Factors Affecting the Performance and Appearance of Laundered Synthetic Fabrics

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Abstract

Published work done on a group of selected natural and synthetic fabrics is reviewed. This work shows that, when laboratory-controlled practical washing and home laundering are compared, good correlation can be obtained although washing in the home was generally poorer than in the laboratory. Large losses in reflectance occur on certain fabrics in some families in the home-laundry study. Polyester-containing fabrics tend to gray by redeposition more than other fabrics investigated. The new permanent-press fabrics seem more susceptible to redeposition than their untreated substrates, from which they are derived. A systematic screening of factors affecting the performance of these fabrics in the laundry indicates that detergent under-usage is a major factor for the failure of polyesters to perform as well as cotton. Laboratory-scale detergency and redeposition studies agree with the practical experiments.

Further work on the relation of chromatic changes on this same group of fabrics is also reported. The blue-yellow scale was found to be extremely important in its effect on ultimate visual preference of the fabrics in this study.

A unit change in apparent yellowness was found to be more than four times as important as a unit change in grayness in determining visual preferences. It was also shown that fabrics of a yellow hue were subjectively unsatisfactory to a panel of judges whereas fabrics with a blue-white hue caused by brighteners tended to be acceptable irrespective of their grayness within reasonable limits. Thus optical brightener effects, or lack of them, appear to be the single most important detergent-related factor in determining the laundered appearance of these fabrics.

Introduction

As the laundering of synthetic fabrics has become more common, the standards of laundry performance of these fabrics have been raised owing to the increasingly higher standards for cleaning cotton. It is widely accepted that many modern synthetic fabrics do not perform as well as desired in the home laundry. For example, Suchecki wrote recently in Textile Industries (1) that "unquestionably the problem giving technologists most concern centers around the staining of polyester cotton." He goes on to describe two approaches taken by Deering Milliken and Celanese Fibers Corporation (with Visa and Fibrite respectively) in an attempt to control this staining phenomenon. Extensive use of these and similar treatments has not yet been widely reported so it is difficult to assess the practical significance at this time.

Discussion

Reflectance Changes in Laundering

A recent paper (2) outlined work by the author and others to reproduce or establish the existence of these shortcomings on an experimental scale; to study the variables of the washing process involved with synthetics; and to point out possible solutions to the laundering problem. This work was involved with the two groups of fabrics shown in Table I. The first group was purchased from Testfabrics Inc. and was studied most thoroughly in controlled Practical Laundry Laboratory washing and in actual family laundry. A second group of fabrics updated Group I to include the trend to the use of polyester-cotton substrates for Durable Press. These fabrics were provided by the Fibers Division of Monsanto. The Hunter Color Difference Meter was used to measure redeposition on the fabrics through the use of the Rd scale of the color-space diagram shown in Fig. 1.

A comparison of the "intrinsic" grayness changes (Δ Rd with UV filter in) for the Group I fabrics is shown in Fig. 2 for the Practical Laundry Laboratory and home-washed swatches. As shown in Table II, considerable family-to-family variation was found in the home-washed fabrics. Among those with poorer performance, the polyester-containing fabrics were found to suffer disproportionately higher losses in reflectance. A systematic investigation of some of the possible factors affecting this poor performance was carried out.

Water Color. The incoming city water at the Practical Laundry Laboratory location has a Lumetron Color Value of 18–26. The decolorizing system

TABLE I

Fabric Identification

Code	Description	Count W × F	Weight oz./yd.
	(Group I)		
C	Mercerized cotton broadcloth	136 × 68	3.5
FC	Above fabric treated with 0.5% fluorinated polymer durable water & oil repellent	136 × 68	3.5
PA	Nylon taffeta (70 den. type 200)	95 × 88	1.9
PE-1	Spun Dacron (type 54)	60(40/2) × 54(30/1)	3.8
PE-2	Fortrel taffeta	44(30/2) × 40(30/2)	4.1
PE-3	Type IV Kodel taffeta (permanent brightener)	44(30/2) × 40(30/2)	4.1
PE/C-S	Dacron 54/cotton–65/35 shirting	88 × 60	2.7
PE/C-P	Dacron 54/cotton–65/35 poplin	....	4.6
	(Group II)		
C-2	Cotton broadcloth mercerized	136 × 60	5.2
PE-C	Polyester, cotton broadcloth	128 × 72	4.4
DP	PE-C with carbamate resin	128 × 72	4.4

