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TEXAS AGRICULTURAL EXPERIMENT STATION
A. B. CONNER, DIRECTOR
COLLEGE STATION, BRAZOS COUNTY, TEXAS

BULLETIN NO. 506 MAY, 1935

DIVISION OF RURAL HOME RESEARCH

Further Studies of the Effect of Sunlight on the Strength and Color of Cotton Fabrics

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†As of March 1, 1935
**In cooperation with U. S. Department of Agriculture.
‡In cooperation with Texas Extension Service.
[a]In cooperation with State Department of Agriculture.

The changes in strength and color of 35 cotton fabrics were measured after each 25 hours of exposure to sunlight until 500 hours of exposure had been reached. The fabrics studied were well known brands, each in white, blue, green, yellow, lavender, and pink. The results of exposure of 22 other fabrics were reported in Bulletin 474. The present report is a continuation of that study. The findings in this report confirm in general those in the previous portion of the study and supply data for additional fabrics.

It was found that the length of time for which the fabrics were exposed had the greatest effect upon loss in strength and that temperature had greater effect than relative humidity. All of the 35 fabrics lost strength as exposure increased but not equally, the losses after 500 hours of exposure varying from 14 to 60 per cent in the warp and from 21 to 76 per cent in the filling. Heavy fabrics of coarse yarns lost less than did light fabrics of fine yarns. The loss in strength of the dyed fabrics varied with the dye or combinations of dyes used, no one color being consistently more resistant in all fabrics, although in general blues were less weakened than other colors. Among the fabrics identical in structure the white lost more strength than did any dyed fabrics with the exception of the pink, indicating that most of these dyes afforded protection against the tendering, or weakening, effect of sunlight.

All white and all colored fabrics changed in color during exposure. Color changes were not dependent upon the color but upon the dye and depth of dyeing. Dark colors appear to fade less than light colors. Variations in loss of strength and color show the importance of using dyes and combinations of dyes which neither tender nor fade objectionably. Guaranteed fabrics underwent less change in color than did those not guaratneed, but "tub fast" fabrics were not light fast. Care should be taken in purchasing fabrics which are to be laundered that they be guaranteed fast to both light and washing. Results of this study suggest that where light fastness is desirable, it is not impossible to attain, nor unreasonable to demand, a minimum fastness, in dyed fabrics, of 100 hours of exposure to sunlight before fading is perceptible.

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BULLETIN NO. 506 MAY, 1935

FURTHER STUDIES OF THE EFFECT OF SUNLIGHT ON THE STRENGTH AND COLOR OF COTTON FABRICS*

MARY ANNA GRIMES

When fabrics are exposed to weather certain alterations take place with resulting changes in strength and in color. The kind and extent of these changes are influenced by the nature of the fabrics and the conditions under which they are exposed. This study was undertaken to determine the changes in strength and color of certain cotton fabrics when exposed to normal conditions of sunlight, temperature, and relative humidity. Fifty-seven well-known cotton fabrics were chosen for study. The effects of exposure upon the color and strength of twenty-two of these fabrics were presented in a previous publication, Bulletin 474. The present Bulletin reports findings obtained from the study of the remaining thirty-five fabrics.

PLAN OF EXPERIMENT

The cotton fabrics included in this study were exposed to sunlight to determine the effect of such exposure upon the strength and color. Exposures were made in direct sunlight with the fabrics uncovered and in a horizontal position. The fabrics were tested after each 25-hour interval of exposure from 25 through 500 hours.

Each fabric was subjected to physical and chemical analyses before exposure to determine the color, the structure of the yarn and fabric, and the nature of the sizes and finishes in the cloths.

The colors of the unexposed and exposed fabrics were measured with a spectrophotometer to determine any changes taking place during each exposure period.

Changes in strength were determined by comparing the breaking strength before exposure with the breaking strength after each of the 20 exposure periods.

The relative effects of hours of exposure, temperature, and relative humidity were determined by correlation analysis.

Comparisons were made of the changes in strength and color with respect to: structure of fabric, color, dye, finish, price, and guarantee.

FABRICS USED IN THIS STUDY

The 35 fabrics used in this study were broadcloths, chambrays, ginghams, suitings, and nainsooks. The broadcloths included a Brittany broadcloth in white and Superlustre broadcloth in blue, green, yellow, lavender, and pink. The ginghams included Everfast and Meadow Lane, each in white, blue, green, yellow, lavender, and pink. With the exception of white, the same colors were used in a well-known brand of chambray. Everfast suiting was chosen as a representative of heavy cotton fabrics and

*Submitted for publication November 6, 1934.

Bluebird nainsook for fine cotton fabric, each in white, blue, green, yellow, lavender, and pink. With the exception of the white broadcloth and white nainsook the fabrics within each group were purchased as identical in structure but differing in color.

The manufacturers of these fabrics were requested to give information concerning the dyes, finishes, and guarantees of their respective products. Permission to use trade names in this report was requested and used where granted.

Physical Analysis of Yarns and Fabrics

Methods.

Detailed descriptions of the apparatus and methods are given in Bulletin 474 (7). All physical tests were made under controlled atmospheric conditions of 65±1 per cent relative humidity at 75±2° F. (7).

The physical analysis of all yarns and fabrics used in this study was made for descriptive purposes and to permit comparisons of the effects of the various structural factors upon the changes in strength and color resulting from exposure to sunlight. The analysis included the determinations of fabric width and thickness, weight per square yard, thread count, ply, yarn size, twists per inch, breaking strength of yarn and of fabric and color measurements. The usual methods for determining the structure of the yarns and fabrics were employed (7).

The breaking strengths of the yarns and fabrics were measured with a Scott serigraph, using two-inch jaws and allowing a distance of three inches between the jaws and a speed of 12 inches per minute. Fabric strips were 1 inch wide by thread count and 7 inches long. The breaking strength of yarns was determined after removing for a distance of three inches the crosswise threads in the center of a strip of fabric containing 100 yarns. This method leaves 2 inches of fabric on each end of the specimen for fastening in the jaws. The average of at least 20 breaks was used for all breaking-strength determinations. The strength-count factors were determined by dividing the strength of 100 yarns by the yarn size. The strength-weight factors were obtained by dividing the breaking strength of the warp plus the breaking strength of the filling by the weight in ounces of one square yard. The twist-constants were determined by dividing the twists per inch by the square root of the yarn size.

The color analyses were made with a Keuffel and Esser spectrophotometer using a magnesium carbonate block with an assumed reflection of 100 per cent as a standard. The reflection of the specimen is expressed in percentage of the standard and is the average of ten readings taken at 20 millimicron intervals, from 440 to 700 millimicrons.

Results.

The physical analyses of the fabrics and yarns are given in Table 1.

Price and Width. The retail price per linear yard was converted into price per square yard in order to place the fabrics on a comparable price basis. In four of the six groups of fabrics the widths approximate 36 inches; therefore

Table 1. Physical analysis of fabrics and yarns

Fabric	Price		Width, inches	Thickness, inches	Conditioned weight in ounces per square yard	Thread count		Yarn size		Twist per inch		Twist-constant[1]	
	Linear yard	Square yard				Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Broadcloth:													
White	0.49	0.497	35.50	0.0061	3.11	150.2	74.4	48.5	51.0	R22.1	R16.2	3.2	2.3
Blue	0.45	0.455	35.63	0.0066	3.19	132.1	64.2	41.3	49.6	R19.1	R17.3	3.0	2.5
Green	0.45	0.453	35.75	0.0064	3.10	132.4	64.3	40.4	48.0	R19.1	R20.6	3.0	3.0
Yellow	0.45	0.453	35.75	0.0065	3.12	132.4	64.0	40.1	48.1	R20.5	R20.9	3.2	3.0
Lavender	0.45	0.453	35.75	0.0063	3.25	132.2	64.3	41.7	50.4	R22.7	R20.1	3.5	2.8
Pink	0.45	0.453	35.75	0.0064	3.09	132.0	64.2	41.2	49.9	R22.3	R21.0	3.5	3.0
Chambray:													
Blue	0.33	0.393	30.25	0.0072	3.09	78.3	64.2	28.5	39.0	R18.5	R22.8	3.5	3.7
Green	0.33	0.390	30.50	0.0071	3.15	78.2	64.1	25.6	39.9	R15.8	R21.4	3.1	3.4
Yellow	0.33	0.390	30.50	0.0075	3.22	78.4	64.3	27.6	34.9	R16.0	R21.0	3.0	3.6
Lavender	0.33	0.393	30.25	0.0071	3.24	78.1	64.0	27.9	38.4	R16.1	R22.1	3.1	3.6
Pink	0.33	0.404	30.13	0.0071	3.19	78.3	64.4	26.9	36.8	R13.1	R22.3	2.8	3.7
Everfast Gingham:													
White	0.59	0.597	35.50	0.0072	2.62	95.6	84.4	52.7	43.8	R24.4	R19.4	3.4	2.9
Blue	0.59	0.597	35.50	0.0074	2.63	95.2	85.4	53.3	47.7	R27.2	R18.4	3.7	2.7
Green	0.59	0.597	35.50	0.0073	2.56	98.1	85.4	53.3	45.8	R28.4	R18.5	3.9	2.7
Yellow	0.59	0.597	35.50	0.0069	2.55	96.8	86.0	54.9	47.0	R25.8	R18.6	3.5	2.7
Lavender	0.59	0.597	35.50	0.0070	2.55	98.4	85.6	53.3	47.9	R25.7	R17.0	3.5	2.5
Pink	0.59	0.597	35.50	0.0072	2.54	97.9	86.8	53.1	46.5	R24.7	R18.6	3.4	2.7
Everfast Suiting:													
White	0.50	0.507	35.50	0.0133	4.61	54.7	46.0	15.1	14.3	R15.9	R12.1	4.1	3.2
Blue	0.50	0.507	35.50	0.0130	4.55	54.2	44.1	13.7	15.4	R16.5	R13.4	4.5	3.4
Green	0.50	0.511	35.25	0.0131	4.60	53.6	44.0	14.6	14.8	R16.3	R12.3	4.3	3.2
Yellow	0.50	0.514	35.00	0.0122	4.69	54.0	44.0	15.0	14.4	R17.2	R12.8	4.4	3.4
Lavender	0.50	0.511	35.25	0.0129	4.71	56.0	46.0	14.7	14.8	R16.4	R13.6	4.3	3.9
Pink	0.50	0.511	35.25	0.0126	4.65	54.7	46.2	14.4	15.0	R16.0	R13.8	4.2	3.6
Meadow Lane Gingham:													
White	0.44	0.495	32.00	0.0063	2.73	83.7	75.3	38.8	44.0	R20.3	R18.0	3.3	2.7
Blue	0.44	0.491	32.25	0.0069	2.62	85.5	76.6	41.2	39.6	R25.0	R19.7	3.9	3.1
Green	0.44	0.495	32.00	0.0063	2.81	84.3	75.5	39.1	42.9	R22.2	R16.8	3.6	2.6
Yellow	0.44	0.491	32.25	0.0061	2.79	83.0	77.7	39.1	39.7	R23.3	R18.0	3.7	2.9
Lavender	0.44	0.491	32.25	0.0068	2.81	84.7	76.0	38.5	41.6	R20.8	R17.7	3.4	2.7
Pink	0.44	0.491	32.25	0.0064	2.72	84.1	75.0	42.2	41.2	R23.1	R15.0	3.6	2.3
Bluebird Nainsook:													
White	0.35	0.332	38.00	0.0061	2.13	85.1	73.4	44.1	64.4	R26.9	R26.2	4.0	3.3
Blue	0.45	0.447	36.25	0.0056	1.68	96.2	75.7	63.9	85.4	R27.3	R33.5	3.4	3.6
Green	0.45	0.450	36.00	0.0050	2.06	108.0	94.2	61.0	83.4	R31.1	R25.4	4.0	2.8
Yellow	0.45	0.450	36.00	0.0052	2.01	108.4	92.3	61.7	95.1	R35.5	R27.5	4.5	2.8
Lavender	0.45	0.450	36.00	0.0052	1.71	99.6	75.3	63.9	88.5	R33.8	R26.7	4.2	2.8
Pink	0.45	0.421	38.50	0.0052	1.55	92.2	80.6	63.9	91.5	R30.4	R29.7	3.8	3.1

[1]Twists per inch divided by the square root of the yarn size.

there is little difference between linear and square yard prices. In the other two groups, Meadow Lane and chambray, the widths are less than 36 inches with a corresponding higher price per square yard. There is a difference of 15 cents per linear yard between the Everfast gingham and the Meadow Lane cloth but of only 10 cents per square yard of fabric. Prices of Meadow Lane and colored broadcloth show a difference of 1 cent per linear yard but approximately 4 cents per square yard.

These comparisons illustrate the importance of considering the widths of fabrics when one is comparing prices.

Weight and Thickness. Comparisons of conditioned weight in ounces per square yard show Everfast suiting to be much the heaviest cloth followed by broadcloth and chambray of approximately equal weight, Meadow Lane, Everfast gingham, and nainsook. A slightly different order is found in the thickness of the fabrics. The Everfast suiting is thickest and the nainsook thinnest. The Everfast gingham and chambray are of approximately the same thickness as are also the Meadow Lane cloth and broadcloth.

Thread Count. In all fabrics the number of warp yarns per inch exceeds the number of filling yarns. The greatest difference occurs in the broadcloths, where the warp yarns are twice the number of filling yarns, this relatively greater proportion of warp yarns being a characteristic of broadcloth. In all but the nainsooks the thread counts within each group are approximately the same. These differences in the nainsook are probably due to the difference in width to which the fabrics were finished, since those with the higher thread counts are narrower.

Yarn Size and Twist. All yarns in these fabrics are single-ply.

The yarns vary in size from approximately 100s in nainsooks to 14s in the suitings. Approximately equal sizes are found in the warp and filling of each of the suitings and Meadow Lane ginghams. The warps are finer in the Everfast ginghams and the fillings finer in the broadcloths, chambrays, and nainsooks.

The twist in all yarns is in the right-hand direction. There is little variation in the number of twists per inch within each group of fabrics. The twist-constants place the twists of the yarns upon a comparable basis and show the warp yarns to be more tightly twisted than the filling with the exception of the chambrays.

Breaking Strength and Strength Factors. The breaking strength of one-inch warp strips given in Table 2 shows the broadcloth to be the strongest group of fabrics followed by the suiting, chambray, Meadow Lane, Everfast gingham, and nainsook groups. The filling shows a different arrangement, the suiting being strongest, then Everfast gingham, Meadow Lane, chambray, broadcloth, and nainsook. The broadcloths, which were strongest in the warp direction, were comparatively weak in the filling.

When the breaking strengths of 100 yarns in each direction of the fabric are compared it is found that the strength of both warp and filling decreases in the same order from the suiting, which is the strongest, through

the chambray, Meadow Lane, broadcloth, Everfast gingham to the nainsook. The lowest strength-weight factors occur in the suiting with comparatively little differences among the other fabric groups.

