



# Standard Test Method for Wet and Dry Yarn-on-Yarn Abrasion Resistance<sup>1</sup>

This standard is issued under the fixed designation D 6611; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method describes the measurement of abrasion resistance properties for manufactured fiber yarns in dry and wet conditions.

1.2 This test method applies to manufactured yarns used in rope making.

1.3 The values stated in SI units are to be regarded as standard. The values given in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles<sup>2</sup>

D 1776 Practice for Conditioning Textiles for Testing<sup>2</sup>

D 2904 Practice for Interlaboratory Testing of a Textile Test Method that Produces Normally Distributed Data<sup>2</sup>

## 3. Terminology

3.1 *Definitions:*

3.1.1 *abrasion, n*—the wearing away of any part of a material by rubbing against another surface.

3.1.2 *apex angle, n*—the angle formed between the incoming and outgoing yarn at the top (and bottom) of the interwrapped yarn area in the static condition (see Annex A1).

3.1.2.1 *Discussion*—In yarn abrasion testing, the state of a yarn, which has been soaked for a prescribed period of time in water before testing and then immersed in water during the abrasion test.

3.1.3 *applied tension, n*—in yarn abrasion testing, the static tension exerted on the weighted end of the yarn by the applied weight.

3.1.3.1 *Discussion*—Tension in the yarn varies along its length during each cycle because of friction and dynamic effects. The tension at any point in the interwrapped yarn

region and at any time may differ substantially from the applied tension but is a function of that applied tension.

3.1.4 *cycles to failure, CTF, n*—in yarn abrasion testing, the number of cycles applied to the yarn before it fails due to abrasion.

3.1.4.1 *Discussion*—Failure is considered to occur when the yarn is completely separated.

3.1.5 *dry, adj*—the state of a yarn which has not been exposed to excessive moisture.

3.1.6 *rope, n*—a compact and flexible, generally torsionally balanced continuous structure, greater than 4-mm ( $\frac{3}{32}$ -in.) diameter, capable of applying or transmitting tension between two points.

3.1.7 *wet, adj*—the state of a yarn which has been exposed to excessive moisture.

3.2 For definitions of other textile terms used in this test method, refer to Terminology D 123.

## 4. Summary of Test Method

4.1 A length of yarn is interwrapped in contact with itself between three pulleys that are positioned in a defined geometry to produce a specific intersection angle. A weight is attached to one end of the yarn to apply a prescribed tension. The other end is drawn back and forth through a defined stroke at a defined speed until the yarn fails due to abrasion upon itself within the interwrapped region. The yarn abrasion test can be conducted in either the dry state or the wet state.

## 5. Significance and Use

5.1 This test method is intended for testing dry and wet abrasion resistance of manufactured fiber yarns. This test method is especially useful for ropes intended for use in the marine environment. The test method has been used with yarns having linear densities ranging from 70 to 300 tex, but may be used with yarns outside these ranges.

5.2 Limited interlaboratory correlation testing has been conducted to date. Single-laboratory testing, in accordance with ASTM practices, has now been conducted. Additional interlaboratory testing, in accordance with ASTM practices, will be conducted after approval of a definitive test method. Test results should be used with caution pending completion of interlaboratory testing.

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.16 on Rope and Cordage.

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<sup>2</sup> *Annual Book of ASTM Standards*, Vol 07.01.

5.3 This test method is not recommended for acceptance testing of commercial shipments in the absence of reliable information on between-laboratory precision.

5.4 If there are differences of practical significance between reported test results for two or more laboratories, comparative tests should be performed to determine if there is a statistical bias between them, using competent statistical assistance. As a minimum the test samples used should be as homogeneous as possible, be drawn from the material from which the disparate test results were obtained, and be 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 or more laboratories should be compared using a statistical test for unpaired data, at a probability level chosen prior to testing. 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.

