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Reference

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ABSTRACT

Tear strength is an important fabric characteristic used to evaluate the serviceability of textile materials and their suitability for particular end uses such as protective clothing. In this study, the effect of test specimen size on tear strength was analyzed. The aim was to determine whether smaller specimens could be used to perform tear strength tests without significantly affecting the test results. The ASTM D5587-15, *Standard Test Method for Tearing Strength of Fabrics by Trapezoid Procedure*, was followed using the standard test specimen size and three smaller sizes. The geometrical characteristics, i.e., trapezoid angle, length of smaller base, and notch length, were unchanged in the smaller specimens, and only the tearing distance through the specimen became shorter as the specimen size was reduced. The test was performed on three fabrics with different structures: plain weave, ripstop, and ripstop with a laminated polymer membrane. Statistical analysis based on the analysis of variance and multiple comparison tests were used to interpret the data. For the plain weave, and ripstop fabrics tested in the warp direction, the results showed no difference in the mean tear strength between the standard-sized specimens and smaller specimens as long as the specimen size did not fall below 55 by 110 mm. Below this size, the distance over which the tear strength was measured became too short for enough high peaks to be recorded and used in calculating the average tearing strength of each specimen. For the laminated fabric tested in both the warp and weft directions, and for the plain weave and ripstop fabrics tested in the weft direction, there were no statistical differences in the mean tear strength between the four specimen sizes, including the smallest size (45 by 90 mm). These results support the use of smaller specimens to accurately determine the trapezoidal tear strength of fabrics when the amount of material available for testing is limited.

Keywords

tear strength, trapezoid test method, specimen size, protective clothing

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Introduction

Tear strength is one of the most important characteristics for predicting the mechanical performance of a fabric in use.[1–3] This measurement helps determine the suitability of textile materials for critical end uses such as protective clothing. Tear strength determined by the trapezoid test method ASTM D5587-15, *Standard Test Method for Tearing Strength of Fabrics by Trapezoid Procedure*,[4] is included as part of the fabric evaluation of various protective clothing performance standards. For example, in the NFPA 1971, *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*,[5] minimum tearing resistance values are specified for all components of the turnout garment, including the outer shells (100 N), thermal barrier, winter liners, and moisture barrier (22 N). Other standards for protective garments such as those for emergency medical operations,[6] for technical rescue incidents,[7] and for chemical protection[8,9] also include tearing resistance requirements following the trapezoid test method.

In the trapezoid test method, the tearing force is applied across the yarns that are parallel to the direction of the force (**fig. 1**). Because the clamps are positioned along the diagonal, nonparallel sides of the trapezoid, the yarn lengths are shortest at the notched side of the specimen, the location where the tear is initiated, and the yarns to be torn are progressively longer across the width of the specimen. As the clamps separate during the test, the first yarn at the tip of the notch tightens and then breaks, followed by successive yarns or groups of yarns in the fabric rupturing one after another as the tear proceeds across the specimen.[10] The angled clamping on the fabric associated with the trapezoid shape of the tested area causes greater stress on the first few yarns closest to the notch because the yarns are shortest at this location.[11] The tear strength is highly dependent on the clamp separation distance set at the beginning of the test; as the distance between the clamps increases, the tear strength increases.[12] Other characteristics that control the tear strength of a fabric include fabric count, yarn mobility and extensibility in the fabric structure, and the initial strength of each yarn.

The tearing behavior of fabrics by the trapezoid procedure has been the subject of several research works. Bellinson[10] described an auxiliary device for performing the trapezoid tearing test; the main motivation was to facilitate the preparation of the specimen and its installation on the apparatus. Ten years later, Hager et al.[12] developed a mathematical approach to predict fabric behavior during a trapezoidal tear test. They concluded that the tear strength depends on the extensibility and breaking strength of the fabric, initial distance between the clamps, and fabric count. In another study, Turl[13] measured the tear strength in military fabrics by two methods: the trapezoid and the tongue (single rip) tear test. They reported that the results varied significantly between the two methods. Steele and Gruntfest[14] showed that the tear strength depends on the trapezoid angle.

