

THE EFFECT OF LIGHT AND OF HEAT ON THE BREAKING
STRENGTH AND COLOR CHANGES OF VISCOSE AND
CELLULOSE ACETATE RAYON FABRICS

by

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INTRODUCTION

Because of the short period of use which rayon has had, much of the background of knowledge that exists for the other common textile fibers is lacking. For linen, wool, cotton, and silk there is a wealth of information, both traditional and scientific, upon qualities, performance and care.

While much study has been made of the effects of light and of heat upon natural fibers, little is known of their effects upon rayon. Studies which have been published on the tendering of the rayons by light and by heat are not consistent.

It is reasonable to expect that both of these treatments would tender the fabric and have an effect upon its color. But exactly how much color change may be expected, or which type of rayon is most influenced is not known.

Information of this character may be helpful in understanding care of rayons by the consumer. It is also possible that it will be of value to the manufacturer and finisher. It has been suggested (29) that the general and traditional habit of looking upon treatments to a textile

material at high temperatures as something to be avoided or carried on as quickly as possible is a prejudice which may be hindering the discovery of useful new information. A knowledge of what happens on the application of heat may help in developing new manufacturing processes and products.

Consequently, the purpose of this study was to secure information concerning the effect of light and of heat upon the dry and wet breaking strength and stretch and upon color changes of viscose and cellulose acetate rayon fabrics with the hope of adding to the information which now exists concerning these effects and of learning which of the two types is most affected by such treatments.

PRESENT STATUS OF KNOWLEDGE

The effect of light on the other common textile fibers has been studied rather completely and important contributions have been made by Cunliffe (6), Wagner (32), Kertess (14), Roberts and Mack (23), Bruner and Goehring (3), Cunliffe and Farrow (7), and Salley (25). While several investigations (11, 33, 12, 19, 27, 13, 17, 1, 4) deal with its effect upon one of the types of rayon, only three studies were found which reported work on both viscose and

cellulose acetate rayons. Waenting (31), in studying the breaking strength of different textiles exposed to light found that acetate rayon showed more sensitiveness to light than did viscose or cuprammonium rayon. Eichler (8) found in a similar study that acetate rayon was deteriorated less by light than silk or the other rayons. Breckenridge, Edgar, and Cranoe (2) found viscose more resistant to the effect of light than acetate or cuprammonium rayon. No study was found which dealt with the effect of light on the color changes to white rayon fabrics.

Similarly, a great deal of work was done in relation to the effect of heat upon wool, silk, linen, and cotton. One of the early and important studies on cotton, carried on by Knecht (15, 16) resulted in the present theory that damage to the cellulose fibers was due to the formation of oxycellulose. Among the other studies recorded are investigations by Saito and Utida (24), Marsh (18), Raynes (22), and Fort (9). Only one study was found which included the effects of heat upon both viscose and cellulose acetate rayons. Breckenridge, Edgar, and Cranoe (2), in their conclusions, stated that viscose rayon was tendered less by heat than cellulose acetate rayon. They employed both moist and dry heat in their study, and an examination

of their tables showed that the moist heat bore out this general conclusion. However, dry heat at 120° C. appears to have lowered the breaking strength of viscose rayon more than it did that of cellulose acetate rayon. No studies were reported on the effect of heat on the color changes of any of the rayons.

PROCEDURE

Representative samples of viscose and cellulose acetate rayon fabrics were chosen. They were subjected to light from a sunlamp and heat in an electric oven for varying periods of exposure. Dry and wet breaking strength determinations were made for each exposure. Analyses of color, using a color analyzer, were made for each exposure, and the data obtained were used to work out the indices of fading.

Materials

Materials used included three white viscose rayons and three white cellulose acetate rayons (Plate I). These included a delustered crepe, a taffeta, and a satin of both

viscose and acetate rayons. They were chosen so that the crepe, for example, of viscose rayon would be as similar in appearance to the cellulose acetate crepe as possible. White fabrics were chosen so that all changes in color and breaking strength would be due to light or heat and not to the presence of dye.

It was determined by previous experiment that if finishing material were present, it would have an inhibiting effect upon color changes which result from heat or light. For this reason, the finishes were removed.

Samples were desized using carbon tetrachloride and an enzyme as described by Committee D-13 (5) and by scouring with soap. The first method would have been difficult and time consuming for such large amounts of fabric. In this method, two five-gram samples were dried to constant weight (B) at 220-230° F. and were extracted for two hours with carbon tetrachloride in a Soxhlet extractor. After allowing them to dry in air, they were washed by repeated immersions in hot distilled water. The samples were then placed in a three to five percent aqueous solution of starch and protein-solubilizing enzymes at 30° C. and thoroughly wet out by repeated squeezing. The enzyme solution was maintained at 50° to 60° C. for one hour. The

samples were removed and rinsed 12 times in fresh portions of distilled water. They were dried to constant weight (C) 220-230° F. The total amount of finishing material was calculated from the following formula:

$$\text{Total percentage of sizing} = \frac{B-C}{B} \times 100$$

Two five-gram samples to be desized by the scouring method were also dried to constant weight (B). They were immersed in one-half percent solution of neutral soapsuds at a temperature of 180° F. (±5°) for 20 minutes, rinsed in hot distilled water 12 times and dried to constant weight (C). The same formula was used to calculate the total amount of finishing material.

The results (Table 1) indicated that it was possible to use the scouring method to remove the finishing material. One or two yard lengths of fabric were desized using this technique, dried following the rinsing, pressed with a steam iron and measured for shrinkage. All tests were made on the desized fabrics.

Physical Tests

The following physical characteristics of the fabric

EXPLANATION OF PLATE I

Samples of Fabrics Used

- Fig. 1. Viscose rayon crepe.
- Fig. 2. Viscose rayon taffeta.
- Fig. 3. Viscose rayon satin.
- Fig. 4. Cellulose acetate crepe.
- Fig. 5. Cellulose acetate taffeta.
- Fig. 6. Cellulose acetate satin.

PLATE I



Fig. 1

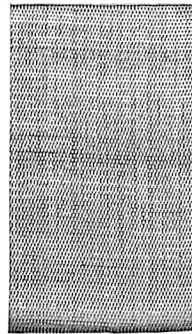


Fig. 2

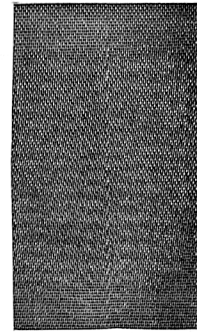


Fig. 3

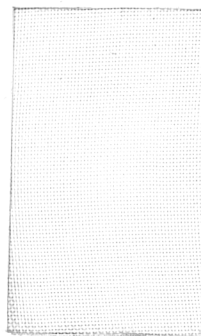


Fig. 4

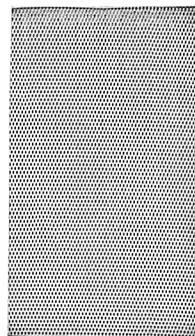


Fig. 5

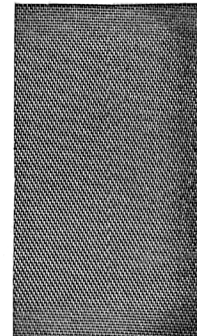


Fig. 6

were determined: weave, thickness, weight per square, thread count, twist, crimp, and yarn counts. The type of weave was analyzed by inspection with a dissecting microscope. Thickness, weight, thread count, and twist were determined according to Committee D-13 (5). Crimp was determined by the Schwarz micro method (26) using camera lucida drawings from sections of the fabric. Yarn counts were made by measuring one yard lengths in the fabric and raveling 100 filling and 100 warp yarns. The dry weights were found, and, by knowing the crimp, the yarn counts were calculated in deniers.

Preparation of Samples

Previous to exposure, samples, warpwise of the fabric, were prepared by the raveled-strip method of Committee D-13 (5). Unexposed controls were prepared also. The raveled-strip method was used because of its superiority over the grab method for experimental work (10), and because the narrow strips were easier to expose.

Exposure to Light and to Heat

The rayon strips were exposed to light from a General Electric Sunlight (Type S-1) for periods of 20, 40, 60, 80, 100, and 120 hours. This lamp gives an intensity of ultra-violet light of 4000 foot-candle minutes as compared to 180,000 foot-candle minutes given by the midsummer noon-day sunlight (21, 28). These periods of exposure were chosen after previous experiment because they gave measurable variation in damage. Exposures were made in a standard atmosphere having a relative humidity of 65 percent (± 2 percent) at 70° F. ($\pm 2^{\circ}$ F.) temperature.

The raveled-strips of fabric were heated in an electric oven with a temperature between $270-280^{\circ}$ F. for 10, 20, 30, 40, 50, and 60 hour periods. The length of the periods and the degree of temperature were chosen because they gave a measurable variation in amount of damage. Fabrics are not ordinarily subjected by the consumer to such high temperature except in ironing. However, high temperature was necessary to speed up the tendering and color changes so that the exposure periods would not be unduly long.

Determination of Breaking Strength and Elongation

Controls and samples damaged by light and heat were broken dry in a Scott automatic power yarn and cloth tester at standard atmospheric conditions after they had been kept at such conditions until moisture equilibrium was reached. Ten samples were broken for each exposure to determine breaking strength and elongation.

The method for wet breaking strength as given by Committee D-13 (5) was modified. The grab method was not used because of the difficulties involved in exposing the samples. Strips prepared by the raveled-strip method were broken, following exposure, after they had been immersed in distilled water for two hours. Average breaking strength and elongation were determined.

Color Analyses

The broken samples from the dry breaking strength determinations were analyzed with the method described by the Bausch and Lomb Optical Company (30) for color attributes according to the Munsell system. After the sector

percentages of neutrals and colors were determined experimentally, the color specifications of hue, saturation, and brilliance were calculated. Then these attributes were converted with Nickerson's formula (20) to a single figure, the index of fading.