Table 2. Breaking strength, strength-count, and strength-weight

Fabric	Breaking sternght of one-inch fabric strips in pounds		Breaking sternght of 100 yarns in pounds		Strength-count factor[1]		Strength-weight factor[2]
	Warp	Filling	Warp	Filling	Warp	Filling	
Broadcloth:							
White	60.77	24.21	28.90	23.60	0.60	0.46	27.32
Blue	53.05	17.57	25.10	19.80	0.61	0.40	22.14
Green	52.72	17.79	27.40	16.90	0.68	0.35	22.75
Yellow	57.16	20.23	30.10	22.10	0.75	0.46	24.80
Lavender	53.36	18.79	28.30	22.40	0.68	0.44	22.20
Pink	53.58	17.68	28.90	18.00	0.70	0.36	23.06
Chambray:							
Blue	43.49	26.51	48.80	35.50	1.71	0.91	22.65
Green	42.04	30.18	47.60	35.90	1.86	0.90	22.96
Yellow	44.74	29.98	48.60	36.00	1.76	1.03	23.20
Lavender	45.25	28.70	50.10	35.10	1.80	0.91	22.82
Pink	45.33	30.78	51.50	33.60	1.92	0.91	23.86
Everfast Gingham:							
White	33.19	31.85	31.00	27.50	0.59	0.63	24.82
Blue	34.07	32.84	27.90	25.60	0.52	0.54	25.44
Green	34.13	31.92	27.80	22.40	0.52	0.49	25.80
Yellow	34.21	33.77	26.90	24.50	0.49	0.52	26.66
Lavender	36.34	34.51	28.30	25.50	0.53	0.53	27.78
Pink	32.01	32.07	25.00	21.60	0.47	0.46	25.23
Everfast Suiting:							
White	50.04	37.97	81.60	66.30	5.40	4.64	19.09
Blue	47.99	34.84	75.10	67.30	5.49	4.36	18.20
Green	51.91	42.20	85.40	78.30	5.85	5.30	20.46
Yellow	51.11	36.62	79.90	63.00	5.33	4.38	18.71
Lavender	57.69	41.65	85.30	75.50	5.79	5.10	21.09
Pink	51.96	36.29	81.40	67.10	5.65	4.48	18.98
Meadow Lane Gingham:							
White	36.39	27.18	37.50	32.60	0.97	0.74	23.29
Blue	37.73	32.81	35.80	35.50	0.87	0.90	26.92
Green	37.56	31.00	36.00	30.00	0.92	0.70	24.40
Yellow	37.06	29.97	37.00	30.40	0.95	0.77	24.03
Lavender	40.39	32.34	41.10	32.10	1.07	0.77	25.88
Pink	35.21	29.14	35.80	29.80	0.85	0.72	23.66
Bluebird Nainsook:							
White	33.59	17.67	31.00	17.00	0.70	0.26	24.07
Blue	29.08	13.88	22.10	13.40	0.35	0.16	25.57
Green	32.06	17.35	22.50	10.90	0.37	0.13	23.99
Yellow	28.84	14.56	21.50	10.00	0.35	0.11	21.59
Lavender	27.48	11.64	20.60	12.40	0.32	0.14	22.88
Pink	31.79	15.38	28.90	13.10	0.45	0.14	30.43

[1]Strength of 100 yarns divided by the yarn size.
[2]Breaking strength of warp plus that of filling divided by the weight in ounces of one square yard.

Chemical Analysis of Sizes and Finishes*

The sizes and finishes, which are applied to yarns and fabrics to facilitate weaving and to enhance the appearance of the finished product, may

*The author is indebted for the chemical analyses used in this report to E. B. Middleton, instructor in inorganic chemistry in the Texas Agricultural and Mechanical College.

influence the changes produced by exposure to sunlight. These added substances may inhibit or accelerate such changes (8, 16). Tests were made to determine the presence of a few of the substances frequently used in the sizing and finishing of cotton yarns and fabrics.

Methods.

All tests were made in duplicate or triplicate.

Qualitative tests were made on the fabrics for glue or gelatin, dextrin, sugar, starch, chloride ions, sulphate ions, magnesium, barium, calcium, and zinc (16).

Quantitative tests were made on the fabrics and on the warp and filling yarns separately. The total size and finish was determined by extracting water-soluble substances and fats and waxes, by stripping with caustic soda and hydrochloric acid, and by ashing. No corrections were made for mechanical losses.

Results.

The results of the chemical tests are given in Tables 3 and 4.

The white broadcloth contained none of the finishes for which the yarns were tested, in either warp or filling. The warp yarns of all of the colored broadcloths gave positive tests for starch while only the blue and pink filling yarns gave this test. This difference suggests that the starch was used in sizing the warp yarns but in washing the finished fabric some starch was transferred to the filling yarns and not removed. The traces of dextrin found in the yarns of some of the colored broadcloths indicate the use of a small quantity in the finish of the fabrics.

A relatively large amount of starch was found in both the warp and filling of all chambrays confirming the statement of the manufacturers that these fabrics were finished with starch. Dextrin was present only in the warp; therefore it was apparently used in the sizing of the warp yarns.

The presence of starch in the warp yarns of the white and pink Everfast ginghams suggests its use in sizing and that the desizing was not complete in these two fabrics. The Everfast ginghams were the only fabrics containing sulphate ions. None of the positive ions for which tests were made were found in these ginghams. No information is available concerning the finishes and dyes used, but the source may have been the antichlor, sodium thiosulphate, or sulphuric acid, used to remove the last traces of chlorine left from the bleaching agent. The presence of the sulphate ions in the filling of the white gingham contra-indicates the dyes as a possible source.

No water-soluble finishes were found in the Everfast suitings with the exception of the white, which was probably lightly starched in the finishing process.

All Meadow Lane ginghams gave positive tests for dextrin and sodium ions. Since dextrin is present in warp and filling yarns it was probably added during the finishing process. No negative ions for which tests were made were found. The source of the sodium ions may be the sodium

bichromate and sodium perborate used in the oxidation of the dyes but this can not be true of the white. The presence of sodium ions in both white

Table 3. Qualitative analyses of water-soluble finishes

Fabric	Warp					Filling				
	Starch	Dextrin	SO_4^{--}	Na^{+}	Cl^{-}	Starch	Dextrin	SO_4^{--}	Na^{+}	Cl^{-}
Broadcloth:										
White	—	—	—	—	—	—	—	—	—	—
Blue	+	—	—	—	—	+	trace	—	—	—
Green	+	trace	—	—	—	—	—	—	—	—
Yellow	+	—	—	—	—	—	—	—	—	—
Lavender	+	—	—	—	—	—	—	—	—	—
Pink	+	trace	—	—	—	+	trace	—	—	—
Chambray:										
Blue	++	+	—	—	—	++	—	—	—	—
Green	++	+	—	—	—	++	—	—	—	—
Yellow	++	+	—	—	—	++	—	—	—	—
Lavender	++	+	—	—	—	++	—	—	—	—
Pink	++	+	—	—	—	++	—	—	—	—
Everfast Gingham:										
White	+	—	—	—	—	—	—	trace	—	—
Blue	—	—	trace	—	—	—	—	trace	—	—
Green	—	—	trace	—	—	—	—	trace	—	—
Yellow	—	—	trace	—	—	—	—	trace	—	—
Lavender	—	—	trace	—	—	—	—	trace	—	—
Pink	+	—	trace	—	—	—	—	trace	—	—
Everfast Suiting:										
White	+	—	—	—	—	+	—	—	—	—
Blue	—	—	—	—	—	—	—	—	—	—
Green	—	—	—	—	—	—	—	—	—	—
Yellow	—	—	—	—	—	—	—	—	—	—
Lavender	—	—	—	—	—	—	—	—	—	—
Pink	—	—	—	—	—	—	—	—	—	—
Meadow Lane Gingham:										
White	—	+	—	trace	—	—	+	—	trace	—
Blue	—	+	—	trace	—	—	+	—	trace	—
Green	—	+	—	trace	—	—	+	—	trace	—
Yellow	—	+	—	trace	—	—	+	—	trace	—
Lavender	—	+	—	trace	—	—	+	—	trace	—
Pink	—	+	—	trace	—	—	+	—	trace	—
Bluebird Nainsook:										
White	—	+	—	trace	trace	—	+	—	trace	trace
Blue	—	+	—	trace	trace	—	+	—	trace	trace
Green	—	+	—	trace	trace	—	+	—	trace	trace
Yellow	—	+	—	trace	trace	—	+	—	trace	trace
Lavender	—	+	—	trace	trace	—	+	—	trace	trace
Pink	—	+	—	trace	trace	—	+	—	trace	trace

and dyed fabrics indicates its retention from the bleaching solution or the antichlor.

Dextrin, sodium, and chloride ions were found in all nainsooks. Dextrin was used in the finish. The sodium and chloride ions were probably retained from the bleaching and antichlor solutions.

All fabrics were tested for mercerization by Lance's method (11). Everfast suitings and broadcloths gave positive tests for mercerization. The other fabrics were found to be unmercerized or too slightly mercerized to give a definite reaction.

Table 4. Quantitative analyses of sizes and finishes

	Fabric				Yarn					
					Warp			Filling		
	Per cent moisture	Per cent fats and waxes	Per cent total finish	Per cent ash	Per cent moisture	Per cent fats and waxes	Per cent total finish	Per cent moisture	Per cent fats and waxes	Per cent total finish
Broadcloth:										
White	6.01	0.72	2.74	0.14	4.11	1.16	2.68	2.16	0.98	2.59
Blue	5.75	0.82	2.62	0.09	3.90	0.99	1.48	3.79	0.73	3.95
Green	4.43	0.83	4.43	0.08	3.79	1.29	2.58	4.26	0.78	4.81
Yellow	4.51	0.96	2.90	0.06	3.74	0.69	5.24	3.12	1.10	4.52
Lavender	5.63	0.93	2.80	0.09	3.88	1.06	3.11	3.14	1.06	3.96
Pink	5.41	0.93	2.32	0.09	4.10	1.29	3.30	3.96	0.84	3.79
Chambray:										
Blue	4.95	0.66	3.34	0.07	3.83	0.73	5.60	4.17	0.83	2.48
Green	5.43	0.42	4.40	0.08	4.38	0.50	5.95	3.91	0.62	2.37
Yellow	4.94	0.43	4.30	0.09	4.02	0.73	7.34	4.40	0.75	2.56
Lavender	4.99	0.57	5.26	0.09	3.35	0.66	8.60	4.23	0.81	1.87
Pink	5.39	0.46	4.85	0.08	4.79	0.67	5.76	4.44	0.74	1.79
Everfast Gingham:										
White	4.77	1.12	1.13	0.06	5.32	0.68	1.51	4.99	0.54	1.74
Blue	5.09	0.70	1.63	0.05	4.52	0.29	1.08	5.25	0.39	1.53
Green	5.03	0.82	0.97	0.06	5.43	0.65	0.87	5.66	0.32	1.33
Yellow	5.24	0.67	1.27	0.05	5.51	0.38	0.66	5.76	0.42	0.69
Lavender	5.39	0.95	1.03	0.07	5.48	0.42	1.17	5.11	0.55	0.97
Pink	4.94	1.08	1.35	0.05	5.33	0.58	1.33	5.17	0.47	1.48
Everfast Suiting:										
White	5.42	0.83	1.67	0.06	4.86	0.55	1.86	4.13	0.52	1.23
Blue	5.83	0.29	0.55	0.06	4.35	0.32	1.24	4.37	0.40	0.40
Green	5.66	0.40	0.59	0.05	4.40	0.39	0.90	4.22	0.40	0.43
Yellow	5.73	0.25	0.96	0.05	4.57	0.24	1.64	4.37	0.41	0.48
Lavender	5.83	0.20	0.72	0.06	4.38	0.36	1.35	5.64	0.25	0.65
Pink	5.42	0.57	0.90	0.08	4.15	0.33	1.23	5.55	0.35	1.15
Meadow Lane Gingham:										
White	4.25	0.33	1.63	0.05	4.81	0.84	1.24	4.61	0.98	0.82
Blue	3.93	0.41	1.68	0.06	4.73	0.76	0.94	4.29	0.80	0.95
Green	3.95	0.31	1.35	0.05	4.97	0.89	0.70	4.82	0.84	1.17
Yellow	4.13	0.24	1.58	0.05	4.69	0.93	1.21	4.82	0.89	1.31
Lavender	4.01	0.37	1.31	0.04	5.06	0.65	1.07	4.89	0.93	1.91
Pink	4.32	0.26	1.63	0.07	5.11	0.96	0.53	4.88	1.02	0.36
Bluebird Nainsook:										
White	5.23	0.42	1.32	0.04	4.28	0.68	0.54	4.17	0.46	0.82
Blue	5.15	0.69	2.82	0.06	3.66	0.63	1.99	3.56	0.80	2.26
Green	5.10	0.43	1.23	0.04	3.67	0.80	1.24	3.23	0.69	1.74
Yellow	4.74	0.60	1.93	0.06	3.59	0.83	1.83	3.36	0.84	2.05
Lavender	5.04	0.53	1.19	0.05	3.57	0.66	1.84	3.85	0.77	2.09
Pink	5.27	0.84	1.28	0.05	3.57	0.65	1.49	4.02	0.88	1.57

The results of the quantitative analyses given in Table 4 show the chambrays contain the greatest amount of total finish followed by the broadcloths. These comparatively large amounts are due to the presence of starch and dextrin. The Everfast and Meadow Lane ginghams, and nainsooks contain approximately the same amount of total finish and the Everfast suitings the least. All fabrics contain approximately the same amount of ash, probably from the minerals normally occurring in the cotton itself.

METHOD OF SAMPLING FABRICS

The specimens to be tested were chosen by a systematic random method previously devised and tested (7).

Before exposures were made each fabric was marked with pencil and drawn threads to permit subsequent identification and location of each specimen in relation to every other specimen. Each specimen was marked with the number of hours of sunlight to which it was to be exposed.

For testing in the warp direction each fabric was marked in columns one and one-half inches apart and in rows seven inches apart. Each column contained five specimens and each row five groups of three specimens each, making a total of 75 specimens in the group. At least two other such groups, each containing 75 specimens, were placed consecutively lengthwise of the fabric. Thus at least 225 warp specimens were tested from each of the thirty-five fabrics.

For testing in the direction of the filling, the specimens were marked across the fabric perpendicular to the selvages. The columns and rows were marked in the same manner as for the warp specimens. The methods of sampling in the warp and in the filling are illustrated in Bulletin 474 (7).

Before exposure all specimens marked "original" were removed and stored in the dark until tested, approximately one month later.

