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A Comparison of Standard Methods for Evaluating the Water Resistance of Shell Fabrics

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Abstract

The water resistance of shell fabrics intended for use in outdoor apparel was measured using three different standard test methods, ASTM D 751, hydrostatic resistance, procedure A (Mullen test -- with and without a fabric support) and Procedure B (Hydrostatic head test). A database of information on their water resistance performance was created. The data collected with different methods were correlated and the advantages and disadvantages of each method were compared.

The Mullen test with a support appears to give higher and more favorable water resistance values on shell fabrics preventing fabric rupture during the test. The hydrostatic head test gave lower hydrostatic pressure values than those measured on the two Mullen tests. The Mullen test is recommended for testing the water resistance of fabrics that have a relatively high water resistance because the Mullen tester applies a wide range of pressure. The hydrostatic head test is recommended for testing the fabrics that have relatively low water resistance. The area of the fabric sample that is in contact with the water is smaller in the Mullen test, so higher pressure levels can be reached and more samples should probably be tested to get a representative value for each fabric type. Furthermore, the hydrostatic head test was deemed more repeatable than the Mullen tests in this study.

Key words: Hydrostatic head test, Mullen test, shell fabric, waterproofness, water resistance.

I. Introduction

The thermal comfort of people depends upon the heat generated by the body and heat transferred from the body surface to the environment. The human body produces metabolic heat at a level which is dependent on physical activity. The greater the physical activity, the higher the heat production.

Heat is lost from the skin surface through conduction, convection, radiation, and evaporation. When clothing is added to the body, it blocks conduction heat losses by trapping still air within fabric structures and between clothing layers. Clothing resists convective losses by preventing convection currents from forming next to the body and by providing a barrier against air currents in the environment and reduces radiant heat loss since the fibers in each fabric layer provide a thermal radiation barrier. It also impedes evaporative heat loss by restricting the transfer of water vapor from the skin surface to the environment.

A shell fabric is the outermost layer in outdoor garments. It may be used alone in light-

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weight garments, lined with a fabric, or used with fiberfil or down and a lining fabric in a multicomponent system to give it more insulation. Since a shell fabric comes in contact with the environment, its ability to block water and wind and to still allow water vapor to go through is very important for maintaining the comfort of the wearer of outdoor clothing. Fabric treatments such as finishes, coatings, and film membranes are added to shell fabrics to reduce or prevent water and wind penetration into clothing layers.

Water resistance is the property of retarding both penetration and wetting by liquid water. The water resistance of fabrics ranges from a moderate level of protection (i.e., water repellent) to a very high level of protection (waterproof). A waterproof fabric has the ability to resist the penetration of water under pressures associated with the end use. Wind resistance is the property of reducing or preventing penetration by moving air. If the fabric is sealed against water penetration under pressure, it is usually sealed from wind penetration also. Water resistance and wind resistance are properties that can be measured on fabrics.

Most standard methods evaluating the water resistance measure the resistance of a fabric to surface wetting or penetration by liquid water. ASTM D 751-95, Standard Test Methods for Coated Fabrics, is the standard method currently used in North America[2]. Hydrostatic resistance Procedure A in this test method uses a Mullen-type hydrostatic tester device to determine the hydrostatic bursting strength or resistance to water penetration of a fabric. This unit gives uniform hydrostatic pressure to the underside of the clamped fabric by means of a piston forcing water into the pressure chamber of the apparatus, and the fabric has to withstand the pressure of water. The pressure is applied until the water penetrates a fabric or a specified pressure is applied against a fabric for a certain period of time. The result is expressed as a hydrostatic resistance value, or as a pass or fail result to meet the test at specified pressure.