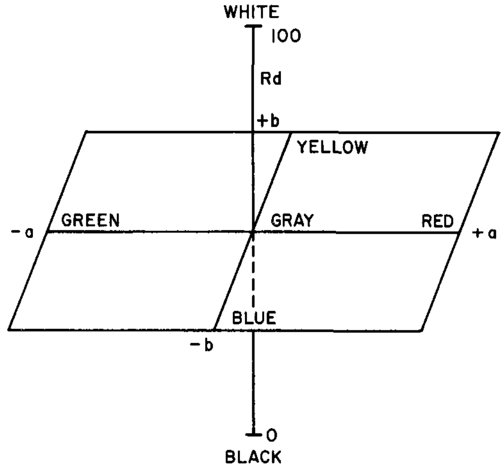

FIG. 1. Color space—R_d, a and b units.

reduces the color to less than 5. The contribution of water color was ascertained by comparing redeposition data obtained by washing in tap water versus decolorized water. Table III shows that the fabrics ranked in the higher performance class in the previous comparison suffered relatively larger losses in the highly colored water whereas the three polyesters actually showed less reflectance loss.

Dye Transfer. To study dye transfer due to lack of sorting, composite swatches were placed in the hands of some homemakers; this time it was requested that they include these in their normal colored loads. As shown in Table IV, all of the fabrics grayed badly, but again it was noted that the polyesters were the least likely to scavenge dyes from the colored water. This is not surprising since the polyesters are most resistant to dyeing by conventional means. The polyester-cotton blends do not behave consistently and can be found in either class. It was concluded that the generally larger whiteness degradation encountered with polyesters in home washing cannot be attributed to color transfer from either tap water or common non-colorfast dyes.

Water Temperature. Soiled laundry was washed in the laboratory by using two cold-water detergents. The bulk of the soiled load was cotton, and it is well known that the detergency of cotton is generally decreased at lower temperatures. It is expected therefore that redeposition would be less at lower washing temperature, if for no other reason than that there is less soil available. This expectation was borne out, as indicated in Table V. Except for the polyamide, redeposition was generally negligible at 70F. It was concluded that cold-water washing is unlikely to account for the generally greater redeposition experienced with the polyesters soiled in the home laundry.

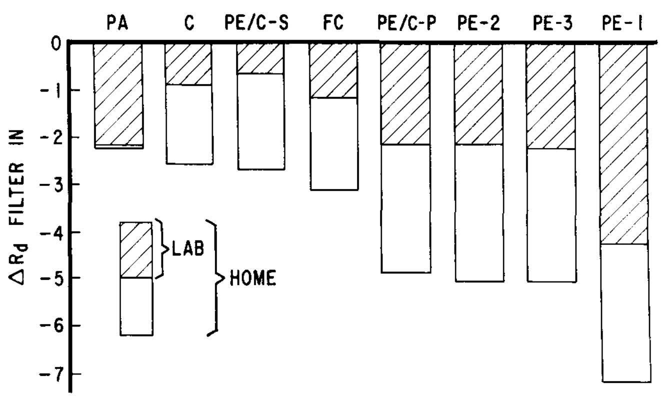

FIG. 2. Redeposition on clean fabrics—10 launderings with "white wash." Intrinsic whiteness (Rd) changes.

TABLE II

Total Reflectance Loss by Families

Family No.	Intrinsic whiteness loss 10 "white washes"
1	26.8
2	46.6
3	84.5
4	15.5
5	41.6
6	28.5
7	8.4
Laundry laboratory	15.5

Bleaching. Similar experiments with the consistent use of dry or liquid chlorine bleach had no major adverse effects on the reflectance of the swatches over 10 cycles. Depending on the type of bleach used, there were some slight increases in the yellowness and/or grayness of Nylon, cotton, and the blends, but, as seen in Table VI, the polyesters were, in general, the least adversely affected by bleach at recommended levels of usage. These findings do not support the statement of Wham (3) to the effect that the over-all whiteness degradation of polyesters results from an interaction of bleach with soils redeposited on the fabric in the washing process.

