Standard Test Method for Abrasion Resistance of Textile Webbing (Hex Bar Method)[1]

This standard is issued under the fixed designation D 6770; 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.

ϵ[1] NOTE—Figure 1 was corrected editorially in May 2002.

1. Scope

1.1 This test method covers the determination of abrasion resistance of textile webbing using a hex bar abrasion tester.

1.1.1 The resistance is expressed as a percentage of retained break strength.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as the standard. Within the text, the inch-pound units are shown in parentheses. 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 nonconformance with this test method.

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

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]

D 1776 Practice for Conditioning and Testing Textiles[2]

2.2 *Other Standard:*

Federal Standard 191, Method 4108 "Strength and Elongation, Breaking; Textile Webbing, Tape and Braided Items"[3]

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 *abrasion cycle*, *n*—one or more movements of an abradant across a material surface, or the material surface across the abradant, that permits a return to its starting position.

3.1.2.1 *Discussion*—The abrasion cycle is dependent on the programmed motions of the abrasion machine and the test standard used. It may consist of one back-and-forth unidirectional movement or one circular movement, or a combination of both. For the hex bar abrasion method a cycle is comprised of two strokes.

3.1.3 *breaking force, n*—the maximum force applied to a material carried to rupture. (Compare *breaking point*, *breaking strength*.)

3.1.4 *standard atmosphere for preconditioning textiles*, *n*—a set of controlled conditions having a temperature not over 50°C (122°F), with respective tolerance of ±1°C (2°F), and a relative humidity of 5 to 25 ± 2 % for the selected humidity, so that drying can be achieved prior to conditioning in the standard atmosphere for testing textiles.

3.1.5 *standard atmosphere for testing textiles*, *n*—laboratory conditions for testing fibers, yarns, and fabrics in which air temperature and relative humidity are maintained at specific levels with established tolerances.

3.1.5.1 *Discussion*—Textile materials are used in a number of specific end-use applications that frequently require different testing temperatures and relative humidities. Specific conditioning and testing of textiles for end-product requirements can be carried out as defined in Practice D 1776.

3.1.6 *stroke*, *n—in hex bar abrasion testing*, one-half of an abrasion cycle that consists of one forward or one backward motion.

3.1.7 *webbing*, *n—in textiles*, a stout narrow fabric with a mass per unit area of at least 0.5 kg/m^2 (0.1 lb/ft^2) for each 25.4 mm (1 in.) of width. (Compare *narrow fabric*, *ribbon*, and *tape*.)

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 Abrasion resistance is measured by subjecting the specimen to unidirectional reciprocal rubbing over a specific bar under specified conditions of tension, stroke length and time. Resistance to abrasion is evaluated by determining the percent retention of breaking force of an abraded specimen compared to an unabraded specimen.

5. Significance and Use

5.1 The measurement of the resistance to abrasion of textile

[1] This test method is under the jurisdiction of ASTM Committee D13 on Textiles and is the direct responsibility of Subcommittee D13.60 on Fabrics, Specific.

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] Available from Superintendent of Documents, Government Printing Office, Washington, DC 20402.

webbing is very complex. The resistance to abrasion is affected by many factors that include the inherent mechanical properties of the fibers; the dimensions of the fibers; the structure of the yarns; the construction of the webbing; the type, kind, and amount of treatment added to the fibers, yarns, or webbing; the nature of the abradant; the variable action of the abradant over the specimen area abraded; the tension on the specimen; the pressure between the specimen and the abradant; and the dimensional changes in the specimen.

5.2 The resistance of textile webbing to abrasion as measured by this test method does not include all the factors which account for wear performance or durability in actual use. While the abrasion resistance stated in terms of the number of cycles and durability (defined as the ability to withstand deterioration or wearing out in use, including the effects of abrasion) are frequently related, the relationship varies with different end uses. Different factors may be necessary in any calculation of predicted durability from specific abrasion data.

5.3 Laboratory tests may be reliable as an indication of relative end use in cases where the difference in abrasion resistance of various materials is large, but they should not be relied upon where differences in laboratory test findings are small. In general, the results should not be relied upon for prediction of performance during actual wear life for specific end uses unless there are data showing the specific relationship between laboratory abrasion tests and actual wear in the intended end use.