FIG. 1
Trapezoidal tear specimen fixed between the clamps.

No studies concerning the influence of the specimen size on the tear strength of fabrics tested by the trapezoid procedure on textiles have been found in the literature. However, there are a few instances where researchers have reported using trapezoidal tear specimens of reduced size. For example, in the study conducted by Dolez et al.,[15] and Dolez and Malajati[16] trapezoidal specimens of 50.8 by 101.6 mm were used because of a limited amount of fabric available. The same specimen size was employed in the research carried out by Nguyen-Tri et al.[17] to fit to the clamp dimensions of the mechanical test frame the authors used. Also, the study of El Aidani et al.[18,19] scaled down the standard dimensions to 50.8 by 101.6 mm. Being able to conduct trapezoidal tear strength measurements on smaller sized specimens would also be useful when working with fabric prototypes of limited quantity, or with samples collected from used garments.

The purpose of this study was to examine whether the tear strength test could be carried out on smaller specimens than the standard size stipulated in ASTM D5587 without affecting the test results. For that purpose, the tear strength by the trapezoid procedure was measured on three fabrics of different structures and materials using the standard specimen size as well as three smaller specimen sizes. The results were analyzed by statistical techniques.

Materials and Methods

TESTED FABRICS

Three fabrics corresponding to different structures encountered in fire protective fabrics were selected for the study: a Nomex IIIA fabric used for fire-resistant coveralls, a Kevlar/PBI fabric used for the outer shell of firefighters' turnout gear, and a Nomex IIIA fabric laminated to an ePTFE membrane (expanded polytetrafluoroethylene) used as the moisture barrier in firefighters' protective clothing. **Table 1** provides the characteristics of the fabrics and **figure 2** shows images of the fabric structures taken with a surface microscope (Leica EZ4W).

TEST METHOD

The tear strength of the fabrics was measured using a constant-rate-of-extension (CRE) type tensile testing machine (Instron Model 5565) equipped with 5-kN load cell and controlled by a computer software program (Bluehill; Instron Corp). The clamps were rubber-coated (25 by 75 mm) and operated with a pneumatic system. Before testing, specimens were conditioned for at least 24 h under standard atmospheric conditions for textile testing (20°C ± 2°C; 65 ± 5 % RH). The trapezoid tearing test procedure was performed according to ASTM D5587. A graphical representation of the different specimen sizes is shown in **figure 3**. The width and length of specimen sizes 2 to 4 were smaller than the size defined in the test method and represented by size 1. However, the specimen length to width ratio was kept at 2:1. In addition, most of the geometrical characteristics of the tearing area were preserved: the angle of the nonparallel sides of the trapezoid (clamp lines), the length of the small trapezoid base, and the length of the notch used to initiate the tear. A template was made for each specimen size and used to mark the fabrics for cutting and to draw the notch line and clamp lines on each specimen.

TABLE 1
Fabric characteristics

Fabric	Fiber Content	Yarn Structure	Fabric Structure	Thickness,[b] mm	Mass,[c] g/m^2	Fabric Count,[d] yarns/cm
1	93 % Nomex/ 5 % Kevlar/ 2 % antistatic fiber	Single spun yarns	Plain weave	0.26	108	36 by 23
2	60 % Kevlar/ 40 % PBI	Spun and filament yarns	Ripstop weave[a]	0.56	254	17 by 14
3	93 % Nomex/ 5 % Kevlar/ 2 % antistatic fiber ePTFE membrane	Single spun yarns	Ripstop weave[a] laminated	0.39	203	32 by 28

Note: [a] Plain weave with paired warp and weft yarns at regular intervals. [b] Measured according to ASTM D1777, *Standard Test Method for Thickness of Textile Materials*, under 1kPa pressure. [c] Measured according to ASTM D3776, *Standard Test Methods for Mass Per Unit Area (Weight) of Fabric*. [d] Measured according to ASTM D3775, *Standard Test Method for End (Warp) and Pick (Filling) Count of Woven Fabrics*.