METHOD OF EXPOSURE

The marked sections of each fabric were thumbtacked to beaver boards and exposed uncovered in a horizontal position upon the roof of a three-story building. Exposures were made between 8:30 a.m. and 4:30 p.m. on sunny days only, between May 22 and October 28, 1929 and between July 3 and September 11, 1930, making a total of 500 exposure hours. A record was kept of the hours of sunshine, temperature, and relative humidity for each 25-hour period, a sunshine recorder, a sling psychrometer, and a barometer being used for these determinations. Readings of temperature, humidity, and atmospheric pressure were made at half-hour intervals.

Each specimen was removed when the hours of exposure had reached the number with which it had been marked, was stored in the dark approximately one month and then tested. Twenty 25-hour exposure periods were thus included in the 500 hours. Before each specimen was removed from adjoining specimens, its width was determined by counting

from the drawn thread the average number of threads in one inch of the fabric.

The breaking strength of each exposed specimen was compared with the breaking strength of the unexposed specimens containing the same yarns. The average change in breaking strength of the various specimens for each exposure period was considered the true change in strength for that particular exposure period. These differences in strength were expressed in percentage loss or gain from the original.

THE EFFECT OF EXPOSURE TO SUNLIGHT ON THE STRENGTH OF THE FABRICS

Factors which may influence the strength of cotton fabrics when exposed to sunlight include the finishes, dye, the structure of the yarns and fabrics, and the environment. The combined effect of these factors upon the strength of the fabrics was expressed as percentage loss from the unexposed specimens. These data are given in Tables 5, 6, 7, and 8.

Effect of Structure on Loss in Strength

Weave.

Only fabrics of plain weave were used in this study; therefore no differences in loss of strength or tendering are due to variation in weave.

Thickness and Weight.

The fabrics range in thickness from the suitings as the thickest, through the chambrays, Everfast ginghams, Meadow Lane ginghams, and broadcloths to the nainsooks. In weight a slightly different order occurs, from the suitings through chambrays, broadcloths, Meadow Lane, and Everfast ginghams to the nainsooks. In resistance to tendering, the fabrics range from suitings, chambrays, Everfast ginghams, broadcloths, and Meadow Lane ginghams to nainsooks. This order is almost identical with that of thickness and not greatly different from that of weight. This indicates that the thick, heavy fabrics offered greater resistance to the penetration of light and were consequently less tendered.

The Meadow Lane ginghams and Pamico suitings (7), which were dyed with the same dyes but which differ in weight, thickness, yarn, structure, and mercerization, afford an opportunity for comparison of the effect of structure on tendering by sunlight. The ginghams lost on an average twice as great a percentage of the original strength as did the suitings. The greater resistance to tendering must be chiefly due to greater resistance of the heavier fabrics to penetration by light and in part to their mercerization.

Thick, heavy fabrics have greater resistance to tendering by sunlight than do thin, light fabrics.

Yarn.

With the exception of the chambray, in which the tendering was approximately equal, the filling yarns of each group were more tendered than

Superlustre Broadcloth

Hours of exposure	White (Brittany)		Blue		Green		Yellow		Lavender		Pink	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
25	+2.40	+0.65	+1.73	+0.66	+3.40	+8.66	+3.23	+1.34	+6.23	2.00	0.85	0.83
50	1.91	+1.99	8.76	+2.87	4.07	+3.81	0.63	+5.07	5.22	+2.37	0.90	1.69
75	10.23	+7.47	7.96	5.75	8.71	+1.98	1.51	+0.82	8.58	2.89	7.35	9.50
100	10.11	+1.13	11.50	11.15	7.99	10.01	5.14	10.41	6.32	9.81	9.67	13.30
125	9.18	13.27	16.37	10.17	13.46	5.73	15.26	+1.74	10.32	9.41	16.33	7.41
150	10.07	7.52	15.03	19.77	13.98	16.56	13.73	4.73	9.98	6.47	15.28	7.41
175	8.93	5.31	12.31	28.81	19.81	18.47	17.97	10.06	4.15	11.76	17.78	16.05
200	13.60	11.50	15.77	24.29	22.88	23.57	17.59	15.38	14.69	21.18	20.82	27.16
225	21.17	6.60	19.40	24.58	24.82	17.37	24.26	11.03	20.18	10.92	21.84	21.43
250	21.64	10.09	21.60	20.00	17.92	19.87	28.36	14.06	15.86	31.76	20.09	16.05
275	25.21	5.98	20.00	15.04	22.41	35.51	17.71	9.03	21.10	24.40	19.80	24.16
300	20.59	12.42	25.00	14.79	16.18	24.30	17.57	25.02	29.62	32.05	23.23	24.32
325	28.90	25.13	28.05	37.30	30.68	42.70	34.25	35.45	27.67	48.23	38.58	38.56
350	32.78	33.42	36.77	43.39	33.16	41.80	33.13	38.94	26.00	39.73	38.26	49.18
375	37.06	27.56	34.07	39.80	29.16	52.56	36.75	38.51	33.19	47.15	38.53	47.34
400	39.69	49.78	33.05	44.30	33.67	49.49	33.35	52.28	36.31	41.49	37.75	50.82
425	39.16	28.16	36.53	40.54	37.10	46.05	36.32	36.82	49.60	45.70	38.99	46.43
450	36.46	33.72	35.67	42.60	37.89	45.50	35.55	39.30	52.06	44.70	37.67	41.35
475	34.64	33.00	35.46	42.89	39.08	43.53	35.35	39.24	47.96	48.59	40.37	43.84
500	34.12	36.86	39.66	44.65	39.43	46.44	40.16	42.77	45.68	53.89	47.26	50.53
Average	21.65	16.45	22.56	25.31	22.45	26.25	22.07	20.70	22.91	26.49	24.57	26.87

Chambray

25			5.72	+1.60	4.30	+0.78	6.79	+2.35	8.34	6.27	6.80	10.13
50			6.40	2.11	5.19	2.67	3.46	+4.72	8.70	3.11	14.25	4.77
75			8.62	0.76	9.60	+2.68	6.36	+2.07	9.90	6.18	10.73	8.09
100			6.90	1.49	9.14	4.07	9.04	1.79	11.97	13.81	8.89	7.83
125			10.42	0.49	8.53	2.22	3.02	11.37	11.55	6.75	8.65	9.79
150			7.03	1.04	10.13	0.03	9.27	5.41	12.30	1.58	11.32	9.13
175			6.77	1.70	11.34	4.83	6.20	6.96	18.45	6.22	12.53	12.18
200			1.08	7.32	12.21	7.34	10.93	22.30	18.25	11.31	16.14	17.20
225			0.45	+1.42	17.14	21.11	11.00	12.46	20.50	10.89	13.39	5.69
250			6.17	+2.42	17.54	10.87	11.48	15.77	20.38	12.55	21.34	2.95
275			4.53	0.60	16.36	18.51	6.28	14.74	12.71	20.03	9.68	5.03
300			0.86	3.55	13.47	26.50	8.18	23.62	14.26	13.30	14.64	5.10
325			11.95	24.23	22.39	31.19	13.80	33.46	17.01	11.54	22.37	24.98
350			20.83	24.28	24.35	25.83	14.35	26.83	20.49	17.66	20.16	22.23
375			17.41	24.03	26.81	28.85	14.72	28.10	22.91	20.56	28.31	30.29
400			19.00	30.18	30.00	38.61	20.12	33.43	25.00	28.57	29.50	36.16
425			20.16	19.23	32.87	27.61	29.16	21.16	32.88	31.95	29.99	25.25
450			21.14	19.09	32.87	25.25	28.95	22.68	34.79	31.17	32.18	27.06
475			24.92	19.90	35.77	29.73	29.13	22.56	34.65	30.33	32.71	27.07
500			25.39	26.59	36.32	33.91	29.89	26.09	33.02	33.73	34.70	34.10
Average			11.29	10.06	18.82	16.78	13.61	15.98	19.40	15.88	18.91	16.25

Table 5. Percentage loss in breaking strength of fabric due to exposure to sunlight for the 20 twenty-five-hour periods—continued

Everfast Gingham

Hours of exposure	White		Blue		Green		Yellow		Lavender		Pink	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
25	+0.86	4.14	4.53	0.06	2.07	3.86	+6.96	+1.95	0.20	8.71	2.03	10.80
50	5.82	1.47	4.79	7.11	2.93	0.56	+6.32	+8.13	0.20	10.79	2.92	16.71
75	6.59	1.44	5.60	1.55	2.99	0.50	1.88	9.58	7.17	5.43	+2.55	14.09
100	12.95	6.59	7.63	5.83	5.21	9.19	+1.23	1.18	7.76	13.65	4.88	16.25
125	17.52	3.53	6.97	8.00	9.61	5.05	6.89	2.63	9.75	20.95	9.23	26.38
150	17.87	6.08	11.36	7.27	15.05	0.06	17.93	8.83	11.53	24.62	5.73	26.37
175	20.68	11.88	10.19	8.16	10.43	16.88	16.13	13.35	14.86	24.01	10.04	25.23
200	23.63	14.68	8.53	9.50	12.29	21.03	12.20	7.85	19.79	30.64	6.44	26.92
225	30.14	26.22	12.97	13.60	18.49	0.77	12.87	16.00	18.28	28.45	15.09	27.40
250	29.01	23.26	20.38	17.55	15.12	13.11	15.46	19.87	21.56	24.49	16.04	26.72
275	17.45	22.38	17.11	15.72	5.76	5.00	11.36	15.89	11.39	35.52	14.13	27.33
300	27.11	39.94	12.15	21.82	11.78	10.07	13.51	27.70	16.47	30.20	10.84	25.12
325	32.59	29.09	23.24	20.13	24.75	34.50	20.88	33.24	18.21	29.90	25.32	29.79
350	38.86	31.59	24.85	23.42	21.55	25.98	22.59	37.90	22.45	26.25	24.95	34.96
375	34.63	33.46	22.77	26.46	28.53	37.54	26.43	37.68	27.16	42.01	29.82	31.14
400	34.75	38.02	26.28	26.61	29.50	28.77	27.00	38.62	27.00	37.03	35.08	36.35
425	33.15	28.56	29.68	24.24	30.64	33.44	26.26	30.78	25.70	34.07	41.08	53.29
450	35.26	28.60	29.72	27.65	31.30	37.59	28.11	29.44	28.07	35.41	41.26	50.98
475	35.82	27.33	29.95	27.50	34.59	38.01	27.89	30.35	28.40	36.49	40.31	52.65
500	37.16	34.10	30.21	30.01	33.52	38.71	30.04	33.55	28.33	38.70	40.99	54.37
Average	24.51	20.62	16.95	16.11	17.31	18.03	15.15	19.22	17.21	26.87	18.68	30.64

Everfast Suiting

25	1.02	2.43	+4.43	2.25	+1.50	1.87	2.82	7.24	+3.94	+4.89	+10.01	+11.34
50	+2.99	3.14	+7.04	2.36	8.58	3.39	7.19	8.58	0.52	+5.58	+12.12	+6.67
75	2.53	7.76	+6.41	0.86	6.53	7.95	8.08	9.81	+6.50	+3.25	+5.22	0.43
100	+3.36	9.75	+3.96	3.88	+4.48	15.10	7.96	12.17	2.37	+3.85	+9.38	3.08
125	1.63	7.83	+6.97	+1.16	2.79	13.68	3.46	5.04	+1.99	7.70	+8.09	+1.34
150	0.00	11.90	2.79	0.98	+1.74	7.62	2.47	10.36	+3.97	4.18	11.24	1.23
175	+1.78	13.67	+4.33	+0.75	+9.79	20.06	5.92	10.84	6.82	4.04	7.24	0.54
200	3.19	15.77	+2.04	2.90	+7.23	16.45	4.91	13.11	5.75	16.69	7.40	3.66
225	3.52	17.45	+1.94	8.33	+9.99	24.36	3.20	21.46	11.76	+0.70	14.07	+11.01
250	3.27	12.27	2.07	8.51	+10.42	17.39	4.48	20.53	14.63	7.27	9.63	+7.97
275	7.31	12.24	+15.00	4.50	0.71	13.08	+0.48	17.74	10.83	9.46	8.87	+5.27
300	8.67	12.38	+15.26	9.30	5.38	15.03	0.44	21.77	11.40	10.55	1.08	+7.50
325	5.13	21.89	+5.48	5.18	3.29	26.52	5.72	16.62	11.39	9.06	18.64	20.95
350	6.04	15.10	+12.06	16.03	7.26	31.96	4.12	14.35	8.46	18.71	17.37	27.55
375	9.60	12.04	+12.32	9.05	4.56	28.20	5.53	17.29	14.42	14.14	10.42	26.90
400	8.50	12.86	2.00	22.20	10.00	38.12	11.20	19.25	15.12	20.84	16.12	28.06
425	7.83	19.12	11.69	16.72	16.93	25.68	15.18	22.39	16.94	25.38	14.18	33.62
450	7.79	19.14	17.01	16.39	17.00	25.67	17.38	26.16	16.10	28.07	15.17	32.16
475	11.36	21.33	13.58	14.87	16.19	29.53	18.95	22.01	15.43	28.39	14.77	33.64
500	14.20	22.83	16.08	21.39	18.09	33.93	17.83	23.58	16.42	31.61	17.55	37.41

Meadow Lane Gingham

Hours of exposure	White		Blue		Green		Yellow		Lavender		Pink	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
25	7.44	7.88	+0.24	0.72	+0.48	1.02	2.48	3.09	+0.04	6.16	+1.37	5.41
50	8.73	13.78	0.96	+0.19	2.79	3.28	2.49	1.41	0.99	5.67	0.36	5.72
75	14.08	11.35	1.46	+1.40	4.47	13.70	15.34	8.01	6.44	6.10	2.24	19.70
100	17.68	27.70	5.29	18.15	4.63	14.13	12.94	18.24	7.68	10.84	7.66	24.98
125	22.62	33.25	6.45	3.44	7.33	24.15	11.80	20.93	7.39	16.08	9.21	28.27
150	25.23	30.73	3.91	7.59	10.02	26.61	8.58	21.59	10.00	14.48	13.80	33.50
175	27.01	41.67	9.64	25.23	13.13	23.63	13.86	28.18	8.00	22.74	14.56	29.23
200	28.30	47.58	5.93	14.67	12.88	29.57	12.82	35.34	8.03	20.23	16.00	39.51
225	33.53	26.28	6.82	21.17	16.39	21.13	14.02	20.41	13.24	14.47	18.48	25.36
250	35.43	31.41	8.47	20.00	19.84	18.70	14.04	16.39	11.58	23.62	21.55	26.91
275	24.36	32.18	7.30	33.93	13.39	25.41	13.39	21.06	6.71	33.01	17.57	30.41
300	23.96	37.83	11.94	21.78	19.87	27.53	14.19	34.70	10.21	17.97	15.46	37.49
325	36.35	45.10	18.45	33.74	19.10	29.71	20.05	40.79	20.18	26.66	26.12	44.67
350	33.44	52.54	18.02	41.47	25.87	33.96	24.60	40.11	18.97	27.15	28.51	48.84
375	41.19	53.06	17.05	48.57	26.95	31.81	22.50	43.86	24.89	28.04	29.27	49.06
400	50.00	58.56	22.12	53.54	31.17	39.27	32.87	56.47	28.22	30.94	35.48	53.00
425	55.20	61.32	26.26	44.78	35.19	54.25	43.23	51.75	31.91	43.59	45.31	62.51
450	58.05	64.66	26.87	46.76	36.90	48.18	46.20	55.76	32.84	44.65	48.59	62.33
475	58.36	64.77	27.77	48.83	39.37	57.27	45.33	57.33	34.99	45.91	48.24	64.31
500	60.34	69.43	29.26	51.32	42.65	61.64	47.88	62.22	35.22	48.02	48.76	65.09
Average	33.07	40.55	12.69	26.71	19.07	29.25	20.93	31.88	15.87	24.32	22.34	37.82