1. AATCC 127, Water Resistance:

Hydrostatic Pressure Test is the standard method that uses the hydrostatic head tester[1]. The resistance of fabrics to the penetration of water under pressure is assessed according to its ability to support a column of water without leaking. The higher the column it can support, the greater its ability to resist pressurized water entry. The result is expressed as water column height. A hydrostatic head resistance of 100 cm or more is regarded as an acceptable level of water resistance for outdoor clothing among manufacturers[6]. Procedure B in ASTM D 751-95 also uses a hydrostatic head tester. These hydrostatic pressure methods are often criticized for lack of realism because rain, even wind-driven rain, will not exert such pressure. Nevertheless, it is also important for a fabric to resist water entry under localized pressure, such as when kneeling on wet ground[3].

In this paper, the water resistance performances of 28 fabrics intended for use in shell fabrics in outdoor apparel were measured using three standard test methods and a database of information on their water resistance performance was created. The data collected with different methods were correlated and the advantages and disadvantages of each method were compared.

Ⅱ. Methods

1. Selection of the Shell Fabrics

The manufacturer, and a brief description of each shell fabric used in this study and their weight and thickness values are given in Table 1. The shell fabrics were organized into four groups according to their treatment type: microporous coating or laminate, monolithic coating or laminate, bicomponent which was a combination of microporous and monolithic, and high density woven fabrics. All of the base fabrics of shell fabrics were plain weaves made of either 100 % nylon or 100 % polyester fabric.

2. Measurement of the Water Resistance of Fabrics

<**Table 1**> Characteristics of Shell

Fabric code No.	Manufacturer	Fabric description	Weight (g/m^2)	Thickness (mm)
1	Nike, Inc.	100 % Microfiber Polyester, Rip Stop Weave	156.74	0.22
2	Toray, Inc.	100 % Nylon, Unbalanced Plain Weave	120.70	0.20
3	Mitsubishi International Corp.	100 % Nylon, Unbalanced Plain Weave	70.17	0.10
4	Mitsubishi International Corp.	100% Nylon, Rip Stop Weave	125.69	0.21
5	Action Sports Fabrics Group	100 % Nylon, Rip Stop Weave	82.49	0.13
6	Action Sports Fabrics Group	100 % Nylon, Unbalanced Plain Weave	117.95	0.17
7	Toray, Inc.	100 % Nylon, Unbalanced Plain Weave	102.64	0.19
8	Nextec Applications, Inc.	100 % Polyester, Unbalanced Plain Weave	83.32	0.13
9	BHA Technologies, Inc.	100 % Nylon, Balanced Plain Weave	106.96	0.21
10	BHA Technologies, Inc.	100 % Polyester, Unbalanced Plain Weave	135.60	0.25
11	Tomen Corp.	100 % Nylon, Rip Stop Weave	67.92	0.09
12	Tomen Corp.	100 % Nylon, Unbalanced Plain Weave	119.53	0.31
13	W. L. Gore & Associates, Inc.	100 % Nylon, Unbalanced Plain Weave	101.89	0.14
14	W. L. Gore & Associates, Inc.	100 % Nylon, Unbalanced Plain Weave	94.06	0.18
15	Helly-Hansen, Inc.	100 % Nylon, Unbalanced Plain Weave	129.85	0.22
16	Toray, Inc.	100 % Nylon, Rip Stop Weave	59.43	0.11
17	Marmot Mountain, Ltd.	100 % Nylon, Rip Stop Weave	75.92	0.11
18	Marmot Mountain, Ltd.	100 % Nylon, Rip Stop Weave	95.23	0.16
19	Columbia Sportswear Company	100 % Nylon, Unbalanced Plain Weave	130.69	0.27
20	Columbia Sportswear Company	100 % Nylon, Unbalanced Plain Weave	152.25	0.28
21	Perseverance Mills Limited	100 % Nylon, Rip Stop Weave	112.46	0.15
22	Unitika America Corp.	100 % Nylon, Unbalanced Plain Weave	208.35	0.34
23	Nike, Inc.	100 % Polyester, Unbalanced Plain Weave	117.29	0.21
24	Brookwood Companies, Inc.	100 % Nylon, Unbalanced Plain Weave	165.40	0.31
25	Akzo Fiber Inc.	100 % Polyester, Unbalanced Plain Weave	123.36	0.20
26	Lowe Alpine Systems, Inc.	100 % Nylon, Rip Stop Weave	140.34	0.29
27	Burlington Industries, Inc.	100 % Nylon, Rip Stop Weave	109.13	0.17
28	Burlington Industries, Inc.	100 % Nylon, Rip Stop Weave	104.88	0.19

