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Influence of Household Fabric Softeners and Laundry Enzymes on Pilling and Breaking Strength

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Pilling is a concern to both textile and apparel manufacturers and consumers because it affects fabric aesthetics and comfort. Fabric pilling is a complex phenomenon comprised of several stages and influenced by a variety of factors. Factors influencing fabric pilling include fiber type and cross-sectional shape, yarn type and construction, and fabrication type and construction. Fabric finishes also play an important role in pilling by affecting some of these textile parameters. For example, singeing and thermosetting reduce fabric pilling and have been used for many years to minimize pilling in fabrics. On the other hand, selected chemical finishes, most notably ubiquitous household fabric softeners, may increase pilling.[1-3]

ABSTRACT

This study was undertaken to examine the unresolved questions surrounding the influence of household fabric softeners and cellulase-enzyme containing laundry detergents on pilling and strength of selected fabrics. Results showed that dryer sheet softeners were not associated with an increase in pilling, a greasy hand, nor increased breaking strength losses in any of the cotton or polyester fabrics included in this study. This was true for both the recommended dose and an overdose of dryer sheet softeners. In contrast, rinse cycle softeners (both the recommended dosage and an overdose) were associated with increased pilling and/or an increase in the size of pills formed on all cotton-containing fabrics, as well as increased breaking strength losses in both the cotton flannel and polyester woven fabric.

Cellulase enzyme detergent additives significantly reduced the amount of pilling on all cotton fabrics, except the cotton interlock knit. It appears that rinse cycle softeners negated some of the beneficial effects of cellulase enzymes on pilling which is another reason to avoid rinse cycle liquid softeners when laundering cotton flannel clothing. The cellulase enzyme detergent additives had no significant negative effects on breaking strength in either of the cotton or polyester woven fabrics included in this study.

Key Terms

Breaking Strength
Cellulase Enzyme Detergent
Fabric Softener
Pilling

BACKGROUND

Fabric Softeners

Although fabric softeners have been in use since the 1930s, their demand increased greatly in the 1950s due to several factors including the introduction of synthetic fibers, detergents, and the advent of the modern washing machine and automatic dryer. Abrasion from mechanical agitation of automatic washers caused surface fuzz formation in fabrics, as well as distortion and entanglement of fibers, more rapidly than earlier wringer washing machines had. The entangled fibers were further set by the automatic dryers; this produced a stiff and harsh hand which prompted interest in and a market for home laundry softeners.[4] In addition, synthetic detergents removed the oils and waxes that served as lubricants in natural fibers. Synthetic detergents, therefore, resulted in very clean but harsh, scratchy, and uncomfortable fabrics to wear.[5] Fabric softeners were needed to counteract these effects. Another factor contributing to the increased use of fabric softeners is that synthetic fibers are prone to static build up which can be objectionable to the wearer. Fabric softeners act as antistatic agents by enabling synthetic fibers to retain sufficient moisture to dissipate static charges.[6]

Household softeners, both liquid and dryer sheet, work by coating yarn and fibers with lubricants and humectants.[7] The lubricants make fabrics feel smooth, soft, and flexible by internal lubrication of the fibers. Humectants help fibers to retain moisture, a factor that is crucial in antistatic treatment.

Until recently, household fabric softeners were formulated from three main chemical classes of cationic surfactants: dialkyldimethyl ammonium compounds, imidazolinium compounds, and diamido alkoxylated ammonium compounds.[8-10] In the 1990s, esters of dimethyl ammonium compounds (so-called ester quats) supplanted all other softener types in Europe due to concerns about the biodegradability of dialkyl quaternary compounds. Only one major U.S. company has switched to ester quats, and did so quietly and without environmental claims around 1996.[11] Dryer sheet softeners "contain essentially the same type of cationic compounds as washer-added liquids, with minor differences to ensure compatibility with the clothes dryer."[12] Dryer sheet softeners impart less lubrication, and therefore less softening, to fabrics than rinse cycle softeners.[9] On the other hand, dryer sheet softeners control static cling better than rinse cycle softeners.[9] Although a number of studies have been published regarding the influence of fabric softeners on textile properties, most of the studies focused on the influence of softeners on fabric hand, absorbency, static properties, abrasion, whiteness, wrinkle recovery, flame retardancy, durable press, and soil release. These did not include fabric pilling. [5, 13-18]

