EFFECTS OF LAUNDERING AND LAYERING ON AIR PERMEABILITY OF SELECTED COTTON AND MAN-MADE FABRICS

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INTRODUCTION

Thermal insulating and windproofing properties of garments are affected by the fabric's air permeability, which may be changed by laundering through loss of fibers, dimensional change, and detergent deposits in the pores of the fabric (16). Increased porosity results when fibers work loose from the fabric during laundering or wear. Changes in dimensional stability may cause an increase or decrease in air flow. The type and amount of dimensional change is dependent on fiber content, yarn and fabric structure, and finish of the fabric. When detergent is deposited in the pores of fabric or when fabric sizings and waxes are removed in laundering, air permeability may be modified.

The air permeability of fabrics is important in assessing the resistance to the passage of air. Jackets with liners make use of the layer principle of one fabric superimposed on another fabric thereby increasing warmth by reducing air flow or by putting a drag on the air so it can be used as an insulator.

The larger interstices or pores of fabrics carry the largest volume of air, but in multiple layers the chances of the large pores being in exact alignment are small (18). The practical application of the effect of superimposing multilayers of fabrics is in the assessment of the resistance of jackets and liners or assemblages of clothing to the passage of air.

Because of the increased use of washable jackets, it was considered desirable to study the affects of laundering on the air permeability of selected fabrics commonly found in these jackets. Therefore, the objectives of the study were:

1) To determine the air permeability before and after laundering for single ply yarn poplin, two ply yarn poplin, and corduroy, fabrics commonly found in jackets, and for light, medium, and heavy weight acrylic pile fabrics found in jacket linings.

2) To determine the effect of the layer principle on air permeability using the above combinations.

Definition of Terms

Jacket shell or shell means a jacket without a lining.

Liner or lining fabric refers to the light, medium, and heavy weight pile fabrics.

Swatches indicate ten and twenty-two inch squares of liner and jacket fabrics cut from the original bolts of fabrics and used in laundering and air permeability tests.

Layer means the combination of the jacket shell and pile fabric used in determining the air permeability of the layered combination.

REVIEW OF LITERATURE

Skinkle and Moreau (30) reported that the first practical application of the determination of air permeability occurred during World War II. Knowledge of air permeability was important in balloon cloth, airplane fabric, parachute fabric, fabrics coated for water resistance and the "windbreaker" type of garment for the armed forces.

Since World War II, air permeability of clothing has been studied in relation to thermal insulation. The fabric's structure determines the warmth and permeability of the clothing by the size, shape, number, and frequency distribution of the air pockets produced in the cellular structure of the fabric (5 and 31).

Robinson (24) found that permeability of a fabric is of little importance in still air because the layer of still air next to the clothing surface has more resistance to diffusion than the clothing itself. But in moving air, the resistance of the clothing and the associated air layers falls off when there is an increase in air movement or air permeability in the fabric. Since clothing, as worn, is exposed to moving air, it is important to know the resistance of the fabric to air penetration. Air ventilation is a hygenic necessity in wearing apparel (5) and the amount of ventilation allowed by a garment will depend on the looseness of fit and on its permeability to air.

Yarn Characteristics

The air permeability of knitted fabrics made of natural and mercerized carded and combed cotton yarns was studied by Fletcher (12). The combed yarns had higher air permeability than the carded yarns in three out of four comparisons. Unmercerized cotton fibers had a higher resistance to air penetration than mercerized cotton fibers. Combed and mercerized yarns are smooth, and fabrics knit of those yarns allow the passage of air more readily than fabrics knit of carded and unmercerized yarns which are fuzzy. Another study (28) also found that smooth filament fibers offer less resistance to air flow than staple fibers.

It has been reported that the amount and direction of twist of a yarn seems to have a great affect on air permeability. Researchers (9 and 27) have established that increased twist lowers the resistance of a yarn to air flow. The twist reduces the yarn diameter; therefore, lowering the cover factor (ratio of fabric surface covered to the whole surface) and increases the pore space of free area between the yarns. The twist direction affects the compactness of the fabric structure (2). When the warp and filling twists are both S- or both Z-twist, the structure will be more compact because of the nesting of fibers at points of contact between the warp and filling. Conversely, S-Z or Z-S twist directions result in a more open fabric structure and consequently higher air permeability.