1) ASTM D 751-95 Standard Test Methods for Coated Fabrics:

Hydrostatic Resistance, Procedure A - Mullen type hydrostatic tester (hand driven Mullen Tester, HJ, Standex Co.)[2]: Maximum pressure applied was 1103.0 kPa (160 psi). The pressure was increased steadily by rotating a handle. At the first appearance of waterdroplets through the specimen, the pressure was read on a dial and the results obtained form three specimens were reported in psi as the hydrostatic resistance of the fabric. The mean values were converted to kPa.

2) In Mullen test, some laminated and coated fabrics separated under pressure and consequently leaked. Therefore, five more specimens were tested with the support of a fabric (plain weave made of 100 % nylon filament) that prevented the rupture of the specimen. The hydrostatic resistance of the fabric was measured in the same manner as for the Mullen test with no support.

3) ASTM D 751-95, Standard Test Methods for Coated Fabrics

Hydrostatic Resistance Procedure B - Rising Water Column Tester (TEXTTEST FX 3000, SCHMID Corp.)[2]: Maximum pressure was 99.9 kPa (999 mbar). The pressure gradient per minute used was 15.0 kPa (150 mbar). The pressure increased moderately, but not sufficient to cause vortexing. At the moment of penetration of the specimen by drops of water at three places, the hydrostatic pressure was recorded. The results obtained from three specimens were reported in mbar as the average hydrostatic resistance of the fabrics. The mean values were converted to kPa.

3. Statistical Analysis

The means and standard deviations for the fabrics on water resistance as measured with the three different test methods) were calculated. Spearman Rank Order Correlation tests were conducted to determine the relationship of each test method to the others. The level of statistical significance was set at 0.05.

Ⅲ. Results and Discussion

1. Water Resistance

When fabrics were not penetrated at the highest level of machine pressure, the pressure level was a censoring limit in the data. Actually no penetration occurred at this maximum pressure. Maximum pressures for the Mullen test and hydrostatic head test were 1103.0 kPa (160 psi) and 99.9 kPa (14.5 psi), respectively. The higher the hydrostatic pressure, the higher the water resistance. The means and standard deviations for the fabrics on water resistance as measured with the three different test methods are shown in Table 2. The hydrostatic pressures on the Mullen test with no support ranged from 33.1 kPa (4.8 psi) to 1103.0 kPa (160 psi) for 13 of the fabrics, which was maximum pressure of the Mullen tester. The hydrostatic pressures measured on the Mullen test with a fabric support ranged from 53.8 kPa (7.8 psi) to 1103. 0 kPa (160 psi) for 16 fabrics. The hydrostatic pressures measured on hydrostatic head test ranged from 4.5 kPa (0.6 psi) to 99.9 kPa (14.5 psi) for 16 fabrics.

ASTM D 3393 specifies 207 kPa (30 psi) as the minimum value for waterproofness using the Mullen tester. According to Bucheck[4], the government test for waterproofness uses the Mullen tester but it specifies 241.32 kPa (35 psi) as the minimum pressure level. W. L. Gore & Associates has published a brochure[7] which classifies a fabric that prevents water entry at pressures greater than 172.37 kPa (25 psi) as "waterproof". This level gives total protection in all wind ad rain conditions and resists pressure from sitting or kneeling on a wet surface. A fabric that prevents water entry at pressures between 13.79 kPa (2 psi) and 172.37 kPa (25 psi) is classified as "highly water resistant". This resists penetration in rain[7]. If this classification is used, the results of both Mullen tests show that all high density woven fabrics are "highly water resistant", but "not waterproof". All the other fabrics are waterproof. Twenty fabrics had hydrostatic pressure over 241.32 kPa (35 psi). Several standards also specify that a fabric which fails to reach a pressure value of at least 35 kPa (5 psi)[2] or 10 kPa (1.45 psi)[5] is considered to have too low a hydrostatic pressure to be measured by the Mullen test. Therefore, the high density woven fabric had too low a hydrostatic pressure to be measured by the Mullen test.