The formulas used to express color in its primary attributes with figures for the sector percentages of color and neutrals, using balanced illumination, are:

$$H \text{ (hue)} = Z - \frac{A_x P_x}{A_x P_x + A_z P_z} (z-x)$$

where x = number of first hue (clockwise in the hue circle)

z = number of the second hue (clockwise in the hue circle)

A = area (expressed in sector percentages)

P = power number (brilliance x saturation)

H = resulting hue

$$S \text{ (saturation or chroma)} = \frac{A_1 S_1 + A_2 S_2}{100}$$

$$B \text{ (brilliance or value)} = \sqrt{\frac{A_1 B_1 + A_2 B_2 + A_3 B_3 + A_4 B_4}{100}}$$

The following, for viscose crepe exposed to heat 10 hours (Table 9), is an example of how the experimental data were substituted in these formulas:

The sector percentages were $YR\ 8/5 = 27$, $Y\ 8/7 = 33$, $N\ 9.4 = 15$, $N\ 9 = 25$.

$x = 15$ (number in the hue circle of hue YR)

$z = 25$ (number in the hue circle of hue Y)

The substitutions were then:

$$H = 25 - \frac{27 (8 \times 5)}{27 (8 \times 5) + 33 (8 \times 7)} \quad (25-15)$$

$$H = 21.31$$

$$S = \frac{(5 \times 27) + (7 \times 33)}{100}$$

$$S = 3.66$$

$$B = \sqrt{\frac{(27 \times 8^2) + (33 \times 8^2) + (15 \times 9.4^2) + (25 \times 9^2)}{100}}$$

$$B = 8.45$$

With these results, the color specifications of hue, brilliance, and saturation can be written out as
 $21.31 \text{ Y } \frac{8.45}{3.66}$.

This technique of using illumination and these formulas for deriving color specifications from the resulting data were practical for the measurement of all colors except the measurements of whites. Because the control and samples damaged by light were brighter than any of the standard discs, imbalanced illumination was necessary.

Using the data with the method of imbalanced illumination necessitated no new formula for hue or saturation. However, the data relating to brilliance required different treatment. For example, the sector percentages for the

viscose crepe control on imbalanced illumination with a ratio 9.4:8 were PB $8/2 = 17$, B $8/2 = 28$, N $7 = 35$, and N $9.4 = 20$ (Table 9). The hue and saturation were calculated:

$$H = 75 - \frac{28 (8 \times 2)}{28 (8 \times 2) + 17 (8 \times 2)} (75 - 65)$$

$$H = 68.77$$

$$S = \frac{(17 \times 2) + (28 \times 2)}{100}$$

$$S = .90$$

In order to introduce the differential of illumination into the computation for the brilliance attribute, it was necessary to work with the actual reflectance values rather than the Munsell numbers. A conversion table (30) with the reflectances for the various Munsell brilliance values was used. The reflectances with the viscose crepe control were $8 = .536$, $7 = .389$, $9.4 = .822$. The summation of the brightness-area products gave the reflectance, thus:

$$R = \frac{(.536 \times 17) + (.536 \times 28) + (.389 \times 35) + (.822 \times 20)}{100}$$

$$R = .5418$$

By the use of other columns in the same conversion table the reflectance of .5418 for the ratio 9.4:8, expressed in brilliance, was found to be 9.42. The color specification was then written out in the usual way, $68.77 \text{ B } \frac{9.42}{.90}$.

To express these color specifications in one figure so that color changes could be visualized more simply, Nickerson's formula was used (20). As originally derived the formula was $I = (C/5) dH/3 + dL + dC/2$ where I = index of fading, H = hue, L = lightness (brilliance or value), C = chroma (saturation), and d = difference. Adjusted to a difference visually equal to $1/3$ chroma step, as suggested by Subcommittee A-7 of Committee D-13 of the A. S. T. M. for the color tolerance, the formula became $I = (C/5) d2H + 6dL + 3dC$ (20). The latter of the two forms was used for the computation of I in this study.

The following example illustrates the substitution with this formula for viscose crepe (Table 9):

Color specifications were 68.77 B $\frac{9.42}{.90}$ for the control and 21.31 Y $\frac{8.45}{3.66}$ for samples exposed to heat 10 hours.

Average chroma then was $\frac{.90 + 3.66}{2}$ or 2.28

dH equalled $68.77 - 21.31$ or 47.46

dL was $9.42 - 8.45$ or .97

dC equalled $3.66 - .90$ or 2.76

Substituted in Nickerson's formula the calculation for I was:

$$I = 2 (47.46) \left(\frac{2.28}{5} \right) + 6 (.97) + 3(2.76)$$

$$I = 57.35$$

The data for breaking strength, elongation, and color changes were tabulated. Graphs comparing the data on the different fabrics were made. Tables and graphs were summarized.

FINDINGS AND DISCUSSION

With all six fabrics, the percent of finishing material as determined by scouring with soap and by extracting with carbon tetrachloride and enzyme, was comparable and, therefore, scouring by soap was considered feasible for removal of finishing material (Table 1).

The fabrics, all of which were purchased the first two months of 1939, ranged in price from $19\frac{1}{2}$ cents to 98 cents per yard. They were similar in thickness, except for the acetate crepe, which was thicker than the other fabrics. The weight per square yard of the two taffetas and two satins was similar. It varied for the two crepes from 2.5 ounces for the viscose crepe to 3.7 ounces for acetate crepe. The thread count, both warp and filling, of the two taffetas and two satins was similar. The acetate crepe had less threads per inch than the viscose crepe. The percentage of crimp was not similar for the two crepes, two

taffetas, or two satins. The direction of yarn twist was Z for all fabrics. The twist varied from 2.6 twists per inch to 5.6 twists per inch with the warp yarns and from 2.0 twists per inch to 5.5 twists per inch with the filling yarns. Yarn counts varied from 36.8 deniers for the warp of viscose taffeta to 251.0 deniers for warp of acetate crepe and from 35.6 deniers for the filling of viscose taffeta to 271.8 deniers for the filling of acetate crepe.

Tables 3 to 8 include wet and dry breaking strength and elongation for the controls and damaged samples of all six fabrics. In general, both light and heat tendered the fabric progressively for each exposure. Elongation tended to decrease with increased damage. Difficulty was experienced with the breaking strength determinations for cellulose acetate taffeta damaged by light. For some reason, for which the writer has no theory, the percentage of breaking strength, wet or dry, did not decrease as might be expected from the behavior of the other fabrics. Further study should be made on the effect of light upon this fabric since the interesting possibility presents itself that the fabric might be actually strengthened by exposure to light.

It was difficult to visualize and compare the data obtained in tabulated form. For this reason, graphs (Figs.

Table 1. Amount of finishing material in the fabrics determined by scouring with soap and by extracting with CCl_4 and enzyme.

Fabric	: Method	:Percent of: :finishing : :material	: Average percent	:
Viscose crepe	Soap	0.5		
		0.4	0.45	
	CCl ₄ & enzyme	0.3		
		0.5	0.4	
Viscose taffeta	Soap	1.2		
		1.6	1.4	
	CCl ₄ & enzyme	1.6		
		1.4	1.5	
Viscose satin	Soap	0.4		
		0.5	0.45	
	CCl ₄ & enzyme	0.4		
		0.3	0.35	
Acetate crepe	Soap	0.7		
		0.0	0.35	
	CCl ₄ & enzyme	0.2		
		0.2	0.2	
Acetate taffeta	Soap	0.6		
		0.7	0.65	
	CCl ₄ & enzyme	0.6		
		0.6	0.6	
Acetate satin	Soap	1.3		
		1.3	1.3	
	CCl & enzyme	1.2		
		1.1	1.15	

Table 2. Description of the fabrics tested including data in relation to the purchase of the materials and their physical characteristics.

Fabric	:Where :purchased	:When :purchased	:Price :per :yard	:Width :(inches)	:Weave	:Luster	:Thickness :(inches)	:Weight :per sq. :yd.(oz.)	: Thread count :		Crimp :		Twist :		: Yarn counts :			
									: warp :	: filling :	(percent)		: warp :	: filling :	: (deniers) :			
											warp	filling	direction:	twist per in.:	direction:	twist per in.:	warp	filling
Viscose crepe	Laros Tex- tile Co. Bethlehem, Pa.	Jan. 1939	\$0.30	41	1 — 1	delustered	0.0059	2.5	98+0	72+0	12.0±0.4	6.7±1.5	Z	5.6±0.1	Z	5.5+0.0	87.2	59.6
Viscose taffeta	Cohn-Hall Marx Co., N. Y. City	Jan. 1939	0.195	39	1 — 1	high luster	0.0067	2.8	111+0	48+0	5.6±0.7	6.5±0.2	Z	2.6±0.0	Z	3.3+0.1	36.8	35.6
Viscose satin	Geo. Innes Co., Wichita, Kansas	Jan. 1939	0.89	39	(4 — 1) ₃	high luster	0.0058	3.4	135+1	63+0	6.4±0.9	2.3±0.3	Z	4.1±0.1	Z	3.4±0.0	93.0	92.6
Cellulose acetate crepe	Rorabaugh- Buck Dry Goods Co., Wichita, Kansas	Jan. 1939	0.59	38	1 — 1	delustered	0.0096	3.7	59+0	52+0	7.0±0.7	13.5±1.0	Z	3.0±0.0	Z	2.7±0.0	251.0	271.8
Cellulose acetate taffeta	Cohn-Hall Marx Co. N. Y. City	Jan. 1939	0.215	39	1 — 1	high luster	0.0075	2.9	110+0	48+0	6.9±0.8	11.0±1.5	Z	3.1±0.1	Z	2.0±0.1	133.3	107.8
Cellulose acetate satin	Emery, Bird, Thayer Co., K. C. Mo.	Feb. 1939	0.98	39 1/4	(4 — 1) ₃	high luster	0.0067	3.5	136+1	66+0	4.4±0.6	6.6±0.6	Z	4.2±0.1	Z	4.9±0.0	87.8	81.0

