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Efforts to Control Pilling in Wool/Cotton Fabrics

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Knit fabrics blended of wool and cotton provide warmth, resiliency, comfort, and aesthetic appeal that can be diminished by pilling. In normal wear and care, pill formation resulting from the contacts among projecting fiber ends at fabric surfaces can render a garment unwearable without causing garment failure. Ultimately, however, pill formation can cause strength losses in yarns and fabric. Through wear, abrasion loosens and releases surface fibers that entangle yet are anchored to fibers embedded within the fabric construction. The relative tenacities and elongations of surface and anchor fibers determine the pilling phenomenon. In fact, the increased use of higher strength synthetic fibers in wool-blended fabrics since the 1950s has led to increased pilling.[1] Fashion and consumer demand dictate the manufacture of textiles with finer yarn counts, lower twist factors, lighter fabric weights, and more pliable fabric constructions that may be comfortable and resilient but can be less resistant to abrasion.

ABSTRACT

To determine nylon's role in pilling and to examine how resistance to pilling can be increased in a commercial wool/cotton/nylon knit blend, new blends without nylon were constructed, unchlorinated wool was substituted for chlorinated (shrinkproofed) wool, and functional finishes were applied. Pilling was measured by an ASTM standard test and the results correlated with an image analysis method. There was less tendency to form pills in blends of wool treated by chlorination, yet unchlorinated wool blends attained higher resistance to pilling when finished with soft acrylic resins combined with dimethylsiloxane, synthetic waxes, glyoxal, and melamine. There was less pilling when nylon was absent. Untreated wool/cotton textiles can be made resistant to pilling provided the appropriate finish is applied. Cost comparisons showed that removing nylon from these blends can offer the consumer a product with good pilling resistance and cost savings to the manufacturer.

KEY TERMS

Cotton
Fiber Blends
Nylon
Pilling
Wool

Extensive study of pill formation, its growth and removal through wear, have led to an understanding of the various stages that develop in pilling. These stages include initiation where fibers entangle on the surface, growth as fibers pull out and become entangled further, and wearing away where the pills break from the anchoring fibers.[2]

In studies of pill density it was shown that rapid pill formation led to high pill density with little pill removal when a strong synthetic fiber comprised the fabric blend of woolen knitwear. Generally, in testing to evaluate pilling, laboratory-simulated wear tests are carried out over five to 40 minutes according to standard test methods. In the case of woolen knitwear pretreated for shrink resistance through oxidative degradation of cystine residues in the proteins of wool with permanganate, it was shown that the pill density after five minutes was most indicative for measuring pill density. Testing for longer periods resulted in pills wearing away, thereby confusing the evaluation.[3]

There is a rich textile tradition of applying finishes to improve the aesthetic and functional aspects of wool and wool blended fabrics for enhanced end-use performance. The action on wool of acrylic, epoxy, polyamide, polyurethane, polyester, polyurea, and silicone-based resins that adhere mechanically or chemically by graft polymerization through the reactive free amino, thiol, or hydroxyl groups on wool have been the subjects of many studies.[4-9]

The objective of this study was to examine the resistance to pilling of a commercial wool/cotton/nylon blended knit fabric by removing the nylon, substituting nonchlorinated wool for chlorinated (shrinkproofed), and applying (to the dyed fabrics) functional finishes that would not impact negatively on fabric handle. Measurements for pilling were performed according to the standard ASTM visual test method. These results were correlated with a new objective method based on digital image analysis that proved to correlate directly with the standard visual test.

Experimental

Fabric Preparation

Three two-layer jersey fabrics were used in this study. Each of the fabric layers, one layer blended of wool/cotton/nylon or wool/cotton and the other layer of 100% cotton, was constructed of single jersey knit and the layers were joined in knitting with stitches spaced 0.5 inches apart. The three fabrics were Fabric 1-T, 50% cotton/40% shrink-treated wool/10% nylon joined to 100% cotton; Fabric 2-T, 60% cotton/40% shrink-treated wool joined to 100% cotton; and Fabric 2-U, 60% cotton/40% untreated wool joined to 100% cotton. A 30-yard lot (15-20 pounds) of each fabric type was knitted, dyed, padded with softener, dried, and finished by J.E. Morgan Knitting Mills Inc.

