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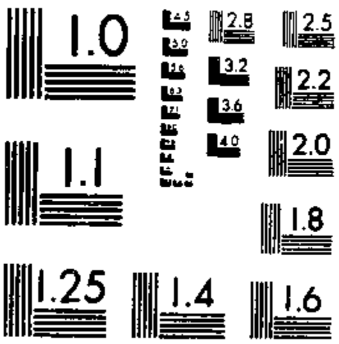

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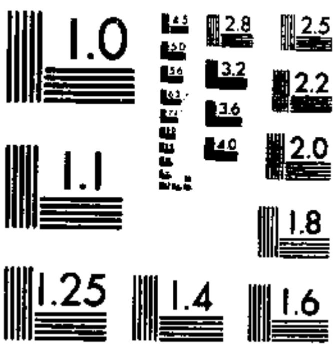

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SERVICEABILITY OF SHEETS

Composed Wholly or in Part of Cotton and Viscose Staple Rayon

by Verda I. McLendon and Suzanne Davison

January 1955 Technical Bulletin No. 1103
U. S. DEPARTMENT OF AGRICULTURE

Serviceability of Sheets Composed Wholly or in Part of Cotton and Viscose Staple Rayon[1]

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INTRODUCTION

Knowledge of the physical and chemical characteristics and performance-in-use of fabrics identical in construction but different in fiber content is important as a basis for evaluating the performance of the materials for household textiles. Several studies have been reported in which certain physical properties of cotton and rayon fabrics have been compared; for the most part, however, these fabrics came from the retail market, and little is known about the details of manufacture or about the kind of fiber that was used.

Reported here are the results of physical, chemical, and microscopic tests on sheetings made entirely or in part from rayon staple and

[1] Submitted for publication May 6, 1954.

[2] Acknowledgment is made of the work of Bess V. Morrison (deceased) in planning and initiating the study; appreciation is expressed to George S. Wham, Jr., formerly textile technologist of the Bureau of Human Nutrition and Home Economics, for supervision of fabric manufacture; to Ida Adelaide Anders, University of Tennessee, and Alpha C. Latzke, Kansas State College, for assistance in planning and making arrangements for the serviceability phase of the project at their respective institutions; to Sarah E. Brier and Jeanne W. Beaty, and to Florence E. Markee and Alice T. West for assistance in carrying out in-service studies at the University of Tennessee and Kansas State College, respectively; to Paul G. Homeyer and Mary A. Clem, Statistical Laboratory, Iowa State College, for assistance in planning the tabulations and analyses, and in planning and supervising the coding, tabulations, and computations of the data, respectively; to Rowena Dowlen for supervision of laboratory analyses; and to the many technicians who assisted in the study.

from cotton of known genetic origin. In a preliminary investigation, 7 sheetings composed of all-cotton, all-rayon, or of different blends of these 2 fibers were evaluated in the laboratory and changes due to repeated launderings were determined. Based on the results of this investigation, sheets composed of all-cotton, all-rayon, and of a 50–50 blend of cotton and rayon were manufactured and placed in service in dormitories at the University of Tennessee and Kansas State College. The effect of actual use on the properties of the sheets was determined after specified intervals of laundering and wear.

MANUFACTURE OF YARNS AND SHEETINGS

Yarns and sheetings composed entirely or in part of cotton and rayon were manufactured by the Textile School of the Clemson Agricultural College, Clemson, S. C., under conditions as accurately controlled and as comparable as the existing facilities and the nature of the fibers would permit. With only a few minor deviations, the manufacturing processes paralleled those used by commercial plants.

An American Upland (Empire Variety) cotton, typical of that normally selected by mills for the commercial production of sheetings, was procured through the cooperation of the Field Crops Research Branch, Agricultural Research Service, U. S. Department of Agriculture. It was of middling grade, $1\frac{1}{32}$-inch staple length, and was grown from pure seed and under isolation by the Georgia Agricultural Experiment Station. Care was exercised in its selection to insure as great uniformity as possible in leaf, character, foreign matter, preparation, color, and staple length. The rayon was 1.5 denier, bright staple, regular viscose, and considered suitable for blending with the cotton. The length of the rayon staple was $1\frac{1}{4}$ inches for the preliminary investigation and $1\frac{9}{16}$ inches for the serviceability phase of the study.

MANUFACTURING SPECIFICATIONS.—Seven lots of yarns were spun for the preliminary investigation and three lots for the serviceability study. The fiber content of these yarns was as follows:

Preliminary investigation:
- All-cotton.
- 5/6 cotton–1/6 rayon.
- 4/6 cotton–2/6 rayon.
- 3/6 cotton–3/6 rayon.
- 2/6 cotton–4/6 rayon.
- 1/6 cotton–5/6 rayon.
- All-rayon.

Serviceability study:
- All-cotton.
- 1/2 cotton–1/2 rayon.
- All-rayon.

Specifications for the construction of yarns and fabrics were as follows:

Item	Warp	Filling
Yarn—		
Type	Carded	Carded.
Number	22's	22's.
Twist multiplier	4.35	3.75.
Twist direction	Z	Z.
Fabric count	64	64.

PRODUCTION OF SHEETINGS.—The bales of raw fibers were opened and scattered on the picker room floor where they remained for 24 hours for conditioning at room temperatures. Opening was done by passing the rayon 2 times and the cotton 3 times through the hopper feeder of the breaker picker with the combing roll set very close. The raw stock was allowed to drop from the hopper feeder to the floor after each successive passage. The fibers for the mixed yarns were blended, sandwich style, on the floor of the picker room. The stock was then passed through three-process picking, carding, two drawings, slubber roving, intermediate roving, and ring spinning.

The organization and speeds of machines employed for the yarn manufacture were identical for all the yarns except that the licker-in and the doffer of the card were slowed for stock containing rayon. Different drafting roll settings were necessarily used for the all-cotton, the 1¼-inch staple rayon, and the 1$\frac{9}{16}$-inch staple rayon. Settings for the two latter fibers were also used for blends of each of these rayons with cotton.

All warps were slashed with the same thin boiling size mixture which consisted of water, cornstarch, and plasticizers, applied at 208° F. The temperature of the drying drums ranged from 220° F. for the first drum to 185° F. for the seventh drum. The yarn was stretched approximately 2 percent during slashing.

Weaving was done on automatic looms. The fabrics for the preliminary investigation were woven 36 inches wide and those for the serviceability study 71 inches wide.

The chemical treatment given the fabrics during the finishing process is shown in tables 1 and 2. The wide fabrics were sewn together, pulled through pot-eyes, brought to open width, dried on drying cans, tentered, and rolled on a cotton sheet range. The heat was considerably reduced on the drying cans and in the tenter frame housing for the all-rayon fabric. No sizing was applied to the finished sheetings and they were not calendered. The fabrics were torn into 108-inch pieces and sewn into sheets with a 3-inch hem at one end and a 1-inch hem at the other end.

EXPERIMENTAL PROCEDURES

Laboratory tests were made on yarns, finished fabrics, and on the laundered-only and laundered-and-used sheetings. All samples were brought to moisture equilibrium under standard conditions of 65 percent relative humidity and 70° F. temperature (*1*).[3]

YARN NUMBER AND TWIST.—The yarn number was determined on a direct reading yarn numbering balance. Ten readings were taken for each set of warp and filling yarns from each of five bobbins. The average of the 50 determinations was recorded as the yarn number.

[3] Italic numbers in parentheses refer to Literature Cited, p. 57.

A twist-tester of the type described in ASTM D-76-49 (*1*) was used to find the amount of twist in the yarns. The average of 50 specimens taken from 5 bobbins of yarn was regarded as the number of turns per inch.

TABLE 1.—*Chemical treatment given the 7 narrow sheetings in the process of finishing*

Fabric and operation [1]	Reagent	Temperature	Time
All fabrics:			
Desizing	Starch-digesting-enzyme	130° F Cooling bath	30 minutes. 12 hours.
Rinsing	Water	180° F	30 minutes.
All-cotton fabric:			
Scouring	Soda ash and a sodium sulfonate of an alkyl oleate.	Boiling	
Rinsing	Water	do	30 minutes.
Scouring	1 percent solution sulphuric acid.	60° F	10 minutes.
Bleaching	1 percent solution 100-volume hydrogen peroxide plus sodium silicate and trisodium phosphate pH 9–10.	175°–180° F	5½ hours.
Rinsing	Water	Boiling	30 minutes.
Cotton-rayon fabrics:			
Scouring	5 percent solution trisodium phosphate and ½ percent solution sodium lauryl sulphate.	do	1 hour.
Rinsing	Water	180° F	30 minutes.
Bleaching	1 percent solution 100-volume hydrogen peroxide plus sodium silicate and trisodium phosphate pH 8–10.	175°–180° F	5½ hours.
Rinsing	Water	180° F	30 minutes.
All-rayon fabric:			
Scouring	3 percent solution trisodium phosphate and ½ percent solution sodium lauryl sulphate.	Boiling	1 hour.
Rinsing	Water	180° F	30 minutes.
Bleaching	½ percent solution 100-volume hydrogen peroxide plus sodium silicate and trisodium phosphate pH 8–10.	175°–180° F	45 minutes.
Rinsing	Water	180° F	30 minutes.

[1] All fabrics were desized, scoured, and bleached in a laboratory dye tub.

TABLE 2.—*Chemical treatment given the 3 wide sheetings in the process of finishing*

Fabric and operation	Reagent [1]	Temperature or pressure	Time	Equipment used
All fabrics:			*Hours*	
Singeing				Gas singer.
Desizing	Malt diatase		3	Pad.
Rinsing	Cold water			Continuous washer.
All-cotton fabric:				
Scouring	3.8 percent sodium hydroxide, 0.5 percent sodium silicate, 2.75 percent synthetic detergents and soaps.	18 p. s. i.	11	Kier.
Rinsing	Water	120° F.	¼	Do.
Bleaching	2 percent 130-volume hydrogen peroxide and 3 percent sodium silicate.	170° F.	8	Do.
Rinsing	Water	120° F.	¼	Do.
Cotton-rayon fabrics:				
Scouring	1.75 percent tetrasodium pyrophosphate, 1.35 percent synthetic detergents and soaps.	175° F.	6	Do.
Rinsing	Water	120° F.	¼	Do.
Bleaching	Same as the all-cotton fabric.			
Rinsing	Water	120° F.	¼	Do.
All-rayon fabric:				
Scouring	Solution of sodium carbonate, soap, and synthetic detergent.	175° F.	1	Dye beck.
Rinsing	Water	120° F.	¼	Do.
Bleaching	Solution of hydrogen peroxide, sodium silicate, and synthetic detergent.	160° F.	1	Do.
Rinsing	Water	120° F.	¼	Do.

[1] Percentages are based on the weight of the cloth.

BREAKING STRENGTH AND ELONGATION.—The breaking strength of the yarn was determined by the single-strand method on an incline-plane serigraph-type machine in accordance with ASTM Method D-180-52T (*1*). The mean of 50 determinations was taken as the strength of the yarn. The elongation of the yarn, automatically recorded at the instant of yarn break, was reported in percent.