The Mullen test provided a high amount of water pressure in a short period of time, so a test specimen sometimes delaminated and burst. When a support was added to the test specimen, this did not happen.

Most of the shell fabrics had higher penetration pressures when they had the support than when they did not have the support during the Mullen test. The hydrostatic head test gave lower hydrostatic pressure values than those measured on the two Mullen tests since the pressure was applied faster and the maximum pressure level on the hydrostatic head tester was lower.

2. Correlations of Water Resistance Tests

The correlation coefficients are shown in Table 3. The Mullen test with no support and the Mullen test with a support had a very high and statistically significant, positive correlation coef-

<Table 2> Results of Different Water Resistance Tests

Fabric code No.	ASTM D 751 Mullen Test with No Support[a] (kPa) (psi)		ASTM D 751 Mullen Test with a Support[a] (kPa) (psi)		ASTM D 751 Hydrostatic Head Test[b] (kPa) (psi)	
	Mean	SD	Mean	SD	Mean	SD
High Density Woven Fabrics with DWR Finish						
1	56.5 8.2	7.6	53.8 7.8	14.9	13.4 1.9	0.4
8	59.3 8.6	14.3	71.7 10.4	6.2	10.7 1.6	0.7
16	33.1 4.8	5.8	56.5 8.2	5.8	4.5 0.6	0.2
Fabrics with Microporous Coating or Laminate						
7	208.2 30.2	12.3	278.5 40.4	43.5	63.1 9.2	1.7
9	177.9 25.8	28.2	177.9 25.8	11.3	97.7 14.2	2.5
10	260.6 37.8	9.0	204.1 29.6	31.4	92.1 13.4	13.5
15	297.8 43.2	49.1	405.4 58.8	34.3	90.3 13.1	10.2
19	132.4 19.2	13.3	137.9 20.0	12.9	37.6 5.4	0.7
20	1036.9 150.4	89.4	1103.0 160	0	99.9 14.5	0
22	1103.0 160	0	1103.0 160	0	99.9 14.5	0
26	420.5 61.0	39.6	471.6 68.4	61.2	86.9 12.6	4.4
27	572.2 83.0	167.0	952.8 138.2	56.5	40.5 5.9	1.1
Fabrics with Monolithic Coating or Laminate						
2	1103.0 160	0	1103.0 160	0	99.9 14.5	0
3	951.4 138.0	18.9	1103.0 160	0	99.9 14.5	0
4	1103.0 160	0	1103.0 160	0	99.9 14.5	0

<**Table 2**> Continuation

Fabric Code No	ASTM D 751 Mullen Test With No Support a (kPa)(psi)		ASTM D 751 Mullen Test With a Support a (kPa) (psi)		ASTM D 751 Hydrostatic Head Testb (kPa) (psi)	
	Mean	SD	Mean	SD	Mean	SD
11	882.4 128.0	14.6	1103.0 160	0	99.9 14.5	0
12	1103.0 160	0	1103.0 160	0	99.9 14.5	0
18	1103.0 160	0	1103.0 160	0	99.9 14.5	0
21	857.6 124.4	94.0	1054.8 153.0	69.6	55.6 8.1	30.6
24	1103.0 160	0	1103.0 160	0	99.9 14.5	0
25	1103.0 160	0	1103.0 160	0	99.9 14.5	0
28	1103.0 160	0	1103.0 160	0	99.9 14.5	0
Fabrics with Bicomponent Treatments						
5	886.6 128.6	31.1	1103.0 160	0	99.9 14.5	0
6	1103.0 160	0	1103.0 160	0	99.9 14.5	0
13	1103.0 160	0	1103.0 160	0	99.9 14.5	0
14	766.6 111.2	21.5	1103.0 160	0	99.9 14.5	0
17	199.9 29.0	37.4	216.5 31.4	43.2	42.2 6.1	2.3
23	1103.0 160	0	1103.0 160	0	99.9 14.5	0