The intimate blended yarns for each fabric were ring spun to size, 20/1, with 18 twists per inch, by Meritas Yarns, from 60s grade wool. The combed cotton yarns were open-end spun to size 20/1.

Dyeing was carried out in a Thies[a] jet dyeing apparatus by a two-bath, two-step sequential process with reactive dye, Levafix Red E2RN, and acid dye, Telon Fast Red ERNA, at a liquor-to-goods ratio (LR) of 5:1, for the run time of eight hours, following conven-

[a]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

tional dyeing procedures. After dyeing, the fabric was rinsed twice at 100F (37.8C) and a third time at 120F (48.9C) with 0.5% by weight of fiber (owf) Hipochem SS-400, anionic product (High Point Chemical Corp.), to remove surface dye before a final fourth rinse. The thoroughly rinsed fabric was removed and passed through a padder to extract water before drying in a Santex calendering, finishing bypass oven set to an input temperature of 335F (169C), through which it was passed at a rate of 12 yd/min for drying at 275F (135C). The calendered fabric was dried in the relaxed state under warehouse climatic conditions. All fabrics were stabilized by this compressive shrinkage process. Garments made from these fabrics carry the label, "machine wash gentle and tumble dry low."

Fabric Finishing

In the initial study to screen finishes to determine the most effective, each finish was applied to three replicates of each test fabric, Fabric 1-T, Fabric 2-T, and Fabric 2-U. The replicates were cut from dyed, unfinished two-yard lengths of each fabric type. The following six finishes and applications were selected as most effective.

Dicrylan WSR, 5% by weight of bath (owb), (Ciba Specialty Chemicals), a durable finish, blend of a nonionic polyurethane (PU) emulsion, anionic polysiloxane and polyisocyanate PU was applied by pad/dry/cure with and without Ultarasof HDP (Ciba Specialty Chemicals), an anionic high density polyethylene, 2% owb, with 0.3% owb sodium bicarbonate. The finished fabrics were cured at 325F (163C) for four minutes.

Synthappret BAP (Bayer Corp.), an anionic water soluble bisulfite adduct of isocyanate-polyisocyanate-polyurethane was applied in concentrations of 0.5% by weight of fiber (owf), 1.0% owf, 2.0% owf, and 3.0% owf from solutions buffered to pH 7.1-7.3. After padding the fabric was dried at 250F (121C) for five minutes and cured at 330F (166C) for one minute.

Glutaraldehyde (Union Carbide) was obtained as a mixture of 50% glutaraldehyde, 50% water, and 0.5% methanol and was applied at 2.5% owb, pH 4.0-4.5, by padding, then dried and cured on a Santex conveyor dryer (Santamatic 2000-Model #CH-9555) at approximately 270-300F (132-149C).

Creamoyl WF-1, WF-2, WF-3, and WF-4 (Scholler Inc.) are fatty amide blends with synthetic waxes. Each formulation was applied in concentrations of 6% owf and 10% owf from solutions buffered pH 7.1-7.3. After padding the fabric was dried at 250F (121C) for five minutes and cured at 330F (166C) for one minute. Creamoyl WF-1 is a blend containing a medium molecular weight acrylic polymer and a dimethyl silicone fluid as the primary active components. Creamoyl WF-2 is a blend containing a medium molecular weight acrylic polymer and synthetic waxes as the primary active components. Creamoyl WF-3 is a blend containing a low molecular weight acrylic polymer and a dimethyl silicone fluid as the primary active components. Creamoyl WF-4 is a blend containing a low molecular weight acrylic polymer and synthetic waxes as the primary active components.