Raveled-strip breaking strengths of the fabrics, both wet and dry, and elongation were measured in accordance with procedures outlined in ASTM D-39-49 (*1*). The mean of 20 values was regarded as the breaking strength of the fabric. The elongations of the 20 strips at instant of fabric break were averaged, the percent calculated and reported.

COUNT AND WEIGHT.—The number of yarns in 1 inch of fabric was counted with a micrometer counter on alternate warp and filling breaking strength strips after they were prepared for testing. The average of five readings was reported as the count.

To determine the weight of the sheetings, five 2-inch square specimens were cut with a die diagonally across the sampling area. The samples were then weighed on a torsion balance calibrated to read in ounces per square yard.

DIMENSIONAL CHANGE.—For the laundered-only sheetings, dimensional changes were determined by measuring three 18-inch distances which had been marked on the fabric in both warp and filling directions. For the laundered-and-used sheets, three measurements were made across the entire length and width of the sheets.

ABRASION.—Resistance to abrasion was determined in accordance with the rotary platform double head method described in ASTM D-1175-51T (*1*). CS-8 calibrase wheels were used with each wheel exerting a pressure of 250 grams. Sufficient 6-inch squares for each testing interval were cut from each fabric and then randomized. Samples were abraded a predetermined number of cycles from 500 to 3,500 in steps of 500. The lint formed during abrasion was removed with a soft brush. At the end of 1,000 cycles the wheels were refaced by running 25 cycles on carburundum paper.

From each specimen 2 warpwise and 2 fillingwise strips were cut 1¼ inches wide, raveled to 1 inch in width and broken on a Suter pendulum-type breaking strength machine having a 1-inch gage length and a capacity of 0 to 100 pounds. The average of 10 readings was regarded as the breaking strength of the fabric. The reduction in strength expressed as percent loss versus cycles of abrasion was taken as the measure of the extent of damage.

FLUIDITY IN CUPRAMMONIUM HYDROXIDE.—Fluidity (reciprocal viscosity) measurements in cuprammonium hydroxide solution were made according to the ASTM Method D-539-51T (*1*), with the following changes: 80-mesh copper gauze was used instead of powdered copper in making up the solution and the samples were dissolved in mixing vials similar to those used by Mease (*5*), then transferred to the viscometers for measurement. The weight of samples used for the viscosity determinations was calculated to give the following solutions for the various sheetings: All-cotton, 0.50 percent; 5/6 cotton, 0.75 percent; 4/6 cotton, 1.00 percent; 3/6 cotton, 1.25 percent; 2/6 cotton, 1.50 percent; 1/6 cotton, 1.75 percent; and all-rayon, 2.00 percent.

VISCOSITY OF CELLULOSE NITRATE IN BUTYL ACETATE.—Viscosity measurements of cellulose nitrate in butyl acetate were made according to the method of Hessler, Merola, and Berkley (*4*). Samples of the sheetings were nitrated for one-half hour at room temperature with a mixture of 56 percent HNO_3, 39 percent H_3PO_4, and 5 percent P_2O_5, using a 1:100 ratio of fiber to nitrating mixture. The viscosities were determined at 25° C. in Cannon-Fenske pipettes, which had been previously calibrated with standard viscosity oils supplied by the National Bureau of Standards. Different size pipettes were used, ranging from a No. 200 for all-cotton to No. 50 for all-rayon. A 0.1-percent concentration of cellulose nitrate was used in all cases. The degree of polymerization (D. P.) of each sample was calculated from the viscosity of the corresponding cellulose nitrate with the formulas $(\eta)=2.3 \log \eta_r (1+0.5 c)$ and $D. P.=270 (\eta)$ as reported by Hessler and others.

Microscopic Study of Fiber Damage.—In the microscopic study of fiber damage in the sheets, the all-rayon yarns were stained by immersing for 1 hour in a 1-percent solution of Brilliant Benzo Blue 6BA Extra (General Dyestuff) at room temperature, washing to remove excess dye, then immersing in a 1-percent solution of Chlorantine Fast Red 5B (CIBA) for 1 hour at the same temperature, washing, and drying. By this method the damaged areas were selectively stained a dark blue while the undamaged areas were reddish purple. Since the cotton fibers were not dyed satisfactorily by this method, the all-cotton and the blended yarns were stained by boiling for 10 minutes in a 1-percent solution of Brilliant Benzo Blue 6BA Extra.

Stained yarns approximately one-half inch long were carefully split into their component fibers and mounted on a slide in a 50-50 mixture of glycerine and water. Classification of damage as low, medium, or high was made according to criteria set up after examining a large number of slides containing typical damaged fibers. For each slide the number of damaged areas in the 3 classifications was counted along successive horizontal lines 2 mm. apart as measured by the vertical scale of the mechanical stage. Five slides were made from each sample and each slide was examined independently by two observers.

PROPERTIES OF YARNS AND FINISHED SHEETINGS

Yarns and Gray Goods

Laboratory analysis of the yarn and gray cloth showed that the twist and yarn number of the yarns, as well as the fiber content and number of yarns per inch of the gray fabrics, were within normal manufacturing tolerances of the specifications.

The dry breaking strengths of the all-cotton and the all-rayon yarns were higher than the blends, and that of the all-cotton was greater than the all-rayon. These findings are in accord with a report on a study of staple length and blend of yarns in which Ashton *(2)* stated that "several blended yarns have lower strengths than either the pure cotton or pure rayon yarns." No definite trend was apparent between breaking strength and fiber content of the blended yarns.

The all-rayon yarns elongated the most and the all-cotton the least. For the blends, elongation increased as the rayon content of the yarns was raised. The most rapid increase occurred in the yarns containing more than 50 percent rayon.

In general the results of measurements of dry breaking strength and elongation on the gray fabrics paralleled those found for the yarns. Values obtained for the cuprammonium fluidity and cellulose nitrate viscosity showed that there had been no appreciable chemical degradation during the manufacture of the gray fabrics.

Finished Sheetings

The results of some physical and chemical measurements on the finished fabrics are shown in table 3. As in the yarns, the all-cotton sheeting had the highest breaking strength, followed by the all-rayon and the blends. As expected, the wet breaking strengths decreased with increasing rayon content. The all-rayon fabric showed the greatest elongation (both wet and dry), but the all-cotton had a greater elongation than most of the blended fabrics. The elongation of the blends was much closer to the all-cotton than to the all-rayon fabric.

Resistance to abrasion was determined only for the sheetings used in the preliminary investigation. Analysis of variance (table 4) shows that the seven sheetings differed significantly in breaking strength when abrasion was applied. Cycles of abrasion affected the breaking strength of the fabrics to a greater degree than type of fabric. Between 0 and 500 cycles of abrasion, the all-rayon sheeting showed a much greater loss in warp breaking strength than the cotton or the blends. Thereafter, the rate of decrease in warp breaking strength of the seven sheetings did not differ significantly (fig. 1). The variation in the effect of abrasion on the filling breaking strength of fabrics was greater than the variation in its effect on their warp breaking strength.

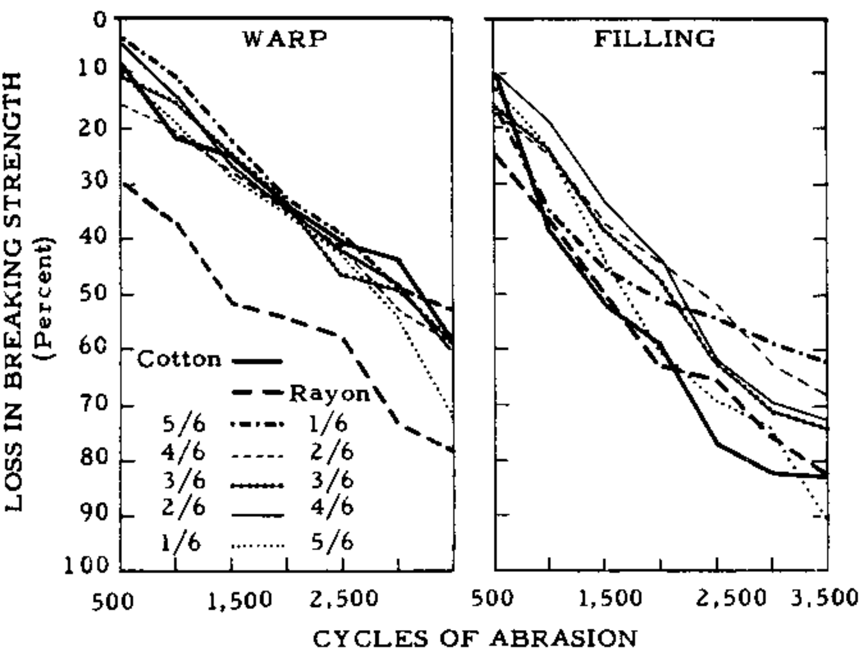

Figure 1.—Breaking strength: Percent change in sheetings as a result of abrasion.

Table 3.—*Some physical and chemical properties of the finished sheetings*

Fabric	Weight per square yard	Yarns per inch		Breaking strength				Elongation				Fluidity	Degree of polymerization
				Dry		Wet		Dry		Wet			
		Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling		
PRELIMINARY INVESTIGATION													
	Ounces			*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*	*Rhes*	
All-cotton	4.6	74	63	50.5	37.9	63.5	53.4	6.4	9.0	10.2	11.6	4.28	6480
5/6 cotton–1/6 rayon	3.9	65	63	34.3	31.4	40.6	38.4	5.0	5.8	8.2	9.6	3.69	5170
4/6 cotton–2/6 rayon	4.1	66	62	33.6	30.4	38.0	29.9	5.1	6.3	8.4	9.3	2.73	4280
3/6 cotton–3/6 rayon	4.1	66	61	33.7	22.2	26.3	21.2	6.3	6.4	8.0	8.0	3.29	3130
2/6 cotton–4/6 rayon	4.2	66	62	30.7	27.6	19.8	15.8	6.0	8.3	7.3	7.8	4.22	2290
1/6 cotton–5/6 rayon	4.1	67	62	27.0	19.1	8.2	6.0	6.6	8.2	5.1	4.8	8.06	1290
All-rayon	4.6	73	64	40.1	30.1	18.8	11.8	15.8	19.9	14.9	12.3	9.65	910
SERVICEABILITY STUDY													
All-cotton	4.0	72	61	55.0	48.2	61.6	51.8	9.0	19.0	13.0	18.4	5.57	6456
1/2 cotton–1/2 rayon	4.4	76	61	47.7	39.9	37.9	32.3	9.6	18.7	13.3	16.8	3.57	3111
All-rayon	4.9	77	61	52.5	42.3	30.4	23.5	17.6	38.0	29.7	32.4	9.31	1007

TABLE 4.—*Analysis of variance of the changes in breaking strengths of sheeting fabrics after 7 cycles of abrasion, 500 to 3,500*

Source of variation	Degrees of freedom	Mean square	
		Warp	Filling
Fabrics	6	1, 955. 16**	1, 104. 68**
Cycles of abrasion	6	5, 210. 74**	6, 105. 19**
Interaction [1]	36	20. 04	54. 98**
Experimental error	441	21. 37	18. 31

[1] Interaction of fabrics times cycles of abrasion.
** Significant at $P = .01$.

