



# Standard Test Method for Measuring Cut Resistance of Materials Used in Protective Clothing with Tomodynamometer (TDM-100) Test Equipment<sup>1</sup>

This standard is issued under the fixed designation F2992/F2992M; 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 covers the measurement of the cut resistance of a material when mounted on a mandrel and subjected to a cutting edge under a specified load using the Tomodynamometer (TDM-100).

1.1.1 This procedure is not valid for high-porosity materials which allow cutting edge contact with the mounting surface prior to cutting.

1.1.2 Test apparatus may have limitations in testing materials with a thickness greater than 20 mm.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

[D123 Terminology Relating to Textiles](#)

[D1000 Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications](#)

[D1776 Practice for Conditioning and Testing Textiles](#)

[F1494 Terminology Relating to Protective Clothing](#)

[F1790 Test Method for Measuring Cut Resistance of Mate-](#)

[rials Used in Protective Clothing with CPP Test Equipment](#)

### 2.2 ISO Standards:<sup>3</sup>

[ISO 13997 Protective Clothing—Mechanical Properties—Determination of Resistance to Cutting by Sharp Objects](#)

## 3. Terminology

### 3.1 Definitions:

3.1.1 *cut resistance, n*—in blade cut testing, the property that hinders cut through when a material or a combination of materials is exposed to a sharp-edged device.

3.1.2 *cut through, n*—in blade cut resistance tests, the penetration of the cutting edge entirely through material as indicated by electrical contact of the cutting edge and the conductive strip or substrate.

3.1.3 *cut through distance, n*—in cut resistance testing, the distance of required travel by the cutting edge to cut through the specimen.

3.1.4 *cutting edge, n*—in cut resistance tests, a sharp-edged device used to initiate cut through of a planar structure.

3.1.5 *no cut, n*—in cut resistance testing, a trial for which the load used is insufficient to cause a cut through in the maximum allowable blade travel of the apparatus.

3.1.5.1 *Discussion*—For this test method, the maximum allowable blade travel is 65 mm [2.6 in.].

3.1.6 *protective clothing, n*—an item of clothing that is specifically designed and constructed for the intended purpose of isolating all or part of the body from a potential hazard; or, isolating the external environment from contamination by the wearer of the clothing.

3.1.6.1 *Discussion*—In this test method, the potential hazard is cutting.

3.1.7 *calculated cutting load, n*—in cut resistance testing, the load required to cause a cutting edge to produce a cut through when it traverses the reference distance across the material being tested.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <http://www.iso.org>.

3.1.7.1 *Discussion*—The calculated cutting load is determined by performing a series of tests at three or more loads as described in Section 11. A material with a higher calculated cutting load is considered to be more cut resistant.

3.1.8 *reference distance, n*—in cut resistance testing, a standardized distance for a blade to travel across a material to produce a cut through.

3.1.8.1 *Discussion*—For this test method, the reference distance is 20 mm [0.8 in.].

3.2 *Additional Terminology*—Terms relevant to textiles are defined in Terminology D123. Terms relevant to protective clothing are defined in Terminology F1494.

## 4. Summary of Test Method

4.1 A cutting edge under a specified load is moved one time across a specimen mounted on a mandrel.

4.2 The cut through distance from initial contact to cut through is determined for each load.

4.2.1 A series of tests, at a minimum of three different loads must be performed to establish a range of cut distance at these different loads.

4.3 The test method is repeated using multiple loads to determine the calculated cutting load for the material.

## 5. Significance and Use

5.1 This test method assesses the cut resistance of a material when exposed to a cutting edge under specified loads. Data obtained from this test method can be used to compare the cut resistance of different materials.

5.2 This test method only addresses that range of cutting hazards that are related to a cutting action by a smooth sharp edge across the surface of the material. It is not representative of any other cutting hazard to which the material may be subjected such as serrated edges, saw blades, or motorized cutting tools. Nor is it representative of puncture, tear, or other modes of fabric failure.

## 6. Apparatus

6.1 *Test Principle*—The principle of the cut test is to measure the distance traveled by a cutting edge as it is maintained under a load during the test. The cut test apparatus

consists of the following primary components (see Fig. 1): (A) blade holder and straight line mechanism (B) a cutting edge, a Specimen (C) with conductive strip (D) and double side Mounting Tape (E) mounted to a (F) mandrel. The apparatus should propel the cutting edge across the specimen until sufficient work is applied to cause the specimen to cut through.