Rhoplex ST 954 (Rohm & Haas Co.), an anionic selfcrosslinking acrylic emulsion (glass transition temperature, T_g = -23C) was applied using two different methods. For fabric pretreatment, 7-8% polymer solids on the weight of the fabric (fabric weight 0.55-0.69 oz/yd^2) were applied by padding using 5% bath solids. The impregnated fabrics were simultaneously dried and cured for five minutes at 302F (150C). In the second application, the same polymer add-on was applied with a collapsible foam coating on each side of the fabric. The diluted Rhoplex ST-954 (10% solids formulation) was mechanically foamed to a density of 80-90 gram/liter and coated on the fabric with a five-mils opening gap. The samples were simultaneously dried and cured for five minutes at 302F (150C).

Freerez 805 MX/Rhoplex K-3/ Aerotex 3030 (BFGoodrich) was applied to the fabrics as a mixture of Freerez 805 MX, 8% owb, a modified glyoxal resin with <0.1% free formaldehyde; Rhoplex K-3, (a nonionic selfcrosslinking acrylic emulsion, glass transition temperature, T_g = -27C, from Rohm & Haas) 2% owb; and Aerotex 3030, 3-5% owb, a hexamethoxymethylmelamine crosslinking agent; Freecat MX Accelerator (BFGoodrich), a buffered magnesium chloride catalyst; lactic acid, 1% owb; and Freetex WLM, 1-2% owb (BFGoodrich) surfactant as compatibilizer for solubility. The solution was diluted with 100F (38C) water to volume for the pad solution. The treated fabric was extracted through rubber rolls to moisture content of 130F (54C), dried in a conveyor dryer at 300F (149C) for three minutes, and cured at 310F (149C) for two minutes.

Pilling Evaluation

Prior to testing for pilling the dyed fabrics were laundered and dried once following AATCC Test Method 135, Dimensional Changes in Automatic Home Laundering of Woven and Knit Fabrics. The laundering procedure was as follows: machine wash normal agitation (AATCC detergent 1993), 120F (49C) wash temperature, tumble dry, delicate. The laundered fabric samples were conditioned at 70F (21C), 65% relative humidity for 24 hours. Pill testing was performed according to ASTM D3512, 1997, Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics. The Random Tumble Pilling Tester was selected for this study. The standard visual test, based upon photographic standards, was used to evaluate pilling on a scale of five (no pilling) through one (severe pilling). Three evaluators were used for visual assess-

Table I. Average Pilling Ratings for Wool/Cotton/Nylon Finished Fabric 1-T

Sample Finishes	Ratings for Random Pilling Standard Visual Test
Control, (dyed, unfinished)	1.5
Dicrylan WRS, 5% with 2% Ultrasof HDP	2.5
Dicrylan WRS, 5% without 2% Ultrasof HDP	2.5
Synthrappret BAP, 0.5%	1.5
Synthrappret BAP, 1.0%	1.5
Synthrappret BAP, 2.0%	1.5
Synthrappret BAP, 3.0%	2.5
Glutaraldehyde 2.5%	1.0
Creamoyl WF-1 6%	2.5
Creamoyl WF-1, 10%	2.5
Creamoyl WF-2, 6%	2.5
Creamoyl WF-2, 10%	3.5[a]
Creamoyl WF-3, 6%	3.0
Creamoyl WF-3, 10%	3.5[a]
Creamoyl WF-4, 6%	2.0
Creamoyl WF-4, 10%	3.0
Rhoplex ST 954, 5% pad/dry/cure	3.0
Rhoplex ST 954, 10% collapsible foam	2.0
Freerez 805 MX, 10%	3.0
Freerez 805 MX/ Rhoplex K-3/ Aerotex 3030	4.0[a]

[a]Finishes resulting in these ratings were applied to Fabrics 2-T and Fabrics 2-U having no nylon. The results of applying the best performance finishes for pill resistance.