The degrees of polymerization of the fabrics, calculated from cellulose nitrate viscosity measurements, decreased consistently with increasing rayon content. The fluidity values did not show a regular increase since a different concentration of cellulose was used in determining the fluidity of each blend.

PRELIMINARY INVESTIGATION

In the preliminary investigation the sheetings were laundered 75 times. The customary commercial procedure for laundering lightly soiled white goods was used, omitting the bleach and sour. The effect of laundering was evaluated by measuring certain physical and chemical properties of the fabrics after specified laundry intervals.

Dimensional Change, Count, and Weight

The percent dimensional change, count, and weight of the seven fabrics after repeated launderings are shown in tables 5 to 7. As is evident from these tables, laundering resulted in shrinkage in both warp and filling directions with a corresponding increase in count and in weight. The greatest changes in these properties took place within the first five launderings, with the all-rayon showing the most and the all-cotton the least change. The all-rayon was the only fabric to show a trend towards increased shrinkage, count, and weight throughout the entire test period. The fabrics containing ⅔ or more cotton were fairly well stabilized after 10 to 20 launderings.

TABLE 5.—*Percent shrinkage with repeated laundering of sheetings composed of cotton, rayon, and blends of cotton and rayon*

Fabric	Warp shrinkage after specified number of launderings						Filling shrinkage after specified number of launderings					
	10	20	30	40	50	60	10	20	30	40	50	60
All-cotton	0	1. 8	1. 1	1. 2	0. 8	2. 8	7. 2	5. 8	6. 6	7. 2	4. 9	5. 4
5/6 cotton–1/6 rayon	4. 2	3. 3	3. 9	4. 6	3. 7	2. 8	12. 3	13. 5	10. 8	10. 9	11. 1	14. 7
4/6 cotton–2/6 rayon	4. 6	3. 8	3. 9	6. 1	3. 9	4. 7	12. 6	14. 3	14. 2	13. 4	13. 5	13. 9
3/6 cotton–3/6 rayon	4. 4	7. 7	4. 1	7. 1	4. 9	4. 7	12. 6	13. 3	11. 8	13. 3	14. 0	15. 1
2/6 cotton–4/6 rayon	5. 7	7. 2	5. 4	7. 2	7. 2	6. 9	14. 9	14. 7	11. 8	12. 5	11. 9	13. 0
1/6 cotton–5/6 rayon	8. 3	7. 2	11. 1	15. 8	12. 2	15. 6	14. 3	12. 9	9. 3	5. 2	5. 7	3. 7
All-rayon	8. 3	17. 2	16. 2	21. 2	19. 4	21. 4	13. 7	16. 9	17. 1	18. 6	18. 9	22. 1

TABLE 6.—*Number of yarns per inch of sheetings composed of cotton, rayon, and blends of cotton and rayon with repeated laundering*

Fabric	Warp, number of yarns per inch after specified number of launderings							Filling, number of yarns per inch after specified number of launderings						
	5	10	20	30	35	45	75	5	10	20	30	35	45	75
All-cotton	72	75	75	74	74	72	75	64	67	65	64	64	66	63
5/6 cotton–1/6 rayon	73	75	74	73	73	72	73	64	66	66	63	63	66	66
4/6 cotton–2/6 rayon	73	75	76	74	74	74	74	66	65	66	64	64	66	62
3/6 cotton–3/6 rayon	74	75	77	75	76	75	75	64	65	66	66	64	66	67
2/6 cotton–4/6 rayon	75	76	77	76	75	75	74	66	65	66	63	69	67	62
1/6 cotton–5/6 rayon	77	77	76	76	74	73	75	64	66	68	64	65	69	65
All-rayon	80	80	81	78	80	82	83	69	69	72	71	71	70	73

TABLE 7.—*Weight per square yard of sheetings composed of cotton, rayon, and blends of cotton and rayon with repeated laundering*

Fabric	Number of times laundered						
	5	10	20	30	35	45	75
	Ounces	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
All-cotton	5.1	5.0	4.8	4.8	4.5	4.8	4.6
5/6 cotton–1/6 rayon	4.9	4.8	4.7	4.4	4.2	4.9	4.4
4/6 cotton–2/6 rayon	5.0	5.0	4.7	4.8	4.3	4.9	4.6
3/6 cotton–3/6 rayon	4.9	5.1	4.9	4.8	4.3	4.9	4.5
2/6 cotton–4/6 rayon	4.9	5.1	5.2	4.4	4.7	4.8	4.4
1/6 cotton–5/6 rayon	4.8	4.9	4.8	4.3	4.3	4.6	4.2
All-rayon	5.5	5.4	5.8	5.5	5.3	5.7	5.7

BREAKING STRENGTH AND ELONGATION

The breaking strength and elongation of the sheetings after laundering are given in table 8. As would be expected from the data on dimensional change, the breaking strength and elongation, dry and wet, increased in both warp and filling directions during the first five launderings. From 5 to 75 launderings, the fabrics containing less than 3/6 cotton showed a decrease in wet and dry breaking strength in both directions. The fabrics with a higher cotton content, however, showed little or no decrease except in the wet breaking strength in the filling direction. Thus, fabrics containing 5/6 and 4/6 cotton showed little advantage over the 3/6 cotton–3/6 rayon blend in the retention of strength during repeated laundering. Decreasing the cotton content below 3/6, however, resulted in a greater loss in fabric strength on laundering. There was little change in elongation in any of the fabrics.

The analysis of variance of the breaking strength data for the seven types of sheetings shows that fabric content is a highly significant factor (table 9). Number of launderings, the second source of variation, is significant in the breaking strength of the dry fabric but not in the wet. Also, the differences among the fabrics changed as the number of washings increased, as indicated by the significant interactions.

TABLE 8.—*Breaking strength and elongation of sheetings composed of cotton, rayon, and blends of cotton and rayon with repeated laundering*[1]

Times laundered (number)	Breaking strength				Elongation			
	Dry		Wet		Dry		Wet	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
	All-cotton fabric							
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
5	51.9	44.2	54.1	60.7	11.5	14.7	13.3	17.7
10	44.3	47.8	53.6	48.1	12.3	17.2	14.6	15.4
20	50.5	42.6	51.6	51.9	11.9	17.9	16.6	17.8
30	47.4	43.0	62.2	51.4	10.7	18.2	15.4	16.8
35	45.3	44.3	51.3	51.0	12.5	16.9	14.8	18.3
45	50.6	45.9	59.4	49.6	10.2	13.8	13.3	14.2
75	49.8	40.0	57.0	43.2	10.1	16.6	16.1	17.4
	5/6 cotton–1/6 rayon fabric							
5	45.0	35.0	45.6	42.0	8.6	14.6	14.6	16.8
10	41.4	39.4	44.4	37.8	11.1	13.6	13.2	14.5
20	46.2	41.0	50.0	44.4	11.0	17.0	14.0	16.9
30	43.9	34.8	46.4	38.6	9.6	15.2	13.8	16.7
35	44.9	36.8	46.4	40.0	12.3	17.1	13.5	15.6
45	45.0	37.3	47.1	39.9	9.2	14.8	10.8	13.3
75	40.4	35.4	41.9	34.0	14.9	17.0	13.5	15.7
	4/6 cotton–2/6 rayon fabric							
5	43.1	33.8	42.7	37.1	10.4	14.4	14.6	16.5
10	45.0	38.0	42.0	37.8	10.3	14.7	14.6	15.3
20	31.9	32.2	32.2	35.2	13.2	18.6	16.6	18.0
30	37.3	31.6	44.0	35.8	14.8	18.5	14.1	16.3
35	41.4	34.8	39.8	30.7	10.0	18.7	16.3	17.6
45	43.0	26.8	39.9	27.4	9.5	13.1	10.1	12.6
75	41.2	34.2	38.8	29.0	10.8	16.5	14.5	15.5
	[illegible] cotton–3/6 rayon fabric							
5	39.2	31.4	34.1	29.6	9.8	14.5	14.2	14.4
10	41.9	33.3	34.6	28.5	11.3	14.3	13.4	15.2
20	34.0	28.4	32.6	27.7	13.0	17.7	15.7	15.9
30	40.7	33.8	34.2	29.8	12.2	17.0	14.0	15.9
35	39.6	30.0	31.7	24.5	10.3	17.7	11.2	14.6
45	39.6	25.9	33.2	24.8	10.3	12.7	11.5	12.9
75	39.3	28.5	38.6	22.2	12.1	16.6	14.3	14.1

See footnote at end of table.

TABLE 8.—*Breaking strength and elongation of sheetings composed of cotton, rayon, and blends of cotton and rayon with repeated laundering* [1]—Continued

Times laundered (number)	Breaking strength				Elongation			
	Dry		Wet		Dry		Wet	
	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
	$\frac{2}{3}$ cotton $\frac{1}{3}$ rayon fabric							
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Percent*
5	38.1	34.4	25.7	23.8	13.3	18.2	14.4	17.4
10	40.1	34.2	28.3	25.0	11.4	18.9	14.8	15.9
20	38.1	31.4	27.8	24.0	15.0	19.4	15.1	16.9
30	37.4	29.0	27.5	20.4	12.5	18.1	14.2	14.9
35	33.4	30.7	25.0	21.9	16.2	16.4	13.7	14.6
45	37.8	28.6	24.8	20.0	9.8	16.2	12.5	13.8
75	33.8	27.1	23.2	16.4	10.9	18.6	13.0	12.7
	$\frac{1}{6}$ cotton $\frac{5}{6}$ rayon fabric							
5	35.9	25.0	15.6	11.8	10.3	16.2	10.8	11.6
10	33.9	26.4	15.2	13.0	12.5	17.3	10.1	12.6
20	32.7	27.5	15.4	14.4	12.9	19.0	12.0	14.9
30	30.4	21.9	14.0	10.2	10.9	17.9	9.4	11.1
35	26.4	21.4	14.0	11.4	12.8	17.6	10.4	12.4
45	29.6	20.4	13.5	9.6	11.4	14.9	8.5	9.9
75	25.3	17.7	12.5	8.8	10.2	13.8	9.8	8.4
	All-rayon fabric							
5	43.5	34.4	17.3	15.8	17.2	26.2	19.8	20.8
10	35.4	31.4	17.0	16.8	19.6	24.9	19.5	22.7
20	31.2	29.0	13.8	15.4	22.2	29.4	23.1	27.1
30	28.6	29.2	12.2	13.6	19.2	26.4	19.6	23.2
35	26.8	26.2	12.4	12.8	20.6	27.4	18.9	21.5
45	25.6	23.0	12.2	11.9	18.6	26.5	19.3	18.5
75	24.2	26.0	10.7	11.9	23.7	32.2	21.1	22.4

[1] Average of 10 observations.