5.5 This test method is conducted at one or several applied tensions that may depend upon the yarn material and size. The number and magnitudes of applied tensions and the number of eight specimen sets generally are agreed upon in a material specification or contract order. Guidance on determining the appropriate number and magnitudes of applied tensions is given in Annex A2.

**6. Apparatus**

6.1 The Yarn-on-Yarn Abrasion Test Apparatus is shown schematically in Fig. 1 and consists of the following:

6.2 *Yarn Guide Pulleys*—Three pulleys are arranged on a vertical frame with the centerline spacing indicated. All of the pulleys have the same diameter. The pulleys have low-friction bearings.

6.3 *Arrangement of Guide Pulleys*—The upper pulley centerlines are separated by  $140 \pm 2$  mm. The lower pulley centerline is  $254 \pm 2$  mm below a line connecting the upper pulley centerlines. This arrangement produces an apex angle of

10.8 radians ( $34^\circ$ ). Other spacings may be used which produce the same apex angle, when analyzed by the procedure given in Annex A1.

6.4 *Wet Testing Arrangement*—For wet testing, the lower pulley is placed on a bar extending down from a support frame, such that a beaker of water can be placed around it to immerse the interwrapped portion of the yarn. The lower pulley has a bushing-type bearing suitable for prolonged service immersed in water.

6.5 *Drive Motor*—An eccentric crank driven by a gear motor is arranged in alignment with one of the upper pulleys. The crank is offset by  $25 \pm 2$  mm from the drive motor shaft to create a yarn stroke of  $50 \pm 4$  mm. The gear motor drives the crank at between 60 and 70 revolutions/min. Other drive arrangements, which accomplish the specified stroke and drive speed may alternatively be used.

6.6 *Multi-Station Tester*—Several test stations may be arranged on a support frame and driven by the same motor.

6.7 *Cycle Counter Arrangement*—A means of counting the number of yarn abrasion strokes to failure is provided. This may be a counter directly connected to the drive motor or a counter, which is indexed by each revolution of the crank or directly by each stroke of the yarn. This counter is arranged to stop counting when the yarn breaks and to retain a count of the number of strokes until it is reset. For multistation testers, such a counter is provided for each yarn station.

6.8 *Yarn Twist Control*—If the yarn has pronounced twist, or if the yarn tends to twist or untwist during testing, a means should be provided to control yarn twist, such as an extension arm on the applied weight which follows a guide.

**7. Sampling and Test Specimens**

7.1 *Primary Sampling Unit*—Consider spools or beams to be the primary sampling unit.

7.2 *Laboratory Sampling Unit*—As a laboratory sampling unit take from the primary sampling unit a total length of yarn

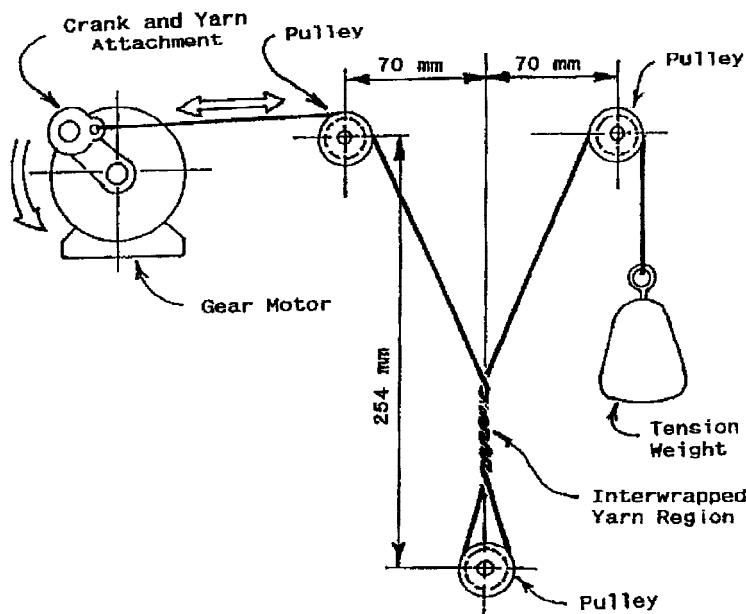


FIG. 1 General Arrangement of the Yarn-on-Yarn Abrasion Test Apparatus

that will provide eight test specimens for each of the applied tensions as determined in Annex A2.