6.2 *TDM-100 Test Apparatus*<sup>4</sup>—The TDM-100 is capable of measuring the entire range of cut resistant materials through a horizontal constant speed of blade movement. The maximum linear displacement of the blade is 70 mm [2.75 in.] for the cutting edge. A constant perpendicular force is applied to the specimen throughout blade movement. The TDM-100 test apparatus (see Fig. 2) consists of a Motor and gearhead (1) with Slide system (2) and Blade support/clamp mechanism (3) and Blade (4) in contact with the specimen mounted on a cantilevered Mandrel and holder (5). The Beam (6) is connected to the mandrel. Cutting edge displacement is measured by a Distance meter (7) capable of measuring to 0.1 mm [0.004 in.]. Weights are placed on the Platen (8). These weights generate the load needed to penetrate the moving edge into the specimen and produce a cut through. The resulting load applied to the specimen against the blade equals twice the total weight placed on the platen. The calibration weights (9) are used to balance the beam with sample prior to adding weight to the lever arm. Movement of the Mandrel and holder mechanism is facilitated by use of the Loading /unloading handle (10). Leveling adjustment is facilitated by the Level mechanism (11). The apparatus should be capable of loads ranging from 10 g to 15 kg [0.35 oz to 33 lb].

6.2.1 *Cutting Speed*—The apparatus shall propel the cutting edge across the specimen at a constant speed of  $2.5 \pm 0.5$  mm/s [0.10 in./s].

6.2.2 *Cut Through Distance*—Cut through is detected by an electrical contact between the cutting edge and conductive strip.

<sup>4</sup> The sole source of supply of the TDM-100 Tomodynamometer is RGI Industrial Products, Inc., 755 Pierre Caisse, St-Jean-sur Richelieu, Quebec, Canada 8C6 7Y5, E-mail: lapointe.louis@rgicanada.com. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

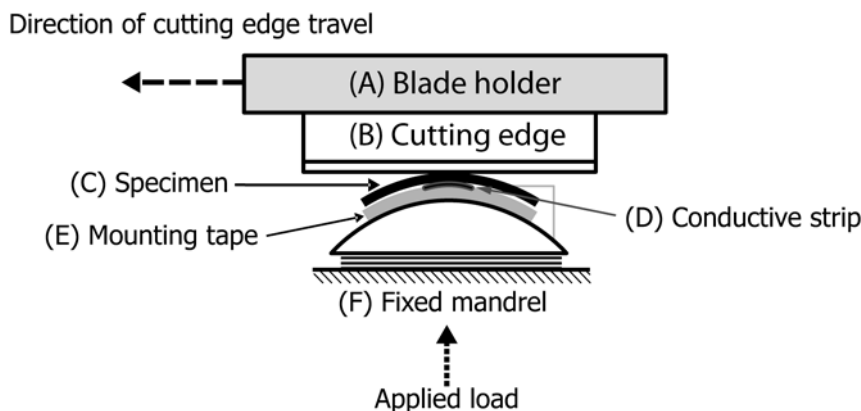


FIG. 1 Schematic of Cut Test Principle

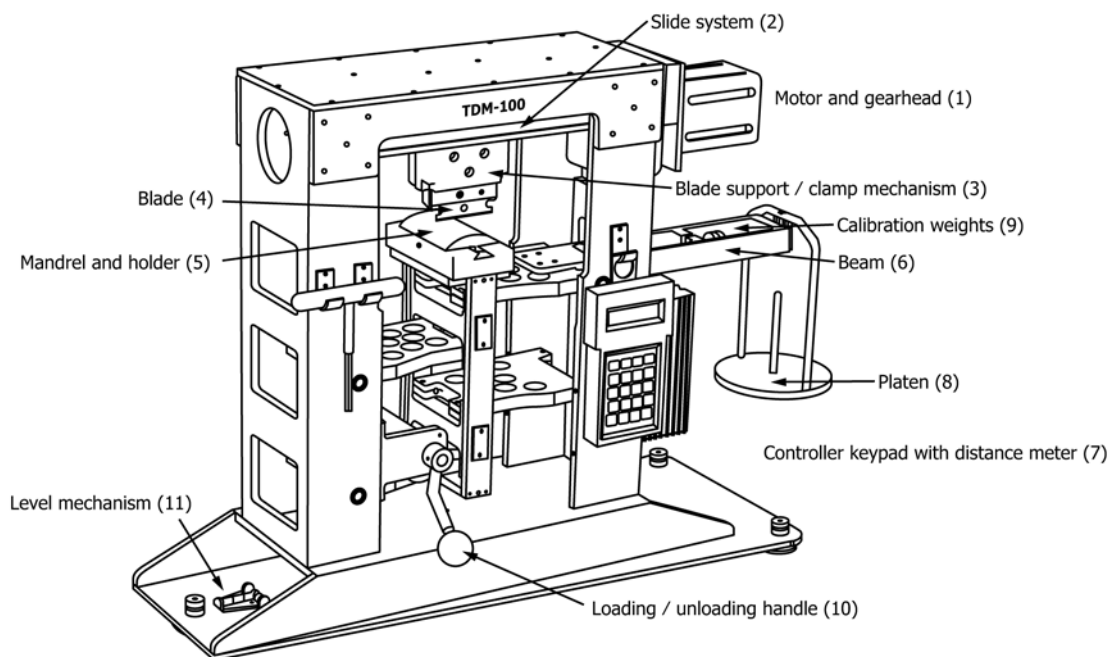


FIG. 2 Schematic of the TDM-100 Tester (Front View)

