASTM Customer Service at service@astm.org.

14. Keywords

14.1 aramid; flat yarn; linear density; tensile properties/tests

APPENDIXES

(Nonmandatory Information)

X1. SUGGESTED GUIDELINE FOR CLAMPING IN TENSILE TESTING

X1.1 Clamp suitability in mechanical testing is a balance of sufficient grip to limit test variation yet no impose damage to the fiber. A determinant of slip in the clamps is the variation observed during testing. This guideline is intended to minimize yarn slippage in the clamps during tensile testing. An indicator of slip in the clamps is the ultimate elongation of the fiber. If variation or significantly higher value is observed in the ultimate elongation, slippage is most likely occurring in the clamps. Pneumatic yarn bollard shaped grips stainless steel faces have been evaluated and found to grip the yarn without noticeable slippage. both a linear and non-linear yarn lay-up are allowed (see Fig. X1.1).

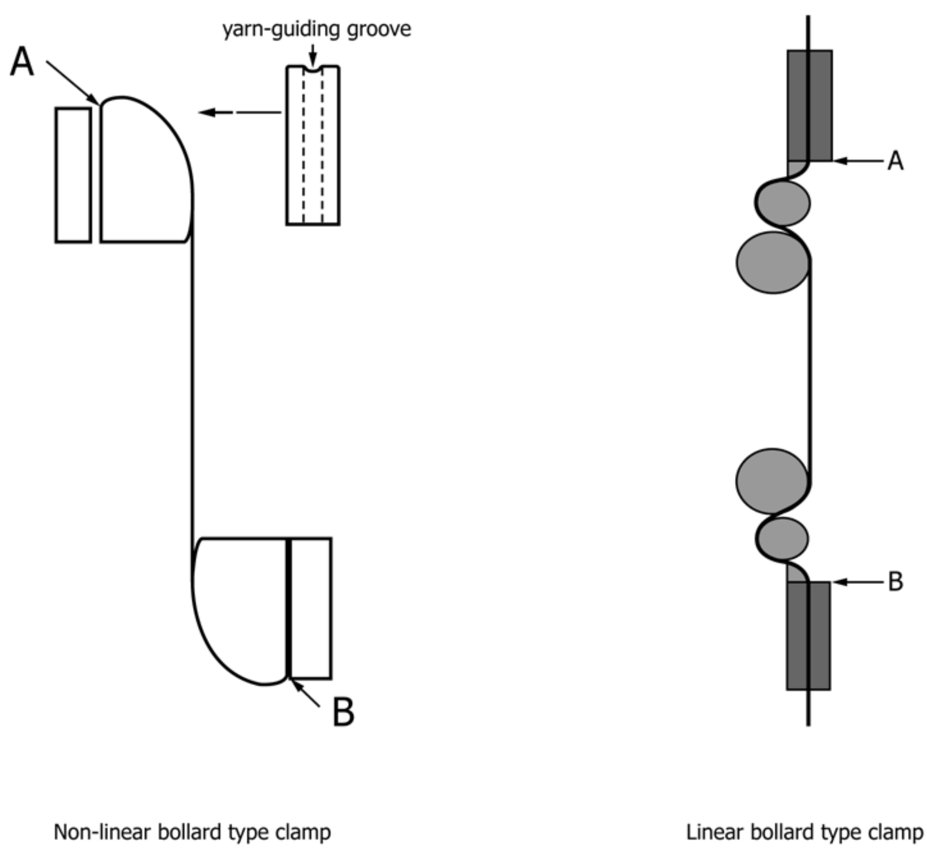

FIG. X1.1 Bollard Type Clamps (Gauge length: length A-B)

X2. RELATION BETWEEN TWISTED AND FLAT YARN MODULUS AND FASE

X2.1 Modulus

X2.1.1 In Hadley[5] and Pan[6], it is described that the modulus of a twisted filament yarn will depend on:

(1) The modulus of the filament material,

(2) The angle of the filaments with the main axis of the twisted yarn, and

(3) The shear between the filaments.

X2.1.1.1 By combining these contributions, the following equation can be derived[5]:

$$\frac{1}{M_{\text{twist}}} = \frac{1}{M_0} + \frac{\overline{\sin^2(\alpha)}}{g} \quad \text{(X2.1)}$$

where:

g = shear modulus between the filaments, Gpa,
$\overline{\sin^2(\alpha)}$ = average filament orientation factor,
M_0 = modulus of the flat yarn, Gpa, and
M_{twist} = modulus of the twisted yarn, Gpa.

The angle α will be influenced by the elongation. Since only small deformations will be considered (≤1 %), it is assumed that this effect is negligible.

X2.1.1.2 The average filament orientation can be estimated from the average of helix shapes of filaments in twisted yarn, as shown in Fig. X2.1.

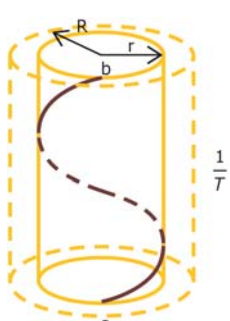

FIG. X2.1 Helix-Path of a Filament in a Twisted Yarn

where:

R = radius of the twisted yarn
r = radius of the filament helix (one full turn of the helix; filament path from a to b)
T = twist level in 1/m

X2.1.1.3 Radius R of the twisted yarn can be found from:

$$R = \frac{1}{f} \cdot \sqrt{\frac{LD}{\rho\pi}} \quad \text{(X2.2)}$$

where:

LD = linear density, kg/m,
ρ = density, kg/m^3, and
f = packing factor.