Fabric Construction and Finishing

Weaving produces a cellular structure that may be compact or loose depending on how tight the yarns are packed into the fabric (5 and 14). The pores of the fabric through which the air may pass are modified by the compactness of the structure. Sale and Hedrick (25) found the air spaces in a fabric vary with density and weave of the fabric. Black and Matthews (5) reported smooth, closely-woven fabrics, particularly those that are starched and glazed, have low permeability to air.

Various finishing techniques have influenced air permeability. Hot calendaring reduced air permeability by flattening yarns so that their cross-sectional shapes were elliptical rather than circular, thus reducing the free area in the fabric (17). Similar results were revealed by Backer (2). Other manufacturing processes such as napping and fulling also alter permeability (25). Any construction factor or finishing process that changes the area, shape, or length of the air flow in a fabric can appreciably change its permeability (17).

Laundering and Detergency

Honegger and Schnyder (16) studied the effect of laundering on air permeability.

> The washing liquor consisted of hard or soft water, soda ash, and soap or other detergents. The air permeability of the fabric was affected in various ways by laundering; loss of fiber increased the porosity whilst deposits of chalk or lime soap reduced it. Fabrics which had been laundered with soft water showed a higher air permeability. Laundering with hard water reduced the permeability of the linen fabric whilst it slightly increased the value for the cotton fabric (16, pp. 32).

The ions of calcium and magnesium in hard water react with the fatty acid portion of soaps to form curds of insoluble calcium and magnesium soaps (21). The calcium and magnesium ions not only make a portion of the soap ineffective as a cleansing agent, but form additional material to be dispersed by the remaining active cleaner. Some of the insoluble metal soaps are deposited on the fabric during laundering and may not be eliminated completely in the suds bath. In the rinse, more of the insoluble soap, together with some of the suspended dirt, may be deposited on the fabric.

No studies were found that investigated the effect of a synthetic detergent in laundering on air permeability of fabrics. One reason for the use of synthetic detergents instead of soaps in laundering is that their lime and magnesium salts are water-soluble and do not precipitate in hard water to form a scum (33).

Dimensional Change in Laundering

Numerous studies (2, 6, 8, 22, and 31) have reported that dimensional change resulting from laundering has a definite affect on the air permeability of the fabric. Sale and Hedrick (25) revealed that after laundering blanket fabrics the number and size of the air cavities decreased thereby reducing the air flow.

In contrast, Bogarty and others (6) found that air permeability increased with shrinkage in wool. In a study on cotton, Quackenbush and Stout (22) found air permeability tended to increase linearly with wear and laundering but reversals may occur during later stages of wear and laundering.

Clayton (8) reported a decrease in air permeability when shrinkage occurred in a wool and cotton twill fabric. However, the author pointed out that only large changes in permeability are significant to a permanent change, because ironing and mangling have an appreciable effect on the permeability.

Layering Principle

Superimposing or layering fabrics has been reported (8, 14, 18, and 23) to reduce air flow by the loss of kinetic energy that results when air travels through multilayers. Lord (18) found that when fabrics were superimposed at random, the air resistance of the assemblage was proportional to the number of layers up to five, the maximum number she tested. This information is valuable in determining the resistance of assemblages of clothing to the passage of air.

In garments such as jackets the purpose of the outer layer is to prevent penetration of wind, whereas the lining may be thick and porous with the purpose of putting a drag on the air to immobilize it. The immobilized air then acts as an insulator (4, 13, and 34).

For warmth, Fonseca and Breckenridge (13) recommended that the outer layer of clothing should insure that the quantity of air entering is sufficiently low so that kinetic energy is lost to prevent the air from entering the inner layers. The lining should provide limited protection in the event the outer layer is damaged.

Air Permeability Instruments

Three main types of instruments are used to measure air permeability.

Frazier air permeability machine. The Frazier air permeability machine is the most widely used instrument for measuring air permeability (27). With this instrument it is possible to test a wide range of fabrics under comparable conditions and permits testing in any part of the fabric without cutting it.

The instrument consists of a suction fan for drawing air through a known area of fabric defined by a circular orifice with a diameter of 70 mm (2.75 inches), and a means of measuring the rate of air flowing through the test area of the fabric. The fabric is clamped over the orifice and a pressure differential between the two fabric surfaces is adjusted to 12.7 mm (0.5 inches) of water. The clamp should effectively eliminate edge leakage.