Fabric Softeners and Pilling

The effect of softeners on pilling is inconclusive and contradictory in literature. Smith and Block state that "fabric softeners may sometimes be effective in reducing pilling, since they lubricate the surface of the cloth and reduce the abrasive forces. On the other hand, they also promote the migration of fibers within spun yarns, especially synthetic fibers, so this technique is not always effective."[19] Tomasino and Guthrie evaluated the effect of silicone (mill applied) softeners on the pilling of modified, disperse dyed, and durable press finished polyester fibers.[3] They found that silicone softeners alone did not significantly influence pilling. However, when silicone softeners were used in combination with acrylic binders, fabric pilling increased noticeably. Niemann and staff members of the Hosiery and Allied Trades Research Association (HATRA) who studied the effect of household softeners on pilling found that an overdose of fabric softener increased fabric pilling.[1,2] Unfortunately, neither Niemann nor HATRA staff identified household softener type (liquid or dryer sheet), or described the fabric types used in their reports, thereby leaving several key questions unanswered. Namely, do both dryer sheet and liquid softeners increase fabric pilling if used in quantities greater than the manufacturer's recommended dosage? And, do knits and wovens of different fiber types respond similarly to an overdose of softener?

Cellulase Enzymes

Another laundry product development that reduces surface fuzziness and pilling is the addition of cellulase enzymes to household laundry detergents.[20,21] Detergents containing cellulase enzymes maintain the "like new" appearance of cotton fabrics. Gormsen, Marcussen, and Damhus, explain that cellulase enzymes hydrolytically remove surface fuzz, which can make fabrics turn dull in appearance after repeated launderings, thereby maintaining the original clarity of the colors, in addition to reducing pilling.[20] Since household fabric softeners are so widely used by consumers, the related question arose about what positive or negative synergistic effects, if any, might fabric softeners and cellulase enzyme-containing detergents have on fabric pilling and fabric strength.

OBJECTIVE

This study was undertaken to examine the influence of household fabric softeners on pilling. The purpose of this study was to investigate the effect of household fabric softeners on pilling and strength of selected woven and knitted fabrics, and the effect of cellulase enzymes in detergents on pilling and strength of selected woven and knitted fabrics.

The need for this research was mentioned in a report issued by the AATCC C2-S2 Technical Subjects Committee which noted that a study "to evaluate the effects of increased use of home laundry softeners in relation to AATCC test methods; i.e., soil release, soil redeposition, appearance, dimensional change, and other physical performance testing such as flammability, etc" was needed.[22] Additionally, questions remain regarding the influence on fabric strength of fabric softeners in combination with cellulase enzymes in laundry detergent formulations.

EXPERIMENTAL

Fabrics

Fabrics evaluated in this study were purchased from Testfabrics Inc. (West Pittson, Pa.) or from Textile Innovators (Windsor, N.C.), and are identified by style number in Table I. Fabrics were selected to represent some of the most common fiber and fabric types available to consumers. The fabrics were also chosen because of their propensity for pilling. Cotton flannel has a nap that makes it pill readily, cotton jersey knit and cotton interlock knit are prone to pilling because of their relatively loose construction, 50/50% cotton/polyester jersey knit readily accumulates pills because it is made from a blend of strong fibers (polyester) and weak fibers (cotton) and also because it has a relatively loose fabric construction, the polyester fabrics (100% Dacron polyester interlock knit and 100% Dacron polyester plain woven fabric) are known for holding onto pills, and both also have relatively loose fabric constructions. The unscoured test fabrics were cut into specimens (12" x 20") and all woven fabric specimens were serged along the raw edges to prevent raveling during laundering.