FIG. 2 Optical microscope pictures: (*A*) fabric 1 face, (*B*) fabric 2 face, (*C*) fabric 3 face, (*D*) fabric 3 back, and (*E*) fabric 3 cross-sectional view.

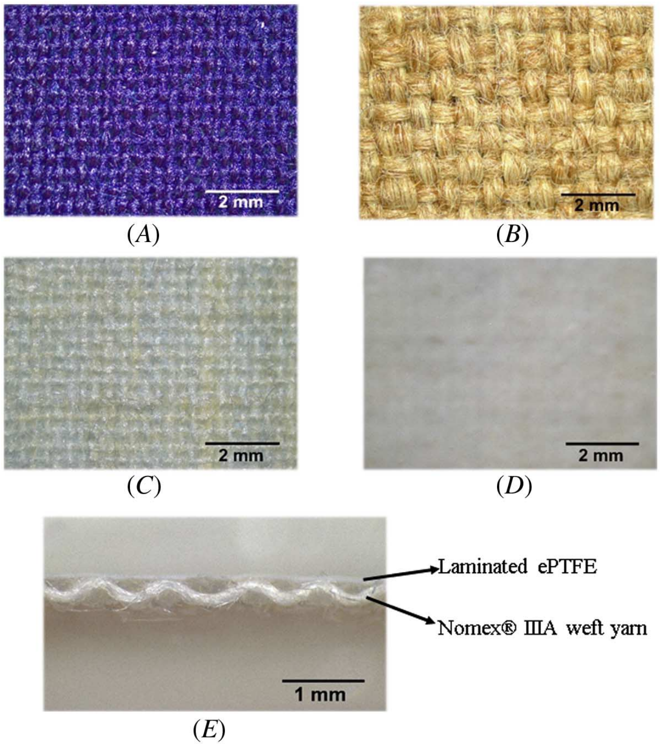
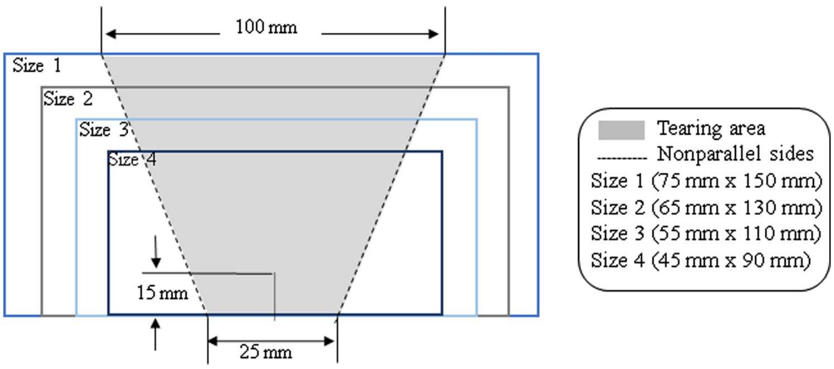


FIG. 3 Geometry and dimensions of the tear strength specimens.



For each specimen size, ten specimens were prepared with the long dimension parallel to the warp direction and ten with the long dimension parallel weft direction of the fabrics. During testing, each specimen was fixed in the pneumatic clamps with the long dimension of the clamps aligned with the nonparallel sides of the trapezoid marked on the specimens. The rate of displacement was set to 300 mm/min. The force and displacement were recorded until the two halves of the specimen were completely separated.