Gurley densometer. With this instrument the time is noted for a given volume of air to pass through a given area of the fabric under an unspecified pressure differential that may not be constant (18). The major limitation of the densometer is that the pressure differential units are essentially arbitrary. An advantage is that it is a relatively simple instrument to operate.

Porosity machine. The third type of instrument is the porosity machine. Basically, it operates by forcing air through a known area of fabric at a constant rate, and the back pressure that develops is measured (29). This instrument is suitable for a limited range of fabrics, because it is not possible to have one rate of flow that is suitable for all types of fabrics. Also it is a complex instrument to operate.

METHOD OF PROCEDURE

An automatic washer and dryer were used to simulate home laundry methods. The air permeability of the fabrics was determined with a Frazier air permeability machine. American Society for Testing Material (ASTM), Committee D-13 (1) test procedures were followed for the thread count, thickness, dimensional stability, and air permeability tests. The resiliency and compressibility tests were performed according to the instruction booklet with the compressometer (11). All testing was carried out in a conditioned environment of 70 $\pm$ 2° F. and 65 $\pm$ 2 per cent relative humidity. Additional information for the equipment and procedures is given below.

Laundry Equipment

A three ring agitator type automatic washer was used for each of the ten launderings. The machine was operated thirty minutes with settings of "normal soil," wash and wear man-made fabric, and automatic cold water.

An automatic tumble dryer was used after each laundering. Both the fabric and cycle selectors were set for wash and wear.

Air Permeability Equipment

A Frazier air permeability machine was used to measure the air flow through the fabrics. The procedure followed to calibrate the instrument is described in ASTM (1) test procedures. Preliminary tests were made to determine which nozzles to use.

Fabric Description and Preparation

One ply 65% Dacron polyester/35% cotton poplin, two ply 65% Dacron polyester/35% cotton poplin, 100% cotton corduroy, and three weights of acrylic pile lining; fabrics commonly found in washable jackets were studied. The pile of the light weight lining fabric was 100% Orlon acrylic, and the knit back was 100% Orlon acrylic; medium weight lining fabric was 100% Acrilan acrylic, and the knit back was 100% Orlon acrylic; and the heavy weight lining fabric was 100% Orlon acrylic, and the knit back was 100% Dynel modacrylic. The acrylic pile fabrics were classified light, medium, and heavy weight on the basis of their weight per square yard, which were 7.63, 9.40, and 14.67 ounces per square yard, respectively.

The size and number of swatches were prepared according to ASTM (1) for dimensional stability and weight tests before laundering. The thread counts, thicknesses, resiliency, compressibility, and air permeability tests were performed on the same swatches that were used for dimensional stability analyses.

Laundry Procedure

The basis for the laundry procedure was information obtained from informal interviews with homemakers and supermarket managers. Young homemakers indicated that washable jackets usually are worn three years and laundered approximately ten times. Supermarket managers in Manhattan, Kansas in the fall of 1968, revealed (3) that the largest selling detergent was high sudsing with whitening agents and enzymatic reactives.

This detergent was used to simulate home laundry methods.

Swatches of jacket shell fabrics were laundered together ten times with enough ballast added to make a four pound load. Swatches from each of the pile lining fabrics were laundered together ten times. No ballast was added because of the bulk and weight of the pile fabric.

Temperature of the water for the wash and rinse cycles was taken for each of the ten launderings. Water hardness was determined with the Taylor Total Hardness Set, using the EDTA method (32), based on a titration with a standard solution of disodium ethylene diamine tetraacetate. The pH of the water was read at the beginning of the wash cycle, during agitation, and during both the rinse cycles.

Jacket fabric swatches were dried in an automatic tumble dryer forty minutes and the pile fabric swatches sixty minutes. The swatches were then conditioned for 24 hours in an environment of 70 ± 2^{o} F. and 65 ± 2 per cent relative humidity.

Physical Tests

Dimensional stability, thread count, air permeability, thickness, compressibility, resiliency, and weight tests were made on the woven and knitted fabrics after zero, one, two, four, six, eight, and ten launderings. Compressibility and resiliency tests were performed only on the three weights of pile fabric, because a previous study (20) indicated that the variance of the compressibility and resiliency of these poplin and corduroy jacket fabrics was slight.