Bluebird Nainsook[1]

25	9.67	5.19	2.75	7.85	3.64	7.07	+1.43	9.17	+7.64	8.32	2.79	1.87
50	8.02	5.94	9.41	14.37	8.20	15.93	4.87	12.53	4.24	23.76	6.90	8.33
75	6.71	17.69	13.76	19.79	11.13	19.85	8.70	23.08	8.44	21.52	9.33	11.97
100	5.81	25.12	14.27	25.96	14.37	30.61	11.50	27.69	12.90	36.16	12.10	15.23
125	8.43	23.60	21.26	28.39	16.80	29.25	14.43	36.92	15.66	39.67	16.41	38.31
150	6.76	19.04	23.25	35.17	26.09	35.70	18.62	31.54	25.45	38.61	18.75	39.24
175	11.61	36.46	28.07	43.18	29.54	41.57	20.63	44.55	27.91	42.74	21.61	36.23
200	10.91	32.73	29.13	39.81	29.61	43.76	27.74	42.40	31.32	51.46	23.55	45.95
225	14.29	22.58	34.65	38.27	34.12	35.03	24.58	33.02	33.96	41.34	25.83	34.53
250	17.12	24.53	36.41	43.00	33.46	40.23	26.79	42.07	40.59	38.30	29.82	37.75
275	22.98	20.03	27.66	41.08	25.64	41.94	26.33	46.48	18.31	52.45	17.66	41.76
300	22.47	22.87	30.64	46.53	28.16	53.10	23.81	48.93	25.69	44.65	37.84	46.93
325	35.85	45.34	41.90	15.28	43.47	46.61	44.79	49.26	48.62	51.89	39.65	60.31
350	39.58	48.75	44.49	17.45	43.47	41.21	40.77	51.40	46.31	65.52	36.32	55.41
375	42.03	50.61	45.11	21.75	45.22	52.72	40.68	56.92	48.40	57.64	39.35	59.25
400	40.98	46.18	47.31	36.00	50.60	49.90	44.11	56.00	48.68	63.16	40.00	63.82
425	40.06	50.33	46.61	62.50	49.38	66.21	45.10	70.27	49.14	70.83	42.01	60.44
450	42.84	50.09	49.57	63.65	51.17	69.08	44.48	70.37	51.81	72.32	46.43	61.74
475	42.46	50.47	50.35	64.45	51.26	68.98	45.19	73.18	52.37	74.42	46.50	61.60
500	45.44	53.86	50.28	69.51	54.72	73.73	49.12	76.30	56.15	76.12	47.81	64.52
Average	23.70	32.57	32.34	34.50	32.50	43.12	28.01	45.10	31.92	48.54	28.03	42.26

[1]All nainsooks are of the same brand but white differs in structure from the dyed nainsooks.

Table 6. Summary by fabric, color, and yarn of the percentage loss in strength after 500 hours of exposure to sunlight

Color	Broadcloth		Chambray		Everfast Gingham		Everfast Suiting		Meadow Lane Gingham		Bluebird Nainsook		Average	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
White	34.12	36.86	----	----	37.16	34.10	14.20	22.83	60.34	69.43	45.44	53.86	38.25	43.42
Blue	39.66	44.65	25.39	26.59	30.21	30.01	16.08	21.39	29.26	51.32	50.28	69.51	31.81	40.58
Green	39.43	46.44	36.32	33.91	33.52	38.71	18.09	33.93	42.65	61.64	54.72	73.73	37.46	48.06
Yellow	40.16	42.77	29.89	26.09	30.04	33.55	17.83	23.85	47.88	62.22	49.12	76.30	35.82	44.13
Lavender	45.68	53.89	33.02	33.73	28.33	38.70	16.42	31.61	35.22	48.02	56.15	76.12	35.80	47.01
Pink	47.26	50.53	34.70	34.10	40.99	54.37	17.55	37.41	48.76	65.09	47.81	64.52	39.51	51.00

were the warp, although in a few cases there was little difference between the two sets of yarns.

Of a total of 700 cases, including the 20 exposure periods for the 35 fabrics, in 500 cases, or 71 per cent, the filling was tendered more than was the warp. In the 3 fabric groups in which the white and the dyed fabrics within each of the groups are identical in structure, in 286, or 79 per cent, of the 360 cases, the filling was tendered more than was the warp. The tension and the twist doubtless influenced this difference. The

Table 7. Summary by fabric and color of the percentage loss in strength after 500 hours of exposure to sunlight

Color	Broadcloth	Chambray	Everfast Gingham	Everfast Suiting	Meadow Lane Gingham	Bluebird Nainsook	Average
	Warp + Filling	Warp + Filling	Warp + Filling	Warp + Filling	Warp + Filling	Warp + Filling	
White	35.49	----	35.63	18.52	64.89	49.65	40.84
Blue	42.16	25.99	30.11	18.74	40.29	59.90	36.20
Green	42.94	35.12	36.12	26.01	52.15	64.23	42.76
Yellow	41.47	27.99	31.80	20.84	55.05	62.71	39.98
Lavender	49.79	33.38	33.52	24.02	41.62	66.14	41.41
Pink	48.90	34.40	47.68	27.48	56.93	56.17	45.26
Average	43.46	31.38	35.81	22.60	51.82	59.60	41.08

warp yarns have greater tension than the filling yarns causing the filling to expose more surface to the light and to protect the warp yarns. The warp yarns, with the exception of the chambray, have a higher twist-constant than do the filling yarns. The higher twist-constant of the chambray filling probably accounts for the comparatively greater resistance to tendering of the filling in this group.

The coarse yarns lost less strength than did the fine yarns as shown by the coarse suitings and fine nainsooks.

Thread Count.

Since the yarn size and twist differ in the warp and filling yarns of these fabrics, differences in resistance to tendering cannot be directly

Table 8. Summary by color and hours of exposure of the percentage loss in strength of three fabrics in which there is identical structure of the white and the dyed fabrics within each group

Hours of exposure	White	Blue	Green	Yellow	Lavender	Pink	Average
100	11.89	6.14	7.30	8.54	6.41	7.91	8.03
200	22.19	6.58	14.20	14.37	16.86	16.66	15.14
300	24.98	12.27	14.95	18.72	16.41	13.75	16.85
400	33.78	25.46	29.47	30.90	26.53	34.02	30.03
500	39.68	29.71	36.64	35.90	33.14	44.03	36.52

attributed to differences in thread count. However, some of the data, such as those for the blue Meadow Lane gingham, offer some proof that

resistance to tendering by light increases with increase in the number of threads per inch. Although the twist-constant is higher in the warp than in the filling of this gingham, the breaking strength of 100 yarns of each and the yarn size of the warp and filling yarns are approximately equal. The number of warp threads exceeds the number of filling threads per inch by approximately 12 per cent. The breaking strength of the unexposed fabric was 15 per cent greater in the warp than in the filling but the percentage loss in strength of the warp due to exposure was only 57 per cent of that of the filling. This greater loss in strength of the filling was undoubtedly due chiefly to the difference in thread count. The greater number of warp threads per inch increased the resistance to light penetration over that of the filling.

These results agree in general with the findings of other studies (5, 7, 18) that greater resistance to tendering by light is found in coarse, hard-twisted yarns, and fabrics of close weave than is found in fine, soft-twisted yarns, and fabrics of open weave.

Relation of Size and Finish to Loss in Strength

The losses in strength of white broadcloth and nainsook cannot be compared directly with the colored fabrics in their respective groups because of differences in structure, as shown in Table 1. However, data in Table 5, summarized in Tables 6 and 7, show greater resistance to tendering in the white broadcloth and white nainsook than in the dyed fabrics of these two groups. The white broadcloth contained approximately the same quantity of finish as do the dyed broadcloths, but gave no positive test for any of the substances for which qualitative tests were made. The white nainsook contains slightly less total finish in the filling than do the dyed nainsooks but all gave evidence of containing the same finishing substances. The greater tendering of the dyed broadcloths and nainsooks probably was not due to the finishes.

The chambrays contain more added substances than any other group. The comparatively large amount of starch and the dextrin may have protected the chambrays from the tendering effect of the sun, as the chambrays show slightly less loss in strength than any of the fabrics of similar type.

The Everfast ginghams and suitings and the Meadow Lane ginghams are each approximately identical in structure within their respective groups; therefore direct comparisons can be made within each group. A summary of the percentage loss in strength of the warp plus the filling of each fabric, given in Table 7, shows the white Meadow Lane to have lost much more strength than any of the dyed ginghams. Since the finish in all Meadow Lane is the same, the difference within this group cannot be attributed to finish but may be due to the fact that the resistance of this fabric was lowered in the bleaching process and that the fabric was unprotected by dye. The Everfast ginghams contain slightly less total finish than the Meadow Lane ginghams but not the same substances. The differences in finish may have had a slight effect on the greater resistance to tendering of the Everfast ginghams.

The Everfast suitings with the exception of a trace of starch in the white, contain none of the finishes for which tests were made; therefore none of the tendering can be attributed to finish.

The suitings and broadcloths gave positive tests for mercerization while the ginghams and nainsooks gave negative tests. The mercerization of the suitings and broadcloths doubtless increased their resistance to tendering, as mercerized fabrics have been found to tender less than unmercerized (5, 7, 19).

It is doubtful if the sizes and finishes used in these fabrics had much effect on the loss in strength.

Effect of Dyes on Loss in Strength

The information furnished by the manufacturers concerning the dyes used in each fabric is given in Table 9. Two firms gave the trade name of each dye; one firm stated that vat dyes were used, and three gave no information.

The protective or tendering effect of each dyeing may be determined by comparisons of the losses in strength of the white with the dyed fabrics as shown in Tables 7 and 8.

The total average percentage losses of strength of the warp plus those of the filling of all fabrics, ranked in order of least loss are: blue, yellow, white, lavender, green, and pink; the losses were 36.2, 40.0, 41.4, 42.8, and 45.3 per cent, respectively,—an average of 41 per cent. Variations from this order of tendering are found in the various fabric groups. Among the broadcloths, the yellow is tendered slightly less than the blue and the lavender more than the pink. Among the nainsooks the lavender is tendered more and the pink less than any other dyed nainsook. It is thought that blues and greens do not cause tendering because they have no absorption band in the near ultra-violet and that the activity of yellows and reds in tendering and fading is due to their ability to absorb light in this region (3, 9, 10, 12, 13, 14). When all the fabrics are grouped by colors, this seems true of the blue and pink, but not of the yellow or green.

Identical structure within a fabric group makes possible comparison of white with dyed fabrics in Meadow Lane gingham and Everfast gingham and suiting. Comparisons of the Meadow Lane ginghams show the white to have lost more strength than any dyed gingham, indicating that the dyes used in this group afforded protection, although not all to the same extent, against the tendering effect of sunlight. The order of protective influence of the dyes in the Meadow Lane ginghams,—blue, lavender, green, yellow and pink,—coincides with the order in the Pamico suitings, which were dyed with the same dyes, as previously reported (7).

The blue, yellow, and lavender dyeings decreased the tendering below that of the white, the green had little effect, and the pink increased the tendering of the Everfast ginghams. The blue suiting was tendered approximately equally with the white indicating that this dye had little effect, but the dyes in the yellow, lavender, green, and pink increased tendering in this order.

Table 9. Finish, dyes, and guarantees of fabrics[1]

Fabric	Bleach	Class and name of dye	Guarantee
Broadcloth[2]:			
White, Brittany	No information	No information	Labeled "Tub fast"
Blue, Superlustre	"	"	
Green	"	"	
Yellow	"	"	
Lavender	"	"	
Pink	"	"	
Chambray:			
Blue	Soda Chemic	Anthrene Blue R.C.X. (Newport Co.) and Ponsol Yellow G. (Du Pont Co.)	No information
Green	"	Anthrene Jade Green (Newport Co.) and Ponsol Yellow G. (Du Pont Co.)	
Yellow	"	Ponsol Yellow G. (Du Pont Co.)	
Lavender	"	Indanthrene Violet B. (General Dyestuffs Co.) and Ponsol Violet R.R. (Du Pont Co.)	
Pink	"	Sulfanthrene Pink B.G. (Du Pont Co.) and Sulfanthrene Pink F.F. (Du Pont Co.)	
Everfast Gingham:			
White	No information	No information	"A money back guarantee and will refund cost of material, cost of making up, etc. of any garment that fades from washing or exposure to the sun or anything that the fabric might encounter as a wash or tub fabric."
Blue	"	"	
Green	"	"	
Yellow	"	"	
Lavender	"	"	
Pink	"	"	
Everfast Suiting:			
White	No information	No information	
Blue	"	"	
Green	"	"	
Yellow	"	"	
Lavender	"	"	
Pink	"	"	

Table 9. Finish, dyes, and guarantees of fabrics—Continued

Fabric	Bleach	Class and name of dye	Guarantee
Meadow Lane Gingham[3]:			
White	Soda Chemic		
Blue	"	2¼ % Carbanthrene Blue B. C. S. Double Paste, (National Aniline Co.) ¼ % Ponsol Violet A. R. Paste, (Du Pont Co.)	
Green	"	3½ % Anthrene Jade Green Paste, (Newport Co.)	"Money Back"
Yellow	"	½ % Carbanthrene Yellow G. Double Paste, (National Aniline Co.)	
Lavender	"	1½ % Anthrene Violet B. N. Extra Paste, (Newport Co.)	
Pink	"	2% Ponsol Red B. N. Double Paste, (Du Pont Co.)	
Bluebird Nainsook:			
White	Chlorine	Vat	"Money back" including "refund of retail price, retail price of trimmings and repay customer for sewing."
Blue	"	"	
Green	"	"	
Yellow	"	"	
Lavender	"	"	
Pink	"	"	

[1]This information was given by and printed with the consent of the manufacturer or dyer.
[2]The company manufacturing these broadcloths has liquidated since this study was begun. The brand "Brittany" has been registered by another firm for use on cotton piece goods.
[3]Manufacturers of Meadow Lane Ginghams state that dyeings were made on all shades with caustic soda and hydrosulphite by the jig dyeing process, except blue, which was dyed by pad and jig method, the color being padded on along with some gum arabic in the unreduced condition, dried, transferred to jig, then dyed with usual amount of caustic and hydrosulphite. Goods were rinsed slightly, oxidized with sodium bichromate and acetic acid except the blue, which was oxidized with sodium perborate. After oxidizing, the fabrics were rope-soaped for 20 minutes. Meadow Lane ginghams were reported mercerized. No other firm gave information concerning mercerization.