Detergent and Cellulase Enzymes

AATCC 1993 Standard Reference Detergent WOB was used in this study. A detergent containing enzymes was prepared by adding cellulase enzymes to the AATCC 1993 Standard Reference Detergent WOB. A multi-component granular enzyme consisting of endogluconase, cellobio-hydrolase, and cellobioses was the enzyme used. Temperature and pH conditions (8.0-8.75) were measured for each laundering cycle. The amount of enzymes used was 0.6 ±0.02 grams per wash load, the amount recommended by the manufacturer.

Laundering

AATCC Test Method 135-98 for Standard Home Laundering Conditions was used with some modifications for laundering the test fabrics. A Kenmore, automatic heavy duty, 70 series, extra-capacity washer and dryer were used for laundering and tumble drying the fabrics. The laundering conditions were: Test No. III, permanent press setting, water level of high, a warm temperature of 41 ±3C, a wash time of 10 minutes, 66 grams of detergent, and a wash load of 1.8 ±0.1 kg, including fabric specimens and ballast of 100% cotton sheeting. All types of fabrics were laundered together in each treatment to simulate home laundering. The number of launderings was limited to ten times because preliminary tests showed that laundering 15 or 20 times did not produce a visually perceptible increase in pilling beyond that which was apparent after ten launderings.

The drying conditions were: Tumble drying Test No. A, permanent press setting, an exhaust temperature of 145C, timed drying. Specimens were tumble dried for only 10 minutes to prevent synthetic fibers from over drying. Since the cotton fabrics were not completely dry after this limited drying time, the cotton

TABLE I.

Mean Pilling Ratings Following Elastomeric Pad Pilling Tests for Selected Fabric Types Laundered Ten Times with Two Detergent Types and Selected Softener Treatments[a]

Fabric and Softener Treatment	Without Enzymes	With Enzymes	Fabric and Softener Treatment	Without Enzymes	With Enzymes
Cotton flannel (TF 425)[b]			**Cotton/polyester jersey (TF 7421)**		
Control-no softener	1.7	1.7	Control-no softener	3.9	3.9
Rinse cycle normal dose	1.3	1.7	Rinse cycle normal dose	2.4	2.8
Rinse cycle overdose	1.3	1.6	Rinse cycle overdose	2.5	2.8
Dryer sheet normal dose	1.6	1.7	Dryer sheet normal dose	3.7	3.9
Dryer sheet overdose	1.5	1.7	Dryer sheet overdose	3.6	3.8
Cotton jersey (TF 437)			**Polyester interlock (TF 730)**		
Control-no softener	2.6	2.6	Control-no softener	4.7	4.7
Rinse cycle normal dose	1.7	2.6	Rinse cycle normal dose	5.0	5.0
Rinse cycle overdose	1.7	2.5	Rinse cycle overdose	5.0	5.0
Dryer sheet normal dose	2.4	2.6	Dryer sheet normal dose	4.7	4.7
Dryer sheet overdose	2.4	2.6	Dryer sheet overdose	4.7	4.7
Cotton interlock (TI 460)			**Polyester woven (TF 761)**		
Control-no softener	1.8	1.8	Control-no softener	4.7	4.7
Rinse cycle normal dose	1.1	1.2	Rinse cycle normal dose	5.0	4.9
Rinse cycle overdose	1.0	1.1	Rinse cycle overdose	5.0	4.9
Dryer sheet normal dose	1.7	1.9	Dryer sheet normal dose	4.6	4.6
Dryer sheet overdose	1.8	1.8	Dryer sheet overdose	4.6	4.7

[a] 1=very severe pilling; 2=severe pilling; 3=moderate pilling; 4=slight pilling; 5=no pilling
[b] TF=Testfabrics; TI=Textile Innovators

specimens were laid on a flat surface to finish drying by air-drying. We deemed it essential for controlling experimental variables to tumble dry all specimens for the same amount of time, even though this necessitated air drying the cotton specimens. The air drying of the cotton specimens simulated a consumer practice of removing cotton t-shirts and men's dress shirts from the dryer while still damp and hanging them to air dry.

