INTERNATIONAL

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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.

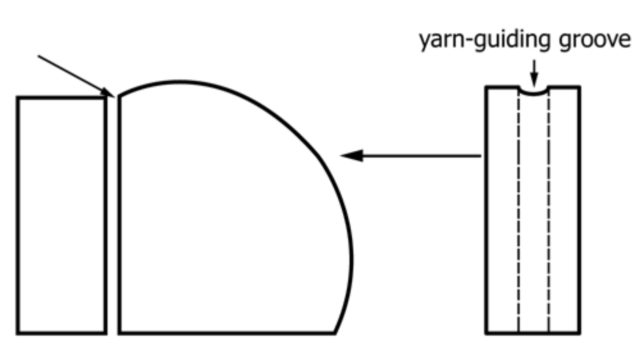


FIG. 1 Example Bollard Type Clamps

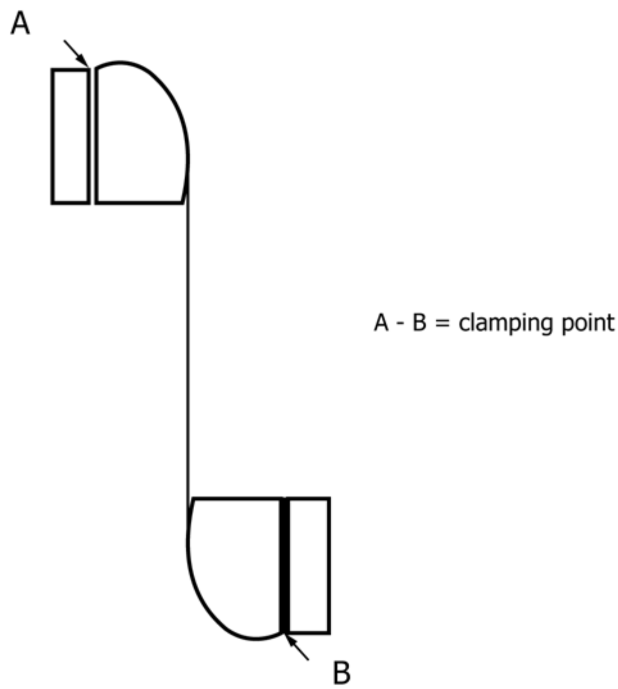


FIG. 2 Gauge Length in Bollard Type Jaws

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 dtex	Twist 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:

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

where:

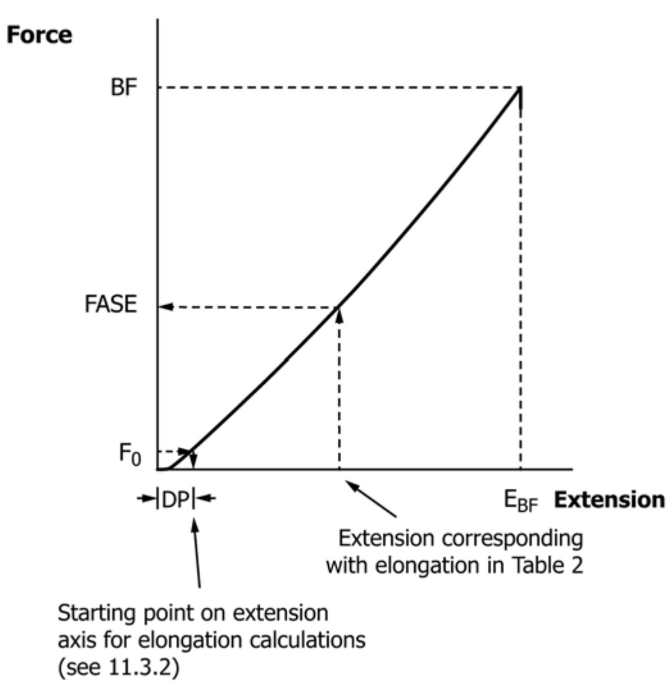
EB = elongation at break, %,
E_{bf} = extension of specimen at the breaking force, mm [in.],
L_s = gauge length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), mm [in.], and
DP = displacement of crosshead to reach the specified pretension of the specimen (see Fig.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

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

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 0.5 1.0	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.

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.

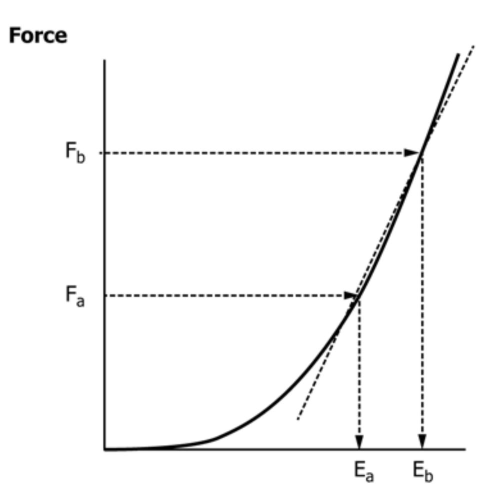
15.1.5.2 *Bias*—See 19.3.

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:

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



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]
Aramid	0.30	[3.5]	0.40	[4.5]

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).

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

$$BT_i = \frac{WB_{si}}{L_0 \cdot LD_d} \quad (15)$$

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 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

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

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

TABLE 5 %CV by Material, Device

Material	Device	N Rows	CV(BF(N))	CV(EB(%))	CV(MOD(CN/Tex))	CV(FASE 0.3%)	CV(FASE 0.5%)	CV(FASE 1.0%)
Kevlar® 1420d	Instron	377	2.1	2.1	4.8	2.5	1.7	1.4
Kevlar® 1420d	Sigma500	200	3	4.1	2	4.3	2.8	2.3
Kevlar® 1420d	Statimat	200	6.3	4.7	2	8.4	7.4	5.2
Kevlar® 1420d	Statimat PT	200	2.7	3.2	3.5	8.3	7.2	4.3
Kevlar® 1420d	Uster	100	1.8	1.8	0.4	1.2	0.9	0.5
Kevlar® 2840d	Instron	386	1.8	2.2	1	2.1	1.5	2.1
Kevlar® 2840d	Sigma500	200	2.3	2.7	1.9	3.6	2.2	1.4
Kevlar® 2840d	Statimat	200	2.7	3.6	2.2	10.1	9.8	6.2
Kevlar® 2840d	Statimat PT	200	2.1	2.5	4	8.3	8.2	4.5
Kevlar® 2840d	Uster	100	2.3	2.3	0.6	1.3	1	0.7
Kevlar® 600d	Instron	400	1.6	1.6	1.9	2.9	1.8	1.6
Kevlar® 600d	Sigma500	200	3.5	4.3	4.5	3.5	3	3.2
Kevlar® 600d	Statimat	200	2.8	2.3	1.6	2.7	1.8	0.9
Kevlar® 600d	Statimat PT	200	1.8	2.2	4	6.4	4.5	3.2
Kevlar® 600d	Uster	100	1.3	1.3	0.6	0.8	0.7	0.6
Nomex® 1600d	Instron	400	1.6	4.6	35.1	2.3	2.2	2.4
Nomex® 1600d	Sigma500	200	2.5	3	8	2.2	1.6	1.3
Nomex® 1600d	Statimat	200	1.3	4.3	5.5	4.5	4.1	3.1
Nomex® 1600d	Statimat PT	200	1.4	5	5.7	22.3	16.1	10
Nomex® 1600d	Uster	100	0.8	3.2	3.7	0.6	0.6	0.7
Nomex® 200d	Instron	400	3.3	8.9	9.4	3	2.4	8.8
Nomex® 200d	Sigma500	200	8.4	5.3	26.1	7.9	9.4	10.8
Nomex® 200d	Statimat	200	2.8	8.8	14.5	20.3	14.3	7.9
Nomex® 200d	Statimat PT	198	4.2	8.6	18.5	19.9	15	9.2
Nomex® 200d	Uster	100	11.6	4.4	84.2	3.8	5.9	8.7
Technora® 1500d	Instron	400	7.9	7.3	0.9	2.2	1.5	2
Technora® 1500d	Sigma500	200	3.1	4.4	1.5	3.8	2.4	1.4
Technora® 1500d	Statimat	300	4.7	13	3.3	14	12.5	12.8
Technora® 1500d	Statimat PT	200	3.3	5	2.4	8.1	6.2	4
Technora® 1500d	Uster	100	1.7	1.5	0.6	1	0.8	0.6
Twaron® 1550d	Instron	400	1.3	1.5	1	3.1	1.8	1.7
Twaron® 1550d	Sigma500	200	1.4	2.4	1.9	3.2	1.7	1.1
Twaron® 1550d	Statimat	300	9.5	27.5	93.5	10.5	12.4	14.7
Twaron® 1550d	Statimat PT	200	2.2	2.9	7.9	12.6	9.6	6.1
Twaron® 1550d	Uster	100	1.7	1.8	0.5	1.4	1	0.7
Twaron® 3100d	Instron	400	1.9	2.3	1.3	4.6	3.9	2.8
Twaron® 3100d	Sigma500	200	2.7	2.3	1.3	8.5	6.2	3.5
Twaron® 3100d	Statimat	300	3.3	4	3.9	10.2	12.1	7.5
Twaron® 3100d	Statimat PT	199	2.1	3.6	3	7.3	7.9	4.1
Twaron® 3100d	Uster	100	2.2	1.7	1	4.1	3.4	2.3
Twaron® 500d	Instron	395	1.5	1.6	1.7	4.3	2.8	2.2
Twaron® 500d	Sigma500	200	3.1	5.1	48.3	8.7	4.3	1.4
Twaron® 500d	Statimat	300	11.7	10.6	106.7	3.7	2.5	1
Twaron® 500d	Statimat PT	200	1.9	2.3	3.4	6.8	4.4	3.1
Twaron® 500d	Uster	100	1.1	0.8	0.9	1.3	1	0.7