7.2.1 Determine the specimen length sufficient to accommodate the distance needed to secure the yarn to the test apparatus motor crank, through the pulley arrangement and to the applied weight, allowing for movement of the crank and weight during the test. Add to this a suitable allowance for the length needed to attach the yarn to the crank and to the weight.

7.2.2 Determine the number and magnitudes of applied tensions as directed in Annex A2.

7.2.3 Remove sufficient yarn from the primary sample prior to taking the laboratory sample to assure the test yarn has not been exposed to light, handling abuse, or other outside influences.

7.2.4 Handle the test specimens carefully to avoid altering its natural state, including twist level.

7.2.5 If testing is not conducted immediately, wind a sufficient length of yarn on a small spool or bobbin and place in a moisture proof container or package, and store in a dark area not exposed to direct sunlight or other strong light sources.

7.3 *Test Specimens*—From each laboratory sampling unit, cut individual specimens to a length as determined in 7.2.

7.3.1 Securely tie knots at each end of the specimen to prevent untwisting. For convenience, a small hook, suitable for engaging the drive attachment and the applied tension, can be attached to each end of the specimen by means of a knot.

## 8. Conditioning

8.1 *Preconditioning for Dry Testing*—In preparation for dry testing, precondition each specimen in an atmosphere with a relative humidity between 55 and 75 % and a temperature between 16 and 25°C (61 and 77°F) for at least 1 h and for sufficient time to bring to equilibrium, as specified in Practice D 1776.

8.2 *Preconditioning for Wet Testing*—In preparation for wet testing, precondition each specimen in a fresh tap water bath at a temperature between 16 and 25°C (61 and 77°F) for 1 h ± 6 min. This may be done either by soaking the yarn in a separate bath prior to mounting it on the test machine or by soaking the

yarn mounted on the test machine prior to beginning testing. If a separate bath is used, care must be taken to avoid damaging the yarn while mounting the yarn for testing.

NOTE 1—The yarn test specification may give a different soak time for testing, with agreement of the interested parties. The yarn should not be soaked for more than the specified time, as the abrasion resistance properties of some yarns is sensitive to the length of soak.

## 9. Procedure

9.1 Handle the test specimen carefully to avoid altering the natural state of the yarn, including the level of twist.

9.2 *Mounting Specimen on Test Machine*—Attach one end of the specimen to the drive motor crank or to an extension tether attached to the crank. Place the specimen over the first upper guide pulley, around the opposite side of the lower guide pulley, under that lower pulley, and across itself and over the second upper guide pulley. This preliminary crossed-yarn position is shown at the left in Fig. 2.

NOTE 2—This position in which the yarn touches itself at the cross-over point but does not yet wrap around itself is referred to as the zero wrap position.

9.3 *Mounting of Weight*—Attach weights of sufficient mass to produce the prescribed applied tension to the other end of the specimen.

9.4 *Application of Yarn Interwraps*—Place the fingers of a hand or a suitable support object within the bight formed by the yarn passing under the lower pulley and temporarily remove the yarn from that pulley. Twist the hand or support object to apply three wraps to the yarn. Replace the yarn around the lower pulley. The resulting yarn interwrap region should appear as shown at the right in Fig. 2.

NOTE 3—The yarn should have three complete warps producing an interwrap angle of 1080° (3 × 360°). The yarn should pass out of the interwrapped region continuing in the same direction as it entered into the region.

NOTE 4—The yarn test specification may give a different number of interwraps for testing a particular yarn category, with agreement of the interested parties.