6.2.3 *Mandrel*—The top surface of the mandrel is a rounded form which has an arc of at least 32 mm [1.25 in.] in a circle having a radius of 38 mm [1.5 in.]. The surface of the mandrel shall be conductive and made of metal.

6.3 *Cutting Edge*—Single-edged razor blades<sup>5</sup> shall be used as the cutting edge. The blades shall be made of stainless steel with a hardness greater than 45 HRC. Blades shall be  $1.0 \pm 0.5$  mm [ $0.039 \pm 0.020$  in.] thick and ground to a bevel width of  $2.5 \pm 0.2$  mm [ $0.098 \pm 0.008$  in.] along a straight edge resulting in a primary bevel angle of  $22^\circ \pm 2^\circ$ . The blade should also contain a honed secondary bevel at the cutting edge with an inclined angle of  $36^\circ \pm 2^\circ$ . Blades shall have a cutting edge length greater than 65 mm [2.56 in.] and shall have a width greater than 18 mm [0.71 in.].

6.4 *Conductive Strip*—A 6-mm [0.26-in.] wide copper or aluminum conductive strip with adhesive backing will be used that is no thicker than 0.3 mm [0.01 in.]. The conductive strip will be centered down the length of the mandrel between the sample and mounting tape. For samples that contain electrically conductive materials, elimination of the conductive metal strip is permitted.

6.5 *Mounting Tape*—Double-sided tape<sup>6</sup> shall be used to secure the test specimen to the apparatus. The tape should have a cloth carrier and rubber-based adhesive on both sides with a total thickness of  $0.38 \pm 0.25$  mm, weight of  $473 \pm 33$  g/m<sup>2</sup>,

and a minimum tensile strength of 90 N/cm (see Test Methods D1000 for details on test methods for adhesive tape).

## 7. Hazards

7.1 The cut test equipment can pose a potential hazard to the technician if proper safety precautions are not followed. The cut test apparatus is to be used only by authorized personnel that have been properly trained.

7.2 Store used blades in a sealed container.

7.3 Remove blades from the apparatus at the end of each test or when the apparatus is not in use.

7.4 Keep hands out of cutting area when a blade is installed in the apparatus and when the apparatus is operating.

7.5 Turn off machine before making instrument adjustments to avoid the chance of a low-voltage shock.

## 8. Sampling and Test Specimens

8.1 *Lot Sample*—As a lot sample for acceptance testing, take at random the number of shipping units directed in an applicable material specification.

8.2 *Laboratory Sample*—As a laboratory sample for acceptance testing, take at random from each shipping unit in the lot sample, the number of packages or pieces directed in an applicable material specification or other agreement between purchaser and the supplier.

8.3 *Protective Clothing Sample*—A sample of actual Protective Clothing Article.

### 8.4 Test Specimens:

8.4.1 Take test specimens at random from each sample.

8.4.1.1 When performing up to fifteen cut tests per specimen, as when determining the reference load of the

<sup>5</sup> Blade 88-0121 Type GRU-GRU textile blade available from Energizer Personal Care, LLC (formerly American Safety Razor Company), One Razor Blade Lane, Verona, VA 24482 has proven satisfactory for this test method. It is the sole source of supply of the apparatus known to the committee at this time. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

<sup>6</sup> Polyken® 108Fr Double-Coated Cloth Tape manufactured by Berry Plastics Corporation or equivalent has proven satisfactory for this test method.

material, the specimen shall have a minimum dimension of 25.4 by 100 mm [1.0 by 4.0 in.].

8.4.1.2 For textile materials, cut the specimen on the bias as to create an angle of 0.785 rad (45°) between the machine and cross-machine directions of the material (see Terminology **D123** for the definition of machine directions of textile materials).

NOTE 1—For small samples of insufficient width to cut the sample on the bias, such as protective clothing, cut the test specimen parallel to the machine direction up to the maximum allowable width and then rotate it 0.785 rad (45°) when mounting it on the apparatus.