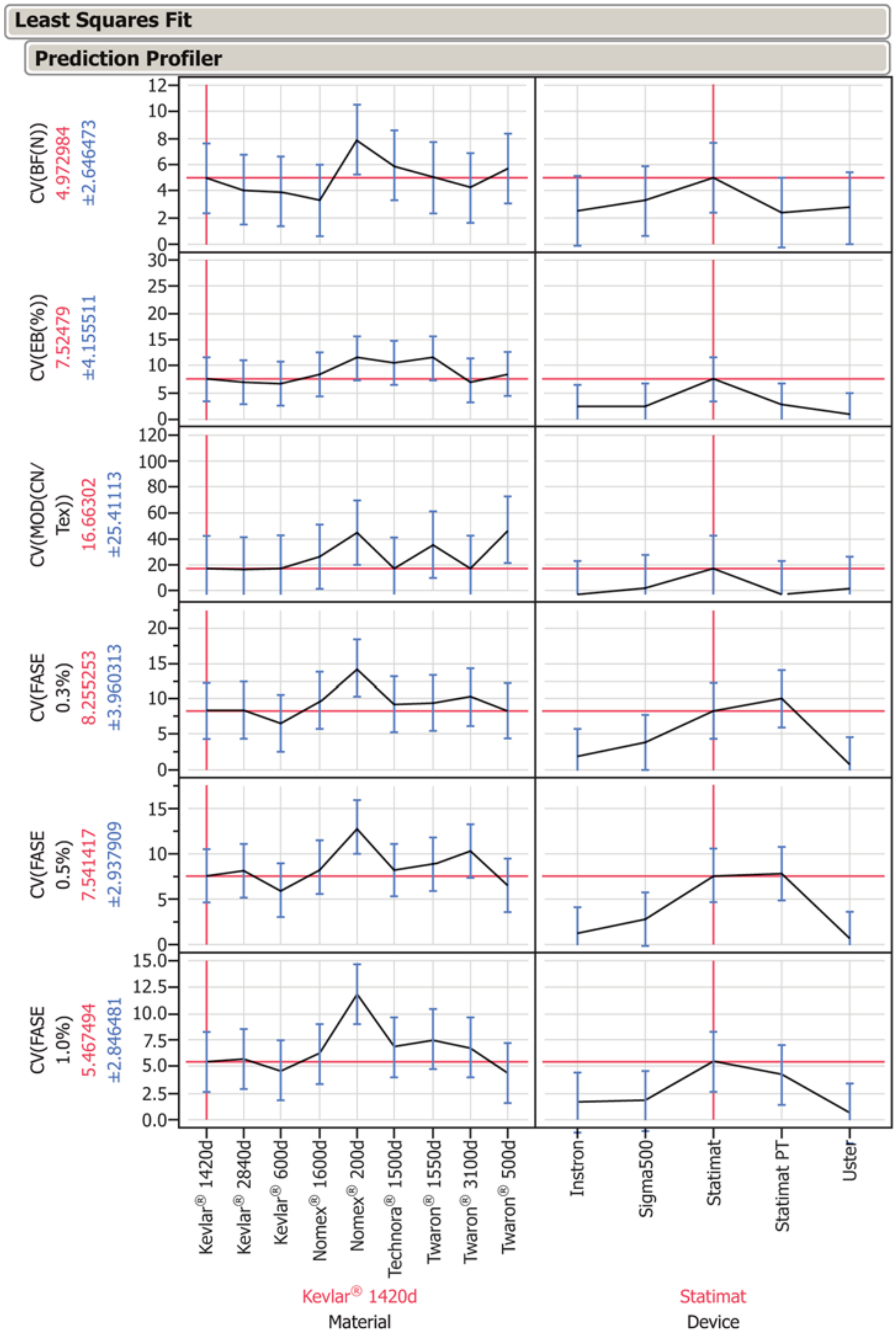


FIG. 5 % CV by Material and Device

TABLE 6 Precision of the Test Method

NOTE 1—
S_r = repeatability standard deviation (pooled within-laboratory standard deviation)
r = repeatability = 2.80 S_r
S_R = reproducibility standard deviation (total standard deviation)
R = reproducibilty = 2.80 S_R

NOTE 2—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.

Break Strength (N)

Material	Device	Var(Lab)	Var(Res)	Tot Var	Var% Lab	Var% Res	s(repeat)	s(Repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	1.47	47.80	49.27	3.0	97.0	6.91	7.02	19.36	19.65
Kevlar® 1420d	Sigma500	0.00	94.44	94.44	0.0	100.0	9.72	9.72	27.21	27.21
Kevlar® 1420d	Statimat	281.62	241.17	522.79	53.9	46.1	15.53	22.86	43.48	64.02
Kevlar® 1420d	Statimat PT	4.40	81.07	85.47	5.1	94.9	9.00	9.24	25.21	25.89
Kevlar® 1420d	Uster	0.00	33.74	33.74	0.0	100.0	5.81	5.81	16.26	16.26
Kevlar® 2840d	Instron	3.34	124.64	127.98	2.6	97.4	11.16	11.31	31.26	31.68
Kevlar® 2840d	Sigma500	0.00	189.38	189.38	0.0	100.0	13.76	13.76	38.53	38.53
Kevlar® 2840d	Statimat	94.24	207.93	302.17	31.2	68.8	14.42	17.38	40.38	48.67
Kevlar® 2840d	Statimat PT	81.56	124.89	206.45	39.5	60.5	11.18	14.37	31.29	40.23
Kevlar® 2840d	Uster	0.00	191.67	191.67	0.0	100.0	13.84	13.84	38.76	38.76
Kevlar® 600d	Instron	0.15	6.59	6.75	2.3	97.7	2.57	2.60	7.19	7.27
Kevlar® 600d	Sigma500	2.94	30.28	33.22	8.9	91.1	5.50	5.76	15.41	16.14
Kevlar® 600d	Statimat	21.81	9.08	30.89	70.6	29.4	3.01	5.56	8.44	15.56
Kevlar® 600d	Statimat PT	1.47	7.88	9.35	15.8	84.2	2.81	3.06	7.86	8.56
Kevlar® 600d	Uster	0.00	4.41	4.41	0.0	100.0	2.10	2.10	5.88	5.88
Nomex® 1600d	Instron	0.27	1.30	1.57	17.1	82.9	1.14	1.25	3.19	3.51
Nomex® 1600d	Sigma500	6.25	0.25	6.50	96.1	3.9	0.50	2.55	1.41	7.14
Nomex® 1600d	Statimat	0.93	0.41	1.34	69.7	30.3	0.64	1.16	1.79	3.24
Nomex® 1600d	Statimat PT	1.20	0.43	1.62	73.8	26.2	0.65	1.27	1.83	3.57
Nomex® 1600d	Uster	0.00	0.37	0.37	0.0	100.0	0.61	0.61	1.71	1.71
Nomex® 200d	Instron	0.02	0.09	0.11	18.9	81.1	0.30	0.34	0.85	0.94
Nomex® 200d	Sigma500	1.21	0.07	1.28	94.6	5.4	0.26	1.13	0.74	3.17
Nomex® 200d	Statimat	0.05	0.06	0.11	46.7	53.3	0.24	0.33	0.68	0.93
Nomex® 200d	Statimat PT	0.17	0.10	0.28	62.7	37.3	0.32	0.52	0.90	1.47
Nomex® 200d	Uster	0.00	1.32	1.32	0.0	100.0	1.15	1.15	3.22	3.22
Technora® 1500d	Instron	1102.36	66.49	1168.86	94.3	5.7	8.15	34.19	22.83	95.73
Technora® 1500d	Sigma500	39.86	116.60	156.46	25.5	74.5	10.80	12.51	30.23	35.02
Technora® 1500d	Statimat	130.73	159.11	289.84	45.1	54.9	12.61	17.02	35.32	47.67
Technora® 1500d	Statimat PT	224.94	64.62	289.56	77.7	22.3	8.04	17.02	22.51	47.65
Technora® 1500d	Uster	0.00	42.38	42.38	0.0	100.0	6.51	6.51	18.23	18.23
Twaron® 1550d	Instron	5.75	19.87	25.62	22.4	77.6	4.46	5.06	12.48	14.17
Twaron® 1550d	Sigma500	10.22	20.73	30.95	33.0	67.0	4.55	5.56	12.75	15.58
Twaron® 1550d	Statimat	1299.21	221.64	1520.85	85.4	14.6	14.89	39.00	41.69	109.19
Twaron® 1550d	Statimat PT	25.85	50.74	76.59	33.8	66.2	7.12	8.75	19.95	24.50
Twaron® 1550d	Uster	0.00	38.55	38.55	0.0	100.0	6.21	6.21	17.39	17.39
Twaron® 3100d	Instron	3.83	212.51	216.34	1.8	98.2	14.58	14.71	40.82	41.18
Twaron® 3100d	Sigma500	18.40	391.96	410.36	4.5	95.5	19.80	20.26	55.43	56.72
Twaron® 3100d	Statimat	271.98	326.01	597.99	45.5	54.5	18.06	24.45	50.56	68.47
Twaron® 3100d	Statimat PT	0.00	259.10	259.10	0.0	100.0	16.10	16.10	45.07	45.07
Twaron® 3100d	Uster	0.00	263.47	263.47	0.0	100.0	16.23	16.23	45.45	45.45
Twaron® 500d	Instron	0.00	4.11	4.11	0.0	100.0	2.03	2.03	5.67	5.67
Twaron® 500d	Sigma500	7.34	12.66	20.00	36.7	63.3	3.56	4.47	9.96	12.52
Twaron® 500d	Statimat	209.26	36.95	246.21	85.0	15.0	6.08	15.69	17.02	43.93
Twaron® 500d	Statimat PT	0.43	6.23	6.66	6.4	93.6	2.50	2.58	6.99	7.22
Twaron® 500d	Uster	0.00	2.20	2.20	0.0	100.0	1.48	1.48	4.15	4.15

TABLE 6 *Continued*

Elongation at Break (%)