Table 3. Dry and wet breaking strength and elongation of viscose rayon crepe.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		32.0±0.1	100.0	0.69±0.01	23.0	13.9±0.3	100.0	0.60±0.02	20.0
Light	20	32.4±0.3	101.2	0.62±0.01	20.7	12.7±0.4	91.4	0.58±0.02	19.3
Light	40	31.8±0.5	99.4	0.58±0.02	19.3	13.5±0.4	97.1	0.58±0.02	19.3
Light	60	30.3±0.6	94.7	0.58±0.01	22.0	12.3±0.5	88.5	0.59±0.01	19.7
Light	80	29.8±0.5	93.1	0.65±0.02	21.7	11.6±0.7	83.5	0.55±0.01	18.3
Light	100	28.4±0.3	88.8	0.61±0.01	20.3	9.5±0.7	68.3	0.47±0.02	15.7
Light	120	28.9±0.3	90.3	0.58±0.01	21.3	12.3±0.3	88.5	0.56±0.01	18.7
Heat	10	22.8±0.6	71.3	0.53±0.01	17.7	7.4±0.5	53.2	0.36±0.02	12.0
Heat	20	24.7±0.4	77.2	0.53±0.02	17.7	6.9±0.6	49.6	0.32±0.02	10.7
Heat	30	18.1±0.9	56.6	0.39±0.02	13.0	3.4±0.3	24.5	0.21±0.01	7.0
Heat	40	16.8±0.5	52.5	0.29±0.01	9.7	2.6±0.2	18.7	0.12±0.01	4.0
Heat	50	17.4±0.4	54.4	0.35±0.01	11.7	2.7±0.2	19.4	0.15±0.01	5.0
Heat	60	17.3±0.6	54.1	0.30±0.02	10.0	2.3±0.1	16.5	0.15±0.01	5.0

Table 4. Dry and wet breaking strength and elongation of viscose rayon taffeta.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		56.0±0.0	100.0	0.76±0.01	25.3	27.3±0.3	100.0	0.83±0.02	27.7
Light	20	53.0±1.1	94.6	0.77±0.01	25.7	25.7±0.2	94.1	1.16±0.01	38.3
Light	40	49.5±2.4	87.6	0.74±0.02	24.7	26.4±0.5	96.7	0.82±0.02	27.3
Light	60	52.0±1.3	92.9	0.76±0.01	25.3	25.6±0.6	93.8	0.78±0.02	25.0
Light	80	51.2±1.1	91.4	0.80±0.02	26.7	25.8±0.5	94.5	0.80±0.02	26.7
Light	100	51.9±1.2	92.7	0.78±0.02	25.0	24.8±0.4	90.8	0.77±0.01	25.7
Light	120	50.0±1.0	89.3	0.82±0.01	27.3	22.9±0.6	83.9	0.77±0.02	25.7
Heat	10	46.2±1.1	82.5	0.68±0.01	22.7	18.5±1.7	67.8	0.61±0.01	20.3
Heat	20	45.9±0.9	82.0	0.65±0.02	21.7	17.4±0.6	63.7	0.58±0.02	19.3
Heat	30	36.2±1.2	64.6	0.50±0.02	16.7	9.7±0.6	35.5	0.35±0.01	11.7
Heat	40	32.2±1.0	57.5	0.37±0.03	12.3	7.2±0.2	26.4	0.29±0.01	9.7
Heat	50	32.9±0.3	58.6	0.41±0.00	13.7	8.5±0.3	31.1	0.29±0.01	9.7
Heat	60	32.6±0.9	58.2	0.42±0.04	14.0	8.4±0.3	30.8	0.29±0.03	9.7

Table 5. Dry and wet breaking strength and elongation of viscose rayon satin.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		91.0±1.0	100.0	0.58±0.01	19.3	43.4±0.4	100.0	0.68±0.01	22.7
Light	20	81.3±1.9	89.3	0.60±0.02	20.0	43.1±0.2	99.5	0.77±0.01	21.7
Light	40	68.7±1.4	75.5	0.70±0.02	23.2	42.1±0.5	97.0	0.66±0.01	22.0
Light	60	77.3±3.6	84.9	0.66±0.02	22.0	41.1±0.1	94.1	0.67±0.01	22.3
Light	80	66.9±1.2	73.5	0.73±0.04	24.3	40.7±0.5	93.8	0.69±0.01	23.0
Light	100	73.0±1.4	80.2	0.75±0.04	25.0	40.8±0.5	94.5	0.68±0.01	22.7
Light	120	70.4±1.5	77.4	0.72±0.04	24.0	40.7±0.4	93.8	0.61±0.01	20.3
Heat	10	76.8±2.6	84.4	0.61±0.01	20.3	37.1±0.8	86.0	0.60±0.02	20.0
Heat	20	64.9±2.3	71.3	0.53±0.02	17.7	27.3±1.7	63.0	0.39±0.02	13.0
Heat	30	56.4±2.4	62.0	0.53±0.02	17.7	22.2±1.1	51.2	0.33±0.01	11.0
Heat	40	53.6±0.7	58.9	0.42±0.02	14.0	19.5±0.9	45.0	0.33±0.03	11.0
Heat	50	54.4±0.8	59.8	0.41±0.01	13.7	20.9±0.7	48.2	0.34±0.02	11.3
Heat	60	42.6±2.1	46.8	0.34±0.07	11.3	17.3±0.9	39.9	0.25±0.01	8.3

Table 6. Dry and wet breaking strength and elongation of cellulose acetate crepe.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		41.0±0.0	100.0	0.55±0.01	18.3	28.2±0.2	100.0	0.78±0.01	26.0
Light	20	41.9±0.2	102.0	0.57±0.01	19.0	28.5±0.2	101.1	0.71±0.02	23.7
Light	40	38.7±0.2	94.4	0.55±0.01	18.3	27.0±0.4	95.7	0.72±0.02	24.0
Light	60	39.7±0.4	96.8	0.49±0.01	16.3	24.6±0.2	87.2	0.70±0.01	23.3
Light	80	36.8±0.5	89.8	0.46±0.01	15.3	24.8±0.2	87.9	0.60±0.01	20.0
Light	100	36.3±0.5	88.5	0.43±0.01	14.3	24.5±0.2	86.9	0.63±0.01	21.0
Light	120	34.3±0.7	83.7	0.40±0.02	13.3	22.9±0.3	78.0	0.57±0.01	19.0
Heat	10	41.8±0.3	102.0	0.54±0.01	18.0	26.0±0.3	92.2	0.70±0.02	23.3
Heat	20	39.3±0.4	95.9	0.49±0.01	16.3	21.3±0.6	75.5	0.63±0.04	21.0
Heat	30	34.6±0.8	84.4	0.34±0.03	11.3	18.1±0.5	64.2	0.52±0.03	17.3
Heat	40	30.7±0.8	75.0	0.45±0.02	15.0	18.0±0.9	63.8	0.43±0.05	14.3
Heat	50	27.1±1.0	66.1	0.40±0.03	13.3	17.5±0.6	62.1	0.43±0.05	14.3
Heat	60	24.0±1.3	58.5	0.35±0.03	11.7	14.4±0.3	51.1	0.22±0.03	7.3

Table 7. Dry and wet breaking strength and elongation of cellulose acetate taffeta.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		36.0±1.0	100.0	0.70±0.01	23.3	22.6±0.6	100.0	0.96±0.04	32.0
Light	20	40.0±0.8	110.1	0.78±0.02	26.0	26.0±0.7	115.0	0.85±0.01	28.3
Light	40	37.6±0.3	104.2	0.78±0.01	26.0	23.8±0.4	105.2	1.09±0.02	36.3
Light	60	40.3±0.4	111.9	0.79±0.01	26.3	24.5±0.2	108.3	1.05±0.01	35.0
Light	80	40.4±0.3	112.0	0.79±0.01	26.3	22.1±0.4	97.8	1.10±0.01	36.7
Light	100	36.8±0.5	102.2	0.77±0.01	25.7	23.2±0.4	102.5	1.16±0.02	38.7
Light	120	35.9±1.0	99.7	0.78±0.01	26.0	26.4±0.5	116.6	0.87±0.02	29.0
Heat	10	33.5±0.9	93.0	0.70±0.03	23.3	16.2±0.5	71.4	0.76±0.02	25.3
Heat	20	31.3±0.6	87.0	0.46±0.01	24.0	15.6±0.6	69.0	0.63±0.06	21.0
Heat	30	31.0±0.6	86.0	0.48±0.04	16.0	12.0±0.4	53.1	0.19±0.02	6.3
Heat	40	31.7±0.3	88.0	0.39±0.03	13.0	10.2±0.7	44.7	0.13±0.01	4.3
Heat	50	31.2±0.3	86.7	0.40±0.02	13.3	10.9±0.5	46.3	0.11±0.01	3.7
Heat	60	30.4±1.1	84.5	0.32±0.04	10.7	9.4±0.6	41.6	0.09±0.01	3.0

Table 8. Dry and wet breaking strength and elongation of cellulose acetate satin.

		Dry				Wet			
		Breaking strength		Elongation		Breaking strength		Elongation	
Exposure:	Hours:	pounds	percent	inches	percent	pounds	percent	inches	percent
Control		52.0±0.0	100.0	0.43±0.01	14.3	28.9±0.3	100.0	0.45±0.03	15.0
Light	20	48.4±0.3	93.1	0.45±0.02	15.0	24.9±0.6	86.2	0.48±0.02	16.0
Light	40	41.2±0.8	79.2	0.41±0.01	13.7	26.9±0.2	93.1	0.58±0.01	19.3
Light	60	45.7±1.5	87.9	0.45±0.01	15.0	26.2±0.4	90.7	0.54±0.01	18.0
Light	80	41.8±0.9	80.4	0.39±0.01	13.0	26.5±0.2	91.7	0.47±0.01	15.7
Light	100	41.8±0.8	80.4	0.39±0.01	13.0	25.3±0.2	87.5	0.50±0.01	16.7
Light	120	39.3±1.6	75.6	0.38±0.01	12.7	27.7±0.3	95.8	0.47±0.02	15.7
Heat	10	42.5±0.7	81.7	0.42±0.02	14.0	25.2±0.4	87.2	0.53±0.02	17.7
Heat	20	39.7±0.6	76.3	0.24±0.03	8.0	20.0±0.5	69.2	0.32±0.03	10.7
Heat	30	40.0±1.2	76.9	0.20±0.01	6.7	17.2±0.5	59.5	0.17±0.02	5.7
Heat	40	40.4±0.1	77.7	0.16±0.00	5.3	16.8±0.4	58.0	0.12±0.01	4.0
Heat	50	39.1±0.2	75.2	0.16±0.00	5.3	16.8±0.4	56.1	0.12±0.01	3.7
Heat	60	35.8±1.1	68.8	0.17±0.01	5.7	12.7±0.6	43.9	0.05±0.00	1.7

1 to 10) were made to illustrate the trend of decreased breaking strength and elongation and to show which fabrics were most damaged.