Fabric Softeners

Two types of commercially-available fabric softeners (rinse-cycle liquid and dryer sheet) were used in this study. Both were produced by the same company and both used ester quat softener formulations. The softeners included in this study were selected because they were among the six leading nationally rated fabric softeners.[7] The overdose for each softener was equal to twice the dosage recommended by the manufacturers. After the washer was filled with water for the rinse cycle, the rinse cycle softener was added and agitation restarted immediately to prevent spotting of fabrics with concentrated softener. Dryer sheet softeners were added to the dryer. One dryer sheet was used for a normal dose and two sheets for an overdose.

Pilling Test and Evaluation

An accelerated pilling test was performed on the laundered fabrics according to ASTM D 3514-96 Standard Test Method for Pilling Resistance and Other Related Surface Changes of Textile Fabrics: Elastomeric Pad. A 0.5 lb weight was used instead of a 1 lb weight because the 1 lb weight proved too heavy and led to surface damage in all fabrics during preliminary testing. Visual pilling ratings were assigned to each specimen by three trained evaluators. Stereomicroscopic examination of selected fabric specimens was performed to better understand pilling mechanisms and morphology.

Breaking Strength

Breaking strength was determined according to ASTM D 5035-96 Standard Test Method for Breaking Force and Elongation of Textile Fabrics (Raveled Strip Method) on the two woven fabrics.

Experimental Design and Statistical Analysis

The design for this experiment was a completely randomized design with a 6 x 5 x 2 factorial treatment structure. The three independent variables for the study were fabric type, softener treatment, and detergent type. The dependent variables were pilling ratings and breaking strength change. The experiment was replicated two times. Analysis of variance (ANOVA) and Tukey's Studentized (LSD) tests were performed on the data to determine which of the independent variables significantly influenced pilling ratings and breaking strength. The level of significance was 0.05 for all tests conducted.

RESULTS AND DISCUSSION

Pilling

Mean pilling ratings for all fabrics are shown in Table I. Because fabric type is known to influence pilling, ANOVA procedures were performed by individual fabric type to provide a more informative analysis.

Cotton Flannel

Pilling ratings for cotton flannel ranged from 1.3 to 1.7, indicating severe pilling. This pilling rate was anticipated since cotton flannel has low twist yarns and a napped surface both of which are known to contribute to pilling. The ANOVA test results showed that detergent type significantly affected pilling ratings of the cotton flannel, but softener type and dosage did

TABLE II.

ANOVA on Pilling Ratings for Selected Fabrics

Fabric and Source	DF	F Value	PR>F	Fabric and Source	DF	F Value	PR>F
Cotton flannel				**Cotton/polyester jersey**			
Detergent Type	1	5.40	0.0425	Detergent Type	1	5.63	0.0391
Softener	4	1.43	0.2927	Softener	4	38.10	0.0001
Detergent x Softener	4	2.23	0.1381	Detergent x Softener	4	0.60	0.6720
Cotton jersey				**Polyester interlock**			
Detergent type	1	23.25	0.0007	Detergent type	1	0.20	0.6643
Softener	4	5.08	0.0170	Softener	4	32.20	0.0001
Detergent x Softener	4	3.83	0.0379	Detergent x Softener	4	0.20	0.9327
Cotton interlock				**Polyester woven**			
Detergent type	1	2.29	0.1615	Detergent type	1	0.40	0.5413
Softener	4	18.42	0.0001	Softener	4	18.25	0.0001
Detergent x Softener	4	0.92	0.4874	Detergent x Softener	4	1.15	0.3882

not (Table II). LSD test results (Table III) showed that repeated laundering using a detergent with cellulase enzymes significantly reduced fabric pilling (increased pilling ratings) on cotton flannel. The use of enzymes presumably contributed to the improved pilling ratings by reducing fabric surface fuzz, as reported by others.[20, 21]