[a] The test was terminated at 1103.0 kPa of pressure and there was no penetration.
[b] The test was terminated at 99.9 kPa of pressure and there was no penetration.

ficient (0.92). Using a fabric support is not specified in standard ASTM D 751. However, the support could prevent fabric rupture during the Mullen test. The support appears to give higher and more favorable water resistance values on WWB shell fabrics. The hydrostatic head test had a high and statistically significant, positive correlation coefficient with the Mullen test with no support (0.88) and with the Mullen test with a support (0.95). If manufacturers have fabrics

<Table 3> Spearman Rank Order Correlation Coefficients for Standard Methods for Measuring Water Resistance

	Water Resistance		
	Mullen Test with No Support	Mullen Test with a Support	Hydrostatic Head Test
Mullen Test with No Support		0.92**	0.88**
Mullen Test with a Support			0.95**

* significant at the 0.05 level
** significant at the 0.01 level

tested on the hydrostatic head test, they can assume that these fabrics would be ranked similarly if they are using the Mullen test, particularly more with a fabric support.

3. Comparison of Water Resistance Tests

The major similarities and differences between test methods are shown in Table 4. The area of the fabric sample that is in contact with the water is smaller in Mullen tester, so higher pressure levels can be reached and more samples should probably be tested to get a representative value for each fabric type. The Mullen test also should be used on fabrics capable of being tested at pressures higher than 10 kPa (1.45 psi) due to the high speed with which the pressure is applied and low sensitivity in measuring pressure. The pressures generated on a fabric when someone is kneeling in wet grass, or sitting on a soaked boat seat, have been estimated at 172.4 kPa~344.7 kPa (25 psi~50 psi). Therefore, the Mullen test has often been criticized due to the high level of pressure that can be applied8). The hydrostatic head test probably would be good to evaluate the water resistance of fabrics that have relatively very low water resistance, such as high density woven fabrics. However, due to more stretching and a longer period of contact with water, the hydrostatic head test has been considered to be somewhat severe also[9].

When the coefficients of variation (% CV) were calculated and compared for the 12 fabrics that were penetrated on the three water resistance methods, the average coefficient of variation for the hydrostatic head test was the lowest (9.5%), followed by the Mullen test with a support (12.3%), and followed by the Mullen test with no support with the highest value (14.6 %), respectively. Therefore, the hydrostatic head test generated more repeatable data than the Mullen tests in this study on shell fabrics.

Ⅳ. Conclusions

The Mullen test provided a high amount of water pressure in a short period of time, so a test specimen sometimes delaminated and burst. When a support was added to the test specimen, this did not happen. Most of the shell fabrics had higher and more favorable water resistance values when they had the support than when they did not have the support during the Mullen test. The Mullen test is recommended for testing the water resistance of fabrics which have a relatively high water resistance because the Mullen tester applies a wide range of pressure and the pressure level can be used to determine which fabrics are "waterproof" according to standards and commonly used scales.

The hydrostatic head test gave lower hydrostatic pressure values than those measured on the two Mullen tests since the pressure was applied faster and the maximum pressure level on the hydrostatic head tester was lower. The hydrostatic head test is recommended for testing the fabrics that have relatively low water. If manufacturers have fabrics tested on the hydrostatic head test, they can assume that these fabrics would have relatively similar results if they are using the Mullen test, particularly with a fabric support.

The area of the fabric sample that is in contact with the water is smaller in the Mullen test, so higher pressure levels can be reached and more samples should probably be tested to get a representative value for each fabric type. Furthermore, the hydrostatic head test was deemed more repeatable than the Mullen tests in this study. Further study should be done on different standard methods measuring other performance characteristics of shell fabrics, such as water vapor transmission properties and water vapor resistance.

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