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TABLE 9.—*Analysis of variance of the breaking strength of the laundered sheetings* [1]

Source of variation	Degrees of freedom	Mean square			
		Dry		Wet	
		Warp	Filling	Warp	Filling
Fabrics	6	7, 121. 08**	7, 084. 72**	34, 901. 30**	25, 762. 04**
Launderings	13	315. 40*	493. 92**	99. 96	218. 48
Interaction [2]	78	99. 59**	44. 63**	68. 41**	114. 89**
Experimental error	882	11. 65	12. 52	9. 43	13. 40

[1] Determinations of breaking strength were made at intervals of 5 launderings.
[2] Interaction of fabrics times launderings.
*Significant at P=.05.
**Significant at P=.01.

CHEMICAL DAMAGE

The cuprammonium fluidities and degrees of polymerization (D. P.) are shown in table 10. As is evident from this table, 75 launderings caused very little chemical degradation in any of the fabrics. The laundry method used, however, was milder than the usual commercial white wash, since no bleach or sour was added.

Table 10.—*Fluidity and degree of polymerization of sheetings composed of cotton, rayon, and blends of cotton and rayon with repeated laundering*

Fabric	Fluidity after specified number of launderings						Degree of polymerization after specified number of launderings				
	5	10	25	35	45	75	5	10	25	35	75
	Rhes	*Rhes*	*Rhes*	*Rhes*	*Rhes*	*Rhes*					
All-cotton	5.49	5.22	5.76	5.98	5.46	6.03	6270	6270	6030	6400	5840
5/6 cotton–1/6 rayon	5.02	5.57	5.13	4.81	4.86	5.32	4400	4490	4480	4520	4500
4/6 cotton–2/6 rayon	3.72	3.50	3.51	3.51	3.63	3.95	3800	3910	3770	3720	3780
3/6 cotton–3/6 rayon	3.56	3.54	3.92	3.86	3.79	3.92	3120	3010	2960	3120	3190
2/6 cotton–4/6 rayon	4.47	4.32	4.75	4.38	4.52	5.13	2120	2090	2260	2240	2250
1/6 cotton–5/6 rayon	8.72	8.77	8.92	8.65	8.76	8.73	1320	1280	1250	1300	1250
All-rayon	10.64	10.73	10.84	10.72	10.61	10.82	940	890	900	920	910

SERVICEABILITY STUDY

On the basis of results of the preliminary investigation, the 50–50 mixture of cotton and rayon was chosen as a representative blend for further evaluation. Sheets made of all-cotton, all-rayon, and the 50–50 blend were manufactured in sufficient quantity for in-service evaluation. All of the sheets of each type were made from the same lot of yard goods. Approximately 50 finished sheets of each type were put in service at the University of Tennessee and a similar number at Kansas State College.

At Tennessee the sheets were used in a men's dormitory and were distributed to a different group each quarter. At Kansas the sheets were used in a women's dormitory and were distributed to a different group each semester. Two sheets were used per bed for 1 week before laundering. The wide hem was always placed at the head of the bed. The sheets were distributed at random, no effort being made to keep types of sheets paired or to record their use as the top or bottom sheet. It was assumed that over a long period, the sheets would be used an equal number of times in each position, and that wear would be uniform at any testing period. As controls, unused sheets of each type were laundered with the used sheets.

Laundering was done commercially by the method commonly used for lightly soiled white goods. Dimensional changes were measured on 7 controls (laundered only) and on 10 laundered-and-used sheets of each type.

One laundered-only and two laundered-and-used sheets of each type were withdrawn for sampling after 5, 20, 30, and 35 launderings at both schools and, in addition, after 40 and 45 launderings at Kansas.

Since dimensional change within the first 5 launderings was so marked, as determined in the preliminary study, statistical analyses were made on all data from sheets laundered only or laundered and used 5 times, and at the intervals specified thereafter.

The sheets were sampled in four areas numbered diagonally from the lower left to the upper right corner (fig. 2). Areas 2 and 3 included that portion of the sheet which O'Brien and Steele (*6*) stated were most probably occupied by the body. Areas 1 and 4 include that section of the sheet near the edge of the bed, and the tuck-in under the mattress.

In each of the 4 areas, 5 warpwise and fillingwise breaking strength determinations were made and the average of the 20 determinations recorded as the strength of the sheet. The number of yarns per inch was taken on 2 strips from each area and the average of 8 determinations reported as the count. The weight was taken at 5 places diagonally across the entire sheet. Two determinations were made in each of the 4 areas for fluidity in cuprammonium hydroxide and 4 determinations for cellulose nitrate viscosity.

At the same time that sheets were sent to Tennessee and Kansas for use, five finished sheets of each type were withdrawn and tested in the laboratories at Beltsville to determine the physical and chemical characteristics of the new fabrics. The properties of the finished sheets were similar to the properties of sheets of the same composition tested in the preliminary investigation (table 3).

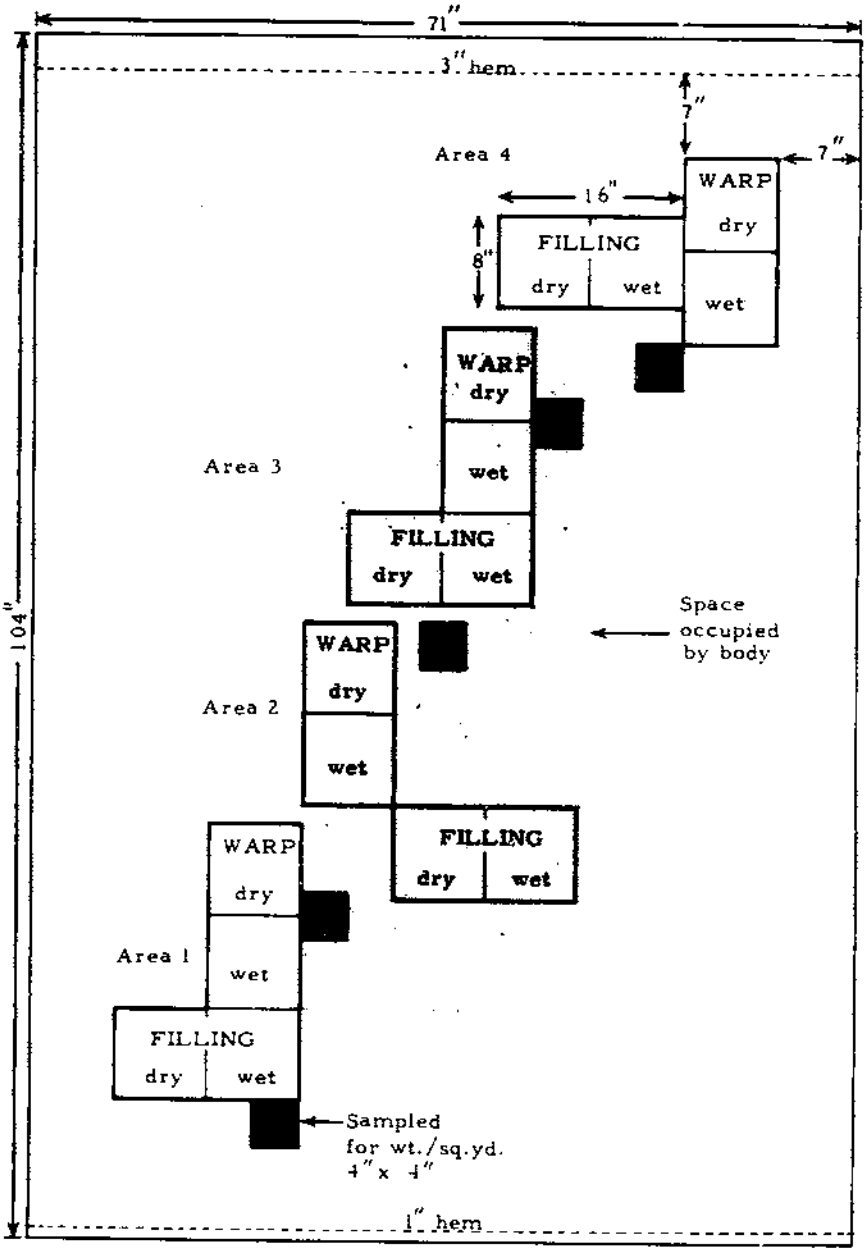

FIGURE 2. -Sampling diagram for sheets.

Dimensional Change, Count, and Weight

The analyses of variance of the data for dimensional change, count, and weight are shown in tables 11 to 14. It is evident from these tables that differences among the 3 fabrics were significant at the 1-percent level and that these differences were much greater than those due to washing or to differences between the 2 schools in which the sheets were tested.

The dimensional changes in the sheets laundered only and those laundered and used at the University of Tennessee and Kansas State College after 5 through 35 washings are given in table 15. All sheets showed a large warpwise shrinkage and a smaller stretch in the filling direction, with the greatest part of the change taking place during the first 5 launderings. In the sheets that were laundered only 5 times the all-rayon showed a warpwise shrinkage of 18.0, the blend 12.0, and the cotton 7.8 percent, while in the filling direction all fabrics stretched about 5 percent. After 35 launderings, the warp shrinkage had increased to 21.9, 15.4, and 9.6 percent, respectively. Little difference was found between dimensional changes in the sheets laundered only and those laundered and used.

Table 11.—*Analysis of variance of dimensional change in warp and filling directions of sheets, laundered only*

Source of variation	Degrees of freedom	Mean square	
		Warp	Filling
Locations (L)	1	19.21	35.98
Types of sheet (T)	2	3,505.83**	209.80**
Washings (W)	4	102.06**	7.64
LT	2	22.15	71.71**
LW	4	7.41	16.13
TW	8	10.41	8.04
LTW	8	3.71	1.77
Sheets of same type within locations, experimental error	15	7.55	9.84
Sheets of same type within locations x washings	60	4.45	1.28
Areas within sheets	42	3.98	3.13
Remainder	168	.43	.71
Total	314		

**Significant at P=.01.

TABLE 12.—*Analysis of variance of dimensional change in warp and filling directions of sheets, laundered and used*

Source of variation	Degrees of freedom	Mean square	
		Warp	Filling
Locations (L)	1	332.08**	96.85**
Types of sheet (T)	2	6,996.41**	231.62**
Washings (W)	4	77.24**	29.40**
LT	2	107.93**	34.59**
LW	4	29.58**	7.96
TW	8	11.31*	14.62*
LTW	8	13.38*	1.82
Sheets of the same type within locations (error a)	42	4.64	6.88
Sheets of the same type within locations x washings	168	1.41	.80
Areas (A)	2	1.54**	4.81**
AL	2	4.21**	12.70*
AT	4	.05	2.79*
AW	8	.24	.98
ALT	4	.06	1.55
ALW	8	.17	.47
ATW	16	.05	.82
ALTW	16	.06	.47
A x sheets of the same type within locations (error b)	84	.18	.75
(Areas x sheets of the same type within locations) x washings	336	.07	.29
Total	719		

*Significant at P=.05.
**Significant at P=.01.