The ASTM D5587 standard has two options for calculating the tearing strength. If the specimen exhibits five peaks or more after the initial peak in the force-extension curve, the first option shall be used; the tearing strength is the average of the five highest peak forces recorded after the first peak. If the specimen exhibits less than five highest peaks, the second option shall be used; the tearing strength is the highest peak force recorded during the test. According to the standard, a peak suitable for calculation should rise or fall by at least 10 % of the force. All specimens for fabric 2 and fabric 3 in both directions (warp and weft) and for fabric 1 in the weft direction showed more than five peaks in the force-extension curve for all specimen sizes; thus, the first option was used for the tear strength calculation. On the other hand, some specimens of fabric 1 in the warp direction exhibited less than five peaks suitable for calculating the average tear strength; therefore, the second option was used for these specimens. This happened independently of the specimen size.

STATISTICAL ANALYSIS

Descriptive statistics were calculated for each fabric and specimen size (mean tear strength and standard deviation). The factor of interest was the specimen size, and the tear strength was the response variable. Analyses were conducted using the statistical software package SPSS Version 25 (IBM Corporation, Armonk, NY). The homogeneity of variances was verified using the Levene's test, and the normal distribution was tested with the Kolmogorov-Smirnov normality test. One-way analyses of variance (ANOVA) were carried out to analyze the influence of specimen size on the mean tear strength of each fabric in the warp and weft directions. If the ANOVA tests showed that the independent variable (specimen size) significantly influenced the mean tear strength, post hoc comparisons tests were performed. Tukey's Honestly Significant Difference (HSD) was used where the means had equal variances, and where the means had unequal variances, Tamhane's test was used. For all analyses, a confidence level of 0.05 was set to establish significance.

Results

TEARING STRENGTH IN THE WARP DIRECTION

The results of the mean tear strength for the three fabrics in the warp direction are displayed in figure 4 as a function of the specimen size. For fabric 1, the mean tear strength varied between 92 ± 5 and 102 ± 7 N. The mean tear strength corresponding to size 4 shows the largest difference from the others. On the other hand, no major variations were noticed between size 1, 2, and 3. For fabric 2, the mean tear strength varied between 138 ± 7 N and 151 ± 5 N. Again, the largest difference was observed for size 4. Finally, for fabric 3, the mean tear strength ranged between 92 ± 6 N and 93 ± 6 N. Fabric 3 exhibited no significant change in the mean tear strength among the four specimen sizes.

TEARING STRENGTH IN THE WEFT DIRECTION

The mean tear strength in weft direction as a function of the specimen size for the three fabrics is shown in figure 5. The mean tear strength for fabric 1 varied between 56 ± 3 N and 59 ± 3 N. In the case of fabric 2, the mean tear strength varied between 107 ± 5 N and 112 ± 8 N. Regarding fabric 3, the mean tear strength varied between 76 ± 3 N and 81 ± 5 N. For fabric 1, the result for size 4 is slightly different when compared to the other

FIG. 4

Variation of the fabric tear force with the specimen size in the warp direction.

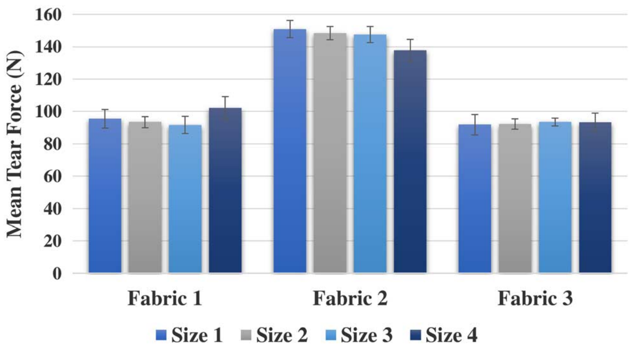
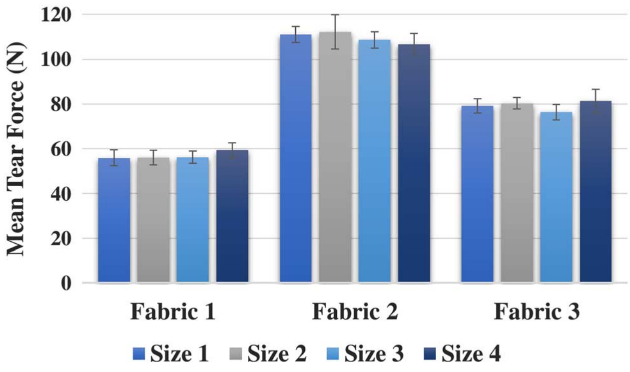


FIG. 5

Variation of the fabric tear force with the specimen size in the weft direction.



sizes. In the case of fabric 2 and fabric 3, slight differences were recorded for the mean tear strength corresponding to the different specimen sizes.