Information from the manufacturers makes possible comparisons of the influence of individual dyes in chambrays and Meadow Lane ginghams. There is no white chambray but comparisons of these dyed fabrics show the blue and yellow to have tendered least, and the lavender, pink, and green to have tendered approximately equally. Three of the chambrays were dyed with Ponsol Yellow G, which was used alone in yellow and in combination with other dyes in the blue and green. The yellow chambray containing this dye alone, was less tendered than any other chambray with the exception of the blue. Since blue chambray was dyed with the same yellow dye in combination with Anthrene Blue R.C.X., the difference in tendering between the yellow and blue suggests that the blue dye afforded greater protection than the yellow or that the dyes gave greater protection when used in combination. The same yellow dye was used in combination with Anthrene Jade Green in the green chambray, in which the loss in strength was greater than in either the yellow or blue. Evidently the green dye either did not add protection or this combination lowered the protective value of the yellow dye. The same green dye was used alone in the Meadow Lane gingham, where the loss in strength was greater than the blue or lavender but less than in either the yellow or pink, confirming the evidence that this green dye did not afford protection when used alone or in combination with Ponsol Yellow G.

From comparisons of the two known yellow dyes, it seems Ponsol Yellow G offered greater protection in the chambray than did Carbanthrene Yellow G used in the Meadow Lane but the difference may have been due in part to difference in concentration, since the chambray was more heavily dyed.

The pink chambray and the pink Meadow Lane gingham were dyed to approximately the same depth. The differences in tendering within each group and between the two pink fabrics suggest that the combination of Sulfanthrene Pink B. G. and Sulfanthrene Pink F. F. used in the pink chambray may have afforded slightly greater protection than did the Ponsol Red B. N. used in the pink Meadow Lane. Slightly greater protection was given by the Anthrene Violet B. N. used in the lavender Meadow Lane than by the combination of Indanthrene Violet B. and Ponsol Violet R. R. used in the lavender chambray. The combination of Carbanthrene Blue B. C. S. and Ponsol Violet A. R. used in the blue Meadow Lane afforded considerable protection against tendering as shown by comparison with the other Meadow Lane ginghams.

Of the thirty dyed fabrics used in this study, the six blue fabrics were less tendered than other colors with the exception of the pink in the nainsook and the yellow in the broadcloth. None of the yellow dyes in these fabrics can be said to have greatly increased tendering although the yellow Meadow Lane and yellow nainsook were tendered slightly more than all but one of the dyed fabrics within these groups. Green and lavender fabrics were in general more tendered than blue or yellow but less tendered than pink fabrics. The greatest tendering occurred among the pink fabrics, the loss being approximately equal to or exceeding that of any other color with the one exception of pink in the nainsooks.

For 2 white and 10 vat-dyed fabrics reported in a previous study (7) the order of resistance to tendering after 300 hours of exposure was: blue, green, lavender, white, pink, and yellow. The blue, green, and lavender dyeings apparently offered protection and the pink and yellow increased tendering. When these 12 fabrics and the 35 of the present report, each after 300 hours of exposure, are compared, the order of resistance to tendering is: blue, lavender, pink, green, yellow, and white.

Resistance to tendering is not dependent upon color alone but upon the nature of the dye or combination of dyes used on the fabric. In general, the fabrics in this study, after 500 hours of exposure, ranked, in order of resistance to tendering, as follows: blue, yellow, white, lavender, green, and pink.

The Effect of Atmospheric Conditions on Loss in Strength

Correlation analysis was used to measure the effect of hours of exposure, temperature, and relative humidity upon the change in the breaking strength of each fabric.

The data secured from the readings of temperature and relative humidity which had been recorded at half-hour intervals, were averaged for each of the twenty 25-hour periods, a half hour or fraction thereof being used as a unit. The averages thus determining for each exposure period are given in Table 10.

The changes in the breaking strength of the warp and filling of each fabric for each exposure period were expressed as the percentage loss from

Table 10. Average relative humidity and temperature of exposure periods of 25 hours each

Period	Number of hours	Relative humidity %	Temperature, ° F.	Dates	
1	25	53.20	81.74	May 22, 23, June 6, 7	1929
2	50	55.57	88.62	June 10, 11, 14, 18	1929
3	75	48.74	91.53	June 18, 20, 21, 24, July 8	1929
4	100	59.88	87.95	July 9, 10, 11, 12, 15	1929
5	125	53.44	91.08	July 16, 17, 18, 19	1929
6	150	52.14	90.83	July 23, 24, August 13, 14	1929
7	175	43.75	91.50	August 15, 16, 19, 20, 21	1929
8	200	46.25	92.11	August 22, 23, 26, 27	1929
9	225	41.77	89.20	August 29, September 25, 26, 27	1929
10	250	41.14	84.44	September 30, October 2, 3, 7	1929
11	275	52.34	82.68	October 14, 16, 17, 18	1929
12	300	27.88	69.85	October 22, 24, 25, 28	1929
13	325	51.41	91.07	July 3, 7, 8, 9	1930
14	350	45.38	95.98	July 9, 10, 14, 15	1930
15	375	45.80	91.65	July 15, 16, 17, 18, 21	1930
16	400	47.88	92.03	July 21, 23, 24, 25, August 6	1930
17	425	41.74	95.83	August 6, 7, 8, 11, 12	1930
18	450	40.67	96.10	August 12, 15, 18, 19	1930
19	475	43.34	92.21	August 20, 21, 22, 27	1930
20	500	45.77	88.63	August 27, 28, September 5, 8, 11	1930

the original strength. These data were smoothed to remove random and irregular fluctuations. The data from the fitted curves were used in the correlation analysis. The original data from which the fitted curves were derived are given in Table 5.

A significant multiple correlation coefficient between the loss in breaking strength and hours of exposure, temperature, and relative humidity was found in the warp and filling in each of the 35 fabrics. In 62 of the 70 cases the coefficients were above .90, in 5 cases between .80 and .90, and in 3 cases the coefficients were .65, .60, and .59 for green, yellow, and blue Everfast suiting warp, respectively. These three low coefficients are due to the erratic behavior of the warp of the blue, green, and yellow suiting. It was thought their peculiar behavior might be due to sampling; therefore more specimens were tested but with similar results. No satisfactory explanation has been found.

Conversion of the coefficients of multiple correlation to coefficients of determination, and read as percentages, show the hours of exposure, temperature, and relative humidity to account for more than 80 per cent of the loss in strength in 64 cases, 70 to 80 per cent in 3 cases, and 35, 36, and 43 per cent in the three remaining cases.

Part correlation coefficients (6) were determined as a means of measuring the effects of each of the three environmental factors. These coefficients are given in Table 11.

The length of time for which the fabrics were exposed was found to have the greatest effect, accounting for 90 per cent or more of the change in strength in the warp in 30 of the cases. In the warps of the yellow Meadow Lane, yellow chambray, and lavender chambray, the time of exposure accounted for 78, 82, and 89 per cent, respectively, and in the blue, green, and yellow suiting for 49, 27, and 44 per cent, respectively. In the filling, more than 80 per cent of the change in strength was accounted for by the effects of the duration of exposure in 32 cases. The three remaining cases were green chambray and lavender chambray and white Everfast gingham with hours of exposure accounting for 70, 73, and 79 per cent of the change in strength.

The part correlation coefficients for relative humidity and temperature show that temperature had a greater effect upon the loss of strength than did relative humidity. These coefficients show that temperature accounted for approximately three times as much change as did relative humidity. The comparatively greater effect of temperature agrees with the findings of a previous study (7) in which the effects of temperature were approximately one and one-half times as great as relative humidity. These findings are contrary to reports that humidity affects loss of strength more than does temperature. The exposure periods covered a range of 26.25° F. and 32 per cent relative humidity. Had a wider range of temperature and relative humidity been maintained than occurred under the natural conditions of exposure, a different relationship might have been established by the use of correlation calculations.

To determine the direction of the effects of hours of exposure, temperature, and relative humidity, and to place these factors on a more comparable basis, the beta coefficients were determined as given in Table 10. The beta coefficients for relative humidity are equally divided between positive and negative signs. In half of the cases a loss in strength was accompanied by an increase in relative humidity, and in half by a

Fabric	Warp						Filling					
	Coefficient of part correlation			Beta coefficient[4]			Coefficient of part correlation			Beta coefficient[4]		
	Hours exposure[1]	Relative humidity[2]	Temperature[3]	Hours exposure	Relative humidity	Temperature	Hours exposure[1]	Relative humidity[2]	Temperature[3]	Hours exposure	Relative humidity	Temperature
Broadcloth:												
White	0.994	0.156	0.440	0.961	0.017	—0.052	0.994	0.148	0.389	0.967	0.016	—0.045
Blue	0.997	0.008	0.405	0.973	—0.001	—0.035	0.959	0.198	0.608	1.087	—0.065	0.245
Green	0.994	0.158	0.528	1.045	0.018	0.070	0.975	0.054	0.214	0.946	—0.012	—0.047
Yellow	0.981	0.086	0.337	1.027	—0.018	0.072	0.970	0.025	0.489	0.890	0.006	—0.125
Lavender	0.979	0.134	0.407	0.927	0.026	—0.086	0.987	0.054	0.432	0.938	0.008	—0.075
Pink	0.985	0.112	0.342	1.025	—0.020	0.065	0.966	0.039	0.378	0.905	0.010	—0.100
Chambray												
Blue	0.999	0.002	0.055	1.000	0.000	0.000	0.949	0.216	0.523	0.845	0.062	—0.173
Green	0.982	0.083	0.124	0.971	0.016	—0.024	0.835	0.025	0.036	0.785	0.013	—0.019
Yellow	0.908	0.054	0.003	0.927	0.023	0.004	0.942	0.033	0.059	0.936	—0.011	—0.020
Lavender	0.944	0.010	0.210	0.996	—0.004	0.074	0.857	0.082	0.218	0.885	0.044	—0.099
Pink	0.955	0.165	0.157	0.939	0.049	—0.046	0.933	0.108	0.264	0.888	0.037	—0.094
Everfast Gingham:												
White	0.959	0.198	0.609	1.088	—0.065	0.246	0.890	0.027	0.137	0.869	—0.012	—0.061
Blue	0.999	0.261	0.602	0.975	0.014	—0.038	0.994	0.022	0.139	0.984	—0.003	—0.016
Green	0.986	0.039	0.330	1.027	—0.007	0.060	0.967	0.120	0.351	0.915	0.029	—0.091
Yellow	0.999	0.000	0.095	1.002	0.000	0.000	0.967	0.049	0.235	0.930	—0.012	—0.060
Lavender	0.988	0.198	0.649	1.071	—0.032	0.141	0.956	0.117	0.367	1.029	—0.037	0.125
Pink	0.999	0.051	0.650	0.998	0.001	—0.003	0.968	0.002	0.277	1.029	0.002	0.088
Everfast Suiting:												
White	0.986	0.056	0.125	0.972	—0.009	—0.021	0.962	0.152	0.485	1.056	—0.046	0.165
Blue	0.697	0.022	0.232	0.784	—0.018	0.192	0.925	0.094	0.198	0.906	0.035	—0.075
Green	0.515	0.172	0.385	0.456	0.132	—0.317	0.995	0.174	0.204	1.004	—0.018	0.018
Yellow	0.660	0.001	0.037	0.702	0.003	0.030	0.969	0.118	0.343	0.920	0.028	—0.085
Lavender	0.959	0.198	0.608	1.079	—0.064	0.244	0.950	0.014	0.084	0.979	0.004	0.027
Pink	0.959	0.198	0.608	1.088	—0.065	0.245	0.895	0.008	0.136	0.879	0.041	—0.060
Meadow Lane Cloth:												
White	0.968	0.006	0.370	1.042	—0.002	0.107	0.993	0.024	0.419	1.031	—0.003	0.056
Blue	0.968	0.156	0.375	0.914	0.037	—0.095	0.995	0.044	0.003	0.996	—0.004	0.000
Green	0.990	0.130	0.129	0.985	0.015	—0.015	0.976	0.042	0.272	1.017	—0.010	0.062
Yellow	0.882	0.083	0.200	0.865	0.039	—0.094	0.991	0.139	0.415	1.030	—0.019	0.062
Lavender	0.992	0.057	0.104	0.987	0.015	—0.013	0.988	0.014	0.221	1.015	0.002	0.036
Pink	0.977	0.032	0.037	0.987	0.007	0.008	0.995	0.060	0.226	1.013	0.006	0.024
Nainsook:												
White	0.974	0.177	0.544	0.882	0.037	—0.144	0.998	0.213	0.609	1.026	—0.013	0.044
Blue	0.988	0.078	0.408	1.035	—0.013	0.074	0.941	0.040	0.487	1.072	0.012	0.216
Green	0.990	0.176	0.778	1.053	—0.027	0.105	0.990	0.125	0.551	1.044	—0.015	0.080
Yellow	0.993	0.112	0.342	1.013	—0.013	0.043	0.998	0.095	0.594	1.030	—0.006	0.048
Lavender	0.959	0.198	0.608	1.088	—0.065	0.245	0.998	0.131	0.475	1.018	—0.007	0.031
Pink	0.991	0.208	0.328	1.018	—0.029	0.047	0.979	0.167	0.362	1.027	—0.036	0.083

[1]Relative humidity and temperature removed.
[2]Hours of exposure and temperature removed.

decrease. This indicates that the relative humidity to which the fabrics were exposed had little effect upon the loss in strength. Of the 70 beta coefficients for temperature, 39 are positive and 31 negative indicating that in 39 of the cases an increase in loss of strength was occompanied by an increase in temperature and in 31 cases by a decrease in temperature.

Correlation analysis shows the length of exposure had a much greater effect on the loss in breaking strength than did temperature or relative humidity. Temperature had a greater effect than relative humidity, in general accounting for three times as much of the change as did the humidity. These findings agree with those of a previous study (7).

EFFECT OF EXPOSURE TO SUNLIGHT ON THE COLOR OF THE FABRICS

The color of none of the thirty-five fabrics remained unchanged during the exposure periods. The rate, type, and extent of color changes varied: some colors changed quickly, others slowly; some became lighter, others darker; while others changed in hue. Color measurements of unexposed and exposed fabrics were made on a spectrophotometer.