5.4 While there has not been extensive interlaboratory testing prior to development of this standard, there has been some quality control testing by manufacturers. An intralaboratory test was conducted to initiate this test method, using a single product. This data will be used to determine a preliminary statement on precision and bias. Subsequent to approval of this standard, a formalized interlaboratory procedure will be initiated under the direction of a professional statistician and will produce a research report. Samples used in this controlled test will be representative of end use applications.

5.5 These general observations apply to most webbings that are used in automotive, aerospace, industrial, and military applications.

5.6 This test method can be used for acceptance testing of commercial shipments but comparisons should be made with caution because estimates of between-laboratory precision are incomplete.

5.7 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, use samples for such comparative tests that are as homogenous as possible, drawn from the same lot of material as the samples that resulted in disparate results during initial testing, and randomly assigned in equal numbers to each laboratory. The test results from the laboratories involved should be compared using a statistical test for unpaired data, as a probability level chosen prior to the testing series. If 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 *Webbing Abrasion Tester*—The webbing abrasion tester consists of a suitable mechanism that will provide a reciprocating motion of the webbing over a standardized hex bar. One end of each specimen is attached to the mechanism and the other end passing over a hexagonal steel rod is attached to a weight. The hexagonal rod is so fixed as to subject the webbing specimen to abrasion on two adjacent edges as the drum moves the specimen across the rod. One example of such a mechanism is a reciprocating drum as illustrated in Fig. 1.

6.1.1 Mass "B" shall be 900 ± 60 g (2 lb ± 2 oz) for webbing with breaking strengths up to 4500 N (1000 lb), 1800 ± 60 g (4 lb ± 2 oz) for breaking strengths of 4500 to 13 500 N (1000 to 3000 lb) and 2400 ± 60 g (5.2 ± 2 lb) for breaking strengths over 13 500 N (3000 lb).

6.1.2 Steel hexagonal rods "C" shall be 6.35 ± 0.03 mm (0.250 ± 0.001 in.) when measured across opposite flat sides and the radius shall be 0.5 ± 0.2 mm (0.020 ± 0.008 in.). The steel shall have a cold drawn finish and a Rockwell Hardness of B-91 to B-101. The edges of the hexagonal rods shall not have any burrs, nicks or scale.

6.1.3 The mechanism "D" shall have a nominal outside diameter of 400 mm (16 in.) or be some mechanism able to

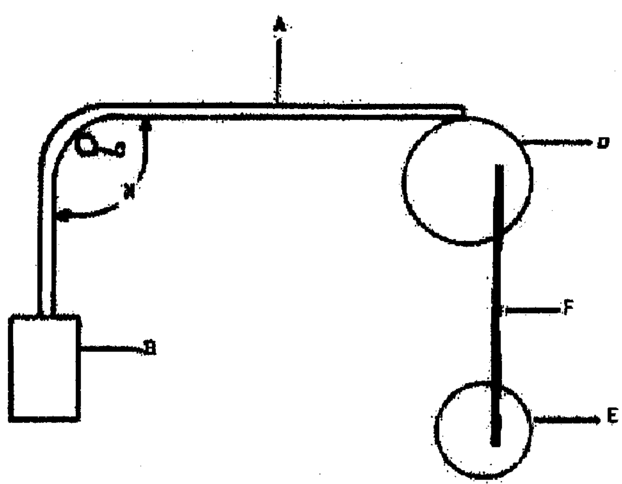

FIG. 1 Webbing Abrasion Tester

produce a reciprocating motion of at least 300 mm (12 in.) over the hex rod with a suitable means for attaching the specimen to be tested without damage to the specimen.

6.1.4 The crank-arm "F" shall be attached to the mechanism "D" and to the driver disk "E" in such a manner that when the specimen is attached to the mechanism, the specimen during the test will oscillate over the hexagonal rod the required distance during each stroke and at the required rate (see 10.4).

6.1.5 The hexagonal rod shall be so placed that specimen "A" with the weight attached to one end and the other end passing over the hexagonal rod and attached to the drive mechanism will form an angle of 85 ± 2° "H".

6.2 *Tensile Testing Machine*, CRE-Type equipped with split-drum webbing clamps as described in Federal Test Method 191b, Method 4108.