Analysis of Data

The mean of the air permeability, F test for variance, and the least significant difference between the means were calculated for the two variables of layering and laundering, as well as the interaction of those variables. Thread counts, weights per square yard, thicknesses, resiliency, compressibility, and dimensional stability were studied for possible explanations to the changes in air permeability after zero, one, two, four, six, eight, and ten launderings.

RESULTS AND DISCUSSION

Water temperatures for the wash cycle averaged 115° F., for the first rinse cycle 84° F., and for the second rinse cycle 85° F. The water had a hardness of one grain per gallon. Average pH of the water at the beginning of the cycle was 9.36, and during agitation it was 9.59, and for rinse cycles one and two, 9.03 and 9.06, respectively.

The air permeability of the six fabrics studied was affected by the laundering process at the 1 per cent level (Tables VII, VIII, IX, and X, pp. 29-30). The layering of each pile fabric with each jacket shell fabric did not change significantly the air permeability of the jacket fabrics (Tables VII, VIII, IX, and X, pp. 29-30). There was a significant difference in air penetration among the weights of pile fabrics (Table X, pp. 30). There was significant interaction between the weight of the pile fabrics and laundering (Table X, pp. 30).

Thread count, weight per square yard, thickness, resiliency, and compressibility were not analyzed statistically because a careful review of the data indicated there were only slight variations in each factor after laundering.

Effect of Layering

There was no significant difference in air permeability for the one ply poplin, two ply poplin, and corduroy when they were layered with the light, medium, and heavy weight pile fabrics in the nine possible combinations (Tables VII, VIII, and IX, pp. 29-30). The pile fabrics were a knit construction and relatively porous. The literature reported that large pores will carry the largest volume of air, and in this study the pile fabric may have had pores too large to effectively reduce air flow through the layered combination.

Effect of Laundering

The one ply poplin, two ply poplin, and the three weights of pile fabrics increased in air permeability with successive launderings, whereas the corduroy decreased in air permeability as the number of launderings increased (Tables I, II, III, IV, V, and VI, pp. 15, 17-18, 20-22).

One ply poplin. An LSD test (Table I, pp. 15) showed a significant difference ($P < 0.05$) in air permeability for the one ply poplin between zero and one, one and two, six and eight, and eight and ten launderings. There was no significant change in air permeability between launderings two and four and four and six. After each laundering there was an increase in air permeability, except after ten launderings the air flow decreased significantly from the reading taken after eight launderings.

Weight and thickness varied little with the continued laundering (Table I, pp. 15). Dimensional change of fabrics was the only other factor studied that seemed to show any relationship to the amount of air flow. The specimens laundered eight times showed the highest air permeability, the specimens laundered six times had the highest percentage of total shrinkage (Specimens laundered twice had the highest per cent (0.7%) of shrinkage in the warp but the filling stretched 0.4% making the

TABLE I

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF ONE PLY POPLIN BASED ON THE NUMBER OF TIMES LAUNDERED (Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering		oz/yd^2 (N=6)	Thickness (pressure) (N=12)		Thread Count Warp x Filling (N=6)
			Warp (N=3)	Filling (N=3)		0.1 lb	1 lb	
0	4.796	-	-	-	5.46	0.012	0.010	129 x 61
1	5.686	-0.3	-0.5	+0.2	5.49	.014	.011	129 x 62
2	5.832	-0.6	-0.7	+0.4	5.45	.015	.011	128 x 61
4	6.005	-0.7	-0.2	+0.1	5.49	.017	.012	129 x 62
6	6.063	-1.1	-0.5	+0.1	5.53	.016	.011	128 x 63
8	6.224	-1.05	+0.1	-0.05	5.48	.017	.011	129 x 63
10	5.873	-1.30	-0.2	-0.05	5.54	0.018	0.012	128 x 63
	Total Dimen. Change*		-1.95	+0.5				

- Shrink
+ Stretch
LSD = 0.130

*Calculated after ten launderings.

total shrinkage for the fabric 0.3%. The total shrinkage for laundry number six was 0.4%.), and was second high in air flow. The changes in dimensions and air flow did not proceed at a regular progression with laundering.