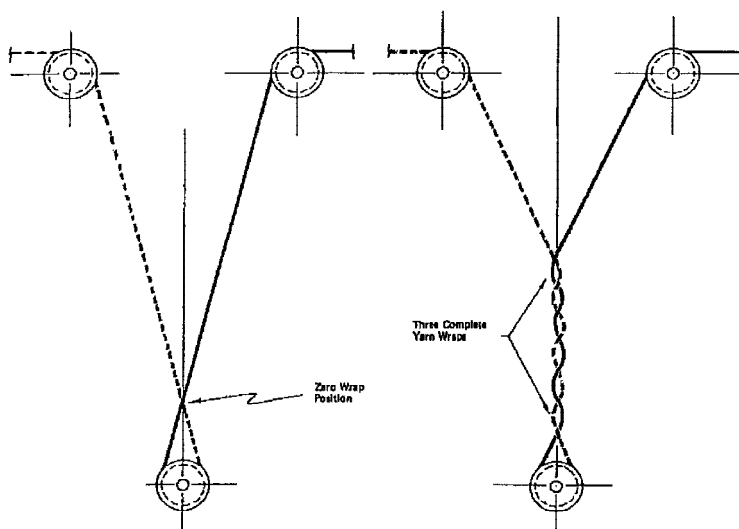


FIG. 2 Correct Method of Counting Number of Yarn Interwraps for Yarn-on-Yarn Abrasion Test Method

9.4.1 *Relation of Direction of Twist to Direction of Interwrap*—If the yarn has a pronounced twist, the interwrap should be applied in the same direction as the twist, unless the yarn test specification gives different instructions.

9.5 *Dry Testing*—For dry testing, conduct the test in an atmosphere with a relative humidity between 55 and 75 % and a temperature between 16 and 25°C (61 and 77°F).

9.6 *Wet Testing*—For wet testing, place a beaker of fresh tap water at a temperature of between 16 and 25°C (61 and 77°F) around the yarn such that the interwrapped region of the yarn is completely immersed.

9.7 *Start of Test*—Reset the counter(s) to zero. Start the drive motor.

9.8 *Conduct of Test*—Carry out the test until the yarn(s) fails due to interyarn abrasion at the applied tension.

9.9 *Conclusion of Test*—After the yarn(s) fails, shut off the drive motor. Record the number(s) of Cycles to Failure (CTF) for each specimen.

9.10 Test eight yarn specimens as directed in this section for each designated applied tension and for each set of test conditions.

## 10. Calculation

10.1 *Mean Cycles to Failure*—Calculate mean cycles to failure by the average-of-logarithms method as follows:

$$M = \text{Ln}^{-1} = \left[ \frac{\text{Ln } CTF_1 + \text{Ln } CTF_2 + \dots + \text{Ln } CTF_N}{N} \right] \quad (1)$$

where:

$M$  = Mean cycles to failure,

$CTF_i$  = Cycles to failure for  $i$  th specimen,

$N$  = Number of specimens,

$\text{Ln}$  = Natural (Naperian) logarithm,

$\text{Ln}^{-1}$  = Inverse natural logarithm,

=  $e^L$ ,

=  $2.71828^{\text{Logarithm}}$ .

10.2 *Log Standard Deviation of CTF*—Calculate the log standard deviation,  $\text{Ln } \sigma$ , of  $CTF$  by the following equation.

$$\text{Ln } \sigma = \sqrt{\frac{(\text{Ln } CTF_1 - \text{Ln } M)^2 + (\text{Ln } CTF_2 - \text{Ln } M)^2 + \dots + (\text{Ln } CTF_N - \text{Ln } M)^2}{N - 1}} \quad (2)$$

where:

$\text{Ln } \sigma$  = Log standard deviation of cycles to failure.