X2.1.1.4 With an optimum hexagonal packing of filament, this packing factor will equal 0.9. By unfolding the helix, the angle can be derived (see Fig. X2.2). From this figure it can be seen that the angle α at position r is given by:

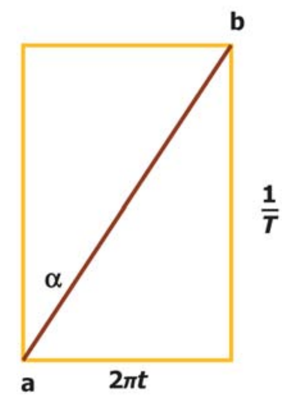

FIG. X2.2 Unfolded Helix-Path of a Filament in a Yarn

$$\alpha = a\tan\left(\frac{2\pi r}{1/T}\right) = a\tan(2\ \pi\ r \cdot T) \quad \text{(X2.3)}$$

X2.1.1.5 The average filament orientation factor can be found from integrating the number of filaments (proportional with 2πr) multiplied by $\sin^2(\alpha)$ divided by the total number of filaments (proportional with πR^2), so

$$\overline{\sin^2(\alpha)} = \frac{\int_0^R 2\pi r \cdot \sin^2(\alpha) dr}{\pi R^2} \quad \text{(X2.4)}$$

Substitution of (4) in (5) and solving the integral results in:

$$\overline{\sin^2(\alpha)} = \frac{\ln\left(\frac{1}{(2\pi RT)^2+1}\right) + 2\pi RT)^2}{(2\pi RT)^2} \quad \text{(X2.5)}$$

X2.1.1.6 From Eq X2.2 it can be seen that there should be a linear relationship between the calculated $\overline{\sin^2(\alpha)}$ and the reciprocal modulus. The intercept is the modulus at zero twist and the slope indicates the shear. In order to test this model, different p-aramid samples have been twisted at different levels. Using the standard procedure for mechanical testing as described in Test Methods D7269, the moduli have been determined. In Fig. X2.3 the results are presented. As shown in this figure the relations are linear. This confirms the model from Eq X2.1. With the procedure presented, different levels of twist have been used. However, according to the standard procedure only one twist level depending on the linear density must be selected. This twist is defined as (see 9.1. of Test Methods D7269:

[5] Hadley, D. W., Pinnock, P. R., Ward, I. M., *Journal of Materials Science*, Vol 4, Issue 2, 1969, pp 152-165.

[6] Pan, N., Brookstein, D., *Journal of Applied Polymer Sciences*, Vol 83, 2002, pp. 610–630.

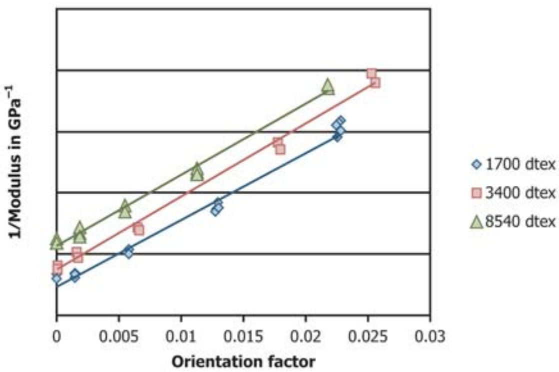

FIG. X2.3 Modulus as a Function of the Orientation Factor. The lines are linear regression lines.

$$T = \frac{1.055}{\sqrt{LD}} \qquad (X2.6)$$

X2.1.1.7 Combining with Eq X2.6, using fill factor f=0.9 and taking ρ=1440 kg/m^3 this results in a constant $\overline{\sin^2(\alpha)}$. Taking g as constant for a specific type of yarn (yarn and finish), the relation between flat and twisted modulus (Eq X2.1) can be simplified to:

$$\frac{1}{M_0} = \frac{1}{M_{\text{twisted, standard}}} - c_{st} \qquad (X2.7)$$

The constant c_{st} can be experimentally derived using:

$$c_{st} = \frac{1}{M_{\text{twisted, standard}}} - \frac{1}{M_0} \qquad (X2.8)$$

X2.2 Force at Specified Elongation (FASE)

X2.2.1 Also, the conversion from twisted to flat yarn is required for FASE03, FASE05, and FASE10 values (force at elongation 0.3 %, 0.5 %, and 1.0 % respectively). Since FASE values are absolute values, the result depends upon the linear density. The use of the values as-such, will result in different correction factors per linear density. In order to make the correction uniform, it is required to convert the FASE to TASE (Tenacity at Specified Elongation) values using Eq X2.9. The conversion from FASE to TASE is given by:

$$TASE = \frac{FASE}{LD} \qquad (X2.9)$$

X2.2.2 Using a procedure similar to the one given for the modulus, FASE (via TASE) of flat yarns have been computed using data from twisted material:

$$\frac{1}{TASE_0} = \frac{1}{TASE_{\text{twisted, standard}}} - c_{st} \qquad (X2.10)$$

where:

$TASE_0$ = TASE of flat yarn, mN/tex, and
$TASE_{\text{twisted, standard}}$ = TASE of standard twisted material, mN/tex.

Combining with Eq X2.10 results in:

$$\frac{1}{FASE_0} = \frac{1}{FASE_{\text{twisted, standard}}} - \frac{c_{st}}{LD} \qquad (X2.11)$$

Note that this equation must be independently applied for every FASE.