Spectrophotometric Analysis of the Fabrics

White Fabrics.

All white fabrics became darker and more yellow as the exposure periods increased (Figures 1 to 5). The lowering of percentage reflection toward the blue end of the spectrum was accompanied by a rise in percentage reflection through the yellow portion of the spectrum. The changes in reflection were not at the same rate or to the same degree in all fabrics. The nainsook was the most nearly white fabric before exposure, with the Everfast gingham of nearly equal whiteness. The nainsook began to show an increase in yellow color earlier than the gingham and was somewhat more yellow at the end of 500 hours of exposure. This difference may have been due to the structure of the fabrics, the thinner nainsook permitting greater penetration of the sun's rays.

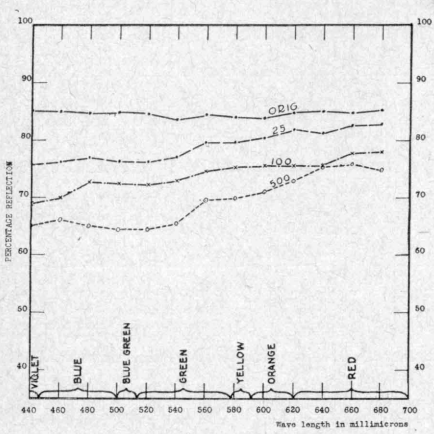

Fig. 1. Color curves for unexposed and exposed white Brittany broadcloth.

The white broadcloth and Everfast gingham became more gray than the other white fabrics, darkening throughout the spectrum to a more nearly equal amount, as shown by the straighter curves in Figures 1 and 2.

The white Meadow Lane, which was a creamy white before exposure,

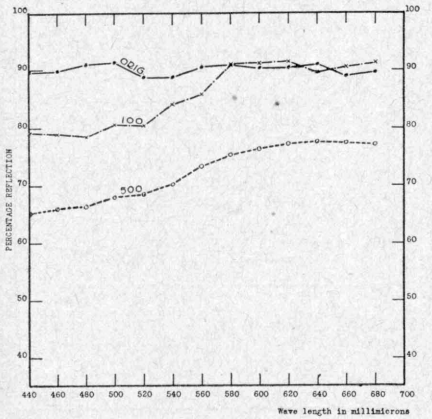

Fig. 2. Color curves for unexposed and exposed white Everfast gingham.

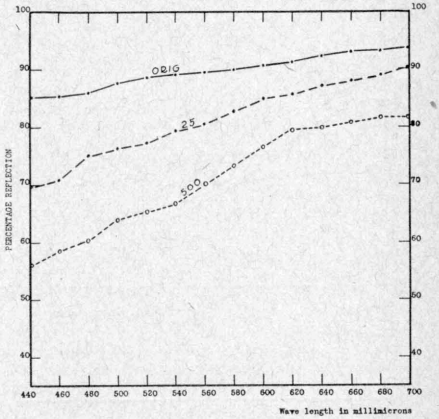

Fig. 3. Color curves for unexposed and exposed white Meadow Lane gingham.

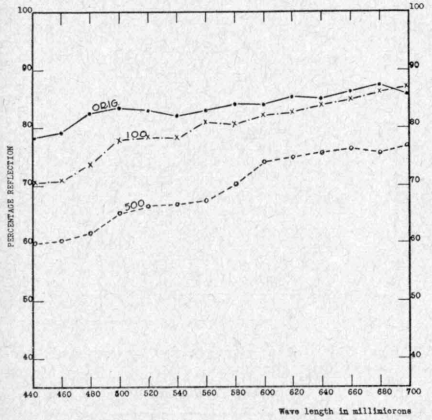

Fig. 4. Color curves for unexposed and exposed white Everfast suiting.

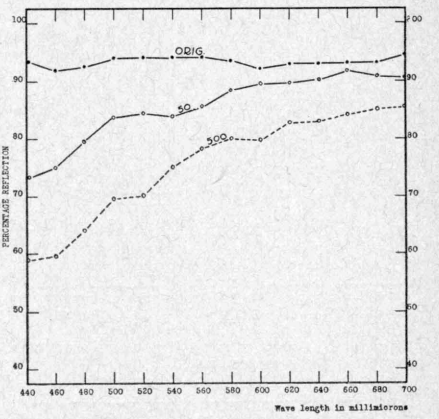

Fig. 5. Color curves for unexposed and exposed white Bluebird nainsook.

increased in yellow until at the end of the exposures it was a light tan in color (Figure 3).

The Everfast suiting underwent less change in color than did any of the other white fabrics, as shown in Figure 4, suggesting that the more coarse, hard-twisted yarns offered greater resistance to penetration by the sun's rays, thus decreasing the formation of oxycellulose, which increases the yellow color in cotton (15).

Blue Fabrics.

Of the six blue fabrics three exhibited remarkable fastness to sunlight, one was nearly as fast, one was somewhat faded, and one had changed until the original color was unrecognizable after 50 hours of exposure.

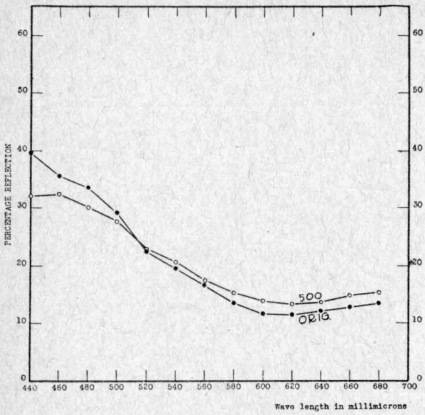

Fig. 6. Color curves for unexposed and exposed blue Meadow Lane gingham.

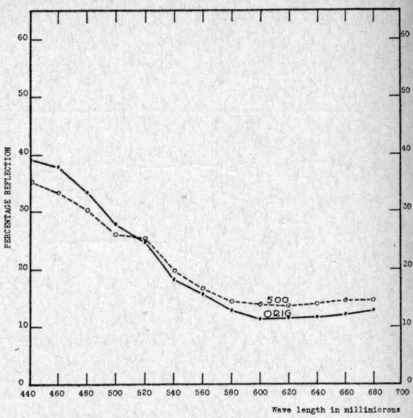

Fig. 7. Color curves for unexposed and exposed blue Everfast gingham.

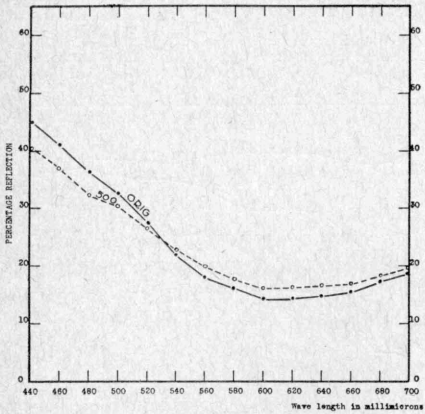

Fig. 8. Color curves for unexposed and exposed blue Everfast suiting.

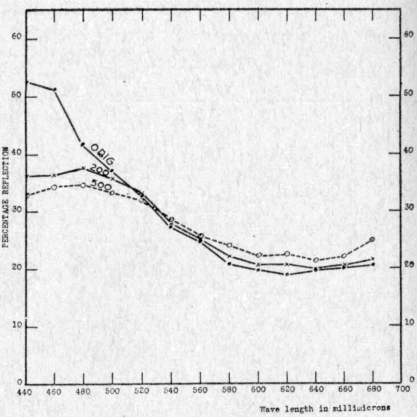

Fig. 9. Color curves for unexposed and exposed blue chambray.

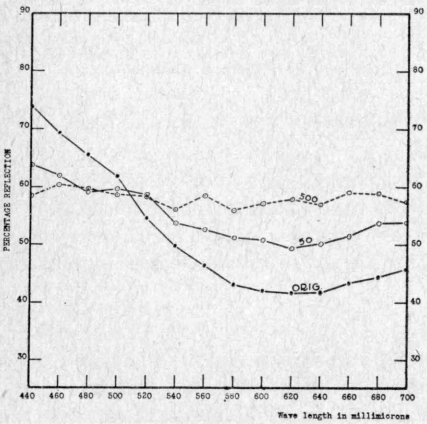

Fig. 10. Color curves for unexposed and exposed blue Bluebird nainsook.

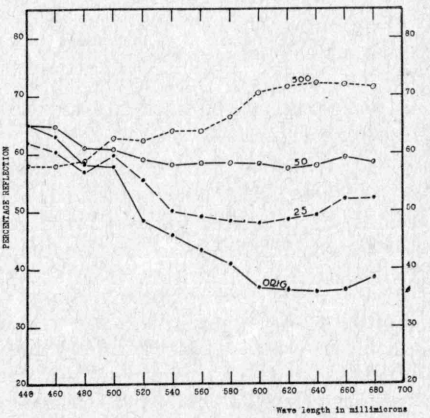

Fig. 11. Color curves for unexposed and exposed blue Superlustre broadcloth.

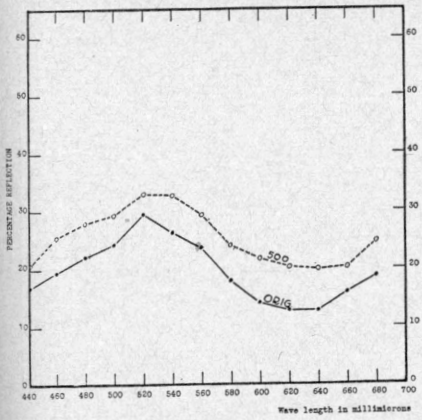

Fig. 12. Color curves for unexposed and exposed green Everfast gingham.

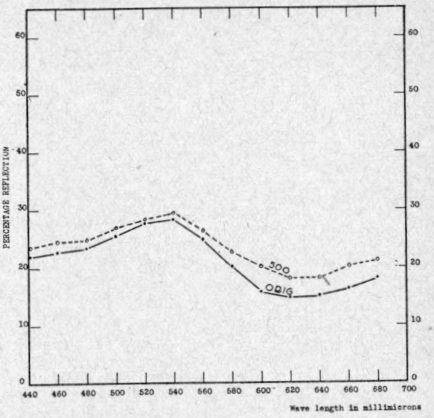

Fig. 13. Color curves for unexposed and exposed green Everfast suiting.

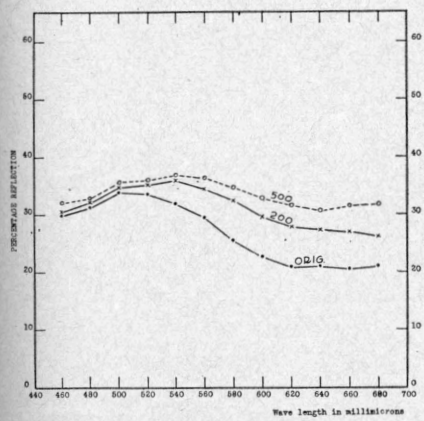

Fig. 14. Color curves for unexposed and exposed green Meadow Lane gingham.

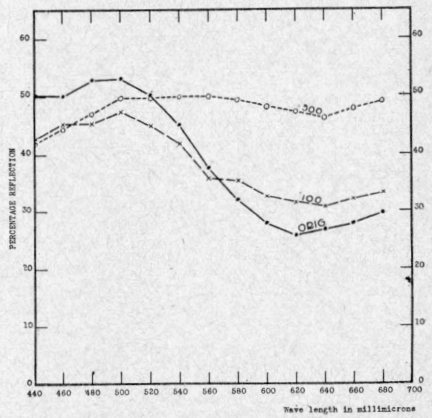

Fig. 15. Color curves for unexposed and exposed green Bluebird nainsook.

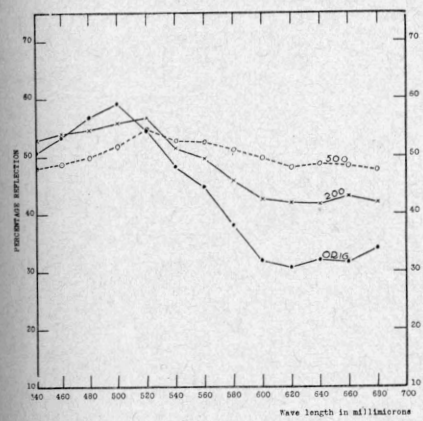

Fig. 16. Color curves for unexposed and exposed green chambray.

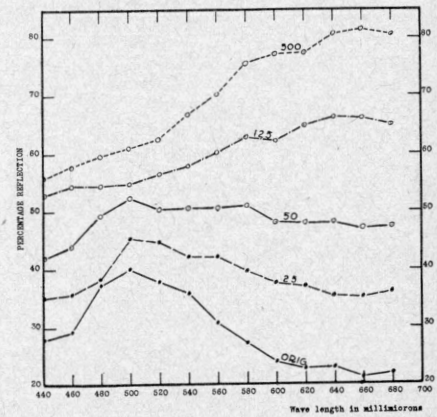

Fig. 17. Color curves for unexposed and exposed green Superlustre broadcloth.

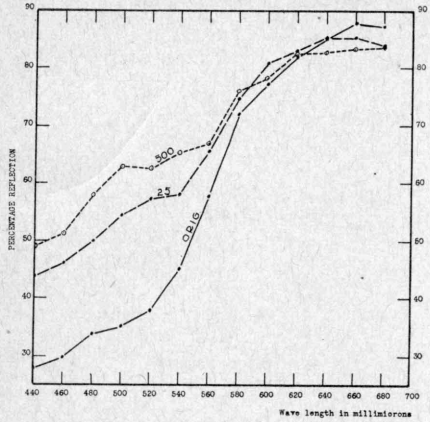

Fig. 18. Color curves for unexposed and exposed yellow (peach) Superlustre broadcloth.

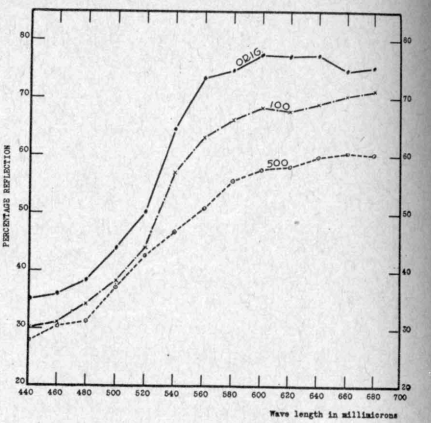

Fig. 19. Color curves for unexposed and exposed yellow chambray.