## 9. Calibration and Standardization

### 9.1 Beam Balancing Procedure – #1:

9.1.1 Remove any sample or tape from the sample holder.

9.1.2 Install sample holder on the base.

9.1.3 Carefully control the vertical movement of the sample holder when unlocking the cam lock device with the loading/unloading handle.

9.1.4 Place the mechanism horizontally.

9.1.5 If mechanism stays in equilibrium, the apparatus is correctly balanced. If mechanism loses equilibrium, follow procedure #2 (9.2) for beam balancing.

### 9.2 Beam Balancing Procedure – #2:

9.2.1 Lock movement of the beam in the higher position with cam lock device.

9.2.2 Remove blade holder with the quick release ball lock device.

9.2.3 Place the mechanism horizontally.

9.2.4 Counterbalance with the two fine adjustment nuts until the mechanism stays in equilibrium.

### 9.3 Validation of Cutting Edge Supply:

9.3.1 *Calibration Material*—Calibration material is a neoprene sheet,<sup>7</sup> having a hardness of 50 ± 5 Shore A and a thickness of 1.57 ± 0.05 mm [0.062 ± 0.002 in.].

9.3.1.1 Store the calibration material under controlled laboratory conditions described in Practice **D1776** in an opaque container to prevent deterioration by heat or ultraviolet light.

#### 9.3.2 Blade Validation Procedure:

9.3.2.1 Take a specimen of the calibration material and follow the mounting procedure as described in **11.1**.

9.3.2.2 Calculate the average cut through distance using a minimum of 1 blade cut out of 20 for each blade supply by performing a cut test with each blade following the test procedure described in **11.2** using a cutting load of 500 gf.

9.3.2.3 To be a valid blade supply, the average cut through distance for the blade supply must be between 15.0 and 25.0 mm [0.6 and 1.0 in.], and the cut through distances for all the tested blades in the supply should not differ by more than 10 mm [0.4 in.].

<sup>7</sup> Fairprene Code: WFP-N2RS (Comparable to NS-5550 Neoprene Sheet Stock Material) manufactured by Longwood Industries, Inc., Greensboro, NC (website [www.fairprene.com](http://www.fairprene.com)) has proven satisfactory for this method. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

## 10. Conditioning

10.1 Condition test specimens as indicated in Practice **D1776**.

## 11. Procedure

### 11.1 Specimen Mounting:

11.1.1 Cover the mandrel surface with double-sided tape and place a 6-mm [0.25-in.] conductive strip with the adhesive side up centered down the length of the mandrel on the double sided tape. Clip the end of this strip to the mandrel, or attach it securely to the electrical circuit that detects cut through. Without stretching or distorting the material, place the test specimen over the tape with the surface to be cut facing up. Apply firm pressure on the specimen to secure it to the mandrel. For samples that contain electrically conductive materials, the conductive strip can be eliminated.

NOTE 2—The tape and strip can also be applied directly to the sample before the test specimen is cut and then mounted directly to the mandrel. This procedure is helpful for materials that curl or distort when being cut from the sample.

11.1.2 Insert the mandrel in the mandrel holder with the sample facing the blade and position mandrel in place.

11.1.3 Balance the beam with sample prior to adding weights to the platen. This can be done either by adjusting the calibration weights or by adding half of the sample mounting weight to the platen.

### 11.2 Test Procedure for Measuring the Cut Through Distance:

11.2.1 Insert a new blade from a validated blade supply in the blade clamp and tighten the blade clamping system.

NOTE 3—Refer to **9.3** for instructions on how to validate the blade supply.

11.2.2 Verify that the cutting arm is at the ready position making certain that only the blade edge and not the corner of the blade will touch the specimen. All cuts should be made with the blade moving right to left.

11.2.3 Select and install weights to produce the desired cutting load.

11.2.4 Zero the blade travel distance meter.

11.2.5 Carefully ease the blade into contact with the specimen and immediately start the apparatus.

11.2.6 After cut through is detected and the motor arm stops, record the cut through distance.

11.2.6.1 If no cut through occurs within 69 mm [2.7 in.] of blade travel, stop the machine and indicate that the load was insufficient to cut through the specimen by reporting a *no cut*.

11.2.7 Lock the lever arm with blade retracted from the specimen, remove the weights, and discard the used blade.

### 11.3 Test Procedure for Determining the Calculated Cutting Load:

11.3.1 Repeat the test procedure described in **11.2** using a minimum of three different loads. The loads should be distributed to produce cut through distances in the range of 5.0 to 50.8 mm [0.2 to 2.0 in.]. When performing multiple cut tests per specimen, each cut should be spaced a minimum of 6.35 [0.25 in.] from the previous cut.