TABLE 13.—*Analysis of variance of count of sheets laundered and used and sheets laundered only*

Source of variation	Degrees of freedom	Mean square: Laundered and used, Warp	Mean square: Laundered and used, Filling	Mean square: Laundered only, Warp	Mean square: Laundered only, Filling
Locations (L)	1	8.46	129.51**	16.92	13.54
Types of sheets (T)	2	957.76**	2,498.26**	654.48**	1,609.56**
Washings (W)	3	9.84*	59.45**	7.26	30.16
LT	2	4.93	28.25**	5.18	13.00
LW	3	20.22**	23.49*	2.64	2.74
TW	6	8.78**	3.40	7.07	7.57
LTW	6	2.08	4.12	[1] 5.90	[1] 7.17
Sheets treated alike (error a)	24	2.26	4.38	----	----
Areas (A)	3	42.84**	13.99**	17.84*	8.59
AL	3	7.67**	1.11	4.42	.42
AT	6	4.20**	7.07**	2.07	2.02
AW	9	4.13**	.61	.57	2.76
ALT	6	1.93	2.12	.75	1.75
ALW	9	3.02**	1.84	.98	.82
ATW	18	1.47	1.48	1.38	.94
ALTW	18	1.80	.91	[2] 3.70	[2] 5.18
Sheets treated alike x areas	72	.89	1.06	----	----
Total	191			----	----

[1] Used as estimate of error a.
[2] Used as estimate of error b.
*Significant at P=.05.
**Significant at P=.01.

The warp shrinkage and filling stretch are reflected by a decrease in the warp count and an increase in filling count for all fabrics (table 16). Most of the change occurred during the first five launderings, the all-rayon showing the greatest and the all-cotton the least change. There was little difference in count between the laundered-only and the laundered-and-used sheets.

During the first 5 launderings, the rayon showed an increase in weight of 0.7 ounce per square yard, the blend 0.3, and the cotton 0.1. Between 5 and 35 launderings, there was a slight decrease in weight in the fabrics (table 17). The laundered-and-used rayon and cotton-rayon sheets were somewhat lighter than the sheets laundered only. This indicates change due to wear as well as to laundering. These differences in weight, however, were very small.

TABLE 14.—*Analysis of variance of weight of sheets laundered and used and sheets laundered only*

Source of variation	Degrees of freedom	Mean square	
		Laundered and used	Laundered only
Locations (L)	1	0.860**	2.340**
Type of sheet (T)	2	29.840**	20.015**
Washings (W)	3	.610**	0.220**
TL	2	.015	.040*
TW	6	.058	.011
LW	3	.780**	.583**
LTW	6	.065	[1] .010
Sheets treated alike (error a)	24	.035	
Areas (A)	3	.243**	.043*
AL	3	.023	.007
AT	6	.025	.025
AW	9	.020	.006
ALT	6	.007	.017
ALW	9	.026	.010
ATW	18	.010	.010
ALTW	18	.023	[2] .011
Sheets treated alike x areas (error b)	72	.012	
Total (laundered and used)	191		
Total (laundered only)	95		

[1] Used as estimate of error a.
[2] Used as estimate of error b.
*Significant at P=.05.
**Significant at P=.01.

The differences in weight of the 4 areas within the laundered-and-used sheets were significant at the 1-percent level (table 14). The areas receiving the most body wear would be expected to become lighter in weight. According to the results of a study by O'Brien and Steele (*6*), areas 2 and 3 should be representative of this type of wear while area 1 from the lower left-hand corner of the sheet should be least influenced by wear. As shown in table 18, after 20 launderings, the all-rayon sheets were found to be lighter in areas 2 and 3 than in area 1. No definite relationship between areas was indicated by the cotton-rayon sheets, and not until 35 launderings did area 2 in the all-cotton sheets differ noticeably from area 1. Differences in count between areas within the sheets were very small—in most cases less than two yarns per inch.

TABLE 15.—*Dimensional change of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*

Type of sheet and number of launderings	Laundered and used						Laundered only					
	Warp, shrinkage			Filling, stretch			Warp, shrinkage			Filling, stretch		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cotton:												
5	7. 89	8. 38	8. 14	5. 69	5. 65	5. 67	7. 72	7. 97	7. 84	4. 84	5. 10	4. 97
10	8. 97	8. 52	8. 74	5. 71	6. 00	5. 86	7. 95	8. 03	7. 99	5. 76	5. 38	5. 57
20	9. 30	9. 44	9. 37	5. 68	6. 39	6. 04	8. 88	9. 62	9. 25	5. 93	5. 19	5. 56
30	9. 62	8. 85	9. 24	6. 30	6. 66	6. 48	8. 82	9. 16	8. 94	7. 09	5. 18	6. 14
35	9. 61	9. 28	9. 50	7. 23	6. 61	6. 92	9. 41	9. 76	9. 58	6. 38	5. 62	6. 00
Average	9. 08	8. 89	8. 98	6. 12	6. 26	6. 19	8. 56	8. 91	8. 74	6. 00	5. 29	5. 65
Cotton-rayon:												
5	13. 24	12. 64	12. 94	7. 02	6. 23	6. 62	12. 97	11. 03	12. 00	6. 97	6. 25	6. 61
10	13. 80	12. 50	13. 15	7. 48	6. 19	6. 84	12. 73	11. 57	12. 15	8. 71	5. 61	7. 16
20	14. 45	13. 80	14. 12	6. 38	5. 56	5. 97	13. 70	13. 99	13. 84	8. 18	4. 58	6. 38
30	14. 03	12. 31	13. 17	8. 09	7. 46	7. 78	13. 02	12. 29	12. 66	9. 23	6. 02	7. 62
35	14. 48	13. 34	13. 91	7. 99	6. 03	7. 01	17. 32	13. 42	15. 37	7. 65	4. 97	6. 31
Average	14. 00	12. 91	13. 46	7. 39	6. 29	6. 84	13. 95	12. 46	13. 20	8. 15	5. 49	6. 82
Rayon:												
5	18. 64	18. 36	18. 50	6. 14	4. 54	5. 34	17. 95	18. 07	18. 01	5. 52	4. 05	4. 78
10	19. 82	17. 74	18. 78	6. 80	4. 78	5. 79	18. 58	18. 72	18. 65	6. 79	3. 32	5. 06
20	21. 86	19. 51	20. 68	4. 21	3. 41	3. 81	21. 03	20. 90	20. 96	5. 52	1. 82	3. 67
30	21. 59	17. 96	19. 78	5. 18	4. 89	5. 04	21. 58	20. 93	21. 26	5. 68	2. 12	3. 90
35	24. 66	18. 79	21. 72	5. 50	4. 04	4. 77	22. 57	21. 31	21. 94	6. 19	2. 45	4. 32
Average	21. 31	18. 47	19. 89	5. 57	4. 31	4. 94	20. 34	19. 98	20. 16	5. 94	2. 75	4. 35

Table 16.—*Mean number of yarns per inch of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*

Type of sheet and number of launderings	Laundered and used						Laundered only					
	Warp			Filling			Warp			Filling		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
Cotton:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
5	70.0	68.4	69.2	66.9	65.3	66.1	69.0	70.2	69.6	65.4	66.4	65.9
20	69.2	68.9	69.0	67.4	67.1	67.2	68.8	68.9	68.8	66.5	67.4	67.0
30	69.1	68.4	68.7	69.0	66.4	67.7	68.6	68.4	68.5	68.4	66.6	67.5
35	68.8	68.2	68.5	67.8	67.3	67.6	68.0	67.9	68.0	67.2	68.0	67.6
Average	69.2	68.5	68.9	67.8	66.6	67.2	68.6	68.8	68.7	66.9	67.1	67.0
Cotton-rayon:												
5	71.3	69.8	70.6	70.0	68.6	69.3	71.5	70.1	70.8	70.1	69.6	69.8
20	71.3	72.1	71.7	70.1	70.7	70.4	71.5	72.0	71.7	71.6	70.8	71.2
30	71.5	70.9	71.2	70.8	70.4	70.6	70.0	71.6	70.8	70.2	71.6	70.9
35	70.6	71.8	71.2	70.8	71.2	71.0	70.4	70.8	70.6	70.9	69.8	70.4
Average	71.2	71.1	71.1	70.4	70.2	70.3	70.8	71.1	71.0	70.7	70.4	70.6
Rayon:												
5	74.1	73.1	73.6	75.7	73.2	74.4	73.8	74.4	74.1	75.8	74.8	75.3
20	74.2	74.4	74.3	76.8	76.7	76.7	74.0	77.1	75.6	77.8	77.5	77.6
30	75.7	74.9	75.3	77.6	74.2	75.9	75.5	75.9	75.7	77.8	75.0	76.4
35	73.4	74.7	74.0	77.6	75.2	76.4	74.4	75.2	74.8	79.4	77.2	78.3
Average	74.4	74.3	74.3	76.9	74.8	75.9	74.4	75.7	75.0	77.6	76.1	76.8

TABLE 17.—*Weight per square yard of all-cotton, cotton-rayon, and all-rayon sheets laundered only and laundered and used at Kansas State College and the University of Tennessee*

Type of sheet and number of launderings	Laundered and used			Laundered only		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average
Cotton:	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*	*Ounces*
5	4. 00	4. 22	4. 11	3. 88	4. 32	4. 10
20	4. 10	3. 91	4. 01	4. 15	4. 00	4. 08
30	3. 70	4. 06	3. 88	3. 60	4. 18	3. 89
35	4. 04	4. 05	4. 04	3. 93	4. 12	4. 02
Average	3. 96	4. 06	4. 01	3. 89	4. 16	4. 02
Cotton-rayon:						
5	4. 58	4. 72	4. 65	4. 50	4. 98	4. 74
20	4. 65	4. 52	4. 59	4. 70	4. 52	4. 61
30	4. 16	4. 60	4. 38	4. 12	4. 75	4. 44
35	4. 38	4. 51	4. 44	4. 60	4. 75	4. 65
Average	4. 45	4. 59	4. 51	4. 47	4. 75	4. 61
Rayon:						
5	5. 18	5. 71	5. 45	5. 32	5. 92	5. 64
20	5. 64	5. 39	5. 51	5. 60	5. 70	5. 65
30	5. 04	5. 36	5. 20	5. 17	5. 80	5. 49
35	5. 28	5. 29	5. 28	5. 48	5. 68	5. 58
Average	5. 28	5. 44	5. 36	5. 39	5. 78	5. 59

TABLE 18.—*Mean differences of weight per square yard between area 1 and areas 2, 3, and 4 within sheets after various intervals of laundering and use*

Type of sheet and comparison of areas	Number of launderings			
	5	20	30	35
Cotton:				
Area 1 vs.:	*Ounces*	*Ounces*	*Ounces*	*Ounces*
Area 2	0	—. 10	—. 13	—. 18
Area 3	+. 02	—. 05	—. 10	—. 05
Area 4	0	—. 62	—. 05	0
Cotton-rayon:				
Area 1 vs.:				
Area 2	—. 07	—. 22	—. 16	—. 12
Area 3	+. 05	0	—. 10	—. 12
Area 4	+. 03	—. 10	—. 13	—. 07
Rayon:				
Area 1 vs.:				
Area 2	—. 17	—. 27	—. 35	—. 30
Area 3	0	—. 25	—. 38	—. 23
Area 4	—. 12	—. 12	—. 20	—. 10

Breaking Strength

The analyses of variance of the breaking strength of the sheets are given in tables 19 and 20. For the laundered-and-used sheets, the differences in mean breaking strengths between locations, types of sheets, laundry intervals, areas within sheets, and most of the interactions of these factors were significant at the 1-percent level. For the sheets laundered only, the greatest differences were found between types of sheets and laundry intervals.