ANALYSIS OF VARIANCE

The results of the ANOVA, including the sum of squares of deviations (SS), degree of freedom (DF), mean square error (MS), F-value, and P-value are shown in **Table 2**. For fabric 1 and fabric 2, significant differences were found between the different specimen sizes in the warp directions ($F_{3,36} = 7.244$, p-value < 0.001 and $F_{3,36} = 11.504$, p-value < 0.001, respectively). On the other hand, there were no significant differences in the mean tear strength between the different specimen sizes in the warp direction for fabric 3 ($F_{3,36} = 0.315$, p-value $= 0.814$).

In the weft direction, there were no statistical differences in the mean tear strength between the different specimen sizes for fabric 1 and fabric 2 ($F_{3,36} = 2.593$, p-value $= 0.068$ and $F_{3,36} = 2.172$, p-value $= 0.108$, respectively). On the other hand, significant differences were obtained for fabric 3 ($F_{3,36} = 3.137$, p-value $= 0.037$). Therefore, the ANOVA results indicate that for fabric 1 and fabric 2 in the warp direction, there is strong evidence to conclude that the mean tear strength is different for at least one specimen size. Regarding the weft direction, the ANOVA results show that for fabric 3, there is moderate evidence to conclude that the mean tear strength is different between the specimen sizes.

MULTIPLE COMPARISON TEST

Because the mean tear strength differences for fabric 3 in the warp direction and fabric 1 and fabric 2 in the weft direction were statistically negligible, they were not included in the multiple comparison test, which only considered fabric 1 and fabric 2 in the warp direction and fabric 3 in the weft direction.

Table 3 shows the p-values from the Tukey HSD tests for fabric 1 and fabric 2 in the warp direction. The results revealed that for fabric 1, there were no significant differences in the mean tear strength between

TABLE 2

Results of the Analysis of Variances

Fabric	Direction	SS	DF	MS	F-Value	P-Value
Fabric 1	Warp	633.512	3	211.171	7.944	<0.001*
	Weft	82.746	3	27.582	2.593	0.068
Fabric 2	Warp	1,000.717	3	333.572	11.504	<0.001*
	Weft	178.288	3	59.429	2.172	0.108
Fabric 3	Warp	20.288	3	6.763	0.315	0.814
	Weft	135.519	3	45.173	3.137	0.037*

Note: * Statistically significant differences.

TABLE 3
P-values for the multiple comparison tests for fabric 1 and fabric 2 in the warp direction

		P-Values	
Specimen Size	Specimen Size	Fabric 1	Fabric 2
1	2	0.822	0.736
	3	0.401	0.515
	4	0.043*	<0.001*
2	3	0.890	0.983
	4	0.005*	<0.001*
3	4	0.001*	0.001*

Note: * Statistically significant differences.

size 1, and both size 2 and 3. The same was observed between size 2 and size 3. However, there were statistically significant differences between size 4 and the other sizes. The absolute difference in mean tear strength between size 4 and size 1 was about 7 N. It was 9 N compared to size 2, and 10 N compared to size 3.

For fabric 2, there was again no significant difference in the mean tear strength between size 1, and both size 2 and 3. The same was observed between size 2 and size 3. On the other hand, statistically significant differences were also found between size 4 and the other sizes. The absolute difference in mean tear strength between size 4 and the other sizes was 13 N with size 1, 11 N with size 2, and 10 N with size 3.