11.3.1.1 Five replicated tests at each of three different loads have been found to be adequate; however, an alternate allocation of test loads may be considered for highly reinforced materials. If possible, the loads should be selected as to produce five data points in the 5 to 20 mm [0.2 to 0.8 in.] cut through distance range, five data points in the 20 to 33 mm [0.8 to 1.3 in.] cut through distance range, and five data points in the 33 to 50.8 mm [1.3 to 2.0 in.] cut through distance range. For more details on selecting the different loads to use with this procedure, see [Appendix X1](#).

## 12. Calculation of Results

### 12.1 Blade Sharpness Correction:

12.1.1 Calculate the blade sharpness correction factor,  $C_s$ , of the blade supply by dividing 20 mm [0.8 in.] by the average cut through distance determined in the blade validation procedure described in [9.3.2](#).

12.1.2 Multiply the measured cut through distances recorded during the test by  $C_s$  to create normalized distance data.

### 12.2 Calculated Cutting Load Determination:

12.2.1 When testing specimens using multiple loads for the purposes of determining the calculated cutting load (see [11.3](#)), perform an inverse regression analysis (see [Note 4](#) and [Note 1](#)) of the cutting loads and the log of the normalized cut through distances to estimate the calculated cutting load required to produce cut through at the reference distance of 20 mm [0.8 in.]. For more details about performing the regression analysis and an example calculation, refer to [Annex A1](#).

NOTE 4—The use of the common logarithm of the cut through distance when performing the regression analysis has been found to provide the most reliable method for estimating the calculated cutting load.

## 13. Interpretation of Results

13.1 Materials that can do either of the following are capable of delivering better cut resistance:

13.1.1 Provide higher cut resistance by demonstrating a longer distance traveled when equal loads are mounted.

13.1.2 Provide higher cut resistance by demonstrating resistance to higher loads at the same cut through distance, which can be accomplished by determining the calculated cutting load for the material.

## 14. Report

14.1 Report the following:

14.1.1 Test was performed in accordance with Test Method F2992/F2992M – for TDM.

14.1.2 Name and model number of the cut testing device used.

14.1.3 *Sample Identification*—Sample description of fabric or material to indicate construction, fiber (or blends), and areal density in  $\text{g/m}^2$  [ $\text{oz/yd}^2$ ],

14.1.4 Identification of blade supply designation and lot number,

14.1.5 Results of the blade validation indicating that the blade supply is valid.

14.1.6 *Test Result*:

14.1.6.1 Report the loads used, the measured cut through distances at each load, the calculated cutting load, the standard deviation, and the coefficient of determination,  $R^2$ , of the regression analysis.

14.1.7 Report any variations in procedure from this test method.

## 15. Precision and Bias

15.1 An interlaboratory test program was conducted in 2002 to obtain precision data for determining the calculated cutting load using the TDM-100.

15.2 Eight different materials were used in that interlaboratory program. Duplicate determinations of calculated cutting loads were made in each of six laboratories.

15.3 The results of the precision calculations for repeatability and reproducibility are given in [Table 1](#).

15.4 The precision of this test method may be expressed in the format of the following statements that use what is called an appropriate value of  $r$  or  $R$ , that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of  $r$  or  $R$  associated with a mean level in [Table 1](#), closest to the mean level under consideration at any given time, for any given material in routine testing operations.

15.5 *Repeatability*—The repeatability,  $r$ , of this test method has been established as the appropriate value tabulated in [Table](#)

**TABLE 1 Precision of the Test Method, Calculated Cutting Load**

NOTE 1—

$S_r$  = repeatability standard deviation,  
 $r$  = repeatability = 2.80 times the square root of the repeatability variance,  
 $S_R$  = reproducibility standard deviation, and  
 $R$  = reproducibility = 2.80 times the square root of the reproducibility variance.

Material	Calculated Cutting Load Average (g)	Within Laboratories		Between Laboratories	
		$S_r$	$r$	$S_R$	$R$
Cotton	446	40.2	112	103.0	286
Leather	184	30.2	84	57.9	160
Woven HMWPE	482	14.6	41	71.5	198
Knit Reinforced HMWPE	3427	111.8	310	172.2	477
Neoprene	504	31.3	87	59.8	166
Neoprene	1050	160.7	446	287.8	798
Woven p-Aramid	376	32.7	91	106.3	295
Knit p-Aramid	1190	40.7	113	150.4	417

1. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated  $r$  (for any given level) must be considered as derived from different or non-identical sample populations.

15.6 *Reproducibility*—The reproducibility,  $R$ , of this test method has been established as the appropriate value tabulated in **Table 1**. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated  $R$  (for any given level) must be considered to have come from different or non-identical sample populations.