Table 19.—*Analysis of variance of breaking strength of sheets laundered only*

Source of variation	Degrees of freedom	Mean square			
		Dry		Wet	
		Warp	Filling	Warp	Filling
Location (L)	1	227.84	63.51	793.62**	852.54**
Type of sheets (T)	2	890.73**	1,072.92*	35,021.08**	34,995.78**
Washings (W)	3	1,570.92**	1,531.82**	2,015.57**	2,182.82**
LT	2	376.72*	641.74	56.12*	296.20*
LW	3	426.81*	668.87	106.31**	164.74
TW	6	39.16	153.52	50.29*	79.33
LTW	6	[1] 63.65	[1] 146.25	[1] 10.14	[1] 51.79
Areas (A)	3	54.61**	15.49	2.65	4.79
AL	3	6.65	21.67	10.79	31.89
AT	6	24.59*	4.46	3.85	6.35
AW	9	6.15	16.53	7.17	19.86
ALT	6	14.03	12.28	8.32	38.83*
ALW	9	16.00	32.33	6.59	10.87
ATW	18	5.93	17.25	6.01	16.18
ALTW	18	[2] 8.56	[2] 25.55	[2] 17.06	[2] 13.26
Sampling error	384	5.23	9.01	5.41	7.74
Total	479				

[1] Used as estimate of error a.
[2] Used as estimate of error b.
*Significant at P=.05.
**Significant at P=.01.

TABLE 20.—*Analysis of variance of breaking strength of sheets laundered and used*

Source of variation	Degrees of freedom	Mean square			
		Dry		Wet	
		Warp	Filling	Warp	Filling
Location (L)	1	305. 67*	808. 87**	2, 424. 11**	3, 050. 57**
Types of sheet (T)	2	885. 05**	8, 421. 76**	41, 803. 69**	35, 378. 03**
Washings (W)	3	5, 006. 65**	8, 237. 26**	9, 238. 95**	10, 005. 05**
LT	2	3, 389. 32**	4, 684. 46**	1, 223. 06**	1, 306. 48**
LW	3	1, 256. 62**	1, 606. 10**	545. 11**	859. 49**
TW	6	400. 64**	756. 46**	575. 71**	1, 233. 87**
LTW	6	286. 76**	315. 94**	23. 28	77. 88
Sheets treated alike (error a)	24	42. 31	48. 26	34. 39	56. 71
Areas (A)	3	1, 373. 99**	1, 535. 07**	1, 811. 28**	1, 741. 89**
AL	3	57. 44*	67. 49	28. 14	36. 61
AT	6	700. 49**	670. 32**	548. 60**	572. 25**
AW	9	144. 49**	229. 22**	142. 00**	206. 02**
ALT	6	9. 81	61. 69	45. 83**	55. 06
ALW	9	9. 41	36. 92	15. 68	20. 38
ATW	18	33. 49*	51. 34	28. 28	62. 25
ALTW	18	15. 56	18. 12	13. 17	23. 56
Sheets treated alike x areas (error b)	72	18. 88	30. 09	12. 82	36. 79
Total	191				

*Significant at P=.05.
**Significant at P=.01.

The breaking strengths of the 3 types of sheets after 5 through 35 washes at the 2 locations, and after 40 and 45 washes at Kansas, with and without wear, are shown in tables 21 and 22. The average breaking strength of both laundered-only and laundered-and-used sheets decreased as the number of launderings increased but the amount of the change varied with the type of sheet and with location (fig. 3).

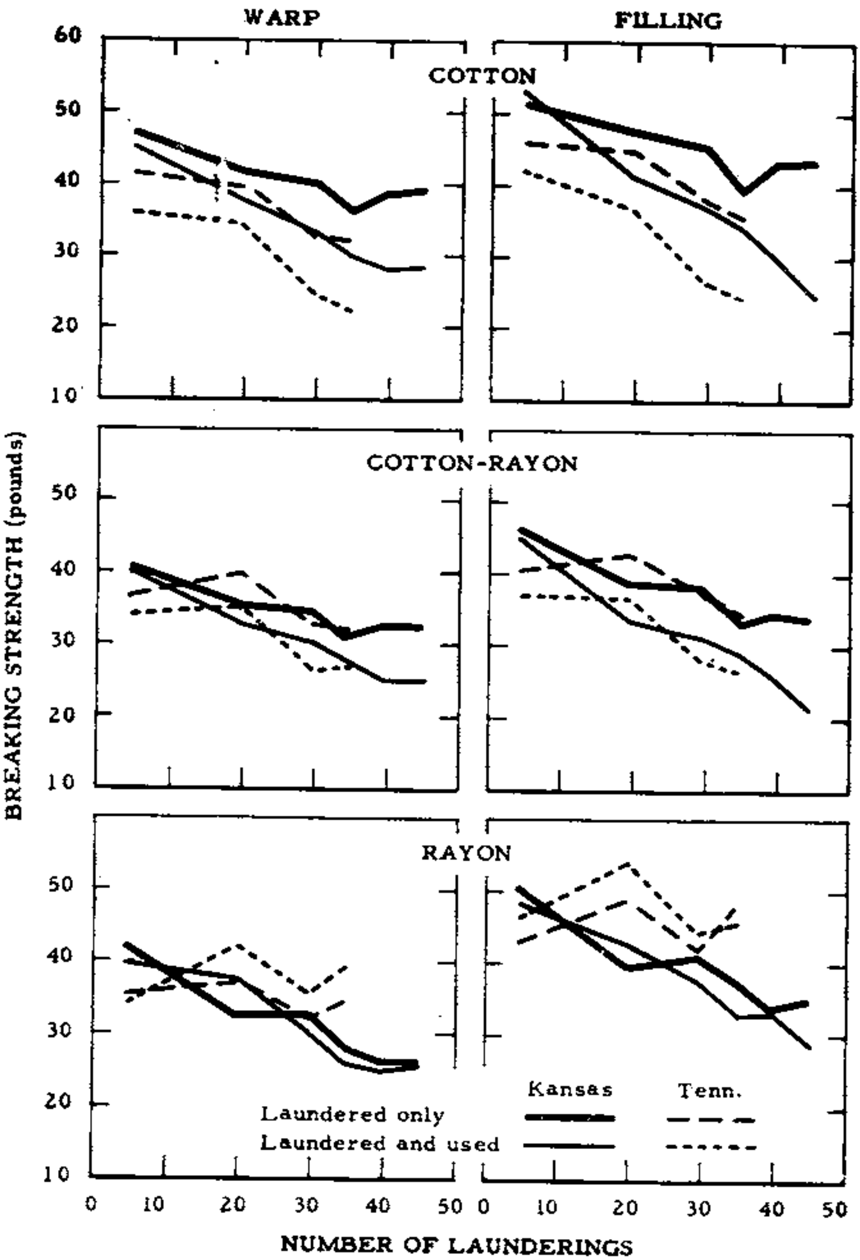

FIGURE 3.—Breaking strength, dry: All-cotton, cotton-rayon, and all-rayon sheets laundered only and laundered and used at Kansas State College and the University of Tennessee.

TABLE 21.—*Breaking strength of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*

Type of sheet and number of launderings	Dry breaking strength											
	Laundered and used						Laundered only					
	Warp			Filling			Warp			Filling		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cotton:												
5	45.46	36.36	40.91	53.31	42.30	47.81	47.22	41.22	44.22	51.65	46.02	48.84
20	38.14	34.45	36.29	41.45	37.21	39.33	41.72	39.58	40.65	47.82	45.18	46.50
30	33.42	24.45	28.94	37.68	26.41	32.05	40.29	32.85	36.57	45.79	38.08	41.94
35	29.95	22.51	26.23	34.32	24.55	29.44	36.30	32.42	34.36	39.22	35.78	37.50
Average	36.74	29.44	33.09	41.69	32.62	37.16	41.38	36.52	38.95	46.12	41.26	43.69
Cotton-rayon:												
5	40.31	34.05	37.18	45.92	37.01	41.47	40.72	36.35	38.54	46.85	40.38	43.62
20	32.78	35.92	34.35	33.70	37.10	35.40	35.60	39.95	37.78	38.98	43.12	41.05
30	30.54	26.90	28.72	31.30	28.29	29.79	34.77	33.10	33.94	38.74	38.50	38.62
35	27.81	27.52	27.67	29.19	27.29	28.24	31.30	32.30	31.80	33.90	34.62	34.26
Average	32.86	31.10	31.98	35.03	32.42	33.72	35.60	35.42	35.51	39.62	39.16	39.39
Rayon:												
5	40.04	34.22	37.13	48.74	42.54	45.64	42.58	35.55	39.06	50.98	43.00	46.99
20	32.98	42.62	37.80	43.45	54.34	48.89	32.90	37.20	35.05	39.52	48.88	44.20
30	30.63	36.22	33.43	37.52	44.20	40.86	32.35	31.88	32.12	41.20	42.32	41.76
35	26.01	39.28	32.64	33.20	46.52	39.86	28.10	34.92	31.51	38.15	48.20	43.18
Average	32.41	38.09	35.25	40.72	46.90	43.81	33.98	34.89	34.44	42.46	45.60	44.03

TABLE 21.—*Breaking strength of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*—Continued

Type of sheet and number of launderings	Wet breaking strength											
	Laundered and used						Laundered only					
	Warp			Filling			Warp			Filling		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Cotton:												
5	53.24	42.95	48.09	58.28	47.22	52.75	54.32	48.42	51.37	58.95	52.40	55.67
20	42.51	37.96	40.24	41.65	39.14	40.39	47.38	46.75	47.06	50.88	50.62	50.75
30	35.80	28.62	32.22	36.18	28.40	32.29	43.95	39.90	41.92	51.90	41.92	46.91
35	32.49	24.90	28.69	34.95	24.78	29.86	42.00	37.88	39.94	44.52	40.65	42.58
Average	41.01	33.60	37.31	42.76	34.88	38.82	46.91	43.24	45.08	51.56	46.40	48.98
Cotton-rayon:												
5	34.31	26.60	30.46	35.59	25.79	30.69	33.22	28.48	30.85	35.10	29.92	32.51
20	22.80	24.32	23.56	23.40	25.06	24.23	29.45	28.05	28.75	31.72	29.85	30.78
30	18.64	16.92	17.78	17.50	17.12	17.32	26.23	24.92	25.58	28.75	27.28	28.02
35	16.71	14.81	15.76	19.05	15.79	17.42	24.58	21.15	22.86	25.20	21.45	23.32
Average	23.12	20.67	21.89	23.89	20.94	22.41	28.37	25.65	27.01	30.19	27.12	28.66
Rayon:												
5	21.36	17.12	19.24	24.34	19.55	21.94	22.68	18.75	20.72	26.08	23.35	24.72
20	14.88	17.08	15.98	20.26	22.68	21.47	15.42	16.70	16.06	19.00	22.35	20.67
30	12.31	13.89	13.10	16.98	17.99	17.48	15.43	13.25	14.34	19.01	18.10	18.56
35	10.76	12.49	11.63	15.09	16.98	16.03	12.10	11.65	11.88	16.28	17.50	16.89
Average	14.83	15.14	14.99	19.17	19.30	19.23	16.41	15.09	15.75	20.09	20.32	20.21