Detergent Under-use. Again, by using the technique of home wash, the composite swatches were soiled by washing with white loads, at normal detergent concentration and at one-half the recommended usage levels. As seen in Table VII, redeposition on all of the fabrics was heavier at low detergent concentration. With cotton the absolute magnitude of this effect was small, i.e., cotton proved to be fairly insensitive to detergent under-usage.

However the "hydrophobic" fabrics suffered a more severe degradation of reflectance when washed at the lower concentration. The polyesters, in particular, exhibited relatively great increases in grayness. This led to the conclusion that the primary factor in the previously observed differences between home and laboratory washing had been identified.

Market research surveys indicate that housewives do tend to under-use detergents in actual practice, particularly the high-foaming types. Therefore it is reasonable to conclude that prevalent washing practice in the home tends to accelerate the development of grayness on polyesters.

Three of the fabrics—cotton breadcloth, polyester-cotton shirting, and a pure polyester—were further checked by using a slight modification of a detergency test devised by Spangler (4). The results of this investigation, carried out by Tergotometer washing of swatches, shows that polyester detergency was ex-

TABLE III

Redeposition on Clean Fabrics—10 Launderings with "White Wash" Effect of Water Color

	Intrinsic Whiteness Changes	
	ΔR_d (Filter in)	
Fabric	Decolorized water	Tap water
C	−0.9	−1.8
FC	−1.2	−2.6
PA	−1.7	−1.7
PE-1	−4.3	−2.4
PE-2	−2.3	−1.7
PE-3	−2.3	−1.2
PE/C-S	−0.7	−1.2
PE/C-P	−2.2	−3.9
Mean	−1.95	−2.06

TABLE IV

Effect of Dye Transfer—10 Home Washes in Colored Laundry

Fabrics	ΔRd (Filter in)
C	− 9.9
FC	−10.1
PA	− 9.8
PE-1	− 7.5
PE-2	− 5.1
PE-3	− 5.3
PE/C-P	− 9.0
PE/C-S	− 4.9

tremely sensitive to changes in concentration of a built, anionic commercial formulation at concentrations below 0.18% (Fig. 3). By including clean swatches of the same fabrics in the Tergotometer load, it was possible to show that redeposition was similarly affected (Fig. 4).

Commercial formulations with nonionic or mixed anionic-nonionic systems showed a similar loss of detergency performance at low concentrations. Investigation of the Group II fabrics with Practical Laundry redeposition and Tergotometer testing showed that redeposition increased in a sequence from cotton broadcloth to polyester-cotton broadcloth to a Durable Press polyester-cotton broadcloth (Table VIII).

This experiment also showed that the presence of some nonionic surfactant favorably influenced the performance of antiredeposition agents since Detergents P and PX contained the same mixture of antiredeposition agents but different active-ingredient systems (Detergent P, all anionic; Detergent PX, anionic-nonionic).

The published work on all these fabrics dealt primarily with reflectance effects relative to detergency and redeposition.

Chromatic Changes in Laundering

A second (and probably more important) area of investigation is the area of chromatic changes and influence of optical brighteners. It is well known that brighteners do not influence the Rd or gray scale appreciably. Their main influence is on the "b" scale

TABLE V

Redeposition—Cold Water Washing, 10 "White Washes"

	ΔRd (Filter in)		
	Random dets. (control)	C.W. det. anionic	C.W. det. nonionic
Fabrics	120F	70F	70F
C	−0.9	−0.4	0
FC	−1.2	0	−0.1
PA	−1.7	−1.8	−2.3
PE-1	−4.3	+0.3	−0.6
PE-2	−2.3	−0.2	−0.6
PE-3	−2.3	+0.2	−0.2
PE/C-S	−0.7	+0.2	−0.2
PE/C-P	−2.2	−0.7	−0.1
Mean	−2.0	−0.3	−0.5