Dry breaking strength in percentage of breaking strength of control for samples exposed to light were plotted in Fig. 1. As mentioned above, the acetate taffeta showed in general an increase in strength. Further study should be made before a definite conclusion can be drawn as to which type of rayon is most affected by light. However, a general trend appears in the results of the study, barring the marked peculiarity of the cellulose acetate taffeta, which might indicate that the dry breaking strength of cellulose acetate rayons was affected more than that of viscose rayons. This is in contradiction to the results of Eichler (8) and of Breckenridge, Edgar, and Cranoe (2) who concluded that the acetates were less affected. It is in agreement with Waenting (31).

Wet breaking strength in percentage of wet breaking strength of the control for samples exposed to light was plotted in Fig. 2. Again acetate taffeta showed a marked peculiarity of response. Similarly, it was difficult to draw conclusions as to which type of rayon showed the greatest damage. A tentative conclusion is offered that

the acetate rayons are affected more when broken wet than are the viscose rayons. This is in agreement with Breckenridge, Edgar, and Cranoe (2).

The percentage elongation for samples exposed to light was calculated by dividing the elongation in inches by three, the number of inches between the jaws of the Scott tester, and multiplying by 100. The percentage elongation curves for samples exposed to light and broken dry were plotted in Fig. 3. They showed little variation in elongation, though a slight decrease was indicated for all fabrics. Conclusions cannot be drawn regarding a difference of behavior for the different types of rayon.

There was more variation and more damage in the percentage elongation of samples exposed to light and broken wet. Likewise, conclusions cannot be drawn regarding a difference in behavior for the two different types of rayon (Fig. 4).

More definite conclusions could be drawn for the samples exposed to heat. A recognizable trend existed for the dry breaking strength (Fig. 5). Heat lowered the percentage of strength for viscose rayon more than it did for acetate rayon. This conclusion disagrees with the general statement of Breckenridge, Edgar, and Cranoe (2) concerning the effect of heat. It agrees, however, with the specific

case in their study of rayons exposed to dry heat at 120° C. The dry heat at 120° C. is fairly comparable to the dry heat used in this study at 270° F. or 132° C.

Results of the wet strength determinations of samples exposed to heat were similar to those for dry breaking strength. Acetate rayons were tendered less than viscose rayons (Fig. 6).

The percentage elongation for dry breaking strength of samples exposed to heat indicated a greater trend toward decreased elongation than for either dry or wet breaking strength for samples exposed to light. No definite conclusions could be drawn concerning which type of rayon showed greatest decrease of elongation (Fig. 7).

A marked decrease of percentage elongation was indicated in the results for the wet breaking strength of samples exposed to heat. In general, the acetate rayons tended to show greater decrease of percentage of elongation (Fig. 8).

The readings and calculations for color changes are given in Tables 9 to 14. An examination of these tables will illustrate why Nickerson's formula was used. The color specifications with all fabrics showed, as can be seen, a marked change, but it would have been difficult to indicate

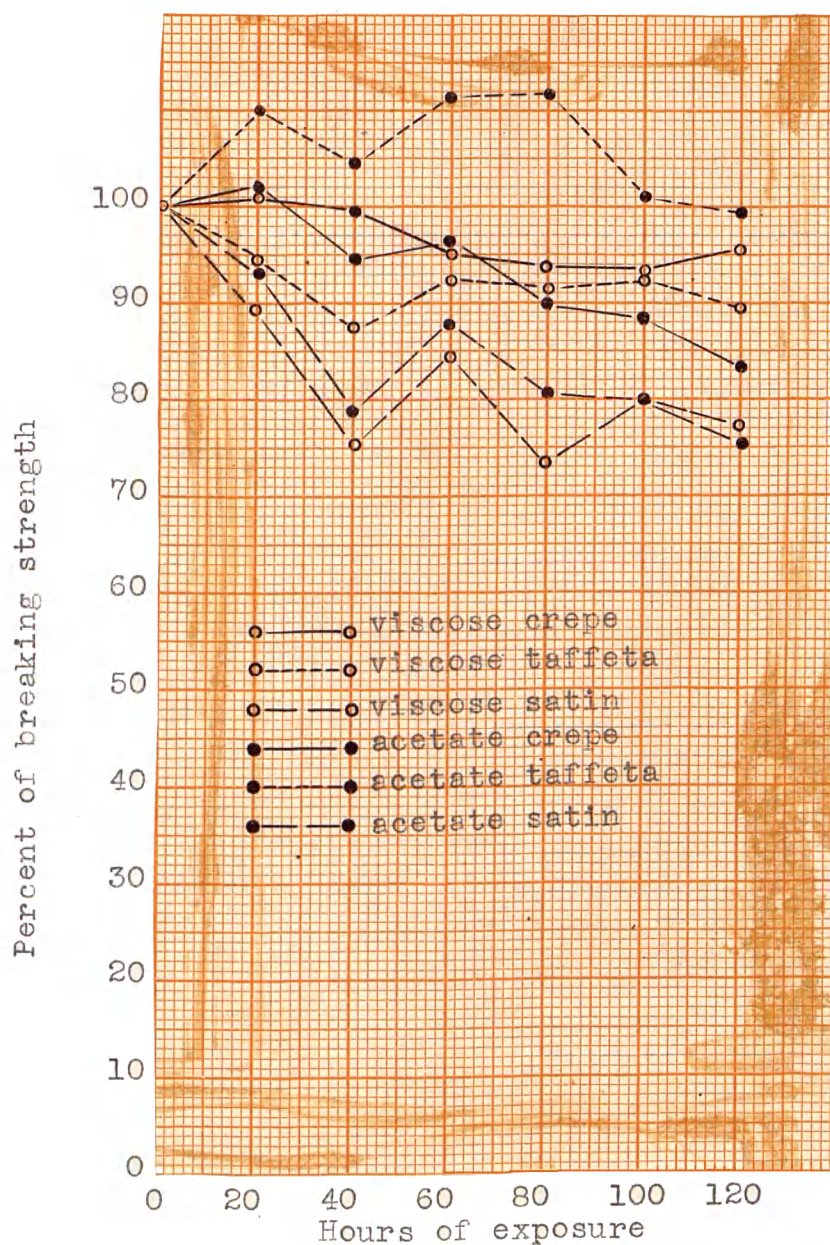


Fig. 1. Dry breaking strength in percentage of dry breaking strength of the control for samples damaged by light.

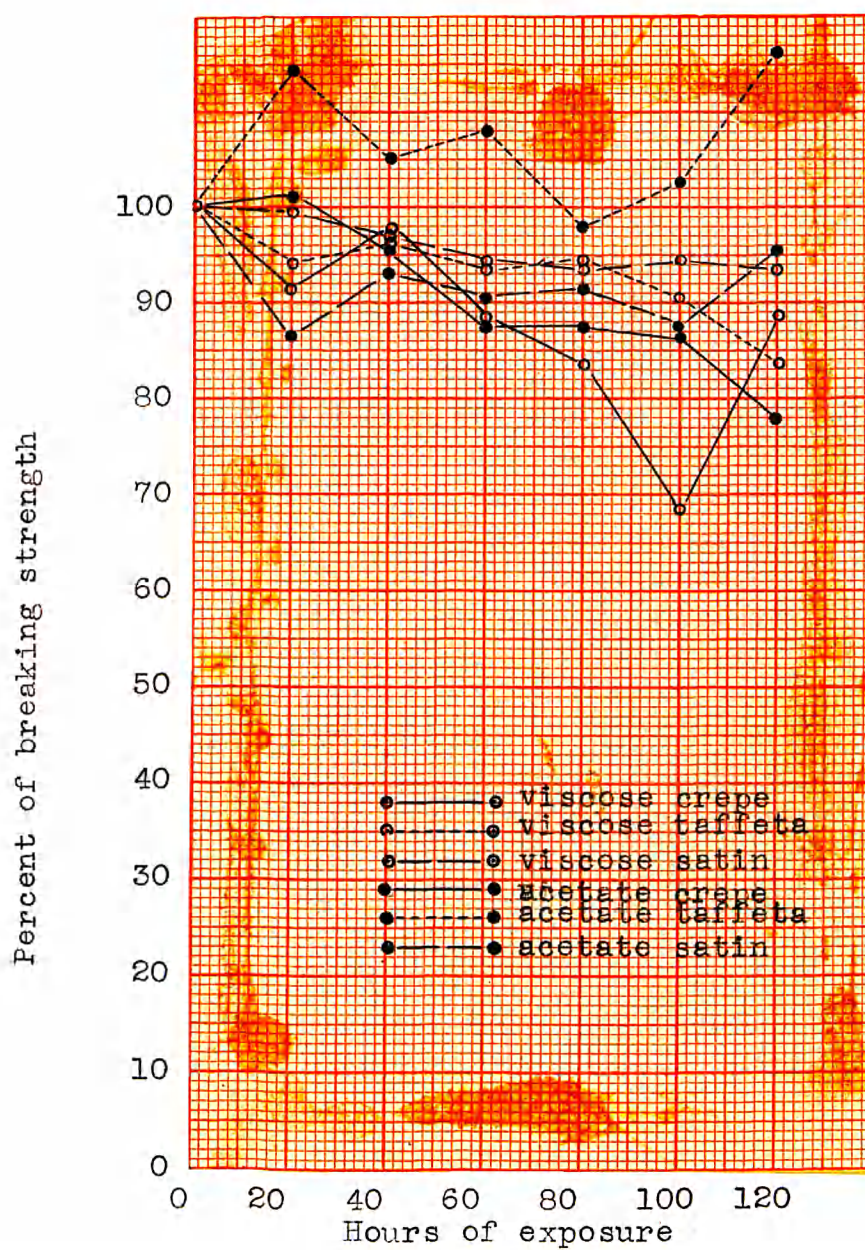


Fig. 2. Wet breaking strength in percentage of wet breaking strength of the control for samples damaged by light.