Material	Device	Var(Lab)	Var(Res)	Tot Var	Var% Lab	Var% Res	s(repeat)	s(Repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	0.0004	0.0026	0.0030	14.7	85.3	0.051	0.055	0.141	0.153
Kevlar® 1420d	Sigma500	0.0091	0.0068	0.0158	57.2	42.8	0.082	0.126	0.230	0.352
Kevlar® 1420d	Statimat	0.0010	0.0126	0.0137	7.7	92.3	0.112	0.117	0.315	0.327
Kevlar® 1420d	Statimat PT	0.0055	0.0043	0.0098	56.3	43.7	0.065	0.099	0.183	0.277
Kevlar® 1420d	Uster	0.0000	0.0020	0.0020	0.0	100.0	0.045	0.045	0.126	0.126
Kevlar® 2840d	Instron	0.0010	0.0022	0.0032	31.0	69.0	0.047	0.057	0.132	0.159
Kevlar® 2840d	Sigma500	0.0021	0.0037	0.0058	35.8	64.2	0.061	0.076	0.171	0.214
Kevlar® 2840d	Statimat	0.0106	0.0034	0.0140	75.9	24.1	0.058	0.118	0.162	0.331
Kevlar® 2840d	Statimat PT	0.0041	0.0023	0.0063	64.2	35.8	0.048	0.080	0.133	0.223
Kevlar® 2840d	Uster	0.0000	0.0032	0.0032	0.0	100.0	0.057	0.057	0.159	0.159
Kevlar® 600d	Instron	0.0001	0.0038	0.0039	2.2	97.8	0.062	0.062	0.173	0.175
Kevlar® 600d	Sigma500	0.0286	0.0161	0.0447	64.0	36.0	0.127	0.211	0.355	0.592
Kevlar® 600d	Statimat	0.0056	0.0051	0.0108	52.4	47.6	0.072	0.104	0.201	0.291
Kevlar® 600d	Statimat PT	0.0070	0.0041	0.0111	63.2	36.8	0.064	0.105	0.179	0.295
Kevlar® 600d	Uster	0.0000	0.0026	0.0026	0.0	100.0	0.051	0.051	0.143	0.143
Nomex® 1600d	Instron	0.4821	1.2726	1.7548	27.5	72.5	1.128	1.325	3.159	3.709
Nomex® 1600d	Sigma500	0.2913	0.5110	0.8023	36.3	63.7	0.715	0.896	2.002	2.508
Nomex® 1600d	Statimat	0.2663	0.8855	1.1518	23.1	76.9	0.941	1.073	2.635	3.005
Nomex® 1600d	Statimat PT	1.0489	0.8167	1.8656	56.2	43.8	0.904	1.366	2.530	3.824
Nomex® 1600d	Uster	0.0000	0.9469	0.9469	0.0	100.0	0.973	0.973	2.725	2.725
Nomex® 200d	Instron	2.5929	3.1473	5.7402	45.2	54.8	1.774	2.396	4.967	6.708
Nomex® 200d	Sigma500	0.0000	1.9680	1.9680	0.0	100.0	1.403	1.403	3.928	3.928
Nomex® 200d	Statimat	4.2611	0.8483	5.1094	83.4	16.6	0.921	2.260	2.579	6.329
Nomex® 200d	Statimat PT	2.6343	1.5248	4.1591	63.3	36.7	1.235	2.039	3.458	5.710
Nomex® 200d	Uster	0.0000	1.5532	1.5532	0.0	100.0	1.246	1.246	3.490	3.490
Technora® 1500d	Instron	0.1108	0.0059	0.1168	94.9	5.1	0.077	0.342	0.215	0.957
Technora® 1500d	Sigma500	0.0454	0.0133	0.0587	77.4	22.6	0.115	0.242	0.323	0.679
Technora® 1500d	Statimat	0.2684	0.0121	0.2805	95.7	4.3	0.110	0.530	0.308	1.483
Technora® 1500d	Statimat PT	0.0827	0.0063	0.0890	92.9	7.1	0.079	0.298	0.223	0.835
Technora® 1500d	Uster	0.0000	0.0042	0.0042	0.0	100.0	0.065	0.065	0.181	0.181
Twaron® 1550d	Instron	0.0003	0.0015	0.0018	17.7	82.3	0.039	0.043	0.109	0.120
Twaron® 1550d	Sigma500	0.0069	0.0017	0.0086	79.9	20.1	0.042	0.093	0.117	0.260
Twaron® 1550d	Statimat	1.0988	0.0145	1.1133	98.7	1.3	0.120	1.055	0.337	2.954
Twaron® 1550d	Statimat PT	0.0080	0.0031	0.0110	72.2	27.8	0.055	0.105	0.155	0.294
Twaron® 1550d	Uster	0.0000	0.0026	0.0026	0.0	100.0	0.051	0.051	0.141	0.141
Twaron® 3100d	Instron	0.0051	0.0046	0.0096	52.6	47.4	0.068	0.098	0.189	0.275
Twaron® 3100d	Sigma500	0.0021	0.0079	0.0101	21.0	79.0	0.089	0.100	0.250	0.281
Twaron® 3100d	Statimat	0.0216	0.0093	0.0308	69.9	30.1	0.096	0.176	0.270	0.492
Twaron® 3100d	Statimat PT	0.0330	0.0053	0.0382	86.2	13.8	0.072	0.195	0.203	0.547
Twaron® 3100d	Uster	0.0000	0.0041	0.0041	0.0	100.0	0.064	0.064	0.180	0.180
Twaron® 500d	Instron	0.0004	0.0026	0.0029	12.7	87.3	0.051	0.054	0.141	0.151
Twaron® 500d	Sigma500	0.0029	0.0290	0.0320	9.2	90.8	0.170	0.179	0.477	0.501
Twaron® 500d	Statimat	0.1184	0.0197	0.1381	85.7	14.3	0.140	0.372	0.393	1.040
Twaron® 500d	Statimat PT	0.0049	0.0033	0.0082	60.0	40.0	0.057	0.091	0.161	0.254
Twaron® 500d	Uster	0.0000	0.0008	0.0008	0.0	100.0	0.028	0.028	0.079	0.079

TABLE 6 *Continued*

Modulus (CN/tex)

Material	Device	Var(Lab)	Var(Res)	Tot Var	Var% Lab	Var% Res	s(repeat)	s(Repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	208628.1	4020.3	212648.4	98.1	1.9	63.41	461.14	177.54	1291.19
Kevlar® 1420d	Sigma500	38316.6	5212.3	43528.9	88.0	12.0	72.20	208.64	202.15	584.18
Kevlar® 1420d	Statimat	2630.5	24199.0	26829.4	9.8	90.2	155.56	163.80	435.57	458.63
Kevlar® 1420d	Statimat PT	87516.4	31464.8	118981.2	73.6	26.4	177.38	344.94	496.67	965.82
Kevlar® 1420d	Uster	0.0	1202.8	1202.8	0.0	100.0	34.68	34.68	97.11	97.11
Kevlar® 2840d	Instron	1572.6	4368.5	5941.1	26.5	73.5	66.09	77.08	185.06	215.82
Kevlar® 2840d	Sigma500	26525.2	5307.1	31832.3	83.3	16.7	72.85	178.42	203.98	499.57
Kevlar® 2840d	Statimat	27711.6	8132.4	35844.0	77.3	22.7	90.18	189.33	252.50	530.11
Kevlar® 2840d	Statimat PT	122010.2	6038.7	128048.9	95.3	4.7	77.71	357.84	217.59	1001.95
Kevlar® 2840d	Uster	0.0	2183.7	2183.7	0.0	100.0	46.73	46.73	130.84	130.84
Kevlar® 600d	Instron	7955.2	4866.1	12821.3	62.0	38.0	69.76	113.23	195.32	317.05
Kevlar® 600d	Sigma500	126246.6	1978.0	128224.6	98.5	1.5	44.47	358.08	124.53	1002.64
Kevlar® 600d	Statimat	1207.8	6985.9	8193.7	14.7	85.3	83.58	90.52	234.03	253.45
Kevlar® 600d	Statimat PT	89845.9	6198.2	96044.0	93.5	6.5	78.73	309.91	220.44	867.75
Kevlar® 600d	Uster	0.0	955.8	955.8	0.0	100.0	30.92	30.92	86.56	86.56
Nomex® 1600d	Instron	1416.5	6.6	1423.1	99.5	0.5	2.57	37.72	7.21	105.63
Nomex® 1600d	Sigma500	67.3	3.6	70.9	95.0	5.0	1.89	8.42	5.29	23.57
Nomex® 1600d	Statimat	11.8	16.1	27.9	42.3	57.7	4.01	5.28	11.24	14.80
Nomex® 1600d	Statimat PT	24.3	12.8	37.2	65.5	34.5	3.58	6.10	10.03	17.07
Nomex® 1600d	Uster	0.0	5.8	5.8	0.0	100.0	2.40	2.40	6.72	6.72
Nomex® 200d	Instron	55.1	50.0	105.1	52.4	47.6	7.07	10.25	19.80	28.71
Nomex® 200d	Sigma500	1163.2	51.4	1214.7	95.8	4.2	7.17	34.85	20.08	97.59
Nomex® 200d	Statimat	228.6	312.2	540.8	42.3	57.7	17.67	23.25	49.47	65.11
Nomex® 200d	Statimat PT	655.3	413.0	1068.3	61.3	38.7	20.32	32.69	56.91	91.52
Nomex® 200d	Uster	0.0	6942.3	6942.3	0.0	100.0	83.32	83.32	233.30	233.30
Technora® 1500d	Instron	604.3	2174.0	2778.2	21.7	78.3	46.63	52.71	130.55	147.58
Technora® 1500d	Sigma500	7854.0	2629.7	10483.7	74.9	25.1	51.28	102.39	143.59	286.69
Technora® 1500d	Statimat	38443.9	5363.4	43807.3	87.8	12.2	73.24	209.30	205.06	586.05
Technora® 1500d	Statimat PT	21512.5	5295.9	26808.4	80.2	19.8	72.77	163.73	203.76	458.45
Technora® 1500d	Uster	0.0	926.5	926.5	0.0	100.0	30.44	30.44	85.23	85.23
Twaron® 1550d	Instron	5221.4	1693.6	6915.0	75.5	24.5	41.15	83.16	115.23	232.84
Twaron® 1550d	Sigma500	30539.5	3251.3	33790.8	90.4	9.6	57.02	183.82	159.66	514.70
Twaron® 1550d	Statimat	497327249.0	77784.7	497405033.7	100.0	0.0	278.90	22302.58	780.92	62447.22
Twaron® 1550d	Statimat PT	558254.6	5997.9	564252.6	98.9	1.1	77.45	751.17	216.85	2103.27
Twaron® 1550d	Uster	0.0	1231.7	1231.7	0.0	100.0	35.10	35.10	98.27	98.27
Twaron® 3100d	Instron	1351.6	2862.7	4214.3	32.1	67.9	53.50	64.92	149.81	181.77
Twaron® 3100d	Sigma500	724.6	3224.8	3949.4	18.3	81.7	56.79	62.84	159.01	175.96
Twaron® 3100d	Statimat	41573.8	3796.6	45370.4	91.6	8.4	61.62	213.00	172.53	596.41
Twaron® 3100d	Statimat PT	32715.1	2715.1	35430.1	92.3	7.7	52.11	188.23	145.90	527.04
Twaron® 3100d	Uster	0.0	2316.2	2316.2	0.0	100.0	48.13	48.13	134.75	134.75
Twaron® 500d	Instron	6794.2	6111.9	12906.2	52.6	47.4	78.18	113.61	218.90	318.09
Twaron® 500d	Sigma500	9157333.8	1945.4	9159279.2	100.0	0.0	44.11	3026.43	123.50	8474.00
Twaron® 500d	Statimat	1122000000.0	1444581.2	1123444581.2	99.9	0.1	1201.91	33517.82	3365.34	93849.91
Twaron® 500d	Statimat PT	69446.7	13884.8	83331.5	83.3	16.7	117.83	288.67	329.94	808.28
Twaron® 500d	Uster	0.0	3043.8	3043.8	0.0	100.0	55.17	55.17	154.48	154.48