10.3  *$\text{Ln } 2\sigma$  CTF Band*—Calculate the log mean  $CTF \pm 2$  standard deviation band by the following equations.

$$\text{Upper } M \pm 2\sigma \text{ Bound} = \text{Ln } M + 2 \text{Ln } \sigma \quad (3)$$

$$\text{Lower } M \pm 2\sigma \text{ Bound} = \text{Ln } M - 2 \text{Ln } \sigma \quad (4)$$

10.4 *Data Adjustment*—If the  $\text{Ln } CTF$  for any of the test stations deviates by more than  $2 \text{Ln } \sigma$  from the  $\text{Ln } M$  or is otherwise judged to be an outlier, then test an additional four yarns and reanalyze the results. Judgement may be used in accepting or rejecting data  $CTF$  data, which deviates more than  $2 \sigma$  from the  $M$  after conducting the additional four tests.

10.5 Present the cycles-to-failure results against applied tension on a semi-log plot, with cycles-to-failure on the log axis. Guidance on presenting the results is given in Annex A2.

## 11. Report

11.1 Report that the yarn-on-yarn abrasion resistance was determined as directed in Test Method D 6611.

11.2 Report the following information for the laboratory sampling unit and for the lot as applicable to a material specification or contract order:

11.2.1 Description of specimens, that is, yarn material, type, source, size, tenacity, etc.

11.2.2 Condition of Specimens, wet or dry, including soak time if this differed from above specified value.

11.2.3 Applied tension, in mN/tex (g/denier) for each series.

11.2.4 Mean cycles to failure,  $M$  at each applied tension.

11.2.5  $\text{Ln}$  standard deviation of cycles to failure,  $\text{Ln } \sigma$  at each applied tension.

11.3 If testing was conducted at more than two applied tensions, plot and report the following information:

11.3.1 Plot the mean cycles to failure  $M$  on the log scale against applied tension on the normal scale on a semi-log graph.

11.3.2 Plot the  $\text{Ln}^{-1}(\text{Ln } M + 2 \text{Ln } \sigma)$  for each applied weight on the same semi-log graph.

11.3.3 Plot the  $\text{Ln}^{-1}(\text{Ln } M - 2 \text{Ln } \sigma)$  for each applied tension on the same semi-log graph.

11.4 Further guidance on presenting the results is given in Annex A2.

## 12. Precision and Bias

12.1 Two synthetic fiber yarns were tested in accordance with Practice D 2904 under conditions shown in Table 1. The testing was performed by a single operator on two multi-station yarn-on-yarn abrasion machines in a single laboratory. A number of series of eight-specimen tests were run under each set of test conditions to obtain estimates of within-laboratory variability.

12.2 Variance component analysis on  $\ln(CTF)$  gave the results provided in Table 2.

12.3 The variance of  $\ln(M)$  is given by  $\text{var}[\ln(\text{series})] + \{\text{var}[\ln(\text{specimen})]/8\}$ . The square root of that value can be considered the repeatability standard deviation for the test method,  $s_r$ , where the calculations are performed on  $\ln(CTF)$ . Those values are given in the “Std. Dev.  $\ln(M)$ ” column of Table 3.

12.4 Method repeatability is defined as the “maximum difference” that can “reasonably” be expected between two test results obtained on the same material when the test results are

**TABLE 1 Conditions for Testing Two Synthetic Fiber Yarns**

Code	Material	Applied Tension (%)	Applied Tension (N)	Condition	Number of Series
1	Enka nylon 140JRT 1400 dtex	2	2.35	Dry	4
2	Diolen polyester 855T 110 dtex	2	1.8	Dry	2
3	Diolen 855T polyester 110 dtex	2	1.8	Wet	2
4	Diolen polyester 855T 110 dtex	6	5.5	Dry	8
5	Diolen polyester 855 T110 dtex	6	5.5	Wet	6

**TABLE 2 Variance Component Analysis**

Code	Average	Var (series)	Var (specimen)	Var (total)
1	9.44	0.0128	0.027	0.0335
2	10.11	0	0.0417	0.0417
3	10.21	0.00186	0.0352	0.0371
4	7.35	0.161	0.851	1.012
5	8.49	0.102	0.128	0.230