Table II. Average Pilling Ratings for Nylon-Free Finished Fabrics 2-T and 2-U

	Ratings for Random Pilling Standard Visual Test	
	Fabric 2-T 60% Cotton/ 40% Treated Wool	Fabric 2-U 60% Cotton/ 40% Untreated Wool
Fabric Samples		
Control (unfinished)	2.5	1.5
Creamoyl WF-2, 10%	4.0[a]	2.0
Creamoyl WF-3, 10%	3.5	1.5
Freerez 805 MX/ Rhoplex K-3/ Aerotex 3030	5.0[a]	4.0[a]

[a]Fabric blends without nylon (Fabrics 2-T and 2-U) can exhibit higher ratings than those containing nylon (Fabrics 1-T).

Table III. Pilling Ratings by Visual Assessment and Digital Image Analysis

Sample Identification	Average Visual Pilling Rating (y)	Image Analysis Pilling Rating (s)	Difference, % [(x-y) / y] x 100
Control	1.50	1.44	-4.00
Synthrappret BAP, 1.0%	1.40	1.45	3.57
Glutaraldehyde, 2.5%	2.00	2.13	6.50
Dicrylan WRS, 5% with Ultrasof HDP	2.50	2.37	-5.20
Creamoyl WF-2, 10%	3.56	3.45	-3.09
Creamoyl WF-3, 10%	3.33	3.45	3.60
Average Root Mean Square Difference			4.48

ment of the replicates and the pilling ratings were averaged as shown in Tables I and II.

The visual results were compared to those obtained by image analysis. The configuration of the image analysis components was as follows. An angular adjustable ring light consisting of eight lights arranged in a circular manner was set at a low lighting angle and positioned 12.7 mm from the fabric samples. All fabrics were positioned with the wool blend side facing the camera and all were at the same viewing angle. Three measurements were made for each of the three fabric replicates (one at the center and one on each of two corners of an imaginary diagonal line across the fabric). The area of interest (AOI) was a 30-mm diameter circle (7.068 cm^2 area). A power regulator was utilized to maintain constant light intensity. The numbers of pills were recorded automatically as light objects in an eight-bit gray scale image that fell within the limits of the derived macro. Comparisons with the standard visual method are shown in Table III.

Results

In preliminary investigations to screen finishes applied to a similar two-layer jersey knit fabric, 65% cotton/25% wool/10% nylon joined to 100% cotton jersey, a five-minute random pill test was established as the testing condition. Pills formed within five minutes of starting the test. With prolonged tumbling to 30 minutes, pills increased and the fabric surface became severely degraded. The finishes shown in Table I were selected from this screening test, applied to Fabric 1-T, and evaluated after a five-minute pilling test.

Digital Image Analysis for Pilling Evaluation

An image analysis system consisting of a charged-coupled device camera, computer, frame grabber, and supporting imaging software was also used to evaluate pilling in Fabric 1-T.[10] The method, developed for this study, had a correlation coefficient of 0.993 when pill ratings derived from it were compared to those obtained by the visual ASTM D 3512 Photographic Standards for Pilling.[11] However, the three-dimensional effects of the fabrics were thought to affect uniform illumination. To overcome this difficulty, a mathematical macro was written that included area and length-to-breadth ratios of the shapes of individual pills as shown in Fig. 1.

A regression analysis was performed comparing the pilling rating of the fabrics in Table III by the image analyzer to the pilling determined by the standard visual method. The resulting graph is shown in Fig. 2 and is of the form:

$$y = 1.2525732 + 301.31708 * x^{-3.3204688} \qquad \text{Eq. 1}$$

where x refers to the number of pills determined by the image analyzer and y refers to the rating determined visually. The correlation coefficient of 0.984 indicates an excellent correlation. The visual pilling rating, the pilling predicted using image analyzer data and Eq. 1, and the percent difference in the results obtained when using these two methods are shown in Table III. Note that the average root mean square difference of the predicted pilling rating from image analysis and the visual pilling rating is only 4.48% which is very good.