TABLE 22.—*Breaking strength, fluidity, and degree of polymerization of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used 40 and 45 times at Kansas State College*

Fabric, times laundered, and used	Dry breaking strength		Wet breaking strength		Fluidity	Degree of polymerization
	Warp	Filling	Warp	Filling		
Cotton:						
Laundered—						
40 times	38.74	43.22	39.40	41.95	14.69	3791
45 times	39.25	43.70	39.52	44.48	15.74	3565
Laundered and used—						
40 times	27.99	30.08	28.70	29.10	19.48	3020
45 times	28.11	24.95	26.08	25.95	20.37	2905
Cotton-rayon:						
Laundered—						
40 times	32.75	34.58	22.42	24.32	8.88	2019
45 times	32.52	33.88	22.28	22.82	9.11	1980
Laundered and used—						
40 times	25.45	26.00	15.96	16.40	11.31	1683
45 times	24.86	21.35	15.02	13.15	11.65	1622
Rayon:						
Laundered—						
40 times	26.18	33.20	11.12	15.28	13.79	654
45 times	26.25	34.88	10.60	14.65	14.12	620
Laundered and used—						
40 times	24.99	33.55	9.69	12.61	15.32	595
45 times	25.90	28.46	9.37	11.36	15.27	550

The sheets used at Kansas State College and the all-cotton sheets used at the University of Tennessee showed a progressive decrease in strength from 5 through 35 launderings. An anomalous increase in strength, however, occurred between 5 and 20 launderings in the cotton-rayon and all-rayon sheets used at Tennessee; these sheets did not show a consistent decrease until after 20 launderings. No explanation can be given for the increase in strength between 5 and 20 launderings at Tennessee. It cannot be explained by dimensional change, since most of the shrinkage took place during the first 5 launderings. Chemical damage was much the same at both locations, which indicates that laundry procedures were similar.

The dry breaking strengths of the cotton sheets used at Kansas were generally higher than those of the rayon or blend. At Tennessee, the cotton sheets also showed the highest strength after 5 launderings but from 20 through 35 launderings, the rayon and cotton-rayon sheets were stronger than the cotton. As would be expected, the wet breaking strength of the cotton sheets was the highest and that of the rayon the lowest in all cases.

The all-cotton and cotton-rayon sheets that had been laundered and used showed a greater loss in strength than the sheets that had been laundered only, and these differences were greater after 35 or 45 than after 5 washes, indicating the influence of wear. At Kansas the all-cotton and cotton-rayon sheets showed a loss in dry warp breaking strength of about 14 percent after 5 launderings without wear and 16 percent after 5 launderings with wear. After 45 launderings the loss in strength was about 30 percent without wear and 48 percent with wear. Very little difference was found in the breaking strengths of the laundered-only and laundered-and-used all-rayon sheets.

TABLE 23.—*Mean differences of breaking strength between area 1 and areas 2, 3, and 4 within sheets after various intervals of laundering and use*

Type of sheet and comparison of areas	Number of launderings			
	5	20	30	35
	Warp			
Cotton:	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Area 1 vs.:				
Area 2	−2.02	−4.73	−7.70	−7.83
Area 3	−5.14	−12.30	−14.48	−15.16
Area 4	−.87	−4.90	−2.16	−3.20
Cotton-rayon:				
Area 1 vs.:				
Area 2	−.65	−2.24	−5.28	−7.15
Area 3	−.58	−6.67	−8.94	−11.45
Area 4	−.30	−2.17	−2.32	−4.13
Rayon:				
Area 1 vs.:				
Area 2	+.53	+.93	−1.42	−.53
Area 3	−2.83	+2.63	−1.66	+.52
Area 4	+2.97	+1.56	−.29	−.53
	Filling			
Cotton:				
Area 1 vs.:				
Area 2	−3.03	−3.75	−9.97	−6.98
Area 3	−1.75	−9.28	−16.29	−16.50
Area 4	−2.25	−9.05	−14.50	−13.18
Cotton-rayon:				
Area 1 vs.:				
Area 2	.97	−3.86	−5.16	−10.33
Area 3	−.36	−6.40	−9.00	−12.00
Area 4	−.40	−4.86	−7.40	−9.03
Rayon:				
Area 1 vs.:				
Area 2	.73	−.30	−1.66	−1.17
Area 3	+1.00	−2.15	−2.35	−.97
Area 4	+2.47	−2.92	+1.02	−.10

The differences in breaking strengths between the areas within the sheets laundered and used at the two locations are shown in table 23. In the all-cotton and cotton-rayon sheets, area 3 showed the greatest loss in breaking strength, compared with area 1, in both warp and filling, and these differences increased with continued use. In general, areas 2 and 4 also showed lower strengths than area 1 after 20 or 30 washes, with area 2 showing a greater loss in warp strength than area 4, but a smaller loss in the filling direction (figs. 4 and 5). The

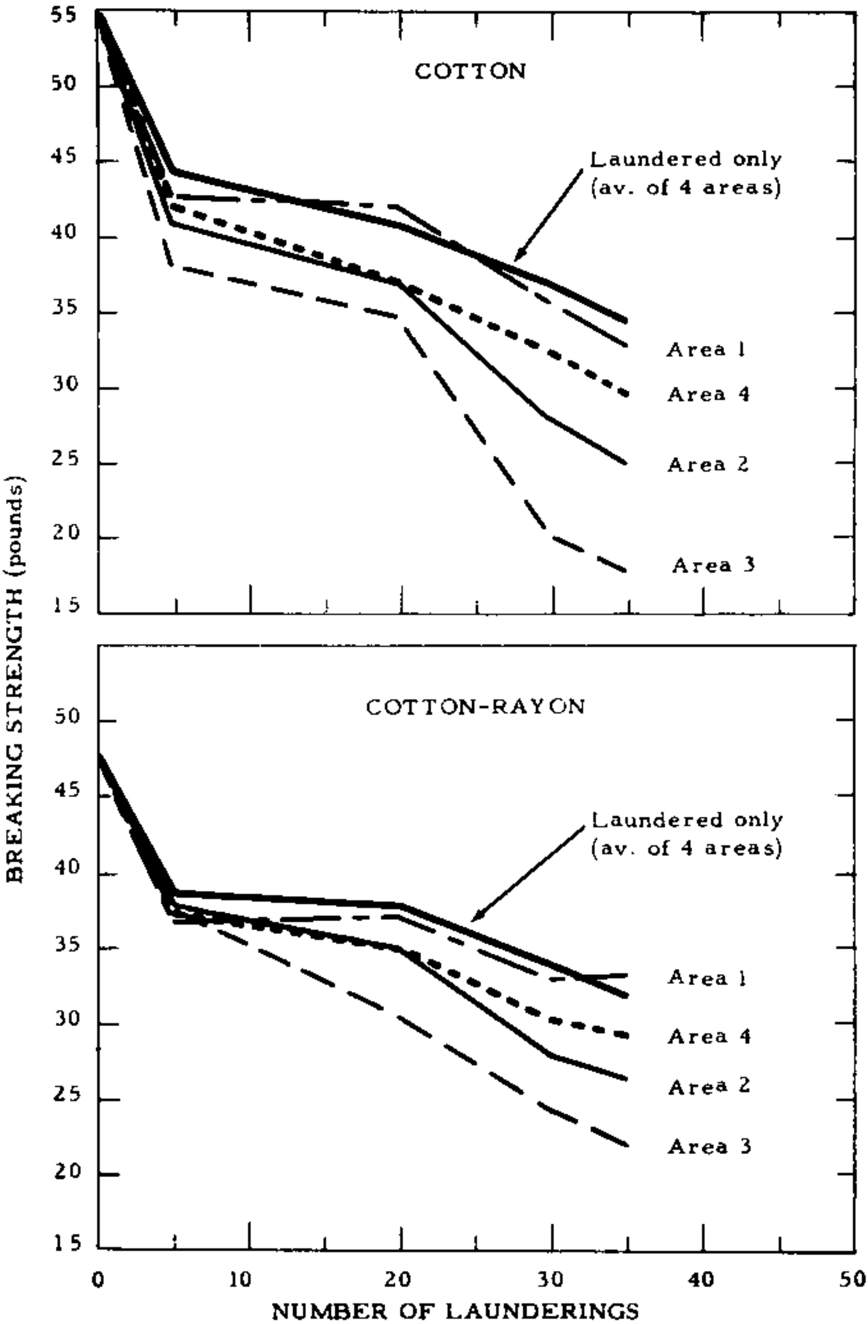

FIGURE 4.—Warp breaking strength, dry: Four areas of all-cotton and cotton-rayon sheets, laundered and used. Average of two locations.

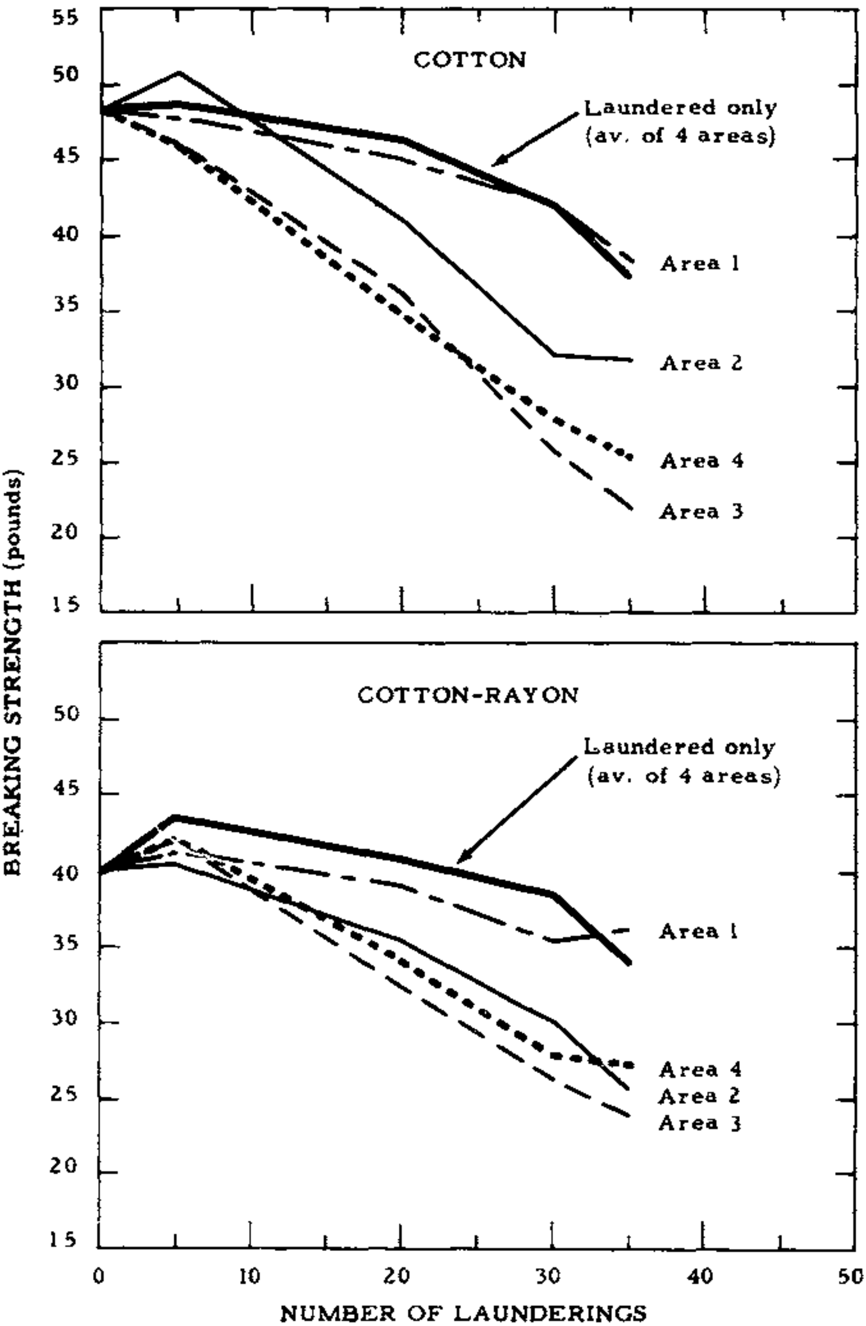

FIGURE 5.—Filling breaking strength, dry: Four areas of all-cotton and cotton-rayon sheets, laundered and used. Average of two locations.