TABLE 6 *Continued*

FASE @ 0.3% (N)

Material	Device	Var(Lab)	Var(Res)	Tot Var	Var% Lab	Var% Res	s(repeat)	s(Repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	0.34	0.54	0.88	38.2	61.8	0.74	0.94	2.06	2.62
Kevlar® 1420d	Sigma500	0.58	0.70	1.28	45.5	54.5	0.83	1.13	2.34	3.17
Kevlar® 1420d	Statimat	11.14	0.45	11.59	96.1	3.9	0.67	3.40	1.87	9.53
Kevlar® 1420d	Statimat PT	12.25	0.63	12.87	95.1	4.9	0.79	3.59	2.22	10.05
Kevlar® 1420d	Uster	0.00	0.14	0.14	0.0	100.0	0.37	0.37	1.04	1.04
Kevlar® 2840d	Instron	0.15	1.54	1.69	9.0	91.0	1.24	1.30	3.47	3.64
Kevlar® 2840d	Sigma500	1.07	1.76	2.83	37.9	62.1	1.33	1.68	3.71	4.71
Kevlar® 2840d	Statimat	50.20	0.88	51.08	98.3	1.7	0.94	7.15	2.63	20.01
Kevlar® 2840d	Statimat PT	34.49	0.65	35.14	98.2	1.8	0.81	5.93	2.26	16.60
Kevlar® 2840d	Uster	0.00	0.54	0.54	0.0	100.0	0.74	0.74	2.06	2.06
Kevlar® 600d	Instron	0.16	0.05	0.21	76.0	24.0	0.22	0.46	0.63	1.28
Kevlar® 600d	Sigma500	0.06	0.09	0.15	41.7	58.3	0.30	0.39	0.83	1.08
Kevlar® 600d	Statimat	0.07	0.06	0.13	53.6	46.4	0.25	0.36	0.69	1.02
Kevlar® 600d	Statimat PT	0.97	0.08	1.05	92.6	7.4	0.28	1.02	0.78	2.87
Kevlar® 600d	Uster	0.00	0.01	0.01	0.0	100.0	0.09	0.09	0.26	0.26
Nomex® 1600d	Instron	0.05	0.02	0.06	74.9	25.1	0.13	0.25	0.35	0.70
Nomex® 1600d	Sigma500	0.00	0.01	0.01	18.5	81.5	0.11	0.12	0.30	0.33
Nomex® 1600d	Statimat	0.06	0.13	0.19	31.6	68.4	0.36	0.44	1.01	1.22
Nomex® 1600d	Statimat PT	5.47	0.19	5.65	96.7	3.3	0.43	2.38	1.21	6.66
Nomex® 1600d	Uster	0.00	0.00	0.00	0.0	100.0	0.05	0.05	0.14	0.14
Nomex® 200d	Instron	0.00	0.00	0.00	59.7	40.3	0.03	0.04	0.08	0.12
Nomex® 200d	Sigma500	0.01	0.00	0.01	88.1	11.9	0.03	0.08	0.08	0.22
Nomex® 200d	Statimat	0.01	0.06	0.08	16.4	83.6	0.25	0.28	0.71	0.78
Nomex® 200d	Statimat PT	0.00	0.07	0.07	1.8	98.2	0.26	0.26	0.73	0.74
Nomex® 200d	Uster	0.00	0.00	0.00	0.0	100.0	0.04	0.04	0.12	0.12
Technora® 1500d	Instron	0.19	0.26	0.45	42.5	57.5	0.51	0.67	1.42	1.88
Technora® 1500d	Sigma500	0.14	0.43	0.57	24.9	75.1	0.65	0.75	1.83	2.11
Technora® 1500d	Statimat	20.90	0.58	21.49	97.3	2.7	0.76	4.64	2.14	12.98
Technora® 1500d	Statimat PT	7.43	0.99	8.42	88.2	11.8	1.00	2.90	2.79	8.13
Technora® 1500d	Uster	0.00	0.07	0.07	0.0	100.0	0.27	0.27	0.76	0.76
Twaron® 1550d	Instron	1.13	0.55	1.68	67.5	32.5	0.74	1.30	2.07	3.63
Twaron® 1550d	Sigma500	0.57	0.28	0.86	66.9	33.1	0.53	0.93	1.49	2.59
Twaron® 1550d	Statimat	12.84	0.85	13.69	93.8	6.2	0.92	3.70	2.59	10.36
Twaron® 1550d	Statimat PT	35.72	0.40	36.12	98.9	1.1	0.63	6.01	1.77	16.83
Twaron® 1550d	Uster	0.00	0.19	0.19	0.0	100.0	0.43	0.43	1.22	1.22
Twaron® 3100d	Instron	0.91	3.54	4.45	20.4	79.6	1.88	2.11	5.27	5.91
Twaron® 3100d	Sigma500	0.87	5.82	6.69	13.0	87.0	2.41	2.59	6.76	7.24
Twaron® 3100d	Statimat	20.92	2.49	23.40	89.4	10.6	1.58	4.84	4.42	13.55
Twaron® 3100d	Statimat PT	13.63	2.66	16.29	83.7	16.3	1.63	4.04	4.56	11.30
Twaron® 3100d	Uster	0.00	3.38	3.38	0.0	100.0	1.84	1.84	5.15	5.15
Twaron® 500d	Instron	0.22	0.11	0.33	66.2	33.8	0.33	0.57	0.93	1.60
Twaron® 500d	Sigma500	0.92	0.11	1.02	89.6	10.4	0.33	1.01	0.91	2.83
Twaron® 500d	Statimat	0.16	0.05	0.21	76.0	24.0	0.23	0.46	0.63	1.29
Twaron® 500d	Statimat PT	0.70	0.21	0.91	77.0	23.0	0.46	0.95	1.28	2.67
Twaron® 500d	Uster	0.00	0.02	0.02	0.0	100.0	0.13	0.13	0.38	0.38

TABLE 6 *Continued*

FASE @ 0.5% (N)