15.7 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since value (of the test property) is exclusively defined by the test method. Bias, therefore, cannot be determined.

## 16. Keywords

16.1 calculated cutting load; cut protection; cut resistance; cut through distance; protective clothing

## ANNEX

### (Mandatory Information)

#### A1. CALCULATED CUTTING LOAD DETERMINATION

##### A1.1 Regression Analysis

A1.1.1 Using the loads as the independent variable,  $x$ , and cut-through distances as the dependent variable,  $y$ , perform an inverse linear regression analysis<sup>8</sup> by first performing a log transformation of the cut-through distances and then calculating the slope and intercept of the regression line as indicated in **Eq A1.1**.

$$y' = b_0 + b_1 x \quad (\text{A1.1})$$

where:

$y'$  = log transformation of the normalized cut through distance,  $\log_{10} y$ ,

$X$  = applied load,

$b_0$  = intercept of the regression line, and

$b_1$  = slope of the regression line.

A1.1.2 The load required to produce a cut through at the reference distance,  $y_r$ , of 20 mm can then be estimated from **Eq A1.2**. This load, known as the calculated cutting load,  $x_r$ , can be used to compare the cut resistance of samples.

Calculated Cutting Load Equation:

$$x_r = (\log_{10}(y_r) - b_0)/b_1 \quad (\text{A1.2})$$

where:

$x_r$  = calculated cutting load, gf, and

$y_r$  = reference distance, 20 mm.

A1.1.3 The standard deviation,  $s$ , and 95 % confidence interval of the calculated load estimate can be calculated using **Eq A1.3 and A1.4**.

Standard Deviation of the Calculated Cutting Load:

$$s = \sqrt{\frac{MSE}{b_1^2} \left[ 1 + \frac{1}{n} + \frac{(x_r - \bar{X})^2}{\sum (x_i - \bar{X})^2} \right]} \quad (\text{A1.3})$$

where:

$MSE$  = mean square error,

$\bar{X}$  = mean load, and

$N$  = number of measurements.

95 % Confidence Interval of the Calculated Cutting Load:

$$x_r \pm t_{(1 - \frac{\alpha}{2}; n - 2)} s \quad (\text{A1.4})$$

##### A1.2 Example Calculation

A1.2.1 An example dataset of loads and normalized cut through distances is provided in **Table A1.1**. The calculated cutting load,  $x_r$ , of the dataset is 435 gf with a standard deviation of 45.4 gf resulting in a 95 % confidence limit of  $\pm 98$  gf ( $337 \leq x_r \leq 533$  gf). The  $R^2$  of regression line is 0.94.

A1.2.2 The results of the regression analysis using standard MS Excel® formulas are shown in **Table A1.2** with the corresponding cell formulas shown in **Table A1.3**. The application of the regression analysis is shown graphically in **Fig. A1.1**. A plot of the untransformed (normalized) cut through distances versus applied load is shown in **Fig. A1.2** illustrating the logarithmic shape of the trend line. The results of the step-wise calculations and parameters are as follows:

Regression Parameters:

**TABLE A1.1 Example Cut Test Data Used to Determine the Calculated Cutting Load**

Load, $x$ , gf	Cut Through Distance, $y$ , mm
200	45.8
200	49.2
200	42.3
200	41
200	45.4
400	20.1
400	22.2
400	18.6
400	20.4
400	24.6
600	12.4
600	15.5
600	13.3
600	10.8
600	8.9

<sup>8</sup> Neter, J., Kunter, M. H., and Wasserman, W., *Applied Linear Statistical Models*, 1990: Irwin Homewood, IL.



TABLE A1.2 Example Spreadsheet Results Used to Determine the Calculated Cutting Load

A	B	C	D	E	F	G	H		
$x$	$y$	$y' = \log_{10} y$	$(x_i - \bar{X})^2$		$n$	15	Number of measurements		
200	45.8	1.66	40000		$\bar{X}$	400	Overall mean load, gf		
200	49.2	1.69	40000		$\Sigma(x_i - \bar{X})^2$	400000			
200	42.3	1.63	40000						
200	41.0	1.61	40000		$b_1$	-1.43E-03	1.92E+00	$b_0$	Regression parameters
200	45.4	1.66	40000		$se_1$	9.93E-05	4.29E-02	$se_0$	
400	20.1	1.30	0		$r^2$	9.41E-01	6.28E-02	$se_y$	
400	22.2	1.35	0		$F$	2.07E+02	1.30E+01	$df$	
400	18.6	1.27	0		$ss_{reg}$	8.17E-01	5.13E-02	$ss_{resid}$	
400	20.4	1.31	0						
400	24.6	1.39	0		$MSE$	3.95E-03	Mean square error		
600	12.4	1.09	40000		$y_r$	20	Reference distance, mm		
600	15.5	1.19	40000		$x_r$	435	Calculated reference load, gf		
600	13.3	1.12	40000				Standard deviation, gf		
600	10.8	1.03	40000		$s$	45.4	95% Confidence limit, gf		
600	8.9	0.95	40000		$x_r \pm$	98			