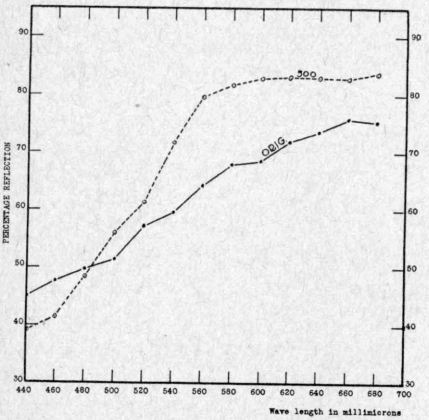

Fig. 20. Color curves for unexposed and exposed yellow Everfast gingham.

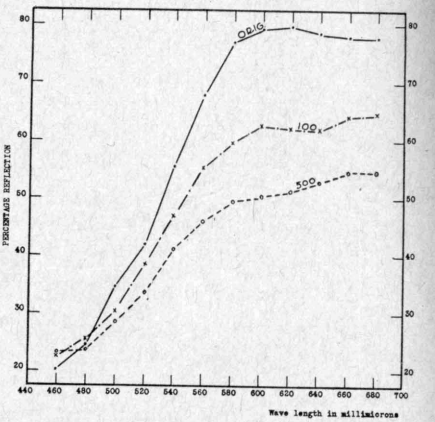

Fig. 21. Color curves for unexposed and exposed yellow Everfast suiting.

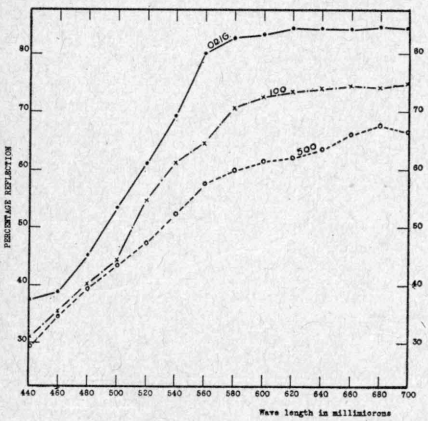

Fig. 22. Color curves for unexposed and exposed yellow Meadow Lane gingham.

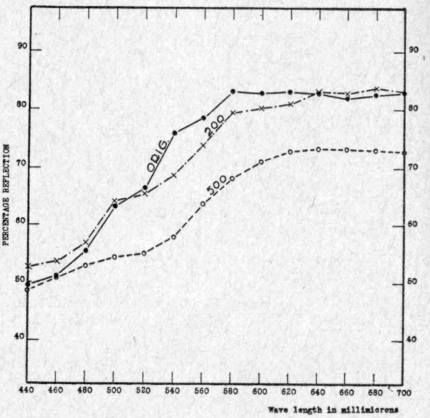

Fig. 23. Color curves for unexposed and exposed yellow Bluebird nainsook.

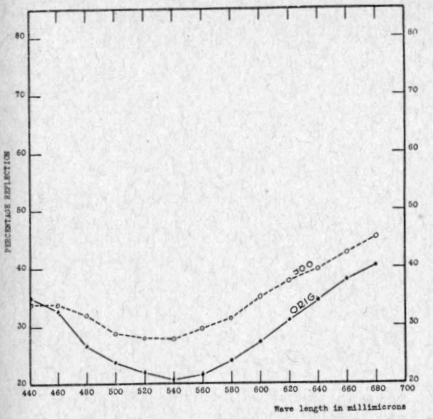

Fig. 24. Color curves for unexposed and exposed lavender Everfast gingham.

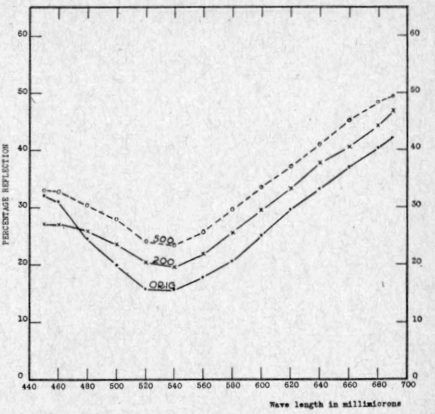

Fig. 25. Color curves for unexposed and exposed lavender Everfast suiting.

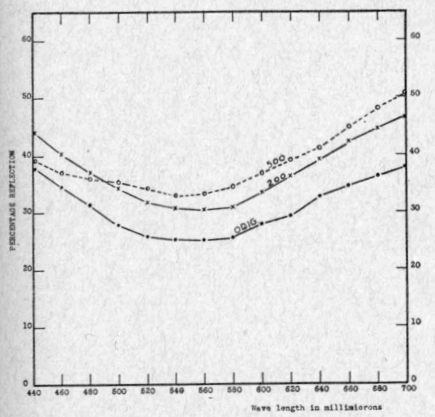

Fig. 26. Color curves for unexposed and exposed lavender Meadow Lane gingham.

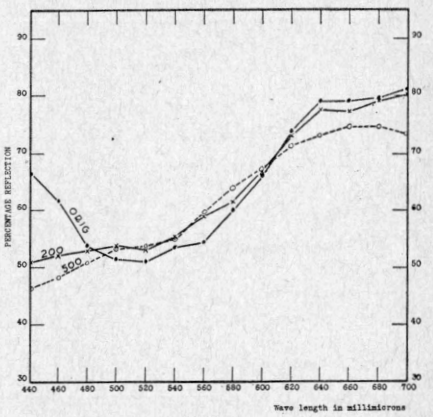

Fig. 27. Color curves for unexposed and exposed lavender Bluebird nainsook.

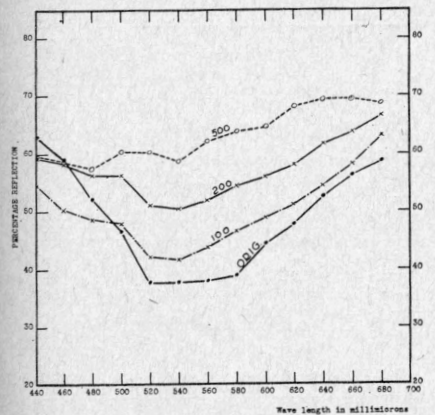

Fig. 28. Color curves for unexposed and exposed lavender chambray.

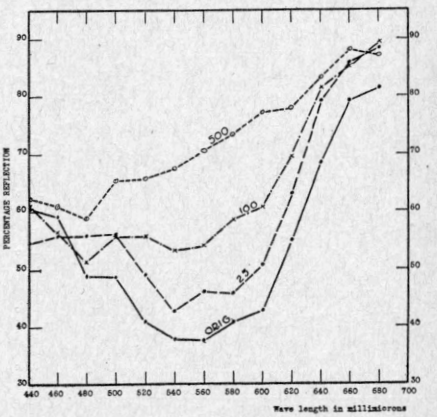

Fig. 29. Color curves for unexposed and exposed lavender Superlustre broadcloth.

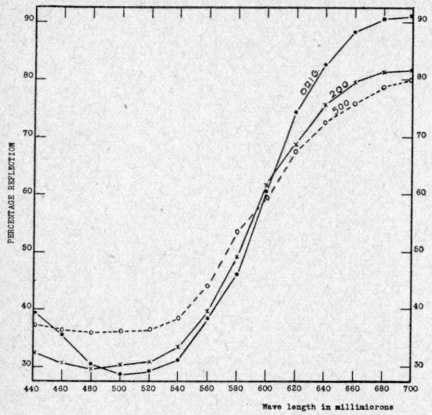

Fig. 30. Color curves for unexposed and exposed pink Meadow Lane gingham.

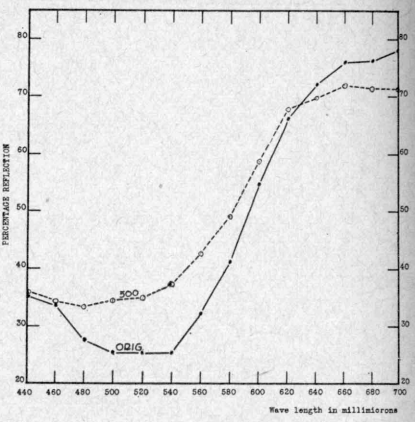

Fig. 31. Color curves for unexposed and exposed pink Everfast gingham.

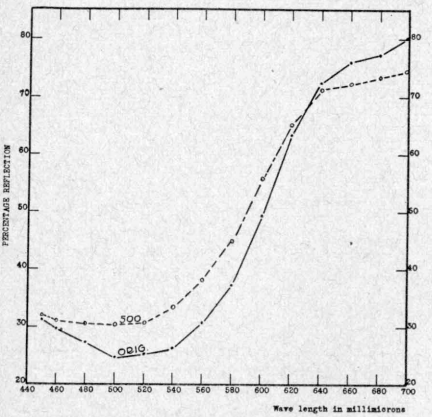

Fig. 32. Color curves for unexposed and exposed pink Everfast suiting.

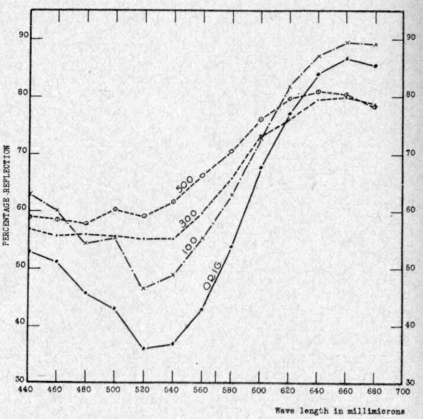

Fig. 33. Color curves for unexposed and exposed pink chambray.

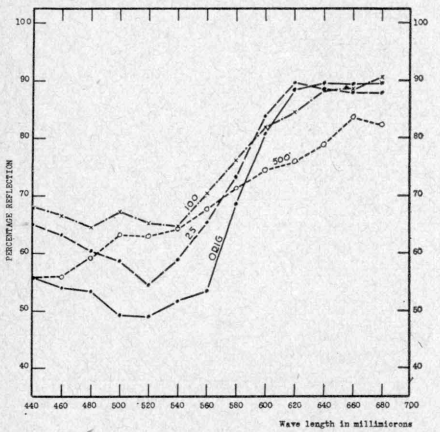

Fig. 34. Color curves for unexposed and exposed pink Superlustre broadcloth.

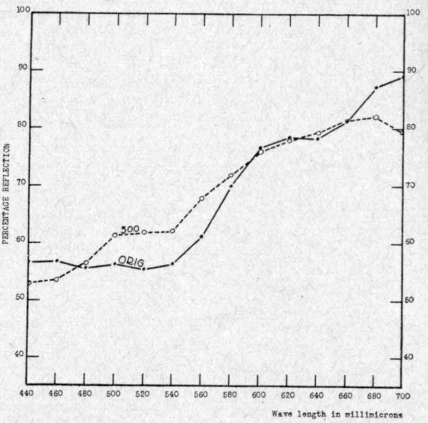

Fig. 35. Color curves for unexposed and exposed pink Bluebird nainsook.

The colors of the Meadow Lane gingham and Everfast gingham and suiting were of approximately the same character and depth. Only slight differences in color could be detected as the exposure periods progressed until at the close of 500 hours of exposure as shown in Figures 6, 7 and 8, all were slightly greyed with a decreased gloss.

The blue of the chambray closely resembled that of the ginghams and suiting and was but slightly less fast. The spectrophotometric curve in Figure 9 shows a greater drop in the blue portion of the spectrum, or a loss in chroma, which resulted in a grayer color. The color of none of these four fabrics, Everfast gingham and suiting, Meadow Lane and chambray, could be judged objectionable even after 500 hours of exposure.

Both the nainsook and broadcloth were a much lighter blue than the other fabrics, as shown by the curves in Figures 10 and 11. The broadcloth showed loss in color at the end of the first day's exposure and after 25 hours was a light blue-gray. After 50 hours little or no blue could be detected. Longer exposure increased the yellow color until after 500 hours the color curve in Figure 13 shows it to be of the same color as the white fabrics exposed the same number of hours.

The blue nainsook became somewhat more gray after 50 hours of exposure and after 500 hours was only slightly blue. Having less color to lose than had the darker ginghams, slight losses appear relatively greater to the unaided eye than do the same losses in the darker blues, but the spectrophotometer, measuring the actual change in color, shows the loss to be greater in the nainsook than in the ginghams and suiting.

Green Fabrics.

The spectrophotometric analyses of the green Everfast gingham and suiting show them to be very similar in their original color and in their reaction to the effects of sunlight (Figures 12 and 13). The gingham became lighter but did not change in hue, a uniform increase in percentage reflection occurring throughout the spectrum. The green suiting showed less change in color, the reflection at the maximum point remaining the same with an increase toward the ends of the curve, resulting in a slightly grayed green. In neither of these fabrics was the change in color perceptible until after more than 100 hours of exposure.

Fading was perceptible but slight in the green Meadow Lane after 100 hours of exposure. The color in this fabric did not merely become lighter as did the Everfast gingham but became more yellow as the percentage reflection increased beyond the green portion of the spectrum (Figure 14).

The green nainsook changed in like manner with the Meadow Lane cloth but to a greater extent. The percentage reflection decreased below 560 millimicrons and increased beyond this point as the fabric became less green and more gray, as shown in Figure 15. At 500 hours it was gray with only a trace of green discernible.

Color changes in the green chambray were only faintly perceptible after 100 hours of exposure. Although the changes occurred later the chambray showed practically the same color changes as did the nainsook but it retained somewhat more green than did the nainsook after 500 hours.

Almost no change in percentage reflection occurred at 520 millimcorns at any of the exposure periods (Figure 16).

The dye used in the green broadcloth was the most fugitive of all the green dyes. This fabric changed from a green through a grey to a yellow during the 500 hours of exposure. At the end of the first day's exposure color changes were noticeable and continued at a rapid rate until after 50 hours the fabric was only faintly green. The rate and extent of color changes are shown in Figure 17.

Yellow Fabrics.

The yellow fabrics include a wide gradation in depth of color, descending from the deep yellow of the suiting, through the chambray, Meadow Lane and Everfast ginghams to the light yellow nainsook. The curves in Figures 18 to 23, inclusive, show that this difference is largely in the wave lengths below 560 millimicrons and not in the regions of the yellow and red. It is in the region above 560 millimicrons, however, that the changes in reflection took place. All of the yellow fabrics became darker upon exposure. The degree to which they darkened is in proportion to the depth of color, as the deeper the color, the lower became the reflection through the yellow and red wave lengths. All yellow fabrics were perceptibly faded before 100 hours of exposure. The changes in the nainsook and Everfast gingham were less noticeable probably because they contained less color originally. The similarity of the curves for the yellow nainsook and Everfast gingham and the white Meadow Lane and nainsook following 500 hours of exposure for each is shown in Figures 23 and 20, and in 3 and 5.

The broadcloth included in this group is not all yellow but is a combination of yellow and pink forming a color called peach. The curves in Figure 18 show that the color had altered considerably after 25 hours of exposure and somewhat more after 500 hours. The greatest change took place within the first 25 hours of exposure and between 460 and 580 millimicrons.

Lavender Fabrics.