The results of the multiple comparison test for fabric 3 in the weft direction are shown in Table 4. Because of unequal variances, the data for fabric 3 in the weft direction was analyzed using Tamhane's test. The post hoc test did not reveal any significant differences between the different sizes. Indeed, the absolute differences in mean tear strength between specimen sizes are not significantly different. The greatest difference was between size 3 and size 4 (5N), which was not significant.

Discussion

Tear strength is a fundamental property used to evaluate fabric serviceability. Standard test methods for determining tear strength specify a number of experimental parameters such as the specimen dimensions, clamping distance, testing speed, etc. However, in some instances, the amount of fabric available for testing is limited, and the researcher may not be able to use the prescribed specimen size, and when this happens, it raises concerns about the reliability and validity of the test results.

In the current study, four different specimen sizes were evaluated for three different fabric types to see if using smaller specimen sizes than stipulated in the ASTM D5587 test method would affect the mean tear strength results. Three fabrics were selected to cover constructions encountered in fire protective clothing: plain weave,

TABLE 4
P-values for the multiple comparison tests for fabric 3 in the weft direction

		P-Value
Specimen Size	Specimen Size	Fabric 3
1	2	0.967
	3	0.366
	4	0.893
2	3	0.065
	4	0.996
3	4	0.149

FIG. 6 Signs of yarn slippage taking place during the tear strength test: (*A*) fabric 1-size 1 and (*B*) zoom-in image of the zone indicated in (*A*).

(*A*) (*B*)

ripstop, and ripstop laminated to an ePTFE membrane. The results of the study showed that for all tested fabrics, only the smallest specimen size gives significantly different results.

The results can be attributed to the fact that tear strength is a local process, involving the formation of a triangular-shaped distortion at the active region of tearing (del zone)[20] where longitudinal yarns (parallel to the tear) slip along the transverse yarns while transverse yarns stretch, align, and jam.[21] The trapezoidal tearing process is mostly controlled by the elongation of the transverse yarns and their breaking strength;[22] it depends also on the number of yarns sharing the load simultaneously, the yarn extensibility and crimp, fabric density, and the initial clamp separation. Only the yarns held by the clamps play a role in the trapezoidal tearing process, contrary to the tongue-tear geometry.[21] Another parameter on which the trapezoidal tear strength depends is the trapezoid angle as shown by Steele and Gruntfest.[14] Purposely, the trapezoid angle was not changed and was the same for all the different specimen sizes investigated in this work. In the case of laminated fabrics, the presence of the laminate decreases the fabrics' flexibility, limiting the deformability of the fabric structure.[23,24] Because of the reduced yarn mobility, the tear strength is decreased.

The tearing length was the only parameter affecting the tearing process that ended up being modified in this study. In the case of the three largest specimen sizes, the tearing length was sufficient for the formation of the five high peaks within a distance of 75 mm in the force-extension curve. These peaks were used to determine the tear strength according to option 1 in the ASTM D5587 test method. For the smallest specimen, the tearing length was sometimes too short to allow five high peaks to be recorded after the first peak. As a result, option 2 was used, which associates the tear strength with the value of the single highest peak and leads to higher values of the tear strength. In other instances, five high peaks could be obtained after the first peak, but these peaks were slightly lower, which lowered the calculated average tear strength. For fabric 3, there were no differences between the four different specimen sizes, contrary to the two other fabrics. The possible reason may be that the ePTFE lamination restricted yarn mobility and limited the extent of the Del zone.[23–25]

It may be noted that, even with the smallest specimen size, there were no problems gripping the specimen in the clamps. A few instances of yarn slippage were noticed (**fig. 6**). However, the slippage occurred with all tested sizes, including the specimen dimensions prescribed in the standard test method (size 1).