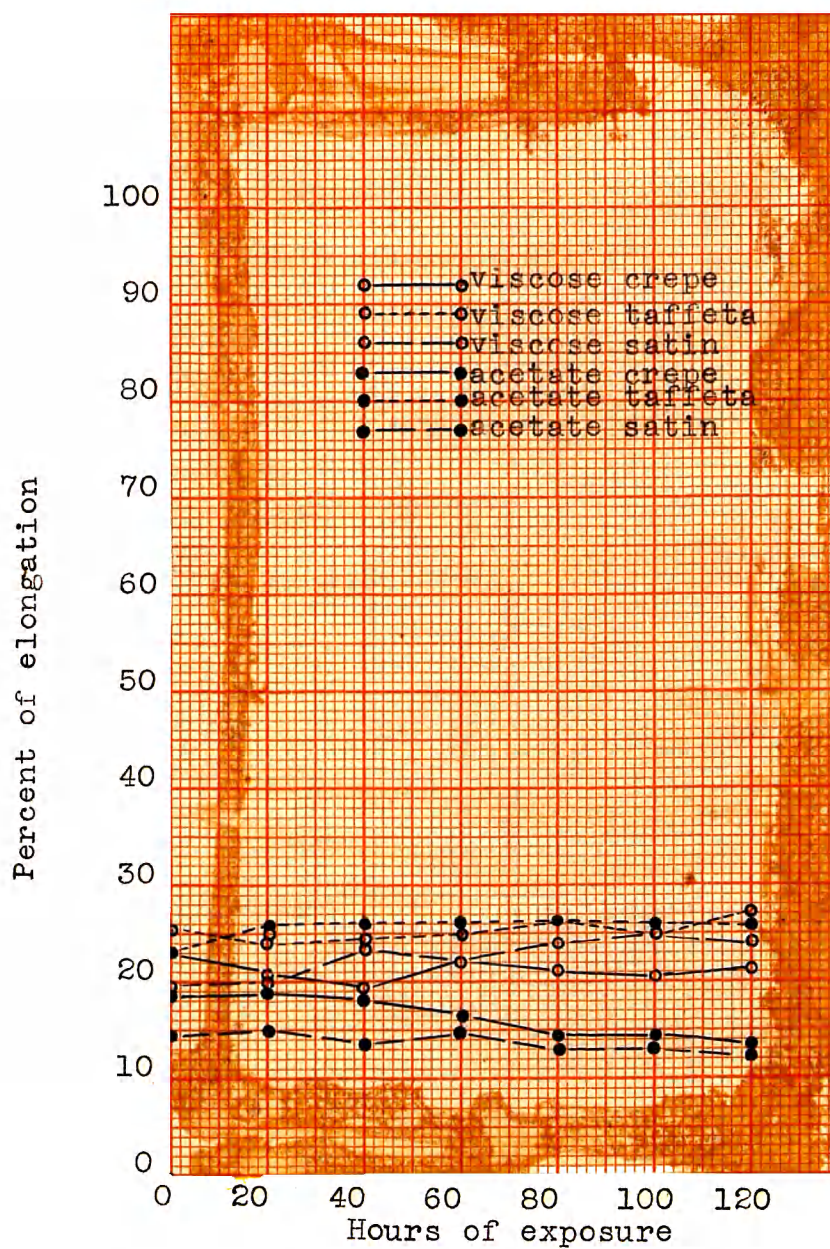


Fig. 3. The percentage of elongation of dry breaking strength of samples exposed to light.

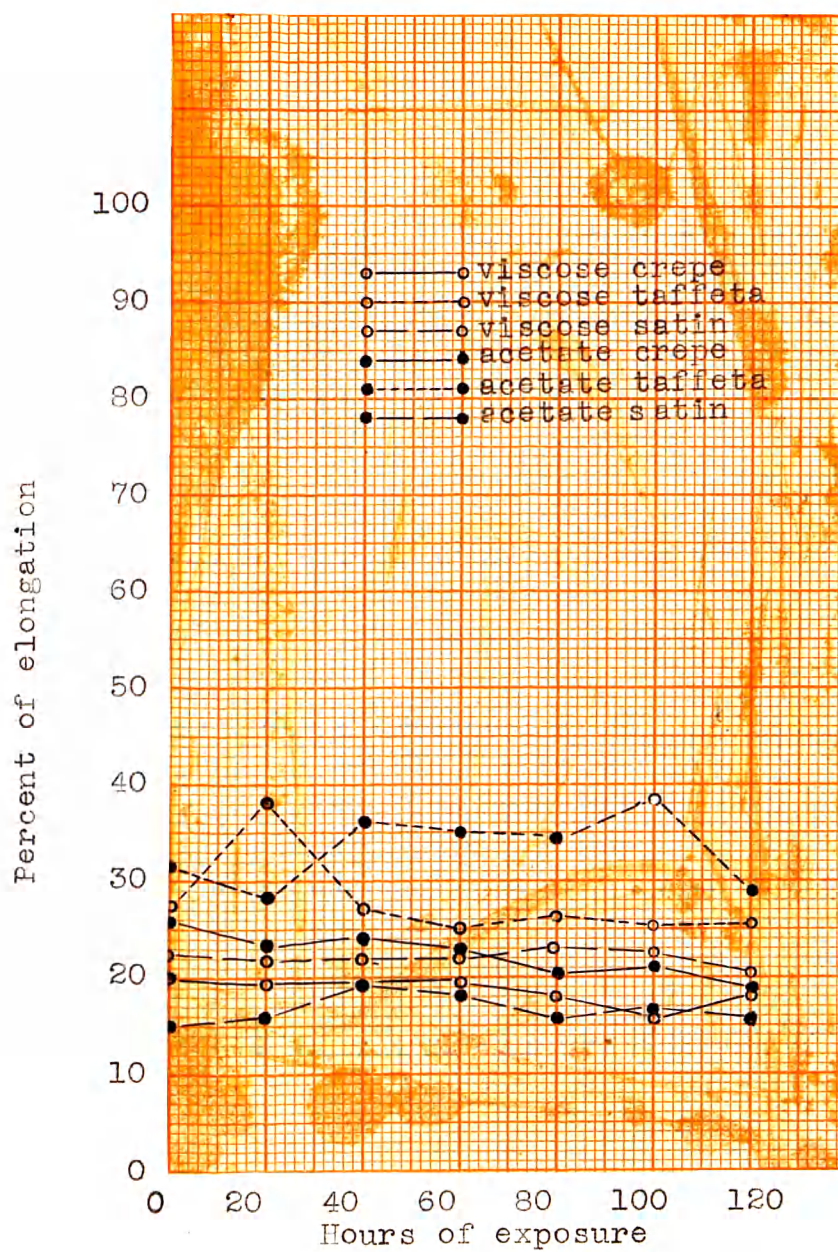


Fig. 4. The percentage of elongation of wet breaking strength of samples exposed to light.

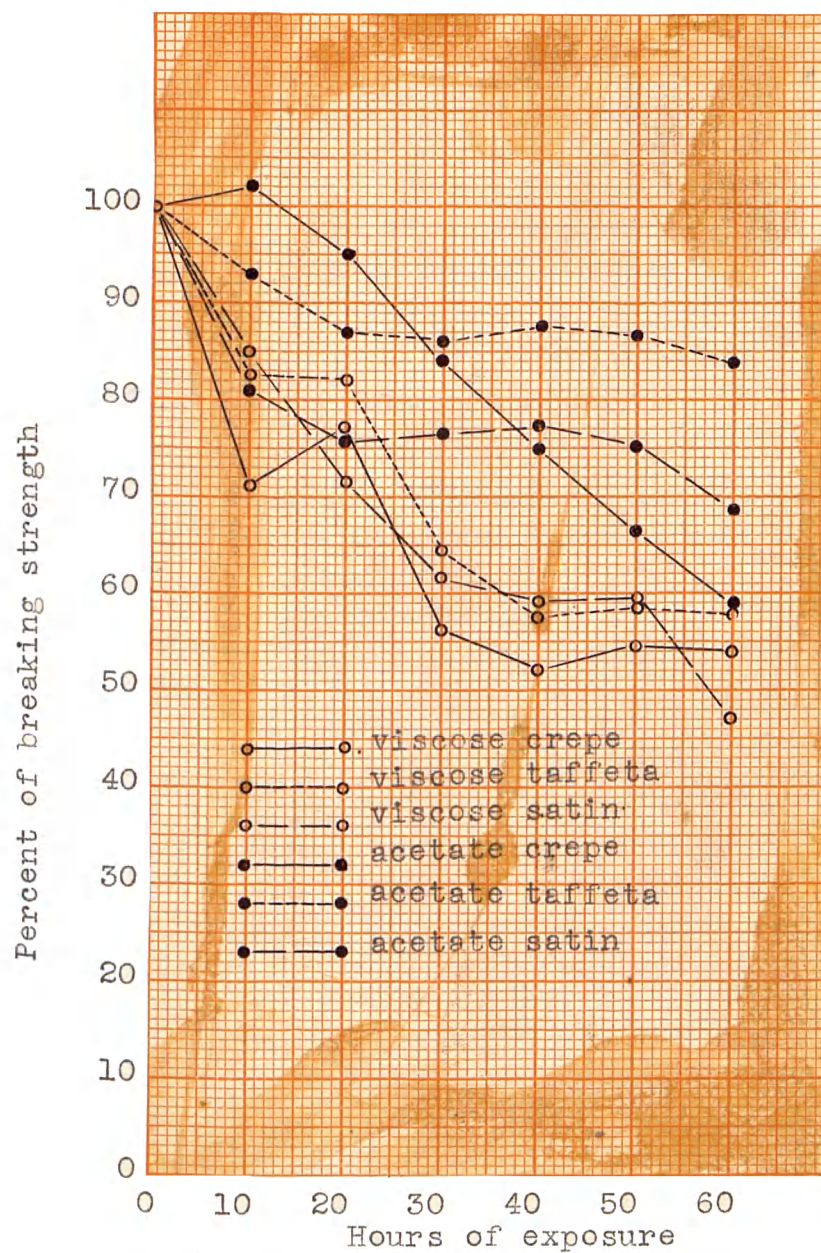


Fig. 5. Dry breaking strength in percentage of dry breaking strength of the control for samples damaged by heat.