Two ply poplin. There was a significant ($P < 0.05$) increase in air permeability for the two ply poplin between launderings zero and one, one and two, two and four, and six and eight (Table II, pp. 17). The difference in air permeability between launderings four and six, and eight and ten was not significant at the one per cent level. The specimens laundered once had the highest percentage of shrinkage (Table II, pp. 17) and the lowest air permeability. The control specimens had the lowest air flow. For this fabric, there seemed to be an increase in air permeability with progressive shrinkage. The variation in weight and thickness was slight with continued laundering.

Corduroy. There was a significant ($P < 0.05$) decrease in air permeability after one and ten launderings, and a significant increase in air permeability after the sixth laundering (Table III, pp. 18). There was a loss in weight and an increase in thickness with the continued laundering, which may have aided in reducing the air flow (Table III, pp. 18). Shrinkage also may have caused the decrease in air permeability, because the specimens laundered once had the greatest amount of shrinkage and the lowest air permeability reading.

Light, medium, and heavy weight pile fabric. There was a significant difference in air permeability among the three weights of pile fabric at the one per cent level before laundering (Table X, pp. 30).

TABLE II

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF TWO PLY POPLIN BASED ON THE NUMBER OF TIMES LAUNDERED
(Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering Warp (N=3)	Filling (N=3)	oz/yd^2 (N=6)	Thickness 0.1 lb (pressure) (N=12)	1 lb	Thread Count Warp x Filling (N=6)
0	2.625	-	-	-	5.66	0.013	0.011	131 x 61
1	2.942	-0.84	-0.9	+0.06	5.68	.015	.011	129 x 61
2	3.086	-1.34	- .6	+ .1	5.80	.016	.011	130 x 61
4	3.235	-1.64	- .3	0	5.83	.018	.012	130 x 62
6	3.252	-1.99	- .3	- .05	5.81	.017	.012	130 x 62
8	3.344	-2.14	- .1	- .05	5.79	.018	.012	130 x 62
10	3.298	-2.49	-0.4	+0.05	5.87	0.019	0.012	130 x 62
		Total Dimen. Change*	-2.5	+0.1				

- Shrink
+ Stretch
LSD = 0.049

*Calculated after ten launderings.

TABLE III

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF CORDUROY BASED ON THE NUMBER OF TIMES LAUNDERED
(Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering Warp (N=3)	Filling (N=3)	oz/yd^2 (N=6)	Thickness 0.1 lb (pressure) (N=12)	1 lb	Thread Count Warp x Filling (N=6)
0	25.98	-	-	-	11.10	0.052	0.040	51 x 56
1	21.36	-3.9	-2.4	-1.5	10.58	.073	.049	52 x 59
2	21.61	-5.1	- .6	- .6	10.68	.077	.051	53 x 58
4	21.69	-6.5	- .8	- .6	10.43	.084	.057	52 x 60
6	22.84	-6.5	- .3	+ .3	10.42	.084	.057	53 x 63
8	22.70	-6.7	- .2	0	10.76	.082	.056	53 x 60
10	21.58	-6.45	+0.05	+0.2	10.52	0.084	0.057	53 x 60
		Total Dimen. Change*	-4.2	-2.2				

- Shrink
+ Stretch
LSD = 0.98

*Calculated after ten launderings.

The heavy weight pile fabric was the least permeable with the light weight pile fabric next, and the medium weight pile fabric had the highest permeability.

Also, there was significant variance attributable to the weights of the three pile fabrics, laundering, and to the interaction of the three different weights and laundering (Table X, pp. 30).

There was a tendency for the air permeability to increase when the light, medium, and heavy weight pile fabrics stretched during laundering (Tables IV, V, and VI, pp. 20-22). The heavy weight pile had the highest amount of air flow when it showed the most shrinkage, so the air flow did not always decrease with shrinkage.

With the continued laundering of the light, medium, and heavy weight pile fabrics, thickness, weight, and compressibility increased and resiliency decreased. The heavy weight pile fabric differed; however, from the other two weights of pile fabric in that the compressibility of it remained the same throughout laundering. There did not seem to be any relation between air permeability to weight, thickness, resiliency, or compressibility.