Scanning Electron Microscopy

Random tumble pilling specimens were examined using a scanning electron microscope in an effort to determine if the presence of nylon fibers

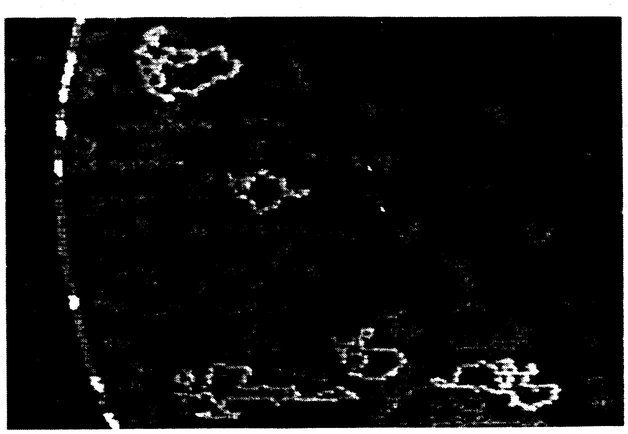

Fig. 1. Area and length-to-breadth ratios of the shapes of individual pills as recorded by image analysis.

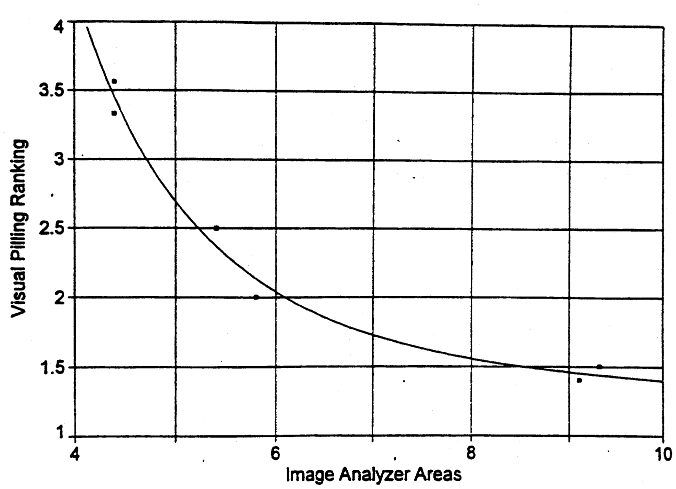

Fig. 2. Comparison of pilling areas automatically selected using an image analyzer and the visual ranking of pilling by using the ASTM D3512 photograph standards.

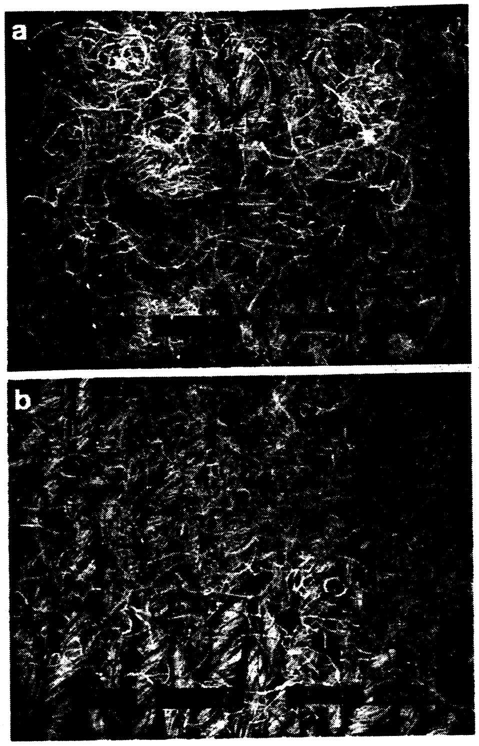

Fig. 3. Scanning electron photomicrographs showing pilling: a. Fabric 1-T containing nylon; b. Fabric 2-T without nylon.