The depth of color in the lavender fabrics ranges from very light in the nainsook, through medium depths in broadcloth, chambray, and Meadow Lane to the deeper color of the Everfast fabrics.

The lavender fabrics show two types of color change. The darker shades in the Everfast fabrics and Meadow Lane gingham show in general an increase in percentage reflection throughout the spectrum as shown in Figures 24, 25, and 26. These fabrics were lighter and more grey after exposure but with no change in hue. The curve for the nainsook in Figure 27, shows greater change in the blue and red portion of the spectrum. The lowering of reflection in these regions shows that the grayness of the fabric has increased and that the lavender has become more pink than blue.

A gradual straightening of the curve for the lavender chambray shown in Figure 28 occurred as the color became more grey. After 500 hours of

exposure the color had changed from a lavender in which blue predominated to a grey in which pink was more apparent than blue. The color changes in the chambray progressed slowly in the early hours of exposure but after 100 hours proceeded at a more rapid rate (Figure 29).

The lavender broadcloth was noticeably faded before the exposure had reached 25 hours and it continued to change color rapidly. Little permanent change occurred in the percentage reflection at wavelengths below 480 millimicrons, somewhat more above 640, with the greatest change occurring between 500 and 640 millimicrons or in the green and yellow portions of the spectrum.

Pink Fabrics.

Figures 30, 31, and 32 show the colors of Meadow Lane gingham and the Everfast fabrics to be very similar, to have undergone the same type of color changes, and to have changed to approximately the same extent. These three fabrics became more grey and decreased in gloss as the exposure periods increased. Perceptible changes did not occur before 100 hours of exposure and subsequent changes progressed slowly.

The pink chambray was noticeably lighter after 50 hours of exposure but after 100 hours the changes occurred more slowly, the pink gradually becoming more gray (Figure 33).

The color curves for the broadcloth show it to have had somewhat different reactions to sunlight (Figure 34). After 25 and 100 hours of exposure the percentage reflection is seen to be practically the same as the original at the red end of the spectrum but higher below 620 millimicrons. After 500 hours of exposure the percentage reflection was lower throughout the spectrum than it was after 100 hours and the curve more nearly straight, showing the fabric to have lost much of its original pink, to be darker and more gray. The broadcloth could not be called a pleasing color after 50 hours of exposure to sunlight.

The nainsook was a light pink or flesh color, as shown in Figure 35. Already quite light, it changed little during the exposure periods but at the close of the 500 hours the reflection was less in the red region and more in the green, with approximately the same reflection in the yellow region. These changes show it to have become less pink and more yellow.

From the color changes occurring in these fabrics it seems possible to secure fabrics in any of these five colors which suffer no appreciable change under 100 hours of exposure to sunlight.

Fastness with Respect to Dyes

The dyes used are known in only the chambray and Meadow Lane fabrics.

From the color curves it is shown that the combination of Anthrene Blue R. C. X. and Ponsol Yellow G. used in the blue chambray and the combination of Carbanthrene Blue B. C. S. and Ponsol Violet A. R. used in the blue Meadow Lane were equally fast to sunlight under normal conditions of exposure. The fastness of the blue chambray agrees with the

rating of Stott (17) that Blue R. C. X. has excellent fastness when used alone or in combination with Yellow G.

Green Meadow Lane was dyed with Anthrene Jade Green used alone, and green chambray with the same dye in combination with Ponsol Yellow G. The combination of dyes produced a more vivid green in the chambray than did the green dye used alone in the gingham, but the chambray underwent greater color changes suggesting that the Yellow G. dye was less fast than the Jade Green or when used in combination the Yellow G. dye slightly reduced the fastness of the green dye. The Ponsol Yellow G. was used alone in yellow chambray and this fabric was changed to approximately the same extent as was the green chambray, indicating further that this yellow was not only of poor fastness when used alone but that it also reduced the fastness of the green dye with which it was combined. When each of the two dyes is used alone the green exhibits greater fastness than does the yellow. These findings agree with Stott (17) who lists Yellow G. as having poor fastness to light when used alone and when used with Jade Green, but lists Jade Green as having good fastness when used alone. Borho (1) found that the greater the amount of yellow used in combination with the green, the less fast the combination. Verification of this statement is found in comparison of the green Meadow Lane in which Jade Green was used alone, with the green chambray in which the green was combined with Yellow G, since the color of the Meadow Lane was changed less than the chambray. Scholefield and Turner (14) found that in mixtures of blue and yellow, the fastness of blue was decreased and the fastness of yellow increased as compared with their respective fastness when dyed alone. These conclusions are borne out in the chambray in which the blue fabric was dyed with a combination of a blue and a yellow dye. This fabric underwent greater color change in the blue portion of the spectrum than in the yellow portion. The chambray dyed with the same yellow dye used alone, changed more in the yellow portion than did the blue chambray in which the yellow dye was combined with blue dye. This was not true in the green chambray in which the same yellow dye was combined with green. Here greater change took place in the yellow portion than occurred at the green wavelengths. The same change occurred in the green Meadow Lane where the same green dye was used alone, indicating that the yellow was not responsible alone for the type of color change which occurred in the green chambray.

The colors of the yellow Meadow Lane and yellow chambray were changed equally upon exposure showing the two dyes, Carbanthrene Yellow G. and Ponsol Yellow G. to be of equal but poor fastness.

The lavender chambray was dyed with Indanthrene Violet B and Ponsol Violet R. R. and the lavender Meadow Lane with Anthrene Violet B. N. The chambray was affected by the sunlight to a greater extent than was the gingham but whether the less fast color was due to the use of individual dyes less fast than the dye in the Meadow Lane or to the combination of dyes in the chambray is not known. It is known that a combination of fast dyes may be less fast than either dye when used alone, or that a combination of a fast with a fugitive dye may be either

fast or fugitive depending upon the particular combination of dyes (2, 3, 9, 10, 13). Stott (17) has found Violet B. N. to possess good fastness to light when used alone as in the Meadow Lane.

The combination of Sulfanthrene Pink B. G. and Sulfanthrene Pink F. F. used in the pink chambray produced a color less fast than the Red B. N. used in the pink Meadow Lane. The fastness of Red B. N. is listed by Stott (17) as excellent.

With the exception of the two dyes used in the pink chambray which belong to the Indigoid group, all dyes in the chambray and Meadow Lane belong to the Anthracene group of dyes.

The Meadow Lane ginghams and Pamico suitings (7) were dyed with the same dyes. Comparisons of the unexposed fabrics show the suitings to be slightly darker than the ginghams, a change which may have been due to greater absorbtion of dyes by the mercerized fabrics. Comparisons of color changes in these ginghams and suitings show the ginghams to have altered somewhat more, probably on account of greater resistance of the coarser suitings to the penetration of light.

The green broadcloth underwent the greatest change in color and the blue Everfast fabrics and blue Meadow Lane gingham the least. Dark colors showed less color change than light colors. Among the darker colors the blues were less changed than other colors but no one color was fast in all fabrics. All white fabrics became yellow, yellow fabrics became darker, and other colors became lighter and more gray when exposed to sunlight.

In general, the fabrics least faded were also least tendered.

Fastness with Respect to Guarantee and Price

The Meadow Lane ginghams, Everfast fabrics, and nainsooks have a "money back" guarantee. The manufacturers of chambray gave no information concerning a guarantee. The broadcloths were labeled "tub fast".

The fastness of color was found to correspond in most cases to the guarantee, the Everfast fabrics and Meadow Lane gingham in all colors but yellow changing less than the other fabrics. The yellow nainsook was less changed than the other yellow fabrics. It must be remembered, however, that the nainsooks were, in most cases, much lighter in color; therefore they were less fast than they probably would have been in dyeings of greater depth (7). Undoubtedly the nainsooks would be considered by the consumer as possessing sufficient fastness for the purpose for which they are generally used.

The chambrays were less fast than either the Everfast fabrics or the Meadow Lane ginghams with the exception of the yellow chambray, which changed color to approximately the same extent as did the suiting and Meadow Lane gingham but somewhat more than did the Everfast gingham and nainsook.

In all colors the broadcloths were much less fast than any other fabric. To test the validity of the "tub fast" guarantee the broadcloths were boiled

for several minutes in a concentrated soap solution, rinsed, and dried. None of them had undergone perceptible color changes; therefore they may possibly be considered fast to washing if not placed in sunlight to dry.

The retail prices at the time of purchase are given for each fabric in Table 1. Comparison of these prices on the basis of square yard, show the Everfast gingham to be more expensive than the Meadow Lane but of finer thread count. The prices of none of the other fabrics can be compared directly, as the fabrics themselves differ greatly. However, the broadcloths, which were similar to the nainsooks and Meadow Lane ginghams in price, were much less fast.

These findings indicate that a guarantee is of value in securing fabrics which are fast to light. While fast-dyed fabrics are naturally more expensive than fabrics dyed with fugitive dyes, price is not as satisfactory a measure of fastness as is the guarantee.

SUMMARY

Thirty-five white cotton fabrics and dyed cotton fabrics including Everfast gingham and suiting, Meadow Lane gingham, broadcloth, chambray, and Bluebird nainsook were exposed to sunlight under normal conditions of temperature and humidity for a total of 500 hours. All fabrics were analyzed before exposure and after each 25 hours of exposure to determine changes in strength and color.

Each of the fabrics underwent changes in strength and color. The rate and extent of change varied greatly among the fabrics. Some lost strength and color early in the exposure periods and continued to lose at a rapid rate while other fabrics had changed little in strength and color even after 500 hours of exposure. The average loss in breaking strength of the warp plus that of the filling, of all fabrics was 41 per cent after 500 hours. These losses ranged from approximately 18 to 49 per cent in the warp and from 34 to 65 per cent in the filling.

The mercerization of the Everfast suitings and broadcloths probably increased their resistance to tendering. Sizes apparently had little effect.

Among the fabrics identical in structure, 8 of 15 dyed fabrics lost less strength than did the white indicating that the dyes used in all Meadow Lane ginghams and the blue, yellow, and lavender of the Everfast gingham offered protection. The blue in the suiting apparently had little effect. The dyes of the remaining 6 fabrics apparently increased the loss in strength. The fabrics of identical structure ranked in order of resistance to the tendering effect of sunlight are: blue, lavender, yellow and green (approximately equal), white, and pink. The blue dye of the suiting offered the greatest protection and the pink of the Meadow Lane the least.

It was found that certain dyes were not equally fast when used alone and in combination with other dyes. These findings emphasize the importance of using dyes and combination of dyes which afford protection against tendering and fading.

The heavier, coarser fabrics were less tendered than the thinner, finer fabrics, probably on account of the greater resistance to the penetration of light.

Correlation analysis of the environmental factors shows that the number of hours of exposure had far more effect upon the loss of strength than had temperature and relative humidity. Temperature had more effect than relative humidity, accounting for approximately three times as much change as did relative humidity.

Exposure to sunlight affected the color of all white and all dyed fabrics, as determined by spectrophotometric analysis. White fabrics became more yellow as the exposure periods lengthened. Dyed fabrics varied in their color changes: some became darker and other lighter, while some changed in hue. The general tendency of most colored fabrics was to become lighter and more gray, the color curve becoming more nearly straight as the exposure increased. The greatest color changes occurred in the broadcloths and the least in the suitings and ginghams. Dark colors in general showed less color change than did fabrics less heavily dyed. Fading was not limited to any one color or colors. All colors underwent considerable change in one or more fabrics but blue and green were in general less changed than yellow, lavender, and pink. The least faded fabrics were in most cases the fabrics least tendered by exposure. Doubtless this greater resistance to fading and tendering was due to the fact that these colors have no absorption band in the region of light most effective in changing strength and color. These findings agree in general with those of a previous study in which 22 cotton fabrics were exposed to sunlight for a total of 375 hours.

This study shows that it is possible to secure colored cotton fabrics which undergo only slight changes in color and which retain much of their original strength even after 500 hours of exposure to sunlight. It is concluded that a requirement of fastness to 100 hours of exposure to sunlight before color changes are perceptible is reasonable and not impossible to attain.

Fabrics guaranteed fast to light were found to be more fast than those not guaranteed. The fabrics guaranteed tub fast were fast to washing but very fugitive in light. For cotton fabrics which are to be exposed to light and which are to be laundered, the consumer should insist that the guarantee includes fastness to both light and washing.

LITERATURE CITED

1. Borho, Ernest. 1930. Light fastness of mixtures of Anthrene Jade Green and vat yellows. Text. World, 77:3650.
2. Cady, William H. 1931. Abnormal fading. Am. Dyestuff Reptr., 20:49.
3. Cady, William H. 1931. Peculiarities of fading. Am. Dyestuff Reptr., 20:232.
4. Clark, Ormond W. 1930. Fast color dyeing in the converting plant. Am. Dyestuff Reptr., 19:55.
5. Cunliffe, P. W., Farrow, F. D. 1928. The loss of strength of cotton exposed to light. J. Text. Inst., 19:T169.

6. Ezekiel, Mordecai. 1930. Methods of correlation analysis. John Wiley and Sons.
7. Grimes, Mary Anna. 1933. The effect of sunlight and other factors on the strength and color of cotton fabrics. Tex. Agr. Exp. Sta., Bul. 474.
8. Kauffman, H. 1931. Iron: catalytic action in tendering. Z. angew, Chem., 44:858. Abs. J. Text. Inst., 23:A32.
9. Landolt, A. 1929. Vat-dyed cotton: tendering by light. J. Text. Inst., 20:A554.
10. Landolt, A. 1931. The tendering of dyed fabrics on exposure to light. J. Text. Inst., 22:A41.
11. Matthews, J. Merritt. 1920. Application of dyestuffs. John Wiley and Sons.
12. Scholefield, F., Goodyear, E. H. 1929. Action of light on cotton dyed with certain vat-dyestuffs. Mell. Textilber, 10:867. Abs. Am. Dyestuff Reptr., 19:506.
13. Scholefield, F., Patel, C. K. 1928. Vat-dyed cotton: tendering by light. J. Soc. Dyers. and Col., 44:268. Abs. J. Text. Inst., 20:A205.
14. Scholefield, F., Turner, H. A. 1933. Vat dyestuffs on cotton. Text. Rec., 51:49. Dyer and Calico Print. 70:27. J. Text. Inst., 24:130.
15. Schorger, A. W. 1926. The chemistry of cellulose and wood. McGraw-Hill Book Company.
16. Smith, G. 1931. The chemical analysis of sized cloth. Am. Dyestuff Reptr., 20:118.
17. Stott, P. H. 1934. Fastness of dyestuffs alone and in combination. Am. Dyestuff Reptr., 23:346.
18. Whittaker, C. M. 1934. Fastness in Textiles. J. Soc. Dyers and Col., 1:165.
19. Zierhold, F. 1928. Cotton: action of ultra-violet light. Abs. J. Text. Inst., 1929. 20:A201.