TABLE IV

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF LIGHT WEIGHT PILE BASED ON THE NUMBER OF TIMES LAUNDERED
(Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering		oz/yd^2 (N=6)	Resil. (%) (N=12)	Compress (in^2/lb) (N=12)	Thickness (pressure) (N=12)		Thread Count Wale x Course (N=6)
			Warp (N=3)	Filling (N=3)				0.1 lb	1 lb	
0	166.2	-	-	-	7.63	44	0.040	0.138	0.087	12 x 24
1	283.0	-2.3	-0.2	-2.1	8.63	35	.042	.144	.088	12 x 23
2	305.6	-4.8	-1.1	-1.4	8.88	33	.050	.159	.093	12 x 24
4	320.6	-6.4	-0.2	-1.4	8.82	33	.051	.160	.093	12 x 25
6	326.8	-6.7	-0.2	-0.1	8.84	36	.046	.158	.093	12 x 24
8	318.9	-8.2	-1.4	-0.1	8.76	32	.051	.163	.094	12 x 25
10	333.0	-6.85	+1.3	+0.05	8.72	30	0.059	0.178	0.098	12 x 24
	Total Dimen. Change*		-1.8	-5.1						

- Shrink
+ Stretch
LSD = 4.55

*Calculated after ten launderings.

TABLE V

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF MEDIUM WEIGHT PILE BASED ON THE NUMBER OF TIMES LAUNDERED (Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering		oz/yd^2 (N=6)	Resil. (%) (N=12)	Compress (in^2/lb) (N=12)	Thickness (pressure) (N=12)		Thread Count Wale x Course (N=6)
			Warp (N=3)	Filling (N=3)				0.1 lb	1 lb	
0	241.9	-	-	-	9.40	35	0.052	0.167	0.104	12 x 23
1	303.3	-5.4	-2.6	-2.8	9.90	28	.054	.179	.110	12 x 23
2	304.8	-7.6	-0.6	-1.6	10.04	25	.065	.205	.118	12 x 23
4	343.7	-11.3	-1.3	-2.4	10.17	37	.058	.189	.117	12 x 23
6	338.4	-11.7	-0.2	-0.2	9.82	31	.055	.191	.116	12 x 23
8	348.4	-11.3	+0.2	+0.2	9.89	30	.055	.182	.113	12 x 24
10	343.2	-12.0	-0.9	+0.2	9.80	27	0.059	0.195	0.120	12 x 24
	Total Dimen. Change*		-5.0	-6.4						

- Shrink
+ Stretch
LSD = 4.55

*Calculated after ten launderings.

TABLE VI

AIR PERMEABILITY, DIMENSIONAL CHANGE, AND OTHER PHYSICAL PROPERTIES OF HEAVY WEIGHT PILE BASED ON THE NUMBER OF TIMES LAUNDERED
(Mean Values)

Laund. No.	Air Flow $ft^3/ft^2/min$ (N=6)	Accumulated Dimen. Change (%)	% Dimen. Change Attrib. to ea. Laundering		oz/yd^2 (N=6)	Resil. (%) (N=12)	Compress (in^2/lb) (N=12)	Thickness (pressure) (N=12)		Thread Count Wale x Course (N=6)
			Warp (N=3)	Filling (N=3)				0.1 lb	1 lb	
0	139.3	-	-	-	14.67	34	0.10	0.278	0.159	13 x 26
1	174.2	-8.2	-3.7	-4.5	16.27	31	.10	.266	.159	13 x 27
2	140.5	-9.8	-1.1	-0.5	16.77	31	.10	.308	.172	13 x 27
4	143.6	-11.7	-0.6	-1.3	17.05	31	.10	.311	.177	14 x 27
6	138.1	-12.0	+0.2	-0.5	16.27	37	.10	.308	.176	14 x 27
8	135.9	-13.7	-0.2	-1.5	16.63	28	.10	.310	.177	13 x 27
10	144.5	-13.3	+0.2	+0.2	16.42	28	0.10	0.318	0.177	14 x 27
	Total Dimen. Change*		-3.1	-7.5						

- Shrink
+ Stretch
LSD = 4.55

*Calculated after ten launderings.