Although statistical analysis of the experimental data indicated that softener treatment had no significant effect on pilling ratings of cotton flannel, visual examination of the specimens subjected to accelerated pilling following laundering revealed that softener type perceptibly influenced the size and nature of the pill formed on cotton flannel. Cotton flannel laundered with rinse cycle softeners tended to exhibit significantly larger and softer pills than specimens treated with dryer sheet fabric softeners or with no fabric softeners when subjected to the elastomeric pad pilling tests (Fig. 1). The controls and specimens treated with dryer sheet softeners formed smaller and harder pills during the elastomeric pad accelerated pilling tests. It was clear that softener treatment influenced pill morphology; however, observers who assigned pilling ratings could not indicate this difference because the ASTM D3514 protocol calls for awarding pilling ratings according to pill size. In fact, different photographic rating standards are used depending on pill size. Dissatisfaction with current methods for evaluating pilling and assigning pilling ratings led to research focused on developing methods for measuring and evaluating pilling more accurately.[23,24]

Softener dosage had no significant effect on the amount of pilling nor on the size and nature of pills formed on cotton flannel. These findings conflict with those of Nieman, who reported that softener overdose was associated with an increase in fabric pilling.[1] This difference in findings may be due to differences in fiber and fabric type. The reason that softener type significantly affected the size and nature of pill formation on cotton flannel, but an overdose of softener did not, may be due to the fact that fibers reach their maximum level of softener sorption and fiber lubrication with the recommended dosage; consequently, increasing softener dosage does not lead to further changes. Hughes, Leiby, and Deviney showed that softeners were absorbed at a faster rate at lower concentrations than higher concentrations.[16]

Cotton Jersey

Cotton jersey knit exhibited less severe pilling than cotton flannel. ANOVA tests showed that detergent type and softener treatment both significantly influenced pilling ratings on cotton jersey knit. A significant two-way interaction between detergent and fabric softeners indicated that the influence of selected softener treatments on pilling depended on detergent type. Generally, pilling of cotton jersey specimens laundered with a detergent containing a cellulase enzyme was less severe than pilling of specimens laundered with a detergent without cellulase enzymes.

Visual evaluation of the cotton jersey after the accelerated pilling tests showed that larger pills were associated with rinse cycle softener treatments (whether or not a cellulase enzyme was present in the detergent), as was true for the cotton flannel. Cotton jersey treated with the dryer sheet softener and controls (no softeners) exhibited smaller and fewer pills. Although larger pills formed during the accelerated pilling tests on the specimens laundered using rinse cycle softeners, fewer large pills were observed on fabric specimens treated with rinse cycle softeners when applied in combination with a cellulase-enzyme containing detergent.

Cotton Interlock Knit

All the cotton interlock knit specimens exhibited severe pilling. This was expected because of the known low pilling resistance of knitted cotton fabrics. The

TABLE III.

LSD Test for Effect of Detergent on Pilling of Selected Fabrics

Treatments	Pilling Rating	Tukey's Grouping	Treatment	Pilling Rating	Tukey's Grouping
Cotton flannel			*Cotton/polyester jersey*		
With enzymes	1.7	A	With enzymes	3.4	A
Without enzymes	1.5	B	Without enzymes	3.2	B

TABLE IV.