Conclusions

Tear strength is a fundamental characteristic used to assess the serviceability and quality of protective clothing. In the present study, the influence of the specimen size on trapezoidal tear strength was examined. The specimen size specified in the test method ASTM D5587 was used as well as three smaller specimen sizes. The trapezoidal angle was kept identical for all sizes. The study was carried out on three fabrics of different constructions used in fire protective clothing: plain weave, rip stop, and ripstop with a laminated polymer membrane.

The findings provide evidence that it is possible to measure fabric tear strength by the trapezoid procedure with smaller specimens than prescribed in the standard test method. For the plain weave and ripstop fabrics in the warp direction, the statistical analysis showed no difference in mean tear strength between the standard sized specimens and smaller specimens as long as the specimen size did not fall below 55 by 110 mm. The results are attributed to the fact that the only parameter that was changed between the different specimen sizes was the tearing length. In the case of the smallest specimen (45 by 90 mm), the tearing length was too short to allow the recording of the five highest peaks after the first peak in the force-extension curve that are used to determine the tear strength as indicated in the test method. For the plain weave and ripstop fabrics in the weft direction as well as the polymer membrane laminated fabric in both directions, there were no statistical differences in mean tear strength between the standard sized and the smaller sizes.

This study provides a scientific basis to support the use by up to 53 % smaller specimens than specified in ASTM D5587. Considering that the trapezoidal angle remains unchanged and the tearing distance through the specimens is of sufficient length to allow for the formation of enough peaks to determine the tear strength. The findings open new opportunities for researchers to obtain meaningful results even when working with fabrics in limited supply, for instance when working with prototype fabric samples or specimens collected from used garments.

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References

1. S. Dhamija and M. Chopra, "Tearing Strength of Cotton Fabrics in Relation to Certain Process and Loom Parameters," *Indian Journal of Fibre & Textile Research* 36 (2007): 439–445.
2. S. H. Eryuruk and F. Kalaoğlu, "The Effect of Weave Construction on Tear Strength of Woven Fabrics," *Autex Research Journal* 15, no. 3 (September 2015): 207–214, https://doi.org/10.1515/aut-2015-0004
3. L. Hunter and J. Fan, "Adding Functionality to Garments," in *Textiles and Fashion: Materials, Design and Technology*, ed. R. Sinclair (2015): 705–737, https://doi.org/10.1016/B978-1-84569-931-4.00028-3
4. *Standard Test Method for Tearing Strength of Fabrics by Trapezoid Procedure*, ASTM D5587-15(2019) (West Conshohocken, PA: ASTM International, approved July 1, 2019), http://doi.org/10.1520/D5587-15
5. *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*, NFPA 1971 (2018) (Quincy, MA: National Fire Protection Association, approved August 17, 2006).
6. *Standard on Protective Clothing and Ensembles for Emergency Medical Operations*, NFPA 1999 (2018) (Quincy, MA: National Fire Protection Association, approved August 21, 2017).
7. *Standard on Protective Ensembles for Technical Rescue Incidents*, NFPA 1951 (2020) (Quincy, MA: National Fire Protection Association, approved November 24, 2019).
8. *Standard Guide for Evaluating Chemical Protective Clothing*, ASTM F1296-08(2015) (West Conshohocken, PA: ASTM International, approved February 1, 2015), http://doi.org/10.1520/F1296-08R15
9. *Standard Specification for Air-Fed Protective Ensembles*, ASTM F2704-17a (West Conshohocken, PA: ASTM International, approved November 1, 2017), http://doi.org/10.1520/F2704-17A
10. H. R. Bellinson, "Simplified Trapezoid Tearing Test," *Textile Research* 7, no. 5 (March 1937): 208–210, https://doi.org/10.1177/004051753700700503
11. C. P. Hamkins and S. Backer, "On the Mechanisms of Tearing in Woven Fabrics," *Textile Research Journal* 50, no. 5 (May 1980): 323–327, https://doi.org/10.1177/004051758005000510
12. O. B. Hager, D. D. Gagliardi, and H. B. Walker, "Analysis of Tear Strength," *Textile Research Journal* 17, no. 7 (July 1947): 376–381, https://doi.org/10.1177/004051754701700704
13. L. H. Turl, "The Measurement of Tearing Strength of Textile Fabrics," *Textile Research Journal* 26, no. 3 (March 1956): 169–176, https://doi.org/10.1177/004051755602600301
14. R. Steele and I. J. Gruntfest, "An Analysis of Tearing Failure," *Textile Research Journal* 27, no. 4 (April 1957): 307–313, https://doi.org/10.1177/004051755702700406
15. P. I. Dolez, N. S. Tomer, and Y. Malajati, "A Quantitative Method to Compare the Effect of Thermal Aging on the Mechanical Performance of Fire Protective Fabrics," *Journal of Applied Polymer Science* 136, no. 6 (September 2018): 1–15, https://doi.org/10.1002/app.47045
16. P. I. Dolez and Y. Malajati, "Resistance of Fire Protective Fabrics toRepeated Launderings," in *Performance of Protective Clothing and Equipment: Innovative Solutions to Evolving Challenges*, ed. K. Lehtonen, B. Shiels, and R. Ormond (West Conshohocken, PA: ASTM International), 100–113, https://doi.org/10.1520/STP162420190079