TABLE VI

Redeposition—10 Launderings with "White Wash" Effect of Chlorine Bleach

	ΔRd (Filter in)		
Fabrics	Control	Dry bleach	Liq. bleach
C	−0.9	−0.8	−2.0
FC	−1.2	−0.4	−1.7
PA	−1.7	−1.0	−0.9
PE-1	−4.3	−3.8	−2.2
PE-2	−2.3	−1.6	−0.3
PE-3	−2.3	−2.8	−1.1
PE/C-S	−0.7	−0.5	−0.6
PE/C-P	−2.2	−2.6	−1.9
Mean	−2.0	−1.7	−1.4

TABLE VII

Wet Soiling: 10 "White Washes" Effect of Detergent Concentration

	ΔRd (Filter in)	
Fabric	Normal Concentration	Half Concentration
C	−1.2	− 2.5
FC	−2.6	− 6.9
PA	−1.8	− 3.7
PE-1	−7.3	−19.4
PE-2	−3.2	− 9.8
PE-3	−3.0	− 9.2
PE/C-S	−1.4	− 4.8
PE/C-P	−5.6	−12.6
Mean	−3.4	− 8.5

of Fig. 1, and their main function is to absorb invisible ultraviolet and, by re-emitting in the visible range, shift the hue of the fabric away from the yellow and toward the blue. By the use of the UV filter, which eliminates the effect of optical brightener on "b" readings, changes in intrinsic yellowness owing to redeposition can be measured (Fig. 5).

The white portion represents the initial "b" reading or intrinsic yellowness of the fabric. The black portion represents the increase in yellowness, which occurs by redeposition. This increase in yellowing because of washing is generally smaller than the absolute value of the initial yellowness, and the total final yellowness ranges from 2 to 4 "b" units for all fabrics. This then represents a minimum amount of optical brightener effect needed at least to neutralize the fabric's intrinsic yellow hue. More would be desirable in order to obtain a blue hue. It will be remembered that none of the Group I fabrics contained an optical brightening agent except one of the polyesters, which contained a permanent brightener incorporated into the fiber during the manufacturing.

Following readings of "b-filter out," Fig. 6 was derived. This graph shows the amount of gain in blueness actually made by each of the fabrics in Group I.

The cottons and polyamide were the only fabrics to pick up sufficient brightener during laundering to overcome the intrinsic yellowness of the fabric. The data show that the prebrightened polyester has been given more than enough brightener during manufacture to overcome the intrinsic fiber yellowness. Whether this is sufficient brightener to give it optimum blue-white appearance is a matter for discussion.

The data shown in Fig. 6 also relate well to the

TABLE VIII

Redeposition at 120F Group II Fabrics

	(ΔRd)			
	0.15% Detergent P		0.15% Detergent PX	
	Practical Laundry	Laboratory Soil	Practical Laundry	Laboratory Soil
C-2	+1.4	+0.2	+3.5	+0.7
PE-C-2	−0.9	−0.1	+0.1	+0.2
DP	−1.2	−0.5	−0.9	+0.4

TABLE IX

Acceptability Fabric Soiled in Family "White Wash"

Fabric	Rd[a]	b[a]	"Acceptable"[b]
			%
C	90.2	−2.7	88
FC	89.2	−2.4	82
PA	87.2	−0.3	62
PE-1	85.1	+3.6	16
PE-2	85.0	+2.9	24
PE-3	87.3	−3.8	72
PE/C-S	87.7	+0.5	36
PE/C-P	87.0	+0.9	44

[a] Filter out readings. Avg. of 5 swatches.
[b] Each swatch voted on by 5 judges in 2 lighting conditions. Fifty ballots cast per fabric.