7. Sampling and Test Specimens

7.1 *Lot Sample*—Take a lot sample as directed in the applicable material specification. In absence of such a specification randomly select five rolls or pieces to constitute the lot sample.

7.2 *Laboratory Sampling Unit*—As a laboratory sampling unit take from each roll or piece one piece of webbing that is 2.8 m (3.0 yd) in length.

7.3 *Test Specimens*—From each laboratory sampling unit, cut 2 test specimens 1.4 m (1.5 yd) in length. Mark one specimen "A" for abraded and the other "U" for unabraded.

7.3.1 When the lot or shipment consists of less than 5 rolls or pieces, randomly select 5 test specimens that represent all rolls or pieces in the lot or shipment.

7.4 Ensure specimens are free of folds, creases, or wrinkles. Avoid getting oil, water, grease, and so forth, on the specimens when handling.

8. Conditioning

8.1 Condition the test specimens to moisture equilibrium for testing in the standard atmosphere for testing textiles in accordance with Practice D 1776 or, if applicable, in the specified atmosphere in which the testing is to be performed.

8.2 In the event of dispute concerning the results of tests that may be affected by the moisture content, test specimen(s) shall be preconditioned by bringing them to approximate moisture equilibrium in the standard atmosphere for preconditioning textiles in accordance with Practice D 1776.

9. Preparation and Calibration of Test Apparatus

9.1 Ensure the test machine is on a level, sturdy surface and free from vibration.

9.2 For hexagonal rods a manufacturer's certificate of compliance shall be acceptable as to the requirements as described in 6.1.2.

10. Procedure

10.1 Condition the "A" test specimens in the standard atmosphere for testing textiles, in accordance with Section 8.

10.2 Attach the required mass (6.1.1) to one end of the test specimen, pass the other end over the hexagonal rod and attach to the drum. The length of the test specimen(s) shall be adjusted, without altering the original length, so that the test specimen(s) will oscillate across the hexagon rod and each end of the abraded area will be equidistant from the ends of the test specimen(s).

10.3 The edges of each new hexagonal rod shall be identified as 1 through 6, and rotated after each use so that no abrading edges are used more than once. Use edge 1 and two for one test specimen, edge 3 and 4 for a second test specimen, edges 5 and 6 for a third test specimen, and then discard the rod.

10.4 Oscillate the mechanism so that the test specimen(s) are given a 300 ± 25 mm (12 ± 1 in.) traverse over the rod at the rate of 1 ± .03 strokes (0.5 cycles) per second for 5000 strokes (2500 cycles). One single stroke is 300 ± 25 mm (12 ± 1 in.) in one direction only.

10.5 After the machine has stopped at the predetermined number of cycles remove the test specimen(s) from the abrading machine.

10.6 Continue as directed in 10.2–10.5 until all the required specimens have been abraded for each laboratory sampling unit.

10.7 Determine the breaking force of the abraded specimens (A) and the unabraded specimens (U) for each laboratory sampling unit in the lot to the nearest 1 % as directed in Fed-Std-191, Method 4108 set as follows:

10.7.1 Attach the split drum webbing clamps in the tensile tester and set the distance between them to 250 mm (10 in.) center to center.

10.7.2 Set the testing speed to 75 ± 25 mm (3 ± 1 in./min).

11. Calculation

11.1 Calculate the average breaking force for the lot of the abraded test specimens from the results of the laboratory sampling units.

11.2 Calculate the average breaking force for the lot of the unabraded test specimens from the results of the laboratory sampling units.

11.3 Calculate the percentage of retained breaking force to the nearest 1 % for the lot using Eq 1:

$$AR = \frac{100A}{U} \tag{1}$$

where:

AR = abrasion resistance, %,
A = average breaking force of the abraded specimens, N (lb), and
U = average breaking force of the unabraded specimens, N (lb).

11.3.1 When data are automatically computer processed, calculations are generally contained in the associated software. It is recommended that computer-processed data be verified against known property values and its software described in the report.

12. Report

12.1 Report that the abrasion resistance was determined in accordance with Test Method D6770. Describe the material or product sampled.