Table IV. Yarn Cost Comparisons for Fabrics 1-T, 2-T, and 2-U

Fabric Description	Base Cost of Yarn per Pound	Cost Difference per Pound vs. Fabric 1-T
Fabric 1-T 50% Cotton/40% Treated Wool /10% Nylon	$3.15	
Fabric 2-T 60% Cotton/40% Treated Wool	$3.09	$0.06
Fabric 2-U 60% Cotton/40% Untreated Wool	$2.99	$0.16

Fig. 4. Scanning electron photomicrograph showing nylon fiber at the interface of pill and fabric surface in Fabric 1-T.

caused greater pilling. A difference in fabric appearance was noted between Fabric 1-T (Fig. 3a) and Fabric 2-T (Fig. 3b), both laundered once and subjected to the pilling test. In Fig. 3a there appears to be more surface roughness indicating a greater tendency for pill formation when nylon fibers are present in the fabric construction whereas in Fig. 3b, the fabric construction is more clearly defined. Close examination of Fig. 4 indicated that few nylon fibers appeared on the outside of pills. They were located within the pills where nylon appears to be both anchored to the fabric with cotton (note characteristic twists in cotton fibers) and wool (note characteristic scales) entangled about it and moving upward through the pill.

Discussion and Conclusion

The data show that in blends of wool treated by chlorination for shrinkproofing (Fabrics 1-T and 2-T) there is less tendency to form pills. It is known that shrinkproofing processes attack and soften the scale tips so that the wool scales lie flat on the fiber surface during washing with alkali.[12] In addition, the use of polymers to render wool unshrinkable has been described as "scale-masking" because, with a uniform film-like deposit, wool becomes unshrinkable and its directional friction effect is decreased so that interfiber adhesion is prevented.[13] Indeed this study shows that treated Fabrics 1-T and 2-T were more pill resistant than untreated Fabric 2-U.

A cost comparison of the blended yarns fabricated with treated and untreated wool, with or without nylon fibers is presented in Table IV. The analysis assumes that the only cost variable will be in that fabric of that fabric layer containing the wool-blended yarn.

By removing nylon there is almost a $0.06 saving in the treated wool blend and a $0.16 saving in the untreated wool blend. For a typical end-use, a men's button-front shirt weighing 13.5 pounds per dozen, this represents a savings of $0.76 per dozen or a savings of $0.06 per shirt. In the case of the untreated wool blend, removing nylon represents a savings of $2.12 per dozen or $0.18 per shirt. Removing nylon therefore can offer the customer a product with good pilling resistance and cost savings to the manufacturer.

When polymer finishes were applied to the blends containing treated wool with nylon fibers, in Fabric 1-T, the glyoxal, acrylic, polyurethane, and polysiloxane-based resins were not as effective as the soft acrylic (low T_g) resins combined with dimethylsiloxane, synthetic waxes, glyoxal, and melamine. The latter provided adequate pilling resistance in the nylon-free blends containing untreated wool (Fabric 2-U) and excellent resistance in the blends without nylon combining cotton with treated wool (Fabric 2-T). Visual assessment and image analysis showed that wool blended fabrics exhibit less tendency to form pills when nylon is omitted from the wool/cotton blend

Pilling can conceivably be controlled by many variables including staple fiber by fineness and length, yarn type by the amount of twists per inch, and choice of fabric construction by yarn configuration. However, fashion dictates may preclude appropriate selections that prevent pilling. The results of this study indicate that untreated wool/cotton textiles blended with nylon can be made resistant to pilling provided the appropriate finish is applied. By removing nylon from blends of untreated and treated wool with cotton, the appropriate finish can impart high pilling resistance. Yet there is still a pressing need for an alternative to fabric finishing for alleviating pilling in untreated wool blends with cotton.

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