TABLE A1.3 Example Spreadsheet Formulas Used to Determine the Calculated Cutting Load

	A	B	C	D	E	F	G	H	
1	x	y	$y' = \log_{10} y$	$(x_i - \bar{X})^2$		n	=COUNT(A2:A16)	Number of measurements	
2	200	45.8	=LOG10(B2)	=(A2-G\$2)^2		X	=AVERAGE(A2:A16)	Overall mean load, gf	
3	200	49.2	=LOG10(B3)	=(A3-G\$2)^2		$\sum (x_i - \bar{X})^2$	=SUM(D2:D16)		
4	200	42.3	=LOG10(B4)	=(A4-G\$2)^2					
5	200	41	=LOG10(B5)	=(A5-G\$2)^2		$b_1$	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	$b_0$
6	200	45.4	=LOG10(B6)	=(A6-G\$2)^2		$se_1$	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	$se_0$
7	400	20.1	=LOG10(B7)	=(A7-G\$2)^2		$r^2$	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	$se_y$
8	400	22.2	=LOG10(B8)	=(A8-G\$2)^2		F	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	df
9	400	18.6	=LOG10(B9)	=(A9-G\$2)^2		$ss_{reg}$	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	=LINEST(C2:C16,A2:A16,TRUE,TRUE)	$ss_{resid}$
10	400	20.4	=LOG10(B10)	=(A10-G\$2)^2					
11	400	24.6	=LOG10(B11)	=(A11-G\$2)^2		MSE	=H7^2		Mean square error
12	600	12.4	=LOG10(B12)	=(A12-G\$2)^2					
13	600	15.5	=LOG10(B13)	=(A13-G\$2)^2		$y_r$	20		Reference distance, mm
14	600	13.3	=LOG10(B14)	=(A14-G\$2)^2		$x_r$	=(LOG10(G13)-H5)/G5		Calculated reference load, gf
15	600	10.8	=LOG10(B15)	=(A15-G\$2)^2		s	=SQRT(((G11/G5^2)*(1+(1/G1)+((G14-G2)^2/G3)))		Standard deviation, gf
16	600	8.9	=LOG10(B16)	=(A16-G\$2)^2		$x_r \pm$	=G15*T.INV.2T(0.05,(G1-2))		95% Confidence limit, gf

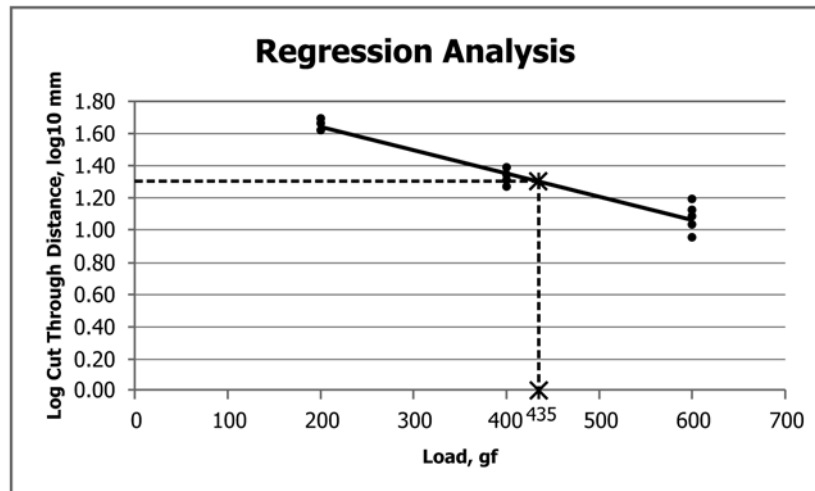


FIG. A1.1 Plot of Applied Load Versus the Log of Normalized Cut Through Distance and Resulting Regression Line and Calculated Cutting Load