SUMMARY AND RECOMMENDATIONS

This investigation was designed to evaluate the effect of laundering on air permeability and the effect of the layer principle on Dacron polyester/cotton poplin, corduroy, and acrylic pile fabrics. The air permeability of each fabric was determined before and after layering the shell and pile fabrics and after zero, one, two, four, six, eight, and ten launderings. Dimensional change, thread count, thickness, resiliency, compressibility, and weight were studied for possible relationships to air permeability.

Laundering. Laundering had a significant effect at the one per cent level on air permeability for the one ply poplin, two ply poplin, corduroy, and three weights of pile fabric. In all cases, except for the corduroy, there was an increase in air permeability with continued laundering. The air flow of the corduroy was reduced with additional laundering.

With progressive shrinkage of the poplins and pile fabrics, the air flow increased but the opposite occurred with the corduroy fabric. There were only slight changes in thread count, weight, thickness, compressibility, and resiliency with laundering and therefore none of those factors appeared to influence the air permeability of the fabrics examined.

Layering. The layering of the knit pile fabric with the jacket shell fabric did not reduce air flow significantly. The air permeability reading for the layered combination approximated the reading received for the jacket shell fabric when tested alone for air permeability.

Recommendations. This experimental study indicates a need for further investigation into the effects of laundering on air permeability of fabrics. It is suggested that yarn twist and structure be included in the analyses since the literature reported that twist has an effect on air permeability and this study found that the two ply poplin had a lower air permeability value than the one ply poplin. These two poplin fabrics were similar except for the ply number.

It is recommended that future studies compare the thermal insulative value of these jackets in moving air to the air permeability values received for the jacket fabrics in this study. This type of study would provide information on the relationship between the air permeability and thermal insulation of clothing.

Another suggestion would be to plan a long-term project that would consist of several studies with each concentrating on determining the air permeability for a certain type of fabric. For example, a study could be done with corduroy fabrics and the variable being the number of wales per inch. A concluding study could then bring together the information obtained from the previous studies and draw conclusions from it regarding the air permeability of various fabrics after laundering.

The final recommendation would be to conduct actual wear tests to correlate with results of laboratory tests.

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APPENDIX

TABLE VII

ANALYSIS OF VARIANCE FOR AIR PERMEABILITY FOR ONE PLY POPLIN AND LIGHT, MEDIUM, AND HEAVY WEIGHT LININGS

Source of Variance	Degrees of Freedom	Mean Square	F Test for Significance
Layers	3	0.431	2.2573
Layers x Swatches	20	0.191	
Laundering	6	4.447	84.1202**
Layers x Laundering	18	0.023	0.4292
Error	120	0.053	
Total	167		

** Significant at the 1 per cent level.

TABLE VIII

ANALYSIS OF VARIANCE FOR AIR PERMEABILITY FOR TWO PLY POPLIN AND LIGHT, MEDIUM, AND HEAVY WEIGHT LININGS

Source of Variance	Degrees of Freedom	Mean Square	F Test for Significance
Layers	3	0.081	0.5103
Layers x Swatches	20	0.158	
Laundering	6	1.528	205.6703**
Layers x Laundering	18	0.003	0.3405
Error	120	0.007	
Total	167		

** Significant at the 1 per cent level.

TABLE IX

ANALYSIS OF VARIANCE FOR AIR PERMEABILITY FOR CORDUROY AND LIGHT, MEDIUM, AND HEAVY WEIGHT LININGS

Source of Variance	Degrees of Freedom	Mean Square	F Test for Significance
Layers	3	91.685	2.3178
Layers x Swatches	20	39.557	
Laundering	6	77.416	12.8506**
Layers x Laundering	18	3.773	0.6262
Error	120	6.024	
Total	167		

** Significant at the 1 per cent level.

TABLE X

ANALYSIS OF VARIANCE FOR AIR PERMEABILITY FOR LIGHT, MEDIUM, AND HEAVY WEIGHT LININGS

Source of Variance	Degrees of Freedom	Mean Square	F Test for Significance
Liners	2	36,514.435	1108.4169**
Liners x Swatches	15	32.943	
Laundering	6	1,837.629	113.5966**
Liners x Laundering	12	598.096	36.9737**
Error	90	16.177	
Total	125		

** Significant at the 1 per cent level.

TABLE XI

AIR PERMEABILITY ($FT^3/FT^2/MIN$) OF THE LAYERED COMBINATION OF ONE PLY POPLIN AND THREE WEIGHTS OF PILE LINING FABRIC BEFORE AND AFTER LAUNDERING