17. P. Nguyen-Tri, R. El Aidani, É. Leborgne, T. Pham, and T. Vu-Khanh, "Chemical Aging of a Polyester Nonwoven Membrane Used in Aerosol and Drainage Filter," *Polymer Degradation and Stability* 101 (March 2014): 71–80, https://doi.org/10.1016/j.polymdegradstab.2014.01.001
18. R. El Aidani, P. Nguyen-Tri, Y. Malajati, J. Lara, and T. Vu-Khanh, "Photochemical Aging of an e-PTFE/NOMEX® Membrane Used in Firefighter Protective Clothing," *Polymer Degradation and Stability* 98, no. 7 (July 2013): 1300–1310, https://doi.org/10.1016/j.polymdegradstab.2013.04.002
19. R. El Aidani, P. I. Dolez, and T. Vu-Khanh, "Effect of Thermal Aging on the Mechanical and Barrier Properties of an e-PTFE/Nomex® Moisture Membrane Used in Firefighters' Protective Suits," *Journal of Applied Polymer Science* 121, no. 5 (March 2011): 3101–3110, https://doi.org/10.1002/app.33991
20. C. M. Krook and K. R. Fox, "Study of the Tongue-Tear Test," *Textile Research Journal* 15, no. 11 (November 1945): 389–396, https://doi.org/10.1177/004051754501501102
21. N. A. Teixeira, M. M. Platt, and W. J. Hamburger, "Mechanics of Elastic Performance of Textile Materials: Part XII: Relation of Certain Geometric Factors to the Tear Strength of Woven Fabrics," *Textile Research Journal* 25, no. 10 (October 1955): 838–861, https://doi.org/10.1177/004051755502501003
22. I. C. Sharma and D. Adhikary, "Comparison of Different Tearing Test Methods," *Indian Journal of Textile Research* 9 (June 1984): 46–54.
23. S. Adanur, "Structure and Mechanics of Coated Textile Fabrics," in *Structure and Mechanics of Textile Fibre Assemblies*, ed. P. Schwartz (Amsterdam, the Netherlands: Elsevier, 2008): 191–216, https://doi.org/10.1016/B978-0-08-102619-9.00006-7
24. Y. Bulut and V. Sülar, "Effects of Process Parameters on Mechanical Properties of Coated Fabrics," *International Journal of Clothing Science and Technology* 23, no. 4 (January 2011): 205–221, https://doi.org/10.1108/09556221111136476
25. V. Masteikaitė and V. Sacevičienė, "A Method for Mobility Estimation of Textile-Polymeric Systems," *Fibers and Polymers* 11, no. 6 (September 2010): 869–876, https://doi.org/10.1007/s12221-010-0869-z