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

12.2.1 Abrasion resistance, percent retained in breaking force.

12.2.2 Breaking force of abraded test specimens.

12.2.3 Breaking force of unabraded test specimens.

12.2.4 For computer-processed data, identify the program (software) used.

13. Precision and Bias

13.1 An intralaboratory test was conducted for the determination of precision and bias of this test method. The results of the test are attached as Table 1.

NOTE 1—Because the intralaboratory test included less than the recommended five laboratories, estimates of precision data may be either underestimated or overestimated to a considerable extent and should be used with special caution.

13.2 *Precision*—A statement on the precision of this test method is being developed. The results will be included when available.

13.3 *Bias*—The procedure of this test method procedures a test value that can be defined only in terms of this test method. There is no independent, referee method by which bias may be determined. No known bias has been determined for this test method.

14. Keywords

14.1 hex-bar abrasion resistance; webbing

TABLE 1 Raw Data from Intralaboratory Test

Lab.	Opr.	Material 1—Before Abrasion						Material 2—After Abrasion						Total Opr. Sum
		Test 1	Test 2	Test 3	Test 4	Test 5	Opr. Sum	Test 1	Test 2	Test 3	Test 4	Test 5	Opr. Sum	
Set 1	1	4.720	4.820	4.600	4.700	4.600	23.440	4.620	4.460	4.680	4.600	4.620	22.980	46.420
	2	4.600	4.720	4.700	4.720	4.680	23.420	4.640	4.600	4.580	4.680	4.600	23.100	46.520
	3	4.580	4.720	4.720	4.560	4.720	23.300	4.620	4.480	4.400	4.520	4.480	22.500	45.800
	4	4.740	4.740	4.520	4.720	4.740	23.460	4.500	4.420	4.640	4.540	4.620	22.720	46.180
	5	4.700	4.660	4.600	4.700	4.680	23.340	4.620	4.620	4.500	4.520	4.380	22.640	45.980
	6	4.600	4.680	4.500	4.480	4.540	22.800	4.380	4.480	4.520	4.400	4.560	22.340	45.140
	Lab Sum						139.760						136.280	276.040
Set 2	1	4.600	4.720	4.600	4.720	4.680	23.320	4.420	4.220	4.180	4.320	4.280	21.420	44.740
	2	4.680	4.700	4.660	4.700	4.640	23.380	4.520	4.500	4.560	4.520	4.640	22.740	46.120
	3	4.660	4.720	4.660	4.660	4.640	23.340	4.460	4.540	4.640	4.500	4.580	22.720	46.060
	4	4.760	4.740	4.640	4.660	4.380	23.180	4.540	4.620	4.620	4.560	4.580	22.920	46.100
	5	4.680	4.700	4.740	4.620	4.680	23.420	4.500	4.440	4.480	4.480	4.440	22.340	45.760
	6	4.640	4.720	4.740	4.840	4.780	23.720	4.600	4.400	4.600	4.520	4.580	22.700	46.420
	Lab Sum						140.360						134.840	275.200
Set 3	1	4.680	4.720	4.700	4.700	4.680	23.480	4.500	4.460	4.480	4.540	4.460	22.440	45.920
	2	4.620	4.600	4.680	4.680	4.620	23.200	4.500	4.560	4.600	4.580	4.640	22.880	46.080
	3	4.560	4.740	4.560	4.680	4.720	23.260	4.660	4.120	4.260	4.520	4.240	21.800	45.060
	4	4.740	4.680	4.720	4.580	4.460	23.180	4.600	4.440	4.360	4.600	4.660	22.660	45.840
	5	4.700	4.700	4.660	4.620	4.700	23.360	4.540	4.480	4.240	4.300	4.260	21.820	45.200
	6	4.700	4.720	4.760	4.720	4.720	23.620	4.580	4.160	4.440	4.380	4.420	21.980	45.600
	Lab Sum		140.120										133.580	273.700
Set 4	1	4.820	4.680	4.680	4.660	4.700	23.540	4.500	4.380	4.440	4.400	4.480	22.200	45.740
	2	4.700	4.720	4.660	4.700	4.700	23.480	4.500	4.460	4.480	4.440	4.420	22.300	45.780
	3	4.680	4.480	4.700	4.720	4.680	23.260	4.300	4.480	4.420	4.260	4.480	21.940	45.200
	4	4.720	4.800	4.740	4.680	4.680	23.620	4.540	4.500	4.500	4.460	4.480	22.480	46.100
	5	4.680	4.700	4.680	4.580	4.660	23.300	4.580	4.600	4.580	4.540	4.560	22.860	46.160
	6	4.660	4.700	4.740	4.580	4.600	23.280	4.600	4.580	4.420	4.660	4.540	22.800	46.080
	Lab Sum						140.480						134.580	275.060
Set 5	1	4.620	4.580	4.680	4.720	4.600	23.200	4.520	4.460	4.460	4.480	4.500	22.420	45.620
	2	4.580	4.660	4.700	4.700	4.680	23.320	4.500	4.540	4.400	4.580	4.500	22.520	45.840
	3	4.720	4.640	4.640	4.660	4.620	23.280	4.540	4.440	4.460	4.600	4.480	22.520	45.800
	4	4.500	4.680	4.620	4.660	4.620	23.080	4.480	4.500	4.520	4.560	4.480	22.540	45.620
	5	4.480	4.760	4.640	4.580	4.700	23.160	4.560	4.420	4.440	4.600	4.380	22.400	45.560
	6	4.680	4.700	4.660	4.700	4.720	23.460	4.280	4.460	4.440	4.500	4.420	22.100	45.560
	Lab Sum						139.600						134.500	274.000
Grand Total							700.220						673.780	1374.000