Material	Device	Var(Lab)	Var(Res)	Tot Var	Var% Lab	Var% Res	s(repeat)	s(repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	0.123	0.911	1.035	11.9	88.1	0.95	1.02	2.67	2.85
Kevlar® 1420d	Sigma500	1.488	1.072	2.560	58.1	41.9	1.04	1.60	2.90	4.48
Kevlar® 1420d	Statimat	29.429	0.718	30.147	97.6	2.4	0.85	5.49	2.37	15.37
Kevlar® 1420d	Statimat PT	29.943	0.900	30.843	97.1	2.9	0.95	5.55	2.66	15.55
Kevlar® 1420d	Uster	0.000	0.247	0.247	0.0	100.0	0.50	0.50	1.39	1.39
Kevlar® 2840d	Instron	0.000	2.722	2.722	0.0	100.0	1.65	1.65	4.62	4.62
Kevlar® 2840d	Sigma500	0.228	3.389	3.617	6.3	93.7	1.84	1.90	5.15	5.33
Kevlar® 2840d	Statimat	148.513	1.732	150.245	98.8	1.2	1.32	12.26	3.68	34.32
Kevlar® 2840d	Statimat PT	106.793	1.494	108.287	98.6	1.4	1.22	10.41	3.42	29.14
Kevlar® 2840d	Uster	0.000	1.117	1.117	0.0	100.0	1.06	1.06	2.96	2.96
Kevlar® 600d	Instron	0.141	0.051	0.192	73.6	26.4	0.23	0.44	0.63	1.23
Kevlar® 600d	Sigma500	0.305	0.131	0.435	69.9	30.1	0.36	0.66	1.01	1.85
Kevlar® 600d	Statimat	0.087	0.073	0.160	54.3	45.7	0.27	0.40	0.76	1.12
Kevlar® 600d	Statimat PT	1.412	0.084	1.497	94.4	5.6	0.29	1.22	0.81	3.43
Kevlar® 600d	Uster	0.000	0.018	0.018	0.0	100.0	0.13	0.13	0.37	0.37
Nomex® 1600d	Instron	0.072	0.032	0.104	69.2	30.8	0.18	0.32	0.50	0.90
Nomex® 1600d	Sigma500	0.001	0.019	0.019	4.2	95.8	0.14	0.14	0.38	0.39
Nomex® 1600d	Statimat	0.159	0.189	0.348	45.6	54.4	0.43	0.59	1.22	1.65
Nomex® 1600d	Statimat PT	6.421	0.181	6.602	97.3	2.7	0.43	2.57	1.19	7.19
Nomex® 1600d	Uster	0.000	0.006	0.006	0.0	100.0	0.08	0.08	0.21	0.21
Nomex® 200d	Instron	0.001	0.001	0.002	43.7	56.3	0.03	0.05	0.09	0.13
Nomex® 200d	Sigma500	0.023	0.002	0.025	93.5	6.5	0.04	0.16	0.11	0.44
Nomex® 200d	Statimat	0.009	0.067	0.075	11.5	88.5	0.26	0.27	0.72	0.77
Nomex® 200d	Statimat PT	0.000	0.080	0.080	0.0	100.0	0.28	0.28	0.79	0.79
Nomex® 200d	Uster	0.000	0.009	0.009	0.0	100.0	0.10	0.10	0.27	0.27
Technora® 1500d	Instron	0.153	0.423	0.577	26.6	73.4	0.65	0.76	1.82	2.13
Technora® 1500d	Sigma500	0.000	0.788	0.788	0.0	100.0	0.89	0.89	2.49	2.49
Technora® 1500d	Statimat	49.088	0.988	50.076	98.0	2.0	0.99	7.08	2.78	19.81
Technora® 1500d	Statimat PT	12.932	1.189	14.121	91.6	8.4	1.09	3.76	3.05	10.52
Technora® 1500d	Uster	0.000	0.132	0.132	0.0	100.0	0.36	0.36	1.02	1.02
Twaron® 1550d	Instron	0.782	0.814	1.596	49.0	51.0	0.90	1.26	2.53	3.54
Twaron® 1550d	Sigma500	0.251	0.516	0.767	32.7	67.3	0.72	0.88	2.01	2.45
Twaron® 1550d	Statimat	57.481	0.962	58.444	98.4	1.6	0.98	7.64	2.75	21.41
Twaron® 1550d	Statimat PT	59.639	0.582	60.221	99.0	1.0	0.76	7.76	2.14	21.73
Twaron® 1550d	Uster	0.000	0.325	0.325	0.0	100.0	0.57	0.57	1.60	1.60
Twaron® 3100d	Instron	2.500	7.625	10.125	24.7	75.3	2.76	3.18	7.73	8.91
Twaron® 3100d	Sigma500	0.991	13.388	14.379	6.9	93.1	3.66	3.79	10.25	10.62
Twaron® 3100d	Statimat	88.682	4.766	93.448	94.9	5.1	2.18	9.67	6.11	27.07
Twaron® 3100d	Statimat PT	51.061	5.201	56.261	90.8	9.2	2.28	7.50	6.39	21.00
Twaron® 3100d	Uster	0.000	6.902	6.902	0.0	100.0	2.63	2.63	7.36	7.36
Twaron® 500d	Instron	0.220	0.142	0.362	60.8	39.2	0.38	0.60	1.05	1.68
Twaron® 500d	Sigma500	0.631	0.143	0.773	81.6	18.4	0.38	0.88	1.06	2.46
Twaron® 500d	Statimat	0.209	0.066	0.275	75.9	24.1	0.26	0.52	0.72	1.47
Twaron® 500d	Statimat PT	0.842	0.227	1.069	78.8	21.2	0.48	1.03	1.33	2.90
Twaron® 500d	Uster	0.000	0.032	0.032	0.0	100.0	0.18	0.18	0.50	0.50

TABLE 6 *Continued*

FASE @ 1.0% (N)

Material	Device	Var(Lab)	Var(Res)	TotVar	Var% Lab	Var% Res	s(repeat)	s(Repro)	Repeatability	Reproducibility
Kevlar® 1420d	Instron	0.949	2.284	3.232	29.3	70.7	1.51	1.80	4.23	5.03
Kevlar® 1420d	Sigma500	9.499	1.613	11.112	85.5	14.5	1.27	3.33	3.56	9.33
Kevlar® 1420d	Statimat	68.800	1.130	69.930	98.4	1.6	1.06	8.36	2.98	23.41
Kevlar® 1420d	Statimat PT	47.398	1.537	48.935	96.9	3.1	1.24	7.00	3.47	19.59
Kevlar® 1420d	Uster	0.000	0.402	0.402	0.0	100.0	0.63	0.63	1.77	1.77
Kevlar® 2840d	Instron	15.986	10.300	26.286	60.8	39.2	3.21	5.13	8.99	14.36
Kevlar® 2840d	Sigma500	3.415	6.412	9.828	34.8	65.2	2.53	3.13	7.09	8.78
Kevlar® 2840d	Statimat	292.739	3.724	296.463	98.7	1.3	1.93	17.22	5.40	48.21
Kevlar® 2840d	Statimat PT	154.427	3.963	158.390	97.5	2.5	1.99	12.59	5.57	35.24
Kevlar® 2840d	Uster	0.000	2.563	2.563	0.0	100.0	1.60	1.60	4.48	4.48
Kevlar® 600d	Instron	0.309	0.118	0.427	72.4	27.6	0.34	0.65	0.96	1.83
Kevlar® 600d	Sigma500	2.429	0.187	2.616	92.9	7.1	0.43	1.62	1.21	4.53
Kevlar® 600d	Statimat	0.006	0.106	0.112	5.8	94.2	0.33	0.34	0.91	0.94
Kevlar® 600d	Statimat PT	2.808	0.105	2.913	96.4	3.6	0.32	1.71	0.91	4.78
Kevlar® 600d	Uster	0.000	0.040	0.040	0.0	100.0	0.20	0.20	0.56	0.56
Nomex® 1600d	Instron	0.171	0.106	0.277	61.9	38.1	0.32	0.53	0.91	1.47
Nomex® 1600d	Sigma500	0.034	0.034	0.068	49.8	50.2	0.18	0.26	0.52	0.73
Nomex® 1600d	Statimat	0.368	0.251	0.620	59.4	40.6	0.50	0.79	1.40	2.20
Nomex® 1600d	Statimat PT	7.764	0.269	8.032	96.7	3.3	0.52	2.83	1.45	7.94
Nomex® 1600d	Uster	0.000	0.020	0.020	0.0	100.0	0.14	0.14	0.40	0.40
Nomex® 200d	Instron	0.017	0.043	0.060	28.4	71.6	0.21	0.24	0.58	0.68
Nomex® 200d	Sigma500	0.116	0.004	0.120	96.5	3.5	0.06	0.35	0.18	0.97
Nomex® 200d	Statimat	0.000	0.061	0.061	0.0	100.0	0.25	0.25	0.69	0.69
Nomex® 200d	Statimat PT	0.007	0.079	0.086	7.7	92.3	0.28	0.29	0.79	0.82
Nomex® 200d	Uster	0.000	0.055	0.055	0.0	100.0	0.24	0.24	0.66	0.66
Technora® 1500d	Instron	2.980	1.037	4.017	74.2	25.8	1.02	2.00	2.85	5.61
Technora® 1500d	Sigma500	0.504	1.130	1.634	30.9	69.1	1.06	1.28	2.98	3.58
Technora® 1500d	Statimat	215.044	1.774	216.818	99.2	0.8	1.33	14.72	3.73	41.23
Technora® 1500d	Statimat PT	21.071	1.563	22.634	93.1	6.9	1.25	4.76	3.50	13.32
Technora® 1500d	Uster	0.000	0.236	0.236	0.0	100.0	0.49	0.49	1.36	1.36
Twaron® 1550d	Instron	2.998	2.100	5.097	58.8	41.2	1.45	2.26	4.06	6.32
Twaron® 1550d	Sigma500	1.138	0.918	2.056	55.3	44.7	0.96	1.43	2.68	4.02
Twaron® 1550d	Statimat	352.450	1.535	353.984	99.6	0.4	1.24	18.81	3.47	52.68
Twaron® 1550d	Statimat PT	99.573	1.238	100.811	98.8	1.2	1.11	10.04	3.12	28.11
Twaron® 1550d	Uster	0.000	0.599	0.599	0.0	100.0	0.77	0.77	2.17	2.17
Twaron® 3100d	Instron	8.450	14.188	22.637	37.3	62.7	3.77	4.76	10.55	13.32
Twaron® 3100d	Sigma500	0.000	25.040	25.040	0.0	100.0	5.00	5.00	14.01	14.01
Twaron® 3100d	Statimat	156.880	10.945	167.825	93.5	6.5	3.31	12.95	9.26	36.27
Twaron® 3100d	Statimat PT	55.853	9.309	65.162	85.7	14.3	3.05	8.07	8.54	22.60
Twaron® 3100d	Uster	0.000	13.157	13.157	0.0	100.0	3.63	3.63	10.16	10.16
Twaron® 500d	Instron	0.437	0.245	0.682	64.1	35.9	0.49	0.83	1.38	2.31
Twaron@ 500d	Sjgma500	0.014	0.215	0.229	6.0	94.0	0.46	0.48	1.30	1.4
Twaron® 500d	Statimat	0.042	0.103	0.145	29.1	70.9	0.32	0.38	0.90	1.07
Twaron® 500d	Statimat PT	1.938	0.314	2.252	86.1	13.9	0.56	1.50	1.57	4.20
Twaron® 500d	Uster	0.000	0.060	0.060	0.0	100.0	0.24	0.24	0.69	0.69