**TABLE 3 Variance**

Code	% Var (series)	% Var (specimen)	Var [ln(M)]	Std Dev ln(M)
1	38	62	0.0154	0.124
2	0	100	0.00522	0.0722
3	5	95	0.00626	0.0791
4	16	84	0.267	0.517
5	44	56	0.118	0.344

obtained in the same laboratory. Those values for  $\ln(M)$  are shown in Table 4. Method reproducibility is defined as the “maximum difference” that can “reasonably” be expected between two test results obtained on the same material when the test results are obtained from different laboratories.<sup>3</sup> The

total standard deviation,  $s_R$ , formed by taking the square root of the sum of intralaboratory and interlaboratory laboratory variance components, cannot be determined from these data.

12.5 Repeatability of other yarns at other applied tensions may differ.

<sup>3</sup> John Mandel and Theodore W. Lashof, 1987, The Nature of Repeatability and Reproducibility. Jour, Quality Technology, 19 (1).

### 13. Keywords

13.1 abrasion; rope; yarn

**TABLE 4 Repeatability**

Code	$s_r$	Repeatability
1	0.124	0.34
2	0.0722	0.20
3	0.0791	0.22
4	0.517	1.43
5	0.344	0.95

## ANNEXES

### (Mandatory Information)

#### A1. METHOD OF CALCULATING YARN APEX ANGLE FOR YARN-ON-YARN ABRASION TESTING

A1.1 *Introduction*—It is very difficult to accurately measure the angle between the interwrapped yarns on the yarn-on-yarn abrasion test machines. It is relatively easy to measure the distance between pulley centers. This attachment describes a method of calculating the yarn angle from the pulley center distances and discusses the importance of correctly determining this angle.

A1.2 *Terminology*—Fig. A1.1 illustrates the general arrangement of the interwrapped yarn on the test machine.

A1.3 *Derivation of Equations*—Symmetry is assumed, that is, the yarn wrap is on a vertical line projecting from the center of the lower pulley and the two apex angles are equal. Also it is assumed that all pulley diameters are the same.

A1.3.1 The solution proceeds as follows:

$$V = L_1 \cos\alpha + L_2 \cos\alpha + W = (L_1 + L_2) \cos\alpha + W \quad (\text{A1.1})$$

$$\cos\alpha = \frac{V - W}{L_1 + L_2}$$

and:

$$L_2 \sin\alpha = r - r \cos\alpha \quad (\text{A1.2})$$

$$H = L_1 \sin\alpha + r - r \cos\alpha = (L_1 + L_2) \sin\alpha$$

$$\sin\alpha = \frac{H}{L_1 + L_2}$$

thus:

$$\tan\alpha = \frac{\sin\alpha}{\cos\alpha} = \frac{H}{V - W} \quad (\text{A1.3})$$

The apex angle then is:

$$\beta = 2 \arctan\left(\frac{H}{V - W}\right) \quad (\text{A1.4})$$

A1.3.2 Note that the apex angle  $\beta$  is independent of the pulley radius  $R$ , assuming all pulleys have the same radius.

A1.4 It is very difficult to accurately measure the yarn apex angle directly. Angle errors are very hard to detect. Some people overlook an error of 5°, and few people detect an error of 2°. Greater accuracy can be achieved by determining the yarn apex angle by the above formula instead of directly measuring this angle.

A1.5 This attention to accuracy in defining the yarn apex angle might seem to be unwarranted; however, a small variation in this angle can sometimes produce a significant variation in the yarn-on-yarn abrasion test results.