LSD Test for Effect of Softener Treatment on Pilling Ratings of Selected Fabrics following Elastomeric Pad Pilling Tests

Fabric and Softner Treatment	Pilling Rating	Tukey's Grouping	Fabric and Softner Treatment	Pilling Rating	Tukey's Grouping
Cotton interlock			*Polyester interlock*		
Control-no softener	1.8	A	Control-no softener	4.7	B
Rinse cycle normal dose	1.1	B	Rinse cycle normal dose	5.0	A
Rinse cycle overdose	1.0	B	Rinse cycle overdose	5.0	A
Dryer sheet normal dose	1.8	A	Dryer sheet normal dose	4.7	B
Dryer sheet overdose	1.8	A	Dryer sheet overdose	4.7	B
Cotton/polyester jersey			*Polyester woven*		
Control-no softener	3.9	A	Control-no softener	4.7	B
Rinse cycle normal dose	2.6	B	Rinse cycle normal dose	5.0	A
Rinse cycle overdose	2.6	B	Rinse cycle overdose	5.0	A
Dryer sheet normal dose	3.7	A	Dryer sheet normal dose	4.6	B
Dryer sheet overdose	3.6	A	Dryer sheet overdose	4.6	B

ANOVA test showed that softener treatment significantly influenced pilling, but the presence of enzymes in the detergent did not. LSD test results (Table IV) showed that cotton interlock knit laundered with rinse cycle softeners exhibited significantly more pilling (had lower pilling ratings) than specimens treated with dryer sheet softeners or no softeners. In addition, the rinse cycle softener treatments were associated with larger pills than other treatments on the interlock knit. There was no difference in the amount of pilling associated with softener overdose versus the recommended dose.

Cotton/Polyester Jersey Knit

The ANOVA test (Table II) indicated that both detergent type and softener treatment significantly affected pilling during the accelerated pilling tests. LSD test results (Table III) showed that cotton/polyester blend jersey specimens laundered with a detergent containing enzymes exhibited less pilling (higher pilling ratings) than those laundered without enzymes regardless of softener treatment. Despite the presence of the polyester fiber, which is impervious to cellulase enzymes, sufficient cotton fibers were present and effectively hydrolyzed by the enzymes to reduce surface fuzz and thereby significantly reduce pilling. LSD tests on softener treatment (Table IV) also showed that specimens treated with dryer sheet softeners or no softener exhibited less pilling than specimens treated with rinse cycle softeners. Rinse cycle softeners (both recommended dose and overdose) once again were associated with increased pilling. Finally, the cotton/polyester jersey, like all the 100% cotton fabrics, exhibited larger pills when treated with the rinse cycle softeners.

Polyester Fabric

Overall pilling for both 100% polyester fabrics was slight with some pilling ratings a perfect 5, indicating no pilling. ANOVA tests showed that softener treatment significantly influenced pilling. As expected, detergent type did not influence pilling on the polyester interlock knit because cellulase enzymes are capable of hydrolyzing only cellulosic fibers. LSD test results (Table IV) showed that polyester knit and woven specimens treated with rinse cycle softeners exhibited less pilling than those treated with dryer sheet softeners or no softener. In fact, there was no perceptible pilling on rinse cycle softener-treated polyester interlock knit (Fig. 1) and very little on the rinse-cycle softener-treated polyester woven. However, although the increased pilling and fuzzing exhibited by the polyester specimens treated with dryer sheet softeners resulted in significantly lower pilling ratings, the difference in pilling ratings between polyester fabrics treated with rinse cycle softeners versus dryer sheet softeners was less than 0.5 on the rating scale of 1 to 5.

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TABLE V.

Mean Percent Change in Breaking Strength for Selected Fabrics Laundered Ten Times with Two Detergent Types and Selected Softener Treatments[a]

Fabric and Softener Treatment	Without Enzymes	With Enzymes	Fabric and Softener Treatment	Without Enzymes	With Enzymes
Cotton flannel			*Polyester woven*		
Control-no softener	+5.0	+0.5	Control-no softener	-5.8	-1.1
Rinse cycle normal dose	-18.5	-14.8	Rinse cycle normal dose	-15.5	-12.3
Rinse cycle overdose	-17.0	-25.8	Rinse cycle overdose	-13.2	-11.3
Dryer sheet normal dose	+3.5	-1.4	Dryer sheet normal dose	-3.5	+0.5
Dryer sheet overdose	+2.4	+4.0	Dryer sheet overdose	-5.0	+5.2