TABLE 7 Test Method Bias Relative to Instron

Property	Material	Sigma500	Statimat	StatimatPT	Uster
BF	Kevlar® 1420d	10.04	22.75	1.30	10.32
BF	Kevlar® 2840d	16.91	25.52	1.17	17.93
BF	Kevlar® 600d	2.90	5.05	−0.34	4.96
BF	Nomex® 1600d	0.27	0.23	0.18	1.49
BF	Nomex® 200d	0.16	−0.43	−0.49	−0.04
BF	Technora® 1500d	0.27	48.37	−23.03	−8.25
BF	Twaron® 1550d	2.02	23.83	0.37	12.11
BF	Twaron® 3100d	21.90	64.40	2.01	24.31
BF	Twaron® 500d	3.60	20.79	0.64	2.21
EB	Kevlar® 1420d	−0.09	0.08	−0.08	−0.01
EB	Kevlar® 2840d	−0.12	−0.10	−0.18	0.01
EB	Kevlar® 600d	−0.06	0.12	0.04	0.03
EB	Nomex® 1600d	0.76	3.91	4.30	−2.52
EB	Nomex® 200d	−1.12	5.53	5.64	−3.21
EB	Technora® 1500d	−0.26	0.73	−0.29	−0.20
EB	Twaron® 1550d	−0.18	−0.35	−0.06	−0.02
EB	Twaron® 3100d	−0.21	0.10	−0.11	0.15
EB	Twaron® 500d	−0.03	0.46	0.04	−0.02
MOD	Kevlar® 1420d	494.42	323.95	632.00	739.29
MOD	Kevlar® 2840d	349.08	1082.01	1140.37	414.01
MOD	Kevlar® 600d	−120.65	−50.60	−83.57	304.72
MOD	Nomex® 1600d	16.74	8.10	6.20	28.42
MOD	Nomex® 200d	5.26	−40.40	−45.49	2.81
MOD	Technora® 1500d	96.28	321.22	302.43	366.34
MOD	Twaron® 1550d	159.60	−12131.62	614.60	503.78
MOD	Twaron® 3100d	55.08	294.81	185.84	132.93
MOD	Twaron® 500d	1933.29	−19309.86	−36.89	335.94
FASE @ 0.3%	Kevlar® 1420d	9.95	3.94	1.74	2.01
FASE @ 0.3%	Kevlar® 2840d	18.25	10.02	9.68	2.82
FASE @ 0.3%	Kevlar® 600d	2.25	0.72	0.39	0.93
FASE @ 0.3%	Nomex® 1600d	3.60	−0.30	0.95	0.10
FASE @ 0.3%	Nomex® 200d	0.43	−0.13	−0.13	0.03
FASE @ 0.3%	Technora® 1500d	8.61	0.14	0.59	1.36
FASE @ 0.3%	Twaron® 1550d	10.41	5.15	0.38	2.71
FASE @ 0.3%	Twaron® 3100d	14.30	4.28	1.81	−1.11
FASE @ 0.3%	Twaron® 500d	2.30	0.21	0.02	0.84
FASE @ 0.5%	Kevlar® 1420d	11.11	5.52	3.20	3.20
FASE @ 0.5%	Kevlar® 2840d	21.65	19.00	18.21	5.33
FASE @ 0.5%	Kevlar® 600d	2.04	0.72	0.18	1.20
FASE @ 0.5%	Nomex® 1600d	3.48	−0.49	0.63	0.20
FASE @ 0.5%	Nomex® 200d	0.45	−0.19	−0.21	0.04
FASE @ 0.5%	Technora® 1500d	9.64	0.11	1.69	2.32
FASE @ 0.5%	Twaron® 1550d	11.46	8.99	1.99	4.28
FASE @ 0.5%	Twaron® 3100d	16.75	10.44	6.18	−0.28
FASE @ 0.5%	Twaron® 500d	2.27	0.21	−0.17	1.15
FASE @ 1.0%	Kevlar® 1420d	11.29	8.58	5.86	5.35
FASE @ 1.0%	Kevlar® 2840d	23.75	28.12	27.23	8.35
FASE @ 1.0%	Kevlar® 600d	0.85	−0.12	−0.87	1.40
FASE @ 1.0%	Nomex® 1600d	2.54	−1.01	−0.34	0.39
FASE @ 1.0%	Nomex® 200d	0.38	−0.42	−0.43	−0.03
FASE @ 1.0%	Technora® 1500d	7.49	−3.84	2.29	3.49
FASE @ 1.0%	Twaron® 1550d	11.23	17.30	3.76	6.53
FASE @ 1.0%	Twaron® 3100d	18.78	16.67	11.95	2.11
FASE @ 1.0%	Twaron® 500d	1.41	−0.43	−1.04	1.30

APPENDIX

(Nonmandatory Information)

X1. ELIMINATION OF BIAS-DIFFERENCES INTRODUCED BY THE TEST-DEVICE

X1.1 Since samples have been supplied in a pre-twisted state, differences in material and handling can be excluded. The cause for the differences can only find its origin by the tensile testers.

X1.1.1 The bias of elongation at break and modulus values are too large for a direct comparison when using different test-devices. Since not only between testers, but also within testers differences can be indicated, it is desirable to have a method for determining the contribution of the test-device to the result.

X1.2 Causes for Differences

X1.2.1 A tensile tester is not infinite stiff. Not only the frame will deform due to an applied force, but also the principle of a loadcell is based on deformation. Different test devices with different loadcells will differ for their stiffness.

X1.2.2 The gripping gradient (gripping point) on clamps largely depend on yarn surface, clamp surface, clamp shape (e.g. bollard type). The gripping gradient will also change during the test. This will lead to a changing (effective) length of the yarn.

X1.3 Determination of Machine Stiffness and Clamp Contribution

X1.3.1 For one yarn sample at a given strain rate the following assumptions can be made:

X1.3.1.1 The real strain () of the yarn sample only depends on the applied force.

X1.3.1.2 At a given force the "deformation" of the tensile tester is constant.

X1.3.1.3 The gripping error is constant at a given force (note: it is the same yarn sample).

X1.3.2 Given these assumptions, deformations of the overall system can be given.

X1.3.2.1 *Yarn:* definition of strain (ε):

$$\varepsilon = \frac{\Delta l_{yarn}}{L_0} \quad (X1.1)$$

X1.3.2.2 *Clamp:* With clamping, the effective contribution to the gauge length inside the clamp is not known. The available yarn length will be the set length ($L_{0,set}$) plus the additional length in the clamp ($L_{clamp,eff}$):

$$L_0 = L_{0,set} + \Delta L_{clamp,eff} \quad (X1.2)$$

X1.3.2.3 *Tensile Tester:* Due to limited stiffness of the testing equipment the measured displacement (Δl_{meas}) will equal:

$$\Delta l_{meas} = \Delta l_{yarn} + \Delta L_{tentester} + L_{clamp,eff} \quad (X1.3)$$

Combining and rearranging yields:

$$\Delta l_{meas} = \varepsilon \cdot L_{0,set} + [(1+\varepsilon) \cdot L_{clamp,eff} + \Delta L_{tentester}] \quad (X1.4)$$

Given the assumptions:

For one yarn sample yarn, strain, tester deformation and additional gauge length are constant at a given force *F* and that ε <<1, the former equation can be simplified to:

$$\Delta l_{meas} = \varepsilon \cdot L_{0,set} + C_{st} \quad (X1.5)$$

This implies that at a given force the real strain ε of the sample equals the slope of the gauge length as a function of the measured clamp displacement.

By measuring at different gauge lengths the equation can solved at a given force level.

Unfortunately, it not possible with a Constant Rate of Elongation (CRE) type of testing machine to sample on exact force levels. This problem can be easily solved using linear interpolation techniques (linear spline). An example is presented in Fig. X1.1.

This way, clamp displacements at a given force level can be obtained.

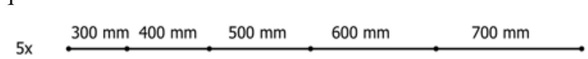
X1.4 Experimental Verification

X1.4.1 *Sampling*—Tensile curves have to be recorded at different gauge lengths. A few points must be considered:

X1.4.1.1 the force at break remains defined at a gauge length of 500 mm; other gauge lengths must be selected around this value.

X1.4.1.2 In order to average the possible variations over the sample, the different lengths should be selected successively. This sequence can be repeated.

X1.4.1.3 From both considerations the following test sequence is selected:



X1.4.1.4 The mechanical properties of a Twaron 1610 and a Kevlar 3160 dtex have been determined at these lengths using an Instron and a Statimat tensile tester (clamp speed 50% of the gauge length). The Statimat tests have been carried out by Textechno in Mönchengladbach.

X1.4.1.5 For every subset of gauge lengths at a certain force, the slope can be computed. This results in a corrected curve. As an example a result for a 1610 dtex yarn is given in Fig. X1.2.

X1.4.1.6 The relation between gauge length and displacement is significant (f=3.25·10-5), meaning it is allowed to use the equation.

X1.4.1.7 At this level of 150 N, the slope gives the elongation ε = 1.18 %. The error in this value is ± 0.09 % (95 % conf. interval). The intercept (0.9161 mm) is the contribution of the tensile tester.