Units are in Thousands of Pounds; for example, 4.820 = 4,820 lb.

TABLE 2 ANOVA Table Reference

Sources of Variation[A]	Sums of Squares[B]	Degrees of Freedom[C]	Mean Squares[D]	Components of Variance Estimated from Observed Mean Squares[E]
L	(4) – (2)	L – 1	SOS / DOF	(MS(L) – MS(O.L)) / (L – 1)
O (L)	(3) – (4)	L(O – 1)	SOS / DOF	(MS(O.L) – MS(S.LO)) / S
S (LO)	(1) – (3)	LO(S – 1)	SOS / DOF	V(S.LO)
Totals	(1) – (2)	LOS – 1		

[A] L = number of laboratories = Laboratories
O(L) = number of operators within laboratories = Operators in Laboratories
S(LO) = number of specimens within laboratories and operators = Specimens in Labs, and Operators
[B] (1) = the sum of the individual observations squared = Σ(individual observations)^2 = Σx^2
(2) = grand totals squared / labs × operators × samples = (Σ grand totals)^2 / LOS = $(\Sigma x)^2$/ LOS
(3) = the sum of operator totals squared / samples per op. = Σ(operator totals)^2 / S
(4) = the sum of lab totals sq. / op. per lab × samples per op. = Σ(laboratory totals)^2 / OS
Note: L, O, and S are respectively the number of laboratories, operators within a laboratory, and specimens within laboratories.
[C] Degrees of Freedom
L – 1 = the total number of labs minus 1
L(O – 1) = the total number of labs × (the total number of operators per lab minus one operator)
LO(S – 1) = the total number of labs × the total number of operators per lab × (the total number of specimens per operator minus one)
LOS – 1 = the total number of labs × the total number of operators per lab × the total number of specimens per operator minus one
[D] Mean Square = sum of the square divided by the degree of freedom
[E] Components of Variance Estimated from Observed Mean Squares
Component of Variance—Single Operator
V(S.LO) = MS(S.LO) = Variance of Specimens in Labs and Operators is equal to the Mean Square S(LO)
Component of Variance—Within Lab
V(O.L) = (MS(O.L) – MS(S.LO)) / S = Variance of Operators in a Lab is equal to the Mean Square O(L) minus the Mean Square S(LO) divided by the number of specimens per operator
Component of Variance—Between Labs
V(L) = (MS(L) – MS(O.L)) / (L – 1) = Variance of Labs is equal to the Mean Square L minus the Mean Square O(L)) divided by the number of labs minus one

TABLE 3 ANOVA Table (from Table 1 Data—Material 1)

Sources of Variation	Sums of Squares[A]	Degrees of Freedom	Mean Squares	Components of Variance Estimated from Observed Mean Squares
L—Laboratories	0.0224	5 –1 = 4	0.0056	0.0003
O(L)—Operators in Labs	0.1658	5 × (6 – 1) = 25	0.0066	0.0004
S(LO)—Specimens in Labs and Operators	0.5734	5 × 6 × (5 – 1) = 120	0.0048	0.0048
Totals	0.7617	5 × 6 × (5 – 1) = 149		