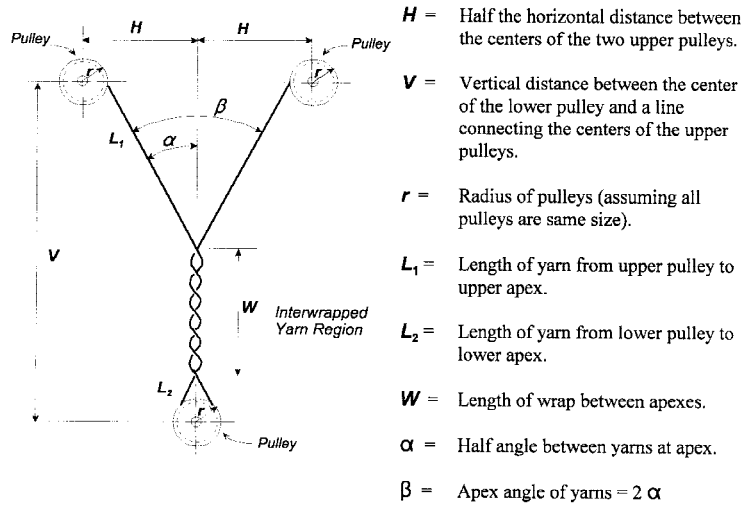


FIG. A1.1

## A2. INSTRUCTIONS FOR SELECTING APPLIED TENSIONS AND PRESENTING RESULTS

A2.1 *Introduction*—Selecting the applied tensions to be used in the yarn-to-yarn abrasion resistance test should be done with consideration of the intended purpose of the test. The test is generally intended for used in determining the abrasion resistant properties of manufactured yarns to be used in ropes, especially for marine applications. An extensive program might be carried out in which several alternative yarns are tested at a number of different applied tensions so that their properties can be compared. A single test with one applied tension might be carried out to verify that the abrasion resistance of a yarn shipment matches that characteristic property of the specified yarn type.

A2.2 For some comparison purposes, it is preferable to set the applied tensions on the basis of percentages of the tenacities of the various fibers. For other purposes, it is preferable to set the applied tensions on the basis of yarn size, for example,  $mN/tex$  (g/den).

A2.3 Suggested ranges of applied tension values for various fiber materials are given in Table A2.1. These are based on past testing of such materials.

A2.4 For typical conventional fiber materials, that is, nylon and polyester, suggested applied tensions may be in the range of 30 to 40  $mN/tex$ . For typical high tenacity fiber materials,

that is aramid and HMPE, suggested applied tensions may be in the range of 60  $mN/tex$ .

A2.5 For characterization purposes, it may be necessary to conduct the yarn-on-yarn abrasion test at many applied tensions. Fig. A2.1 is a comparison of the mean CTF results from wet yarn-on-yarn abrasion tests on two nylon yarns. The base yarn is identical, and the tenacities are the same. Yarn 1 had a conventional marine finish and yarn 2 had an improved marine finish. The shapes of such plots generally is reproducible and can serve as a means of identifying a particular yarn finish.

A2.6 For comparison purposes, it may be sufficient to conduct the test at only several applied tensions. The performance difference shown in Fig. A2.1 would have been identified by testing at only several tension levels in the range of 100 to 800 g.

A2.7 For quality control purposes, it may be sufficient to conduct the test at only one or several applied tensions, provided that these tensions are chosen to be representative of the fiber finish and to differentiate it from other fiber finishes.

A2.8 The scatter of yarn-on-yarn abrasion test data may also be an indicator of yarn finish and quality. Fig. A2.2 is a plot of the mean CTF and the mean  $\pm 2\sigma$  values. The wide scatter shown at 400 and 700 g is thought to represent a region in which the abrasion mode was undergoing a transition between sliding abrasion and plowing abrasion, as indicated from SEM examination of broken yarns. For some purposes it may be preferable to plot both mean CTF and scatter in this manner to show such phenomena.