[a] Positive number= % strength gain; negative number= %strength loss

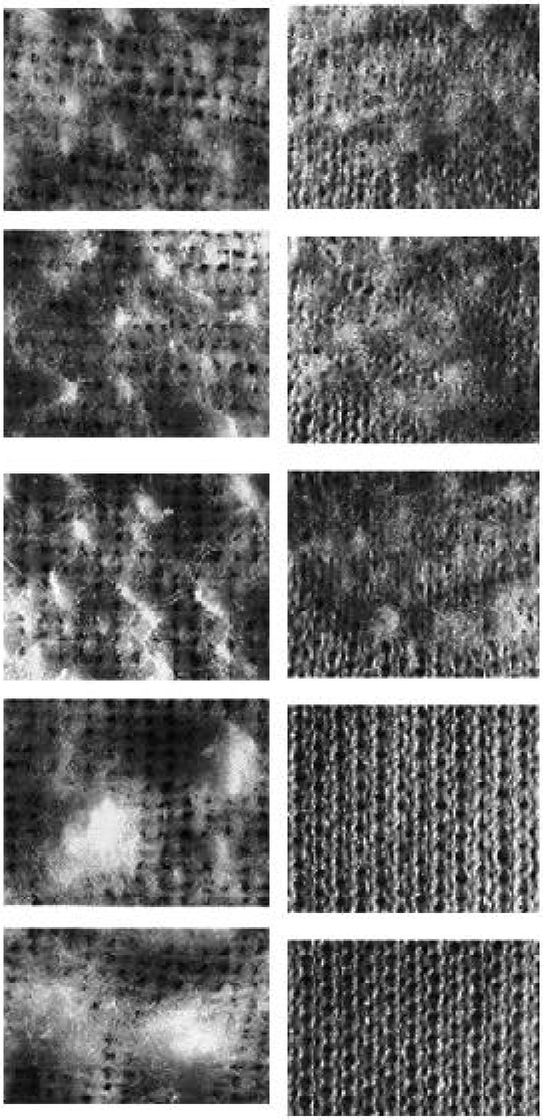

Fig. 1. Photomicrographs (29x) showing softener effect on pilling. Left column, cotton flannel laundered 10 times (*from top to bottom):* control, dryer sheet normal dose, dryer sheet overdose, rinse cycle softener normal dose, rinse cycle softener overdose. Right column, polyester interlock laundered 10 times (*from top to bottom*) control, dryer sheet normal dose, dryer sheet overdose, rinse cycle softener normal dose, rinse cycle softener overdose.

fiber strength and lubrication of the fibers afforded by the rinse cycle softeners may have prevented fiber breakage during the accelerated pilling test, thereby reducing pilling on both the knitted and woven polyester fabrics. The dryer sheet softeners did not provide as much softener lubrication as the rinse cycle softeners, and therefore the polyester fabrics treated with dryer sheet softeners exhibited more pilling.

Breaking Strength

Mean percent change in breaking strength (Table V) is given for the two woven fabrics studied. Once again, fabric type confounded the effect of detergent type and softener treatment on fabric strength change. Therefore, further analysis was done by individual fabric type.

Cotton Flannel

ANOVA (Table VI) showed that detergent type did not significantly influence breaking strength of the cotton flannel, but softener treatment did. The LSD results revealed that fabrics treated with rinse cycle softeners exhibited significant decreases in breaking strength, whereas controls and fabrics treated with dryer sheet softeners exhibited slight increases in breaking strength.