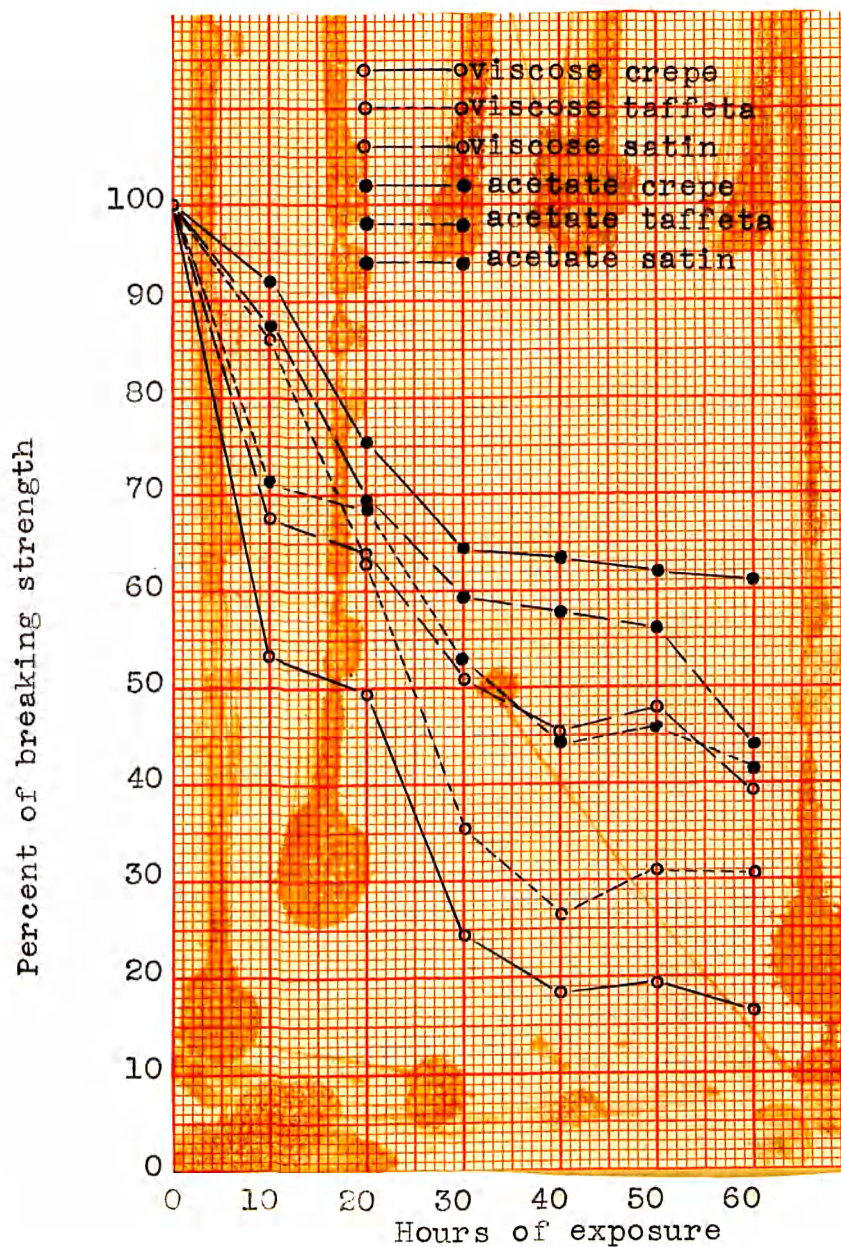


Fig. 6. Wet breaking strength in percentage of wet breaking strength of the control for samples damaged by heat.

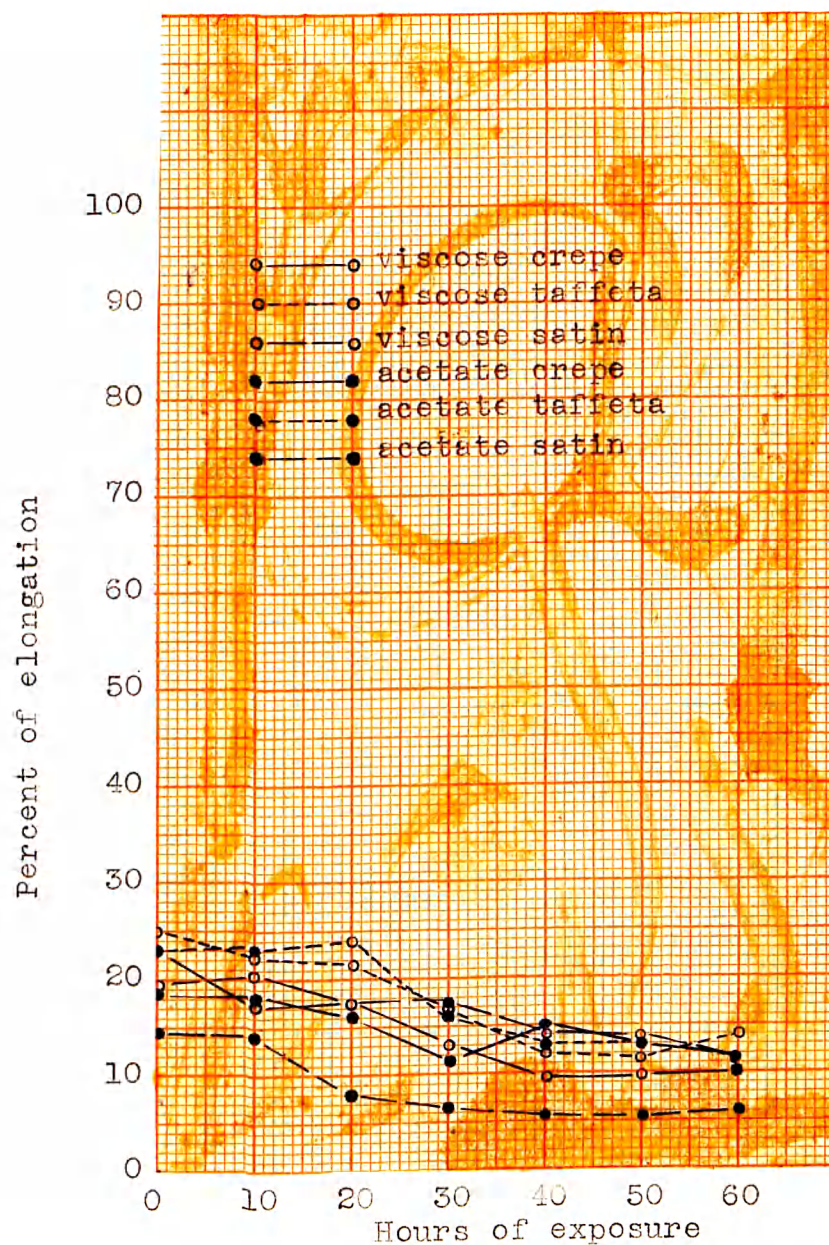


Fig. 7. The percentage of elongation of dry breaking strength of samples exposed to heat.

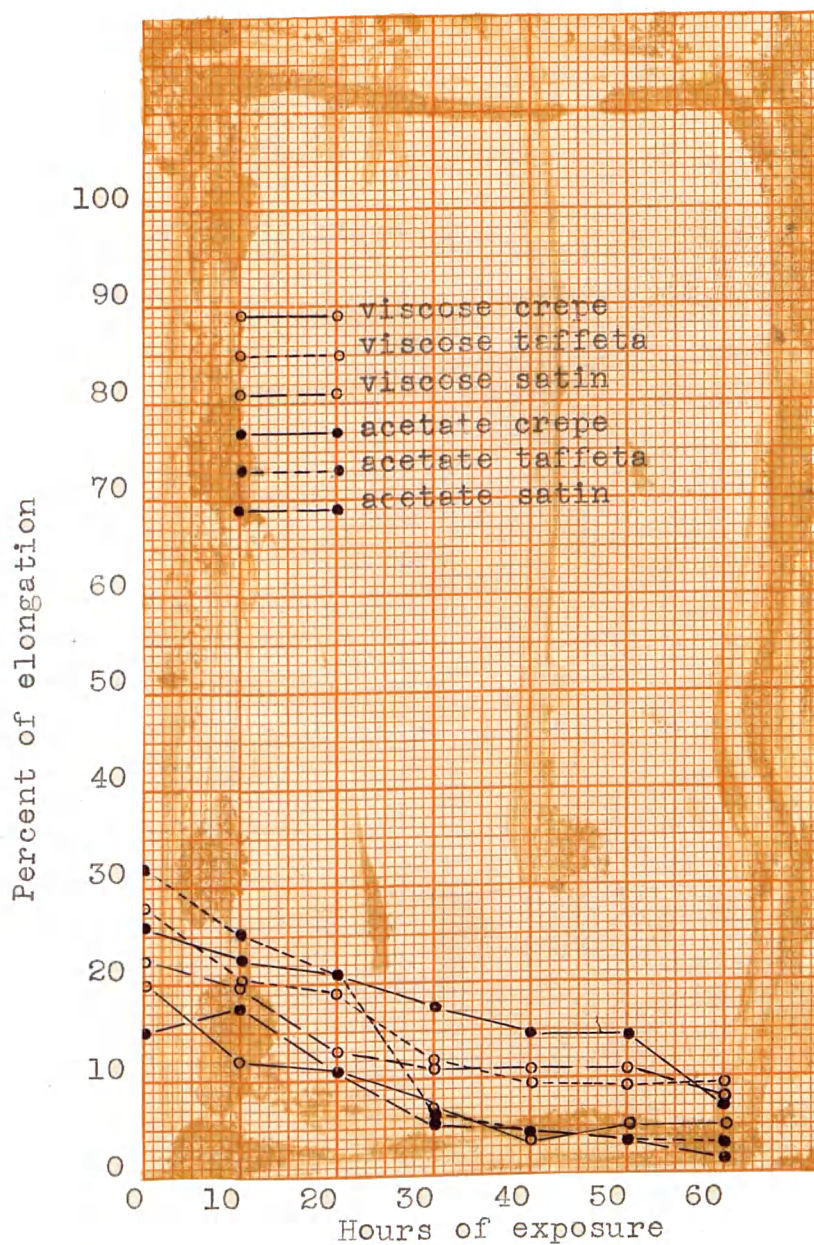


Fig. 8. The percentage of elongation of wet breaking strength of samples exposed to heat.