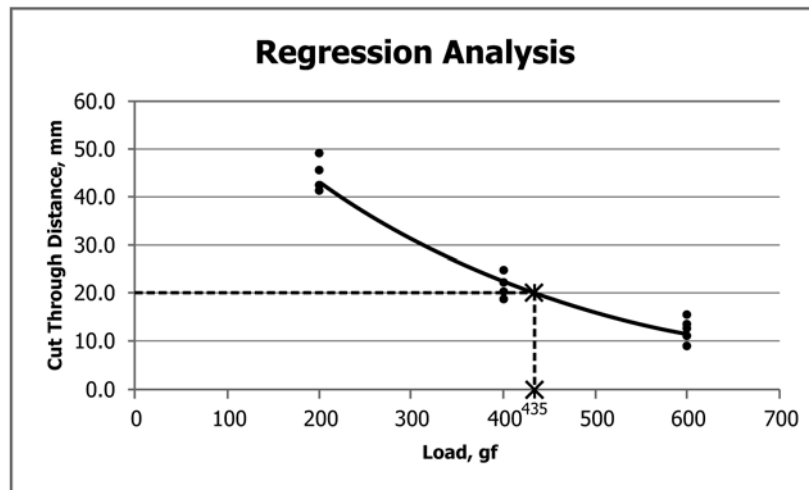


FIG. A1.2 Plot of Applied Load Versus the Normalized Cut Through Distance and Resulting Regression Line and Calculated Cutting Load

$$\begin{aligned}
 n &= 15 \\
 b_0 &= 1.922 \\
 b_1 &= -1.43\text{E-}3 \\
 MSE &= 3.95\text{E-}3 \\
 X &= 400 \\
 \Sigma(x_i - X)^2 &= 400\,000
 \end{aligned}$$

Regression Equation:

$$y' = 1.922 - 0.00143x \quad (\text{A1.5})$$

Calculated Cutting Load:

$$y_r = 20.0 \text{ mm} \quad (\text{A1.6})$$

$$x_r = \frac{\log_{10} 20.0 - 1.922}{-0.00143} = 435 \text{ gf} \quad (\text{A1.7})$$

$$s^2 = \frac{0.00395}{-0.00143^2} \left[ 1 + \frac{1}{15} + \frac{(435 - 400)^2}{400000} \right] = 2065 \quad (\text{A1.8})$$

$$s = \sqrt{2065} = 45.4 \text{ gf} \quad (\text{A1.9})$$

95 % Confidence Limit and Interval:

$$t_{(1 - \frac{0.95}{2}; 13)} = 2.16 \quad (\text{A1.10})$$

$$x_r \pm 2.16(45.4) = 435 \pm 98 \text{ gf} \quad (\text{A1.11})$$

$$337 \leq x_r \leq 533 \text{ gf} \quad (\text{A1.12})$$



## APPENDIX

### (Nonmandatory Information)

## X1. CUTTING LOAD SELECTION

### INTRODUCTION

The calculated cutting load is determined by performing a series of cut tests at three or more loads. A material with a higher calculated cutting load is considered to be more cut resistant, and the calculated cutting load can be used to compare the cut resistance of various materials. The selection of the proper loads used for the test is important for determining the correct estimate of the calculated cutting load. The use of three different loads selected as to produce five data points in the 5 to 20 mm [0.2 to 0.8 in.] cut through distance range, five data points in the 20 to 33 mm [0.8 to 1.3 in.] cut through distance range, and five data points in the 33 to 50 mm [1.3 to 2 in.] cut through distance range has been found to be adequate.

### X1.1 Load Screening Procedure

X1.1.1 For new or unknown materials, the selection of loads may require an exploratory screening experiment to determine the range of loads that will cause a cut through of the specimen. It is recommended to perform a series of cut tests as described in 11.2 using an increasing or decreasing series of load covering the expected load range of the material.

X1.1.1.1 When testing a material with a low expected cut resistance (calculated cutting load less than 1000 gf), select a starting load of 200 g and increase the load in 100 g increments until a cut through occurs. Continue testing in further 100 g

increments until a cut through distance less than 5 mm is observed to determine the lowest and highest loads that should be used when testing this material.

X1.1.1.2 For a highly cut resistant material (calculated cutting load greater than 1000 gf), it may be more practical to start at a higher load, for example 1000 g, and test in increments of 500 g.

X1.1.1.3 An example screening experiment result for two unknown materials is shown in Table X1.1 and Table X1.2.

**TABLE X1.1 Example Screening Experiment for Material with Low Cut Resistance**

NOTE 1—Loads selected for testing: 300, 450, 600 gf.

Applied Load, gf	Measured Cut Through Distance, mm	Selected Load
200	No Cut	Minimum Load
300	49.8	
400	25.3	
500	10.2	
600	2.5	Maximum Load

**TABLE X1.2 Example Screening Experiment for Material with High Cut Resistance**

NOTE 1—Loads selected for testing: 1500, 1750, 2000 gf.

Applied Load, gf	Measured Cut Through Distance, mm	Selected Load
1500	45.0	Minimum Load
2000	4.2	Maximum Load
2500	2.5	



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