[A] Calculations for Sums of Squares
(1) Σx^2
$4.72^2 + 4.82^2 + ... + 4.70^2 + 4.72^2$ = 3,269.4820
(2) $(\Sigma x)^2$ / LOS
$(700.22)^2$ / (5) (6) (5) = 3,268.7203 = [490,308.0484 / 150 = 3268.7203]
(3) Σ(operator totals)^2 / S
$(23.44^2 + 23.42^2 + ... + 23.16^2 + 23.46^2)$ / 5 = 3,268.9086 = [16,344.5428 / 5 = 3,268.9086]
(4) Σ(laboratory totals)^2 / OS
$(139.76^2 + 140.36^2 + ... + 140.48^2 + 139.50^2)$ / (6) (5) = 3,268.7427 = [98,062.2820 / 30 = 3,268.7427]

TABLE 4 ANOVA Table (from Table 1 Data—Material 2)

Sources of Variation	Sums of Squares[A]	Degrees of Freedom	Mean Squares	Components of Variance Estimated from Observed Mean Squares
L—Laboratories	0.1270	5 –1 = 4	0.0317	0.0004
O(L)—Operators in Labs	0.7505	5 × (6 – 1) = 25	0.0300	0.0045
S(LO)—Specimens in Labs and Operators	0.9018	5 × 6 × (5 – 1) = 120	0.0075	0.0075
Totals	1.7793	5 × 6 × (5 – 1) = 149		

[A] Calculations for Sums of Squares
(1) Σx^2
$4.62^2 + 4.46^2 + ... + 4.50^2 + 4.42^2$ = 3,028.3092
(2) $(\Sigma x)^2$ / LOS
$(673.78)^2$ / (5) (6) (5) = 3,026.5299 = [453,979.4884 / 150 = 3026.5299]
(3) Σ(operator totals)^2 / S
$(22.98^2 + 23.10^2 + ... + 22.40^2 + 22.10^2)$ / 5 = 3,027.4074 = [15,137.0372 / 5 = 3,027.4074]
(4) Σ(laboratory totals)^2 / OS
$(136.28^2 + 134.84^2 + ... + 134.58^2 + 134.50^2)$ / (6) (5) = 3,026.6569 = [90,799.7068 / 30 = 3,026.6569]

TABLE 5 Components of Variance

	Components of Variance	
	Material 1	Material 2
V(L)—Between Laboratories	0.0000	0.0004
V(O.L)—Within Laboratory	0.0004	0.0045
V(S.LO)—Single Operator	0.0048	0.0075

The above data is from the ANOVA Tables (see Tables 3 and 4).
Components of Variance that are negative are reflected as zero (0).

TABLE 6 Components of Variance as Standard Deviations

	Components of Variance as Standard Deviation	
	Material 1	Material 2
Single Operator Precision	0.069	0.087
Within-Laboratory Precision	0.019	0.067
Between-Laboratory Precision	0.000	0.021

Components of Variance as Standard Deviation are the Square Roots of the Components of Variance (see Table 5).
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.

TABLE 7 Critical Differences

	Critical Differences	
	Material 1	Material 2
Single Operator Precision	0.10	0.12
Within-Laboratory Precision	0.11	0.22
Between-Laboratory Precision	0.11	0.23

Critical Difference is calculated after determining the Standard Error (see Tables 9 and 10).
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.

TABLE 8 Confidence Limits (Bias)

	Confidence Limits (Bias)	
	Material 1	Material 2
Single Operator Bias	0.07	0.08
Within-Laboratory Bias	0.08	0.16
Between-Laboratory Bias	0.08	0.16

Confidence Limits are calculated after determining the Standard Error (see Table 9 and Table 11).
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.

TABLE 9 Determining Standard Error

NOTE—Standard Error must be determined before the Critical Difference can be calculated.
S_T = the Standard Error.
S_S = the Single Operator Component of Variance as Standard Deviation (see Table 6).
S_W = the Within Laboratory Component of Variance as Standard Deviation (see Table 6).
S_B = the Between Laboratories Component of Variance as Standard Deviation (see Table 6).
n = the number of specimen observations per operator minus 1 (S – 1).
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.