Table 9. Color changes for viscose rayon crepe using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control*		PB 8/2 = 17 B 8/2 = 28 N 7 = 35 N 9.4 = 20	68.77 B $\frac{9.42}{.90}$									
Light*	20, 40, 60, 80	PB 8/2 = 13 B 8/2 = 32 N 7 = 35 N 9.4 = 20	67.89 B $\frac{9.42}{.90}$	0.90	0.88		0.00		0.00		0.30	
Light*	100, 120	PB 8/2 = 10 B 8/2 = 35 N 7 = 35 N 9.4 = 20	67.23 B $\frac{9.42}{.90}$	0.90	1.54		0.00		0.00		0.54	
Heat**	10	YR 8/5 = 27 Y 8/7 = 33 N 9 = 25 N 9.4 = 15	21.31 Y $\frac{8.45}{3.66}$	2.28	47.46		0.97		2.76		57.35	
Heat**	20	YR 6/12 = 15 Y 8/12 = 35 N 8 = 30 N 9.4 = 20	22.57 Y $\frac{8.02}{6.00}$	3.45	46.20		1.40		5.10		87.42	
Heat**	30	YR 6/12 = 27 Y 8/12 = 28 N 8 = 30 N 9.4 = 15	20.80 Y $\frac{7.75}{6.60}$	3.75	47.97		1.67		5.70		99.00	

* Readings taken with imbalanced illumination, ratio 9.4:8.

** Readings taken with balanced illumination.

Table 9. (cont.).

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Heat**	40, 50	YR 6/12 = 35 Y 8/12 = 25 N 7 = 30 N 9.4 = 10	19.88 YR $\frac{7.22}{7.20}$	4.05	48.89		2.20		6.30		111.30	
Heat**	60	YR 6/12 = 15 Y 8/12 = 55 N 7 = 20 N 9.4 = 10	23.20 Y $\frac{7.70}{8.40}$	4.65	45.47		1.72		7.50		117.36	

** Readings taken with balanced illumination.

Table 10. Color changes for viscose rayon taffeta using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control*		PB 8/2 = 27 B 8/2 = 29 N 7 = 25 N 9.4 = 19	69.82 B $\frac{9.54}{1.12}$									
Light*	20, 40	PB 8/2 = 25 B 8/2 = 31 N 7 = 25 N 9.4 = 19	69.46 B $\frac{9.54}{1.12}$	1.12	0.36		0.00		0.00		0.18	
Light*	60	PB 8/2 = 21 B 8/2 = 34 N 7 = 12 N 9.4 = 33	68.82 B $\frac{9.88}{1.10}$	1.11	1.00		0.34		0.02		2.52	
Light*	80, 100	PB 8/2 = 27 B 8/2 = 29 N 7 = 8 N 9.4 = 36	69.82 B $\frac{9.94}{1.12}$	1.12	0.00		0.40		0.00		2.40	
Light*	120	PB 8/2 = 20 B 8/2 = 36 N 7 = 8 N 9.4 = 36	68.56 B $\frac{9.94}{1.12}$	1.12	1.26		0.40		0.00		2.94	
Heat**	10	YR 8/2 = 10 Y 8/6 = 30 N 9 = 15 N 9.4 = 45	24.00 Y $\frac{8.80}{2.00}$	1.56	45.82		0.74		0.88		35.52	
Heat**	20	YR 8/2 = 12 Y 8/6 = 52 N 7 = 28 N 9.4 = 8	24.28 Y $\frac{7.84}{3.36}$	2.24	45.54		1.70		2.24		57.72	

* Readings taken with imbalanced illumination ratio 9.4:8.

** Readings taken with balanced illumination

Table 10. (cont.).

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Heat**	30	YR 6/8 = 20 Y 8/8 = 35 N 7 = 15 N 9.4 = 30	22.02 Y $\frac{7.96}{4.40}$	2.76	47.80		1.58		3.28		72.12	
Heat**	40, 50	YR 6/8 = 17 Y 8/8 = 49 N 5 = 17 N 9.4 = 17	22.94 Y $\frac{7.50}{5.28}$	3.20	46.88		2.04		4.16		84.72	
Heat**	60	YR 6/8 = 36 Y 8/8 = 34 N 5 = 18 N 9.4 = 12	20.57 Y $\frac{7.06}{5.60}$	3.36	49.25		2.48		4.48		94.50	

** Readings taken with balanced illumination.

Table 11. Color changes for viscose rayon satin using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control*		B 7/4 = 12 BG 8/2 = 38 N 8 = 10 N 9.4 = 40	58.55 BG $\frac{9.96}{1.24}$									
Light*	20, 40, 60, 80, 100, 120	B 7/4 = 8 BG 8/2 = 42 N 8 = 10 N 9.4 = 40	57.50 BG $\frac{9.99}{1.16}$	1.20	1.05		0.03		0.08		0.90	
Heat**	10	YR 8/4 = 10 Y 8/5 = 23 N 9 = 10 N 9.4 = 52	22.42 Y $\frac{8.66}{1.55}$	1.40	36.13		1.30		0.31		28.92	
Heat**	20	YR 8/4 = 17 Y 8/5 = 32 N 9 = 8 N 9.4 = 43	22.81 Y $\frac{8.69}{3.24}$	2.24	35.74		1.27		2.00		45.66	
Heat**	30	YR 8/4 = 15 Y 8/8 = 45 N 9 = 30 N 9.4 = 10	23.57 Y $\frac{8.48}{4.20}$	2.72	34.98		1.51		2.96		55.98	
Heat**	40	YR 8/4 = 15 Y 8/8 = 65 N 9 = 10 N 9.4 = 10	23.96 Y $\frac{8.25}{5.80}$	3.52	34.59		1.71		4.56		72.66	
Heat**	50	YR 8/4 = 21 Y 8/12 = 41 N 7 = 24 N 9 = 13	23.55 Y $\frac{7.89}{5.76}$	3.50	35.00		2.07		4.52		75.12	
Heat**	60	YR 8/5 = 20 Y 8/12 = 50 N 5 = 20 N 9 = 10	23.57 Y $\frac{7.60}{7.00}$	4.12	34.98		2.36		5.76		89.04	

* Readings taken with imbalanced illumination ratio 9.4:8.

** Readings taken with balanced illumination.

Table 12. Color changes for cellulose acetate rayon crepe using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control *		PB 6/6 = 14 B 7/4 = 11 N 7 = 15 N 9.4 = 60	71.21 PB $\frac{9.97}{1.28}$									
Light*	20, 40, 60, 80, 100, 120	PB 6/6 = 13 B 7/4 = 16 N 7 = 14 N 9.4 = 57	70.11 PB $\frac{9.94}{1.42}$	1.35	1.10		0.06		0.14		1.38	
Heat**	10	YR 8/2 = 38 Y 8/5 = 18 N 7 = 25 N 9.4 = 19	20.42 Y $\frac{9.53}{1.66}$	1.47	49.21		0.44		0.38		32.70	
Heat**	20	YR 8/2 = 45 Y 8/8 = 15 N 5 = 46 N 8 = 22	20.36 Y $\frac{8.95}{1.94}$	1.61	49.15		1.02		0.66		39.96	
Heat**	30	YR 8/2 = 24 Y 8/8 = 15 N 5 = 46 N 8 = 15	22.15 Y $\frac{8.22}{1.68}$	1.48	49.06		1.75		0.40		40.74	
Heat**	40	YR 8/2 = 15 Y 8/8 = 22 N 5 = 48 N 8 = 15	23.54 Y $\frac{8.15}{2.06}$	1.67	47.67		1.82		0.78		45.12	
Heat**	50	YR 8/2 = 19 Y 8/8 = 31 N 5 = 35 N 8 = 15	23.67 Y $\frac{8.56}{2.86}$	2.07	47.54		1.41		1.58		52.56	
Heat**	60	YR 8/5 = 10 Y 7/8 = 30 N 5 = 48 N 8 = 12	23.07 Y $\frac{7.71}{2.90}$	2.09	48.14		2.26		1.62		58.74	

* Readings taken with imbalanced illumination ratio 9.4:8.

** Readings taken with balanced illumination.

Table 13. Color changes for cellulose acetate rayon taffeta using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control* **		B 7/4 = 8 BG 8/2 = 9 N 5 = 45 N 9 = 38	61.08 B $\frac{9.66}{.50}$									
Light***	20	B 7/4 = 10 BG 8/2 = 6 N 5 = 52 N 9 = 32	62.45 B $\frac{9.48}{.52}$	0.51	1.37		0.29		0.02		2.04	
Light***	40, 60, 80, 100, 120	B 7/4 = 10 BG 8/2 = 4 N 5 = 58 N 9 = 29	63.14 B $\frac{9.22}{.48}$	0.49	2.06		0.55		0.02		3.78	
Heat**	10	YR 8/2 = 20 Y 8/6 = 30 N 7 = 10 N 9 = 40	23.18 Y $\frac{8.32}{2.20}$	1.35	37.90		1.45		1.70		34.26	
Heat**	20	YR 8/2 = 15 Y 8/6 = 45 N 7 = 20 N 9 = 20	24.00 Y $\frac{8.02}{3.00}$	1.75	37.08		1.75		2.50		43.98	
Heat**	30	YR 8/2 = 30 Y 8/12 = 35 N 7 = 15 N 9 = 20	23.75 Y $\frac{7.96}{4.80}$	2.65	37.33		1.71		4.30		62.76	
Heat**	40	YR 8/2 = 30 Y 8/12 = 35 N 7 = 20 N 9 = 15	23.75 Y $\frac{7.96}{4.80}$	2.65	37.33		1.81		4.30		63.36	
Heat**	50, 60	YR 8/5 = 35 Y 8/12 = 30 N 7 = 20 N 9 = 15	21.73 Y $\frac{7.96}{5.35}$	2.93	39.35		1.81		4.85		71.52	

*** Readings taken with imbalanced illumination ratio 9.4:7.

** Readings taken with balanced illumination

Table 14. Color changes for acetate satin using Nickerson's formula.