A2.9 Data scatter may indicate problems with the test procedure. For example, applying fewer or more interwraps or applying the strong tension during one test will produce an outlier. It is recommended that data points which lie beyond  $\pm 2\sigma$  be examined and discarded from the analysis if there is

TABLE A2.1 Suggested Ranges of Applied Tension Values for Various Fiber Materials

Material	Applied Tension Range	
	Lowest Tension, % Tenacity	Highest Tension, % Tenacity
Nylon, dry	2	6
Nylon, wet	1	5
Polyester	2	6
Aramid	1	3
HMPE	1	5

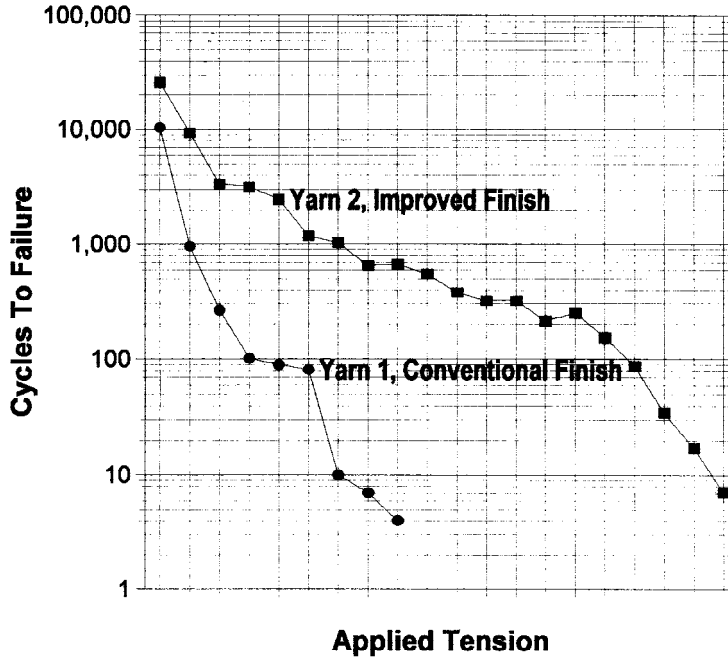


FIG. A2.1 Example Plot of Yarn-on-Yarn Abrasion Test Results, Comparison of Yarns

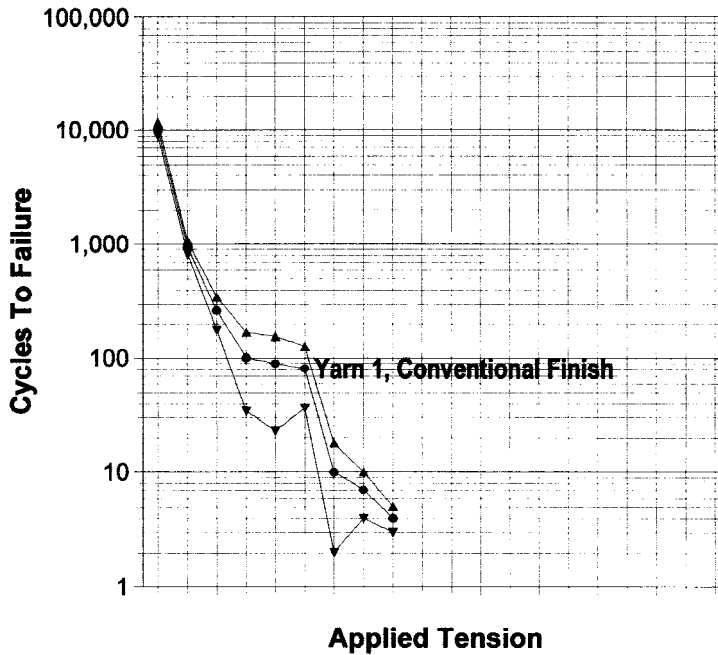


FIG. A2.2 Plot of Yarn-on-Yarn Abrasion Test Data, Characterization of Yarn Finish

reason to suspect them. When eight tests are conducted at an applied tension and more than one data point is an outlier, then it is recommended that an additional four tests be conducted and the data then be reanalyzed.

A2.10 Data scatter may indicate problems with the test

machine. For example, if data points from one test station generally or consistently are lower than at the other stations, this station should be examined. One of the bearings may be failing. The spacing of the pulleys may be improperly set. The counter may be malfunctioning.

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