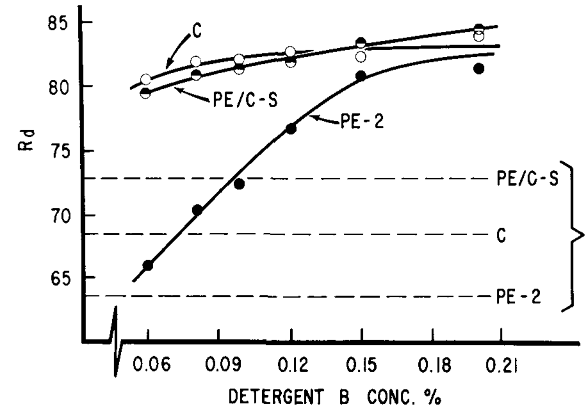

FIG. 3. Detergency of Spangler soil.

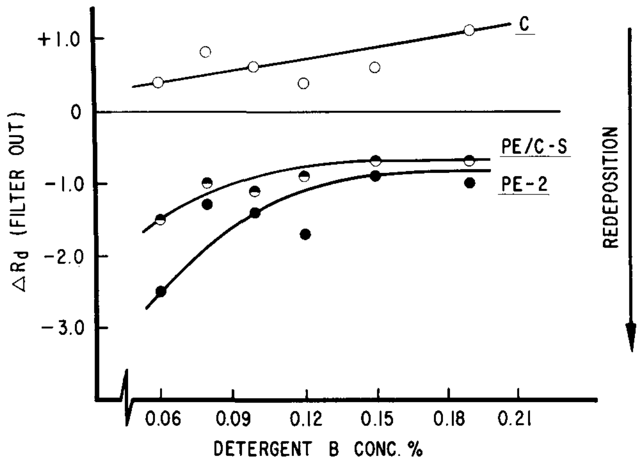

FIG. 4. Redeposition of Spangler soil in washing.

conclusions of earlier work on these same fabrics. Detergent under-use was found to be the biggest contributor to loss of reflectance in the family washes. The evidence shown here indicates a lower level of brightener build-up on all fabrics in the family wash compared with the Practical Laundry Laboratory. At the time this work was done, difference in brightener build-up could still be noted after 10 washes. Current levels of brighteners in commercial detergents show little difference in build-up after five washes.

The effect of using an economically feasible level of polyester substantive brightener in the detergent is real and measurable, as shown in Fig. 7.

This effect, coupled with the now prevalent practice of mass-applied brightening, will go a long way toward maintaining an acceptably appearing polyester. Table IX shows the positive visual effect of the mass-applied brightener of Polyester 3. Since it is identical to PE-2 in construction and since their intrinsic soiling profiles were nearly the same, the improvement in absolute visual acceptability can be attributed solely to the mass-applied brightener.

The direct comparison of PE-3, washed 10 times in various detergents containing no polyester brightener, with PE-3, washed 10 times in detergent containing the polyester brightener, resulted in 100% visual preference for the latter condition. It is conceivable that the absolute acceptability of PE-3 would im-

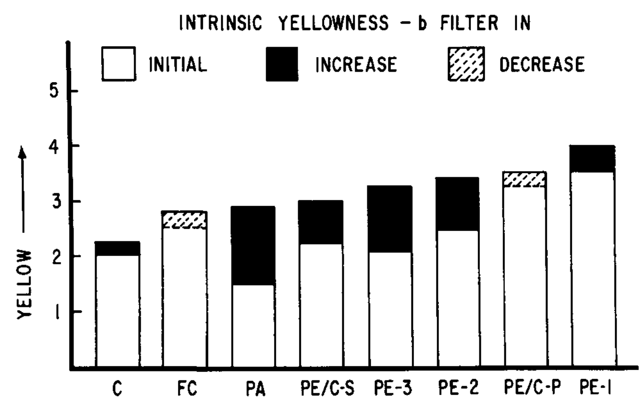

FIG. 5. Redeposition, yellowness changes, 10 "white washes" in the home.