Exposure :	Hours	:Sector :percentages	:Color :specifications	:Average: :chroma :	dH	:	dL	:	dC	:	I	:
Control***		PB 6/6 = 12 B 8/4 = 16 N 7 = 58 N 9.4 = 14	69.57 B $\frac{9.90}{1.36}$									
Light***	20, 40, 60, 80, 100, 120	PB 6/6 = 11 B 8/4 = 12 N 7 = 58 N 9.4 = 19	70.07 PB $\frac{9.98}{1.14}$	1.25	0.50		0.08		0.22		1.38	
Heat**	10	YR 8/5 = 8 Y 8/5 = 11 N 5 = 55 N 9.4 = 26	20.78 Y $\frac{9.57}{0.95}$	1.16	48.79		0.33		0.41		25.80	
Heat**	20	YR 8/5 = 10 Y 8/5 = 9 N 5 = 55 N 9.4 = 26	19.74 YR $\frac{9.57}{0.95}$	1.16	49.83		0.33		0.41		26.34	
Heat**	30	YR 8/5 = 10 Y 8/5 = 20 N 5 = 55 N 9.4 = 26	21.67 Y $\frac{9.93}{1.50}$	1.43	47.90		0.03		0.14		27.96	
Heat**	40	YR 8/5 = 13 Y 8/5 = 13 N 5 = 53 N 9.4 = 21	20.00 Y $\frac{9.54}{1.30}$	1.33	49.57		0.36		0.06		28.68	
Heat**	50	YR 8/2 = 11 Y 8/8 = 15 N 5 = 49 N 7 = 25	23.45 Y $\frac{8.85}{1.42}$	1.39	46.12		1.05		0.06		32.10	
Heat**	60	YR 8/2 = 9 Y 8/8 = 20 N 5 = 59 N 7 = 12	23.99 Y $\frac{8.68}{1.78}$	1.57	45.58		1.22		0.42		37.20	

*** Readings taken with imbalanced illumination ratio 9.4:7.
 ** Readings taken with balanced illumination.

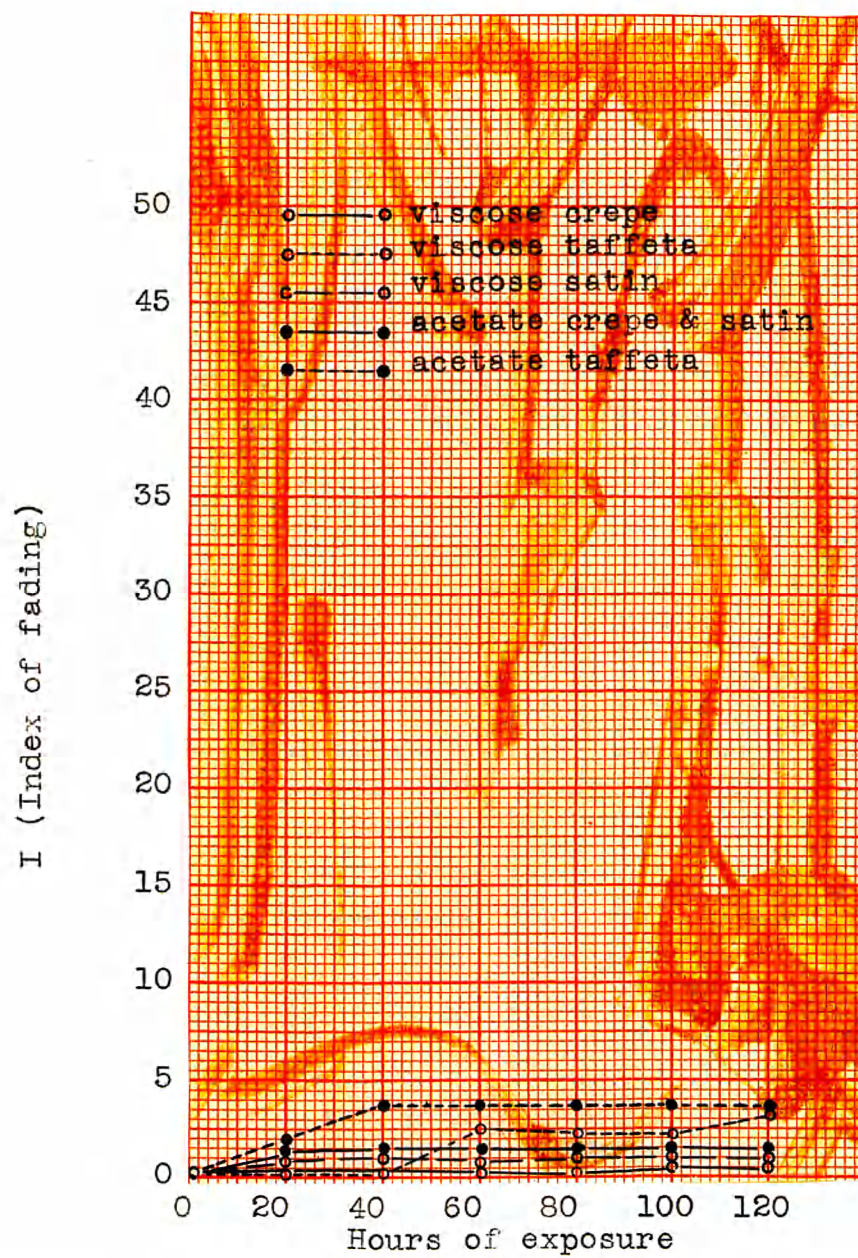


Fig. 9. Color changes of samples exposed to light plotting the I of Nickerson's formula.

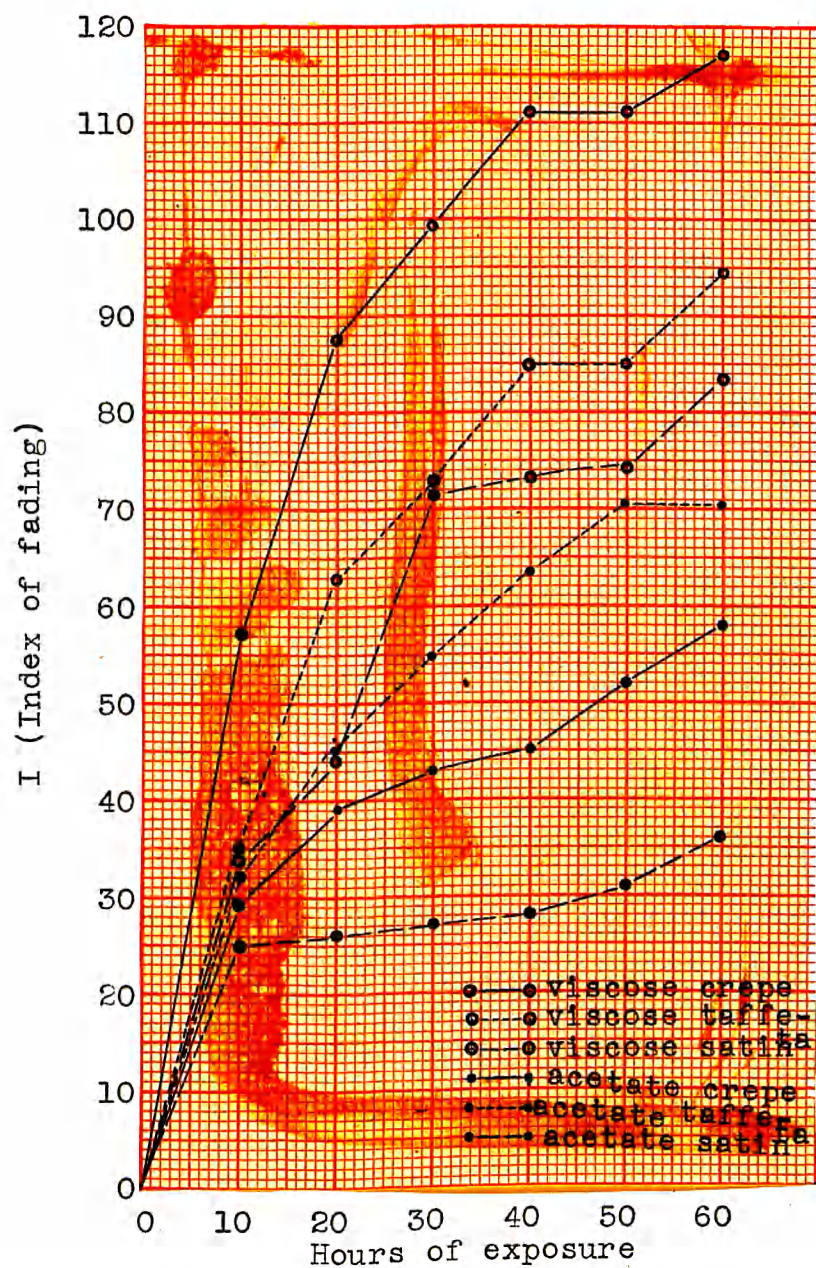


Fig. 10. Color changes of samples exposed to heat plotting the I of Nickerson's formula.

a trend in this change. The I, as worked out with Nicker-son's formula, clearly showed the change in color.

With all fabrics, there was little change of color with exposure to light. These changes have been plotted in Fig. 9. No definite conclusions can be drawn as to which type of rayon was most changed in color.

There was a decided change in color for samples of all fabrics exposed to heat. These changes have been plotted in Fig. 10. Viscose rayons are shown in this graph to be changed more than acetate rayons. This trend is especially noticeable after 20 hours of exposure.

CONCLUSIONS

1. Heat and light affect the dry and wet breaking strength, elongation, and color changes of white viscose and cellulose acetate rayon fabrics.

2. Heat lowers the breaking strength of viscose rayon fabrics more than that of cellulose acetate rayon fabrics.

3. Heat changes the color of viscose rayon fabrics more than that of cellulose acetate rayon fabrics.

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