Fiber lubrication by softeners may have caused increased fiber mobility resulting in weak spots that, in turn, caused yarns to rupture more easily. This is consistent with the findings of Simpson who reported that silicone softeners reduced tensile strength in resin treated-cottons.[25] These findings also are consistent with the work of AATCC's Midwest ITPC Committee, which reported that softeners generally decreased bursting strength of cotton fabrics.[17]

The minimal gain in breaking strength for control specimens and specimens treated with dryer sheet softeners could be due to fabric shrinkage. When fabrics shrink, warp and weft yarns move closer together and become more coherent resulting in increased breaking strength. Dryer sheet softeners did not reduce breaking strength in cotton flannel because the flannel does not absorb them sufficiently to give high lubricity.

Detergent type had no significant influence on strength change for cotton flannel. This shows that the cellulase enzymes did not hydrolyze sufficient fiber to affect breaking strength within ten launderings.

Polyester Woven Fabric

ANOVA (Table VI) indicated that both detergent type and softener treatment significantly influenced fabric strength. In addition, there was a two-way interaction between detergent type and softeners indicating that the effect of detergent type on percent change in breaking strength of the polyester woven fabric depended on softener treatment. Polyester fabric specimens laundered with rinse cycle softeners (both normal and overdose) exhibited the greatest strength losses (Table V). Lubrication of fibers by the rinse cycle softeners presumably increased fiber mobility, resulting in fiber slippage and thereby reducing the breaking strength of the fabric.

Greater strength losses were observed in polyester fabric specimens laundered using a detergent without cellulase enzymes than in specimens laundered in detergent containing enzymes. The reason for this unexpected difference may be due to a greater build up of fabric softener on polyester fabrics laundered using a detergent without enzymes. Softener build up increases fiber lubricity that, in turn, reduces fabric breaking strength. It is theo-

TABLE VI.

ANOVA on Mean Change in Breaking Strength for Selected Fabrics Laundered Ten Times

Fabric and Source	DF	F Value	PR>F	Fabric and Source	DF	F Value	PR>F
Cotton flannel				*Polyester woven*			
Detergent Type	1	2.10	0.1784	Detergent Type	1	80.16	0.0001
Softener	4	35.38	0.0001	Softener	4	509.33	0.0001
Detergent x Softener	4	0.23	0.2312	Detergent x Softener	4	6.31	0.0084

rized that the cellulase enzymes may have hindered softener build up on the polyester fibers in some way, perhaps by blocking pores on the surface of the fiber.

CONCLUSION

Dryer sheet softeners were not associated with an increase in pilling, a greasy hand, nor increased breaking strength losses in any of the cotton or polyester fabrics included in this study. This was true for both the recommended dose and an overdose of dryer sheet softeners. In contrast, rinse cycle softeners (both the recommended dosage and an overdose) were associated with increased pilling and/or an increase in the size of pills formed on all cotton-containing fabrics, as well as increased breaking strength losses in both the cotton flannel and polyester woven fabric. It must be acknowledged that all of the fabrics included in this study had a propensity for pilling and that rinse cycle softeners may not promote pilling in high quality unnapped cotton-containing fabrics. Nevertheless, it appears wise to avoid rinse-cycle fabric softeners when laundering cotton flannel shirts, pajamas, and other flannel sleepwear. Although rinse cycle softeners were associated with reduced pilling in the polyester fabrics included in this study, the reduction in pilling was small and the polyester woven fabric exhibited significant losses in breaking strength and developed a greasy hand and observable yellowing when a rinse cycle softener was used.

Cellulase enzyme detergent additives significantly reduced the amount of pilling on all cotton fabrics, except the cotton interlock knit, supporting detergent manufacturers' claims that cellulase enzymes are effective in reducing fuzzing and pilling in some cotton fabrics. However, the cellulase enzymes had no effect on pill size for any cotton fabrics studied. It appears that rinse cycle softeners negated some of the beneficial effects of cellulase enzymes on pilling, which is another reason to avoid rinse cycle softeners during laundering of cotton flannels. Finally, the cellulase enzyme detergent additives had no significant negative effects on breaking strength in either of the cotton or polyester woven fabrics studied.

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