X1.5 Contribution of the Test Device

X1.5.1 The intercept of the relation between gauge length and clamp displacement is the contribution of the testing

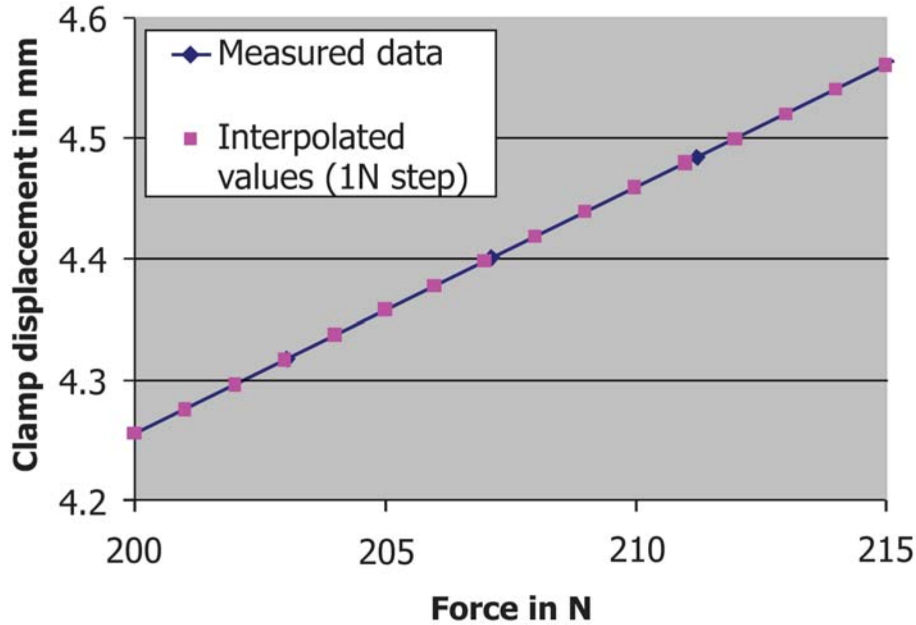


FIG. X1.1 Linear Spline Technique

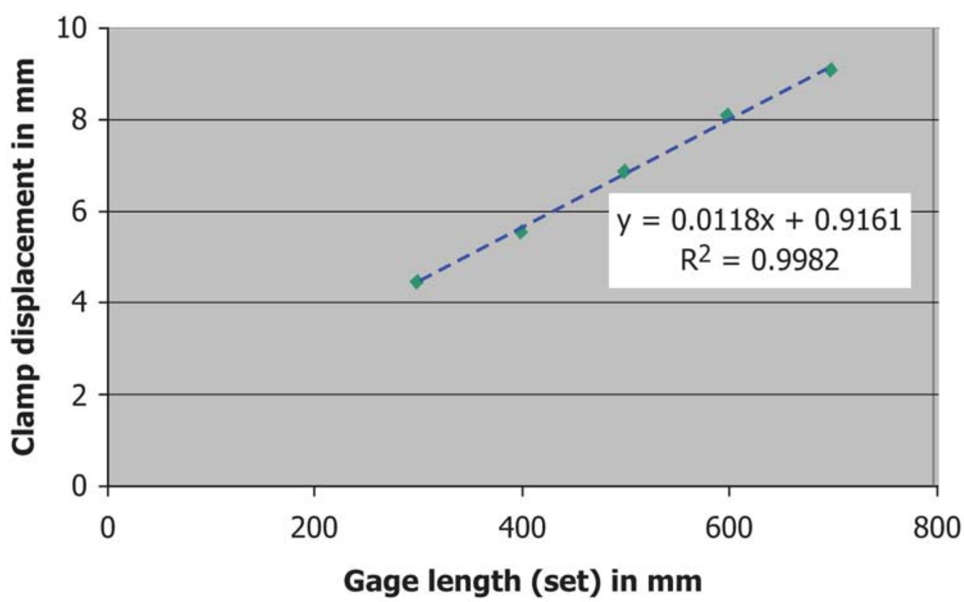


FIG. X1.2 Measured Clamp Displacement as a Function of the Gauge Length (Twaron 1610 dtex, 150 N force level)

device (ε <<1). For both used testers this contribution is calculated for the Kevlar 3160 dtex sample. The result is shown in Fig. X1.3.

X1.5.1.1 At a gauge length of 500 mm and an elongation at break of approximately 2.5 %, a clamp displacement of about 12 mm is expected. From above figure it can be found that an

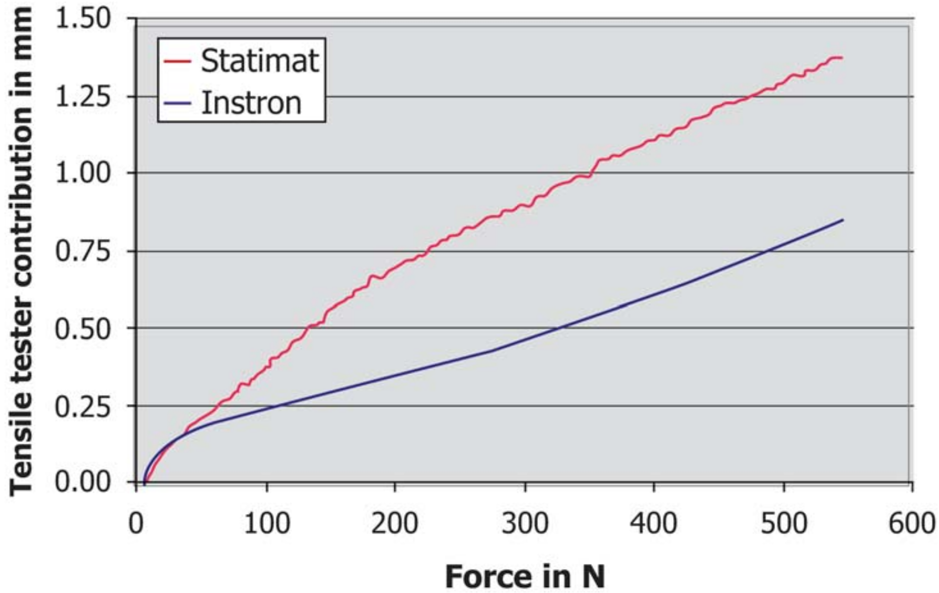


FIG. X1.3 Tensile Tester Deformation

additional displacement from the testers of 0.8 or 1.3 mm is present. This will lead to a relative deviation in elongation at break of 7 or 11 %.

X1.6 Corrected Sress-Strain Curves

X1.6.1 Examples of "raw" and corrected curves from an Instron and a Statimat tester are shown in Fig. X1.4.

X1.6.1.1 The initial differences (dashed lines) disappear after the correction (drawn lines). Based upon these constructed curves, mechanical parameters can be determined.

X1.7 Breaking Force

X1.7.1 The breaking force will remain the value as measured at 500 mm gauge length.

Sample		Breaking Force, N
1610		
dtex	Instron	373
—	Statimat	367
—		—
3160		
dtex	Instron	603
	Statimat	555

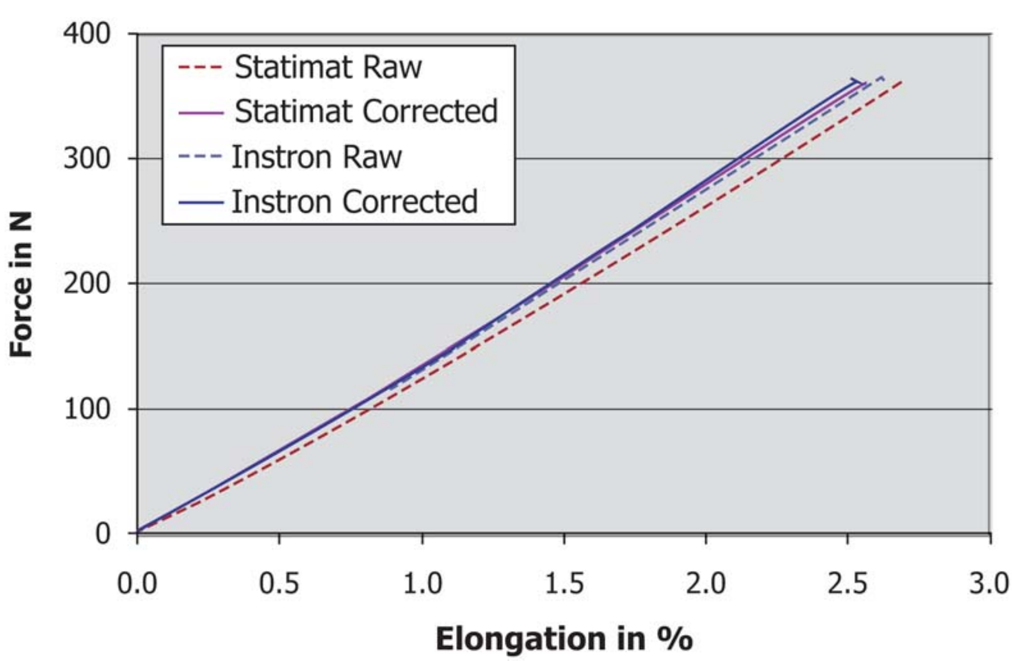


FIG. X1.4 Raw and Corrected Elongation-Force Curves

X1.7.1.1 Since the Breaking Force is defined at 500 mm, the value for the corrected curve is the same.

X1.7.1.2 Note that the breaking force for the 3160 dtex sample is too low (status 2005). This can be attributed to the clamping of the sample. By adjusting clamping conditions (pressure), the discrepancy in breaking force is eliminated (see Table 3).

X1.8 Force at Specified Elongation Values

X1.8.1 This procedure can be done at every force point leading to an elongation-force curve without any disturbance of the tensile tester.

X1.8.2 The mechanical parameters as FASE values can be derived as described in Section 14. A comparison of results is shown in Table X1.1.

X1.8.3 A major improvement can be seen at the different FASE values. Original differences are up to an unacceptable level of 10%., after correction the maximum deviation is less than 2% (1 N difference!). The results also show clearly that Instron values are also significantly influenced. This indicates that the overall procedure leads to improved mechanical characterization of the material.

X1.9 Elongation at Break

X1.9.1 The elongation at break cannot always be obtained directly from the elongation-force curves. The problem is that for getting the elongation at break data the different gauge lengths must be available. This is not always the case as shown in Table X1.2 for the 1610 dtex sample.

X1.9.2 When the 500 mm sample has the lowest strength, all other samples will have a clamp position at this force. In this case, there is no problem in computing the elongation at break using the method described. When the 500 mm sample has the highest force, within the other data no information about the clamp-position is present. In this case, it is not possible to compute an elongation at break.

X1.9.3 Intermediates can also be found, but in this case, due to the limited amount of data points, the result will be less reliable.

X1.9.3.1 Possible Solutions:

(1) Use other tester influence data of the same sample-.⇒Complex process.

(2) Leave out a result.⇒Less data points, less accurate.⇒Only 500 mm data, no results will be given.

TABLE X1.2 Force at Break at Different Gauge Lengths

Length, mm	Possible Force at Break, N	Not Possible Force at Break, N
300	377	370
400	361	368
500	359	371
600	364	367
700	365	368

(3) Extrapolation of tensile test curves⇒It is not know on beforehand how many curves need to be extrapolated. This way of working is therefore undefined.