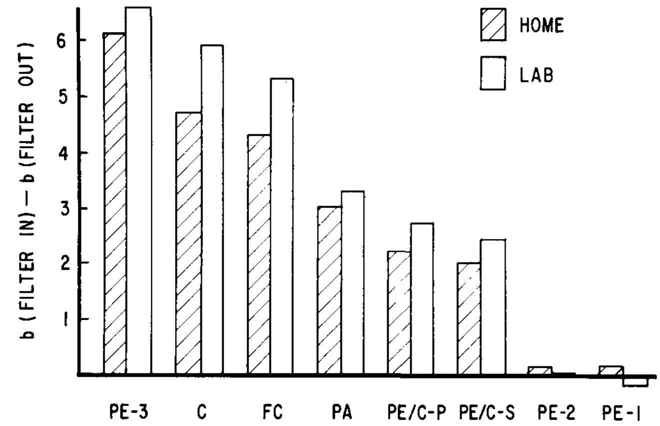

FIG. 6. Brightener intensity after 10 washes, random detergents.

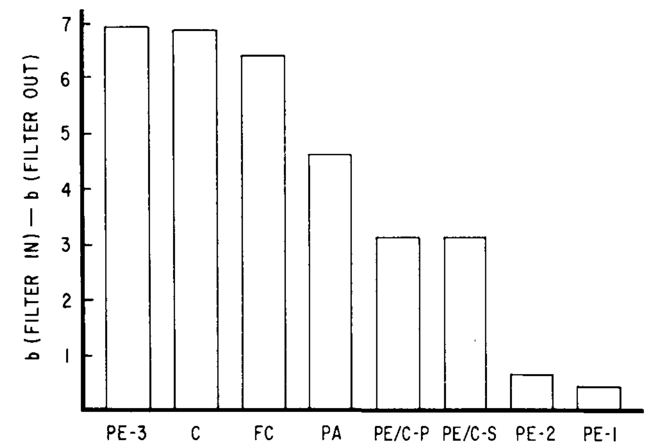

FIG. 7. Brightener intensity after 10 washes, detergent with polyester brightener.

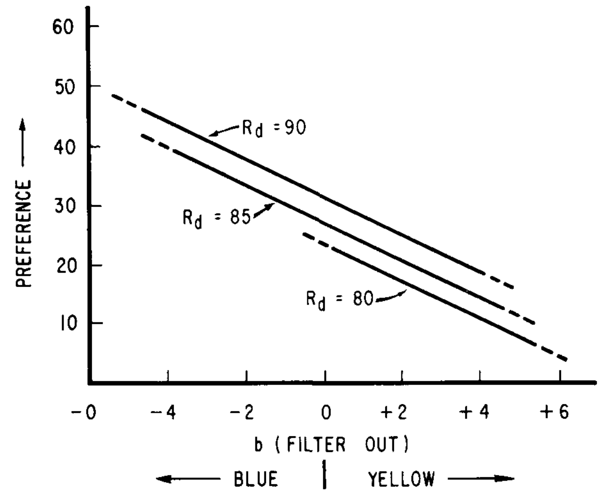

FIG. 8. Preference function for C = −38. P = 0.778, Rd −3.32, b −38.

TABLE X

Preference Average (7 Replicates) After 10 "White Washes" in the Home

Fabric	P[a]
C	44.6
FC	42.1
PE-3	33.4
PA	30.4
PE/C-P	28.0
PE/C-S	22.4
PE-2	17.0
PE-1	11.0

[a] Maximum P = 56.0.

prove to some point nearer the "respectable" cotton level simply by washing a prebrightened polyester with a detergent containing polyester brightener.

The acceptability relationships shown in Table IX and the work discussed below served as a basis for an experiment in the correlation of the mass of instrumental data and the visual preference of the human panel.

A great deal of work has been done to arrive at single number expressions of whiteness, based on instrumental readings. This work has been reviewed by Diehl (5), in a paper presented at Brussels in 1964. Diehl obtained a correlation of a single-number expression of whiteness with perceptual impressions of whiteness. However the region selected for correlation was that of washed fabrics where the whites involved are neutral to yellow whites only, hence the equation may not have as much utility for evaluations of chromatic whites in the blue region. More recently (6) the Rhode Island Section of the AATCC contributed an instrumental evaluation of textiles in terms of an average-observer response.

Visual preference rankings were determined through a random assignment of swatches to an incomplete Latin square plan (7), in which each swatch was directly compared once and only once with every other swatch. The total of the rankings is the "P" value and ranges from a possible minimum of 0 to a maximum of 56. The average preference for each is shown in Table X.