	Air Permeability						
	Laundry Numbers						
	Zero	One	Two	Four	Six	Eight	Ten
One Ply Poplin alone	4.796	5.686	5.832	6.005	6.063	6.224	5.873
With Lt. Wt. Pile	4.664	5.510	5.664	5.767	5.886	6.082	5.716
With Med. Wt. Pile	4.832	5.455	5.620	5.744	5.945	5.530	5.869
With Heavy Wt. Pile	4.698	5.433	5.587	5.677	5.736	5.889	5.762

TABLE XII

AIR PERMEABILITY ($FT^3/FT^2/MIN$) OF THE LAYERED COMBINATION OF TWO PLY POPLIN AND THREE WEIGHTS OF PILE LINING FABRIC BEFORE AND AFTER LAUNDERING

	Air Permeability						
	Laundry Numbers						
	Zero	One	Two	Four	Six	Eight	Ten
Two Ply Poplin alone	2.625	2.942	2.086	3.235	3.252	3.344	3.298
With Lt. Wt. Pile	2.542	2.896	3.026	3.181	3.202	3.281	3.253
With Med. Wt. Pile	2.559	2.896	3.040	3.178	3.207	3.243	3.236
With Heavy Wt. Pile	2.508	2.906	2.988	3.118	3.172	3.174	3.164

TABLE XIII

AIR PERMEABILITY ($FT^3/FT^2/MIN$) OF THE LAYERED COMBINATION OF CORDUROY AND THREE WEIGHTS OF PILE LINING FABRIC BEFORE AND AFTER LAUNDERING

	Air Permeability						
	Laundry Numbers						
	Zero	One	Two	Four	Six	Eight	Ten
Corduroy alone	25.93	21.36	21.61	21.69	22.84	22.70	21.58
With Lt. Wt. Pile	24.91	19.84	19.82	19.30	18.91	18.97	18.65
With Med. Wt. Pile	24.83	20.58	19.28	19.29	20.40	19.30	18.66
With Heavy Wt. Pile	21.39	17.52	19.34	17.04	17.72	19.10	17.35

TABLE XIV

AIR PERMEABILITY ($FT^3/FT^2/MIN$) OF LIGHT, MEDIUM, AND HEAVY WEIGHT PILE LINING FABRIC BEFORE AND AFTER LAUNDERING

	Air Permeability						
	Laundry Numbers						
	Zero	One	Two	Four	Six	Eight	Ten
Lt. Wt. Pile	166.25	283.00	305.03	320.58	326.80	318.92	332.95
Med. Wt. Pile	241.87	303.27	304.82	343.65	338.40	348.42	343.22
Heavy Wt. Pile	139.27	174.17	140.52	143.58	138.07	135.93	146.20

EFFECTS OF LAUNDERING AND LAYERING ON AIR PERMEABILITY OF SELECTED COTTON AND MAN-MADE FABRICS

by

SHARON BRANT FRANKENBERY

B. S., Kansas State College, 1968

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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1970

The effects of laundering and layering on air permeability of 100% cotton corduroy, one and two ply 65% Dacron polyester/35% cotton poplins, and three weights of acrylic pile fabric were studied. After zero, one, two, four, six, eight, and ten launderings, all fabrics were measured for air permeability and dimensional stability. Thread counts, weights per square yard, thicknesses, compressibility, and resiliency were determined also after the above designated launderings. The shell fabrics were layered with the pile fabrics in all possible combinations, and air permeability was determined for each.

The layering of the pile and shell fabrics did not significantly change the air permeability of the shell. The air flow results for the layered combinations approximated those received for the shell fabrics alone.

Laundering increased air permeability of the poplin fabrics and the three pile fabrics. Corduroy showed a significant reduction in air flow after laundering. Laundering significantly affected the air permeability of the pile fabrics at the one per cent level but they were not affected uniformly. The three pile fabrics differed significantly in air permeability with the heavy weight pile having the lowest reading followed by the light weight fabric.

The two poplins and the pile fabrics increased in air permeability after shrinkage but the opposite was true for the corduroy after shrinkage. Thread count, weight per square yard, thickness, compressibility, and resiliency tests did not appear to be related to air permeability in this study.