	Material 1	Material 2
Standard Error—Single Operator		
$S_T = (S_S^2/ n)^{1/2}$	$S_T = (S_S^2/ n)^{1/2}$	$S_T = (S_S^2/ n)^{1/2}$
	$S_T = (.069^2/ 5 - 1)^{1/2}$	$S_T = (.087^2/ 5 - 1)^{1/2}$
	$S_T = 0.035$	$S_T = 0.043$
Standard Error—Within Laboratory		
$S_T = [S_W^2 + (S_S^2/ n)]^{1/2}$	$S_T = [S_W^2 + (S_S^2/ n)]^{1/2}$	$S_T = [S_W^2 + (S_S^2 / n)]^{1/2}$
	$S_T = [.019^2 + (.069^2/ 5 - 1)]^{1/2}$	$S_T = [.067^2 + (.087^2/ 5 - 1)]^{1/2}$
	$S_T = 0.040$	$S_T = 0.080$
Standard Error—Between Laboratories		
$S_T = [S_B^2 + S_W^2 + (S_S^2/ n)]^{1/2}$	$S_T = [S_B^2 + S_W^2 + (S_S^2/ n)]^{1/2}$	$S_T = [S_B^2 + S_W^2 + (S_S^2/ n)]^{1/2}$
	$S_T = [0.00^2 + 0.019^2 + (0.069^2 / 5 - 1)]^{1/2}$	$S_T = [0.021^2 + 0.067^2 + (0.087^2/ 5 - 1)]^{1/2}$
	$S_T = 0.040$	$S_T = 0.083$

TABLE 10 Calculating Critical Difference

NOTE—1.414 = the Square Root of 2
z = 1.96 (the 95% Probability Level)
S_T = the Standard Error (see Table 8).
S_T = the Standard Error—Single Operator = 0.035 (Material 1); 0.043 (Material 2)
S_T = the Standard Error—Within Laboratory = 0.040 (Material 1); 0.080 (Material 2)
S_T = the Standard Error—Between Laboratories = 0.040 (Material 1); 0.083 (Material 2)
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.[A]
Critical Difference = 1.414 z S_T = 1.414 × 1.96 × S_T

	Material 1	Material 2
Critical Difference—Single Operator	CD = 1.414 z S_T	CD = 1.414 z S_T
	CD = 1.414 (1.96) (0.035)	CD = 1.414 (1.96) (0.043)
	CD = 0.10	CD = 0.12
Critical Difference—Within Laboratory	CD = 1.414 z S_T	CD = 1.414 z S_T
	CD = 1.414 (1.96) (0.040)	CD = 1.414 (1.96) (0.080)
	CD = 0.11	CD = 0.22
Critical Difference—Between Laboratories	CD = 1.414 z S_T	CD = 1.414 z S_T
	CD = 1.414 (1.96) (0.040)	CD = 1.414 (1.96) (0.083)
	CD = 0.11	CD = 0.23

[A] Critical Differences (see Table 7).

TABLE 11 Determining Confidence Limits

NOTE—z = 1.96 (the 95% Probability Level)
S_T = the Standard Error (see Table 8).
S_T = the Standard Error—Single Operator = 0.035 (Material 1); 0.043 (Material 2)
S_T = the Standard Error—Within Laboratory = 0.040 (Material 1); 0.080 (Material 2)
S_T = the Standard Error—Between Laboratories = 0.040 (Material 1); 0.083 (Material 2)
Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.[A]
Confidence Limits (±) = z S_T= 1.96 × S_T

	Material 1	Material 2
Confidence Limits—Single Operator	CL = z S_T CL = (1.96) (0.035) CL = 0.068	CL = z S_T CL = (1.96) (0.043) CL = 0.085
Confidence Limits—Within Laboratory	CL = z S_T CL = (1.96) (0.040) CL = 0.078	CL = z S_T CL = (1.96) (0.080) CL = 0.157
Confidence Limits—Between Laboratories	CL = z S_T CL = (1.96) (0.040) CD = 0.078	CL = z S_T CL = (1.96) (0.083) CD = 0.162

[A] Critical Differences (see Table 8).