(4) Use the "tensile tester contribution curve" for estimating the error in the measurement

X1.9.3.2 The meaning of this last point will be explained. From the earlier mentioned Eq X1.6:

$$\Delta l_{meas} = \varepsilon \cdot L_{0,set} + C_{st} \quad (X1.6)$$

combined with the estimated C_{st} (contribution of the tester) at the Breaking Force level and the measured clamp displacement at break, the strain can be computed:

$$\Delta l_{meas} - C_{st} = \varepsilon \cdot L_{0,set} \quad (X1.7)$$

X1.9.3.3 Additionally, $L_{0,set}$ is the gauge length at pretention. Given the slight extrapolation and the linearity at the end of this curve (see Fig. X1.5), this solution is judged as the most applicable for tackling this problem.

X1.9.3.4 Although linearity can be recognized at the end of this curve, it is important to define the start and end point of the range that can be used for this. A correlation matrix covering all possible start and end-points is graphically presented in Fig. X1.5. This graph shows that the selection of the end-point is not critical at all. The most logical choice is to take the last value of the curve as end-point.

X1.9.3.5 But since it is most important that the estimated elongation is stable, for start and end points the elongation is computed. A linear regression of the "error curve" between these start and end-points, the "error" at the Force at Break at 500 mm gauge length can be estimated. As described before, this value can be used for calculating the corrected elongation at break. In Fig. X1.6, an example is presented.

X1.9.3.6 Between different start and end-points, the regression and the calculation of the elongation at break has been done. In Table X1.3 these results are listed.

TABLE X1.1 Comparison of FASE Values

Sample		Uncorrected			Corrected		
		FASE03, N	FASE05, N	FASE10, N	FASE03, N	FASE05, N	FASE10, N
1610 dtex							
	Instron	37	63	130	39	66	134
	Statimat	34	59	123	39	66	133
	Relative difference, in %	–7.4	–6.1	–4.9	0.4	0.0	–0.5
3160 dtex							
	Instron	62	111	235	69	121	252
	Statimat	57	100	213	68	120	250
	Relative difference, in %	–8.7	–9.8	–9.3	–1.8	–0.6	–0.7

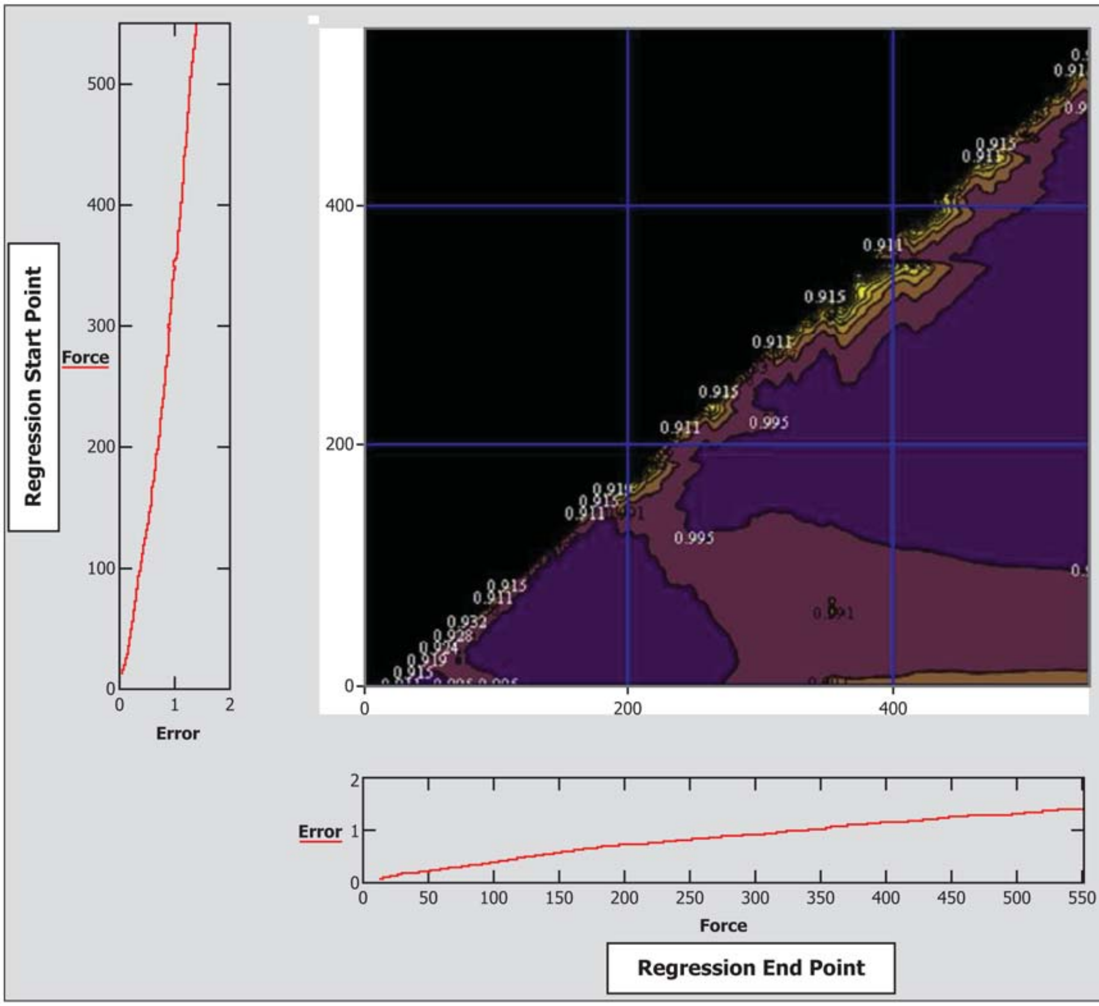


FIG. X1.5 Correlation Matrix for Linear Regression of the Test Device Contribution

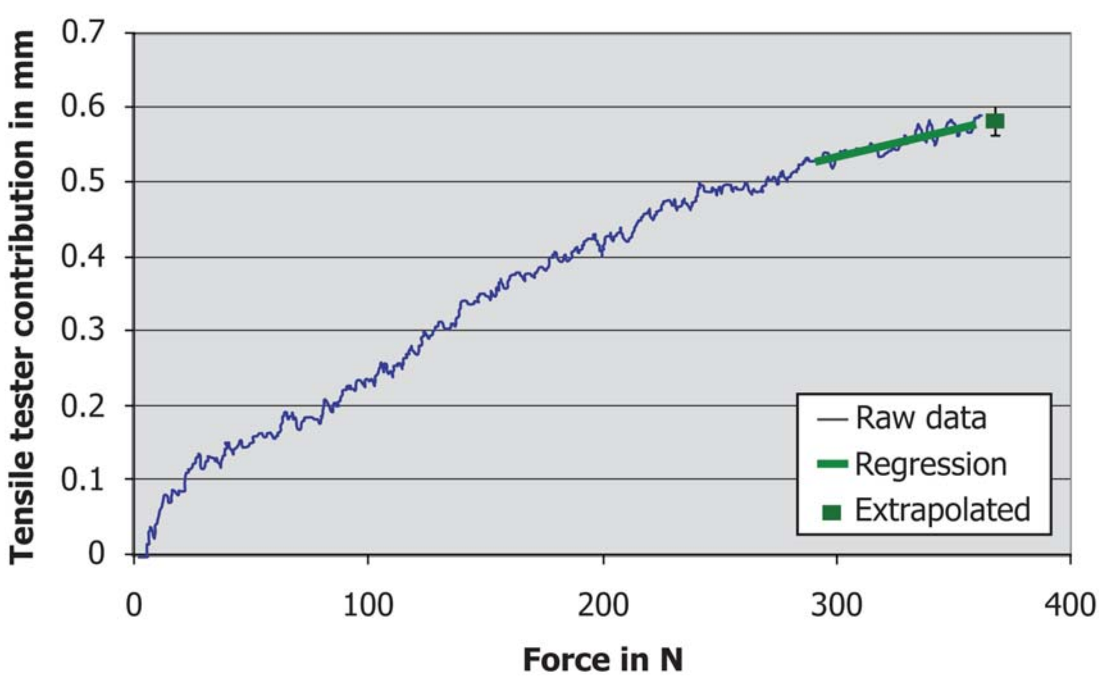


FIG. X1.6 Extrapolation of the "Error Curve" Used for Calculating the Elongation at Break

TABLE X1.3 Elongation of Break Based on Different Start and End Values of the Error Curve

		End		
	Start	90	95	100
Instron	70	2.557	2.557	2.557
	80	2.557	2.557	2.557
	90	—	2.557	2.557
Statimat	70	2.639	2.639	2.640
	80	2.644	2.641	2.640
	90	—	2.643	2.641

X1.9.3.7 The start and end values are the relative load levels in % of the minimum force at break found at the different gauge lengths.

X1.9.3.8 Between the ranges selected, no differences can be found.

X1.9.3.9 Given results from Table X1.3, the following is – partly arbitrary- defined: Start at 80 % of the maximum force. End at 100 % of the maximum force. The elongations at break values with and without the correction are listed in Table X1.4.

X1.9.3.10 Due to the low Breaking Force, also the elongation at break will show a too low value.

TABLE X1.4 Elongation at Break

Sample		Breaking Force, N	Uncorrected Elongation at Break, %	Corrected Elongation at Break, %
1610 dtex				
	Instron	373	2.66	2.57
	Statimat	367	2.75	2.63
	Rel. diff., %		3.6	2.6
3160 dtex				
	Instron	603	2.34	2.20
	Statimat	555	2.36	2.10
	Rel. diff., %		1.1	–

X1.10 Discussion

X1.10.1 The construction of the mechanical testing equipment has a significant influence upon the derived mechanical characteristics of high-performance fibers. This can be found for both the standard testing equipment as for automated testers. An experimentally simple method can be applied in order to find and correct for this influence. Differences introduced by the tester can be significantly eliminated.