It should be possible to correlate these preference rankings with instrumental readings. As a mathematical model, the equation $P = K_1Rd + K_2b + K_c$ was chosen, where P is the visual preference obtained from the panel, K_c is a fabric constant, and K_1 and K_2 are coefficients of the Rd (reflectance) and b (color) readings on the reflectometer. The "a" values (red-green scale) were found to have little effect in this near-white region, i.e., the coefficient K_3 in a K_3 term is zero.

By using multiple-regression analysis, values of the coefficients were fitted by the computer (Control Data 160A) so as to minimize the sum of the squares of the calculated and observed differences. Table XI gives the fitted values. From the values of the coefficients it is apparent that a unit change in b value has a far more critical effect (4.25 times as much) on preference than a unit change in Rd.

TABLE XI

Fitted Coefficients for Equation of Preference

$P = K_1 R_d + K_2 b + K_c$

K_1 (R_d Coefficient) = +0.778

K_2 (b Coefficient) = −3.32

Fabric	Kc (Fabric constant)
C	−33.7
FC	−33.8
PE/C-P	−35.7
PA	−37.5
PE-2,3	−39.1
PE-1	−40.2
PE/C-S	−41.8

TABLE XII

Preference Ratings: Analysis of Variance

Source	Deg. of Freedom	Sums of squares	Mean square	F
K_1 (R_d)	1	6,943	6,943	214
K_2 (b)	1	3,761	3,760	116
C (Fabrics)	6	337	56	1.7
Residual	47	1,526	33	
	55	12,567		

Term	Coefficient	Stand. error	t
R_d	0.778	±0.228	3.41
b	−3.32	±0.422	7.87

The goodness of the fit was checked by tabulation of the differences between calculated and observed preferences for each cloth. The fit was equally good for all the fabrics. The statistical significance of the various coefficients is shown by the analysis of variance shown in Table XII. The sums of squares are the amounts by which the residual sums of squares are reduced by successive fitting of the terms for R_d, b, and fabrics. The F values for K_1 and K_2 are obviously highly significant.

The significance of the regression coefficient K_1 and K_2 may also be expressed by calculating the standard error of each coefficient, assuming a "best-fit" value for the other coefficients. This is shown at the bottom of Table XII.

From the analysis of variance it can be concluded that effects attributable to variation in fabric construction have a minor role in determining visual preference as there is no significant reduction in the residual-error variance as a result of including a fabric effect. This is not to say that fabric construction does not play a major role in soiling or laundering characteristics. Work in this laboratory and others has shown this to be an outstanding contributor to both soilability and cleanability.

The general effect of R_d and b values on preference rankings of the panel is illustrated by the plot for a hypothetical fabric with a fabric constant, K_c of −38 (Fig. 8). It predicts that the panel would prefer a fabric with a reflectance of 85 and b value of −3 to one with a reflectance of 90 and b value +1.

This emphasizes a point made previously that the visual preference deficiencies of polyester fabrics soiled by redeposition can be overcome to a great extent by the incorporation of an optical brightener in the fiber and in the laundry detergent.

It should be pointed out that the fabrics were rated by the panel in incandescent light, which minimizes but does not completely eliminate the brightener fluorescence. If the ratings had been made in fluorescent or sunlight, the effect of the brightener on preference would be expected to have been even greater.

ACKNOWLEDGMENTS

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REFERENCES

1. Suchecki, S., Textile Industries *130*(9), 136 (1966).
2. Hunter, R. T., C. R. Kurgan and H. L. Marder, JAOCS *44*, 494–497 (1967).
3. Wham, G. S., 18th National Home Laundry Conference Report, pp. 14–19 (1965).
4. Spangler, W. G., B. R. Schaafsma and H. D. Cross III, JAOCS *42*, 723 (1965).
5. Diehl, F. L., Proceedings of 4th International Congress on Surface Activity (1964).
6. Rhode Island Section AATCC, Am. Dyestuff Rep., p. 997, November 21, 1966.
7. Cochran, W. G., and G. M. Cox, "Experimental Designs," Plan 13.3A, p. 533.