TABLE 12 Miscellaneous Information

Mean (Average Measurement of all Observations)	
Material 1—Before Abrasion	Material 2—After Abrasion
4.668	4.492
Mode (The Most Frequently Occurring Measurement of all Observations)	
Material 1—Before Abrasion	Material 2—After Abrasion
4.700	4.480
Median (The Middle Measurement of all Observations)	
Material 1—Before Abrasion	Material 2—After Abrasion
4.680	4.500

Units are in Thousands; for example, 4.820 = 4,820 lb / 0.10 = 100 lb, and so forth.

TABLE 13 Critical Difference Percentages for Grand Total Averages

Single Operator Critical Difference at 95% Probability, Percent of Grand Averages											
Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Single Op. Critical Diff	/ 100 =	Percentage	Observation	Average	×	Single Op. Critical Diff	/ 100 =	Percentage
1	140.044	×	0.10	/ 100 =	0.13	1	134.756	×	0.12	/ 100 =	0.16
5	23.341	×	0.10	/ 100 =	0.02	5	22.459	×	0.12	/ 100 =	0.03
30	4.668	×	0.10	/ 100 =	0.00	30	4.492	×	0.12	/ 100 =	0.01
Within Lab (Set) Critical Difference at 95% Probability, Percent of Grand Averages											
Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Within Lab. Critical Diff	/ 100 =	Percentage	Observation	Average	×	Within Lab. Critical Diff	/ 100 =	Percentage
1	140.044	×	0.11	/ 100 =	0.15	1	134.756	×	0.22	/ 100 =	0.30
5	23.341	×	0.11	/ 100 =	0.03	5	22.459	×	0.22	/ 100 =	0.05
30	4.668	×	0.11	/ 100 =	0.01	30	4.492	×	0.22	/ 100 =	0.01
Between Lab (Sets) Critical Difference at 95% Probability, Percent of Grand Averages											
Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Within Lab. Critical Diff	/ 100 =	Percentage	Observation	Average	×	Within Lab. Critical Diff	/ 100 =	Percentage
1	140.044	×	0.11	/ 100 =	0.15	1	134.756	×	0.23	/ 100 =	0.31
5	23.341	×	0.11	/ 100 =	0.03	5	22.459	×	0.23	/ 100 =	0.05
30	4.668	×	0.11	/ 100 =	0.01	30	4.492	×	0.23	/ 100 =	0.01

TABLE 14 Confidence Limits Percentages for Grand Total Averages

Single Operator Confidence Limits at 95% Probability, Percent of Grand Averages

Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Single Op. Con. Limits	/ 100 =	Percentage	Observation	Average	×	Single Op. Con. Limits	/ 100 =	Percentage
1	140.044	×	0.07	/ 100 =	0.09	1	134.756	×	0.08	/ 100 =	0.11
5	23.341	×	0.07	/ 100 =	0.02	5	22.459	×	0.08	/ 100 =	0.02
30	4.668	×	0.07	/ 100 =	0.00	30	4.492	×	0.08	/ 100 =	0.00

Within Lab (Set) Confidence Limits at 95% Probability, Percent of Grand Averages

Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Within Lab. Con. Limits	/ 100 =	Percentage	Observation	Average	×	Within Lab. Con. Limits	/ 100 =	Percentage
1	140.044	×	0.08	/ 100 =	0.21	1	134.756	×	0.16	/ 100 =	0.30
5	23.341	×	0.08	/ 100 =	0.02	5	22.459	×	0.16	/ 100 =	0.04
30	4.668	×	0.08	/ 100 =	0.00	30	4.492	×	0.16	/ 100 =	0.01

Between Lab (Sets) Confidence Limits at 95% Probability, Percent of Grand Averages

Material 1—Before Abrasion						Material 2—After Abrasion					
Observation	Average	×	Within Lab. Con. Limits	/ 100 =	Percentage	Observation	Average	×	Within Lab. Con. Limits	/ 100 =	Percentage
1	140.044	×	0.08	/ 100 =	0.11	1	134.756	×	0.16	/ 100 =	0.22
5	23.341	×	0.08	/ 100 =	0.02	5	22.459	×	0.16	/ 100 =	0.04
30	4.668	×	0.08	/ 100 =	0.00	30	4.492	×	0.16	/ 100 =	0.01