differences in breaking strengths between area 1 and the other areas of the all-rayon sheets showed no definite trend.

The uniformity of damage within the used rayon sheets and also between the sheets laundered only and those in service, is difficult to explain. There is a possibility, however, that since the laundered rayon sheets were too short to tuck in at the top and bottom of the bed due to the excessive shrinkage, there may have been a tendency to use them more often as a top sheet, so that they actually received less wear than the cotton or blended sheets. Also, the greater shrinkage in the rayon sheets with consequent increase in weight and strength would tend to offset the loss in strength to larger degree than in the other sheets.

ELONGATION

Analyses of variance of the percent elongation of the three types of sheets laundered only and laundered and used, show that the fiber content had the greatest influences on elongation (tables 24 and 25).

TABLE 24. *Analysis of variance of percent elongation of sheets laundered only*

Source of variation	Degrees of freedom	Mean square			
		Dry		Wet	
		Warp	Filling	Warp	Filling
Locations (L)	1	2,890.03**	1,097.17**	4,963.35**	3,872.62**
Types of sheet (T)	2	8,336.56**	8,320.19**	4,743.90**	7,136.82**
Washings (W)	3	784.08**	1,138.63**	1,117.21**	1,515.74**
LT	2	5.26	58.92	448.42**	173.94
LW	3	333.43*	346.75**	354.89**	456.21**
TW	6	76.96	54.67	59.64	75.11
LTW	6	[1] 57.78	[1] 31.45	[1] 29.01	[1] 40.93
Areas (A)	3	5.51	26.97**	8.84	14.36
AL	3	17.80*	2.74	5.34	5.38
AT	6	3.56	2.88	11.18*	2.49
AW	9	5.27	2.26	2.68	10.53
ALT	6	6.94	4.90	9.48	8.80
ALW	9	4.53	6.27	4.27	5.39
ATW	18	3.31	3.15	5.09	7.17
ALTW	18	[2] 4.02	[2] 4.31	[2] 3.71	[2] 6.08
Sampling error	384	1.70	1.43	2.15	2.56
Total	479				

[1] Used as estimate of error a.
[2] Used as estimate of error b.
*Significant at P=.05.
**Significant at P=.01.

The effect of laundering was significant at the 1-percent level; however, the interaction between washings and locations is significant and indicates that the influence of laundering was not consistent at the two locations.

The percent elongation of the all-rayon sheets was approximately twice that of the all-cotton (table 26). The average dry percent elongations warpwise were 12.3, 17.4, and 26.9 for the laundered-and-used all-cotton, cotton-rayon, and all-rayon, respectively. In most instances, the elongation of the 50–50 blend of cotton and rayon was nearer that of the cotton than the rayon.

TABLE 25.—*Analysis of variance of percent elongation of sheets laundered and used*

Source of variation	Degrees of freedom	Mean square			
		Dry		Wet	
		Warp	Filling	Warp	Filling
Location (L)	1	4, 753. 05**	2, 876. 30**	7, 330. 02**	7, 582. 51**
Type of sheet (T)	2	17, 510. 02**	16, 326. 60**	11, 041. 26**	14, 554. 15**
Washings (W)	3	2, 469. 61**	3, 395. 41**	4, 820. 56**	5, 772. 38**
LT	2	87. 44	188. 85**	292. 76**	153. 48*
LW	3	557. 12**	328. 04**	832. 06**	1, 070. 64**
TW	6	48. 48	65. 20*	215. 42**	151. 74**
LTW	6	52. 60	79. 86**	90. 52**	104. 46*
Sheets treated alike (error a)	24	26. 04	20. 82	24. 33	28. 54
Areas (A)	3	86. 84**	234. 58**	157. 49**	130. 13**
AL	3	22. 05*	9. 61	2. 06	15. 34*
AT	6	15. 56	16. 04	17. 01*	13. 47*
AW	9	17. 77	20. 93*	40. 04**	43. 08**
ALT	6	3. 48	13. 94	13. 46	17. 93*
ALW	9	7. 46	9. 91	14. 43	8. 18
ATW	18	3. 19	8. 74	9. 46	9. 99
ALTW	18	5. 20	7. 85	13. 86	15. 41**
Sheets treated alike (error b)	72	6. 60	7. 84	7. 32	6. 65
Total	191				

*Significant at P=.05.
**Significant at P=.01.

TABLE 26.—*Percent elongation of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*

Dry elongation

Type of sheet and number of launderings	Laundered and used						Laundered only					
	Warp			Filling			Warp			Filling		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cotton:												
5	18.85	11.37	15.11	20.24	13.16	16.70	18.41	11.25	14.83	20.58	12.34	16.46
20	15.54	12.21	13.87	16.84	12.32	14.58	16.52	11.34	13.93	16.60	12.20	14.40
30	12.59	8.60	10.60	12.04	8.85	10.44	13.02	11.18	12.10	12.82	11.26	12.04
35	11.25	7.82	9.54	10.87	7.73	9.30	13.32	9.36	11.34	11.92	9.83	10.88
Average	14.56	10.00	12.28	14.99	10.52	12.76	15.32	10.79	13.05	15.48	11.41	13.44
Cotton-rayon:												
5	25.14	15.88	20.51	22.29	16.41	19.35	24.71	14.60	19.65	23.79	15.51	19.65
20	21.24	17.42	19.33	19.10	17.21	18.16	22.26	18.31	20.28	20.85	18.70	19.78
30	17.28	14.25	15.76	15.97	12.95	14.46	19.74	15.69	17.72	16.34	16.62	16.48
35	16.95	11.31	14.13	15.25	9.20	12.22	14.40	11.50	12.95	13.66	10.56	12.11
Average	20.15	14.71	17.44	18.15	13.94	16.05	20.28	15.02	17.65	18.66	15.35	17.00
Rayon:												
5	35.56	25.28	30.42	34.23	26.46	30.34	35.20	24.20	29.70	33.87	26.82	30.34
20	30.42	29.67	30.04	29.78	30.58	30.18	31.84	28.42	30.13	29.00	31.63	30.32
30	25.62	23.87	24.74	24.38	24.04	24.21	23.58	25.28	24.43	24.08	24.92	24.50
35	22.58	21.94	22.26	20.76	21.29	21.02	28.06	21.04	24.55	25.75	22.56	24.16
Average	28.54	25.19	26.87	27.29	25.59	26.44	29.67	24.74	27.20	28.17	26.48	27.33

TABLE 26.—*Percent elongation of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*—Continued

Type of sheet and number of launderings	Wet elongation											
	Laundered and used						Laundered only					
	Warp			Filling			Warp			Filling		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cotton:												
5	18. 79	13. 50	16. 14	21. 84	15. 17	18. 51	18. 18	12. 86	15. 52	20. 00	14. 14	17. 07
20	16. 18	15. 04	15. 61	17. 16	16. 37	16. 77	17. 50	15. 51	16. 50	18. 57	17. 55	18. 06
30	13. 12	9. 37	11. 24	13. 22	9. 36	11. 29	12. 74	12. 08	12. 41	13. 56	12. 08	12. 82
35	13. 41	7. 50	10. 46	14. 08	7. 48	10. 78	14. 66	10. 44	12. 55	16. 02	10. 31	13. 16
Average	15. 37	11. 35	13. 36	16. 58	12. 10	14. 34	15. 77	12. 72	14. 25	17. 03	13. 52	15. 28
Cotton-rayon:												
5	23. 85	14. 22	19. 03	25. 77	14. 52	20. 15	24. 72	12. 90	18. 80	24. 48	13. 76	19. 12
20	18. 52	17. 28	17. 90	19. 54	17. 99	18. 76	20. 50	18. 69	19. 60	20. 08	19. 80	19. 94
30	12. 46	9. 26	10. 86	11. 95	9. 90	10. 93	17. 99	12. 58	15. 28	17. 66	12. 75	15. 20
35	13. 41	7. 97	10. 69	14. 58	8. 56	11. 57	16. 77	9. 77	13. 27	17. 42	9. 98	13. 70
Average	17. 06	12. 18	14. 62	17. 96	12. 74	15. 35	20. 00	13. 48	16. 74	19. 91	14. 07	16. 99
Rayon:												
5	37. 47	23. 56	30. 51	38. 58	24. 52	31. 55	36. 26	20. 66	28. 46	38. 38	25. 23	31. 80
20	28. 08	27. 81	27. 94	31. 70	32. 28	31. 99	30. 50	25. 44	27. 97	32. 34	31. 78	32. 06
30	23. 58	16. 89	20. 23	26. 05	18. 62	22. 33	26. 42	18. 28	22. 34	28. 66	19. 59	24. 12
35	22. 66	12. 81	17. 74	23. 96	16. 23	20. 09	25. 00	14. 84	19. 92	26. 42	18. 46	22. 44
Average	27. 95	20. 27	24. 11	30. 07	22. 91	26. 49	29. 54	19. 80	24. 67	31. 45	23. 77	27. 61

The mean elongations were very similar for each type of sheet whether laundered only or laundered and used, dry or wet, and irrespective of direction. The mean differences in percent elongation at the 2 locations, however, were significant at the 1-percent level. With but few exceptions, the percent elongation was higher at Kansas than at Tennessee. For all types of sheets, the average elongation decreased as the number of launderings increased; however, at Tennessee there was no consistent decrease until after 20 launderings (fig. 6).

When the mean values for the two schools were used, the differences between the percent elongations of the areas within all sheets laundered only and the all-rayon sheets laundered and used were very small. In the all-cotton and the cotton-rayon laundered-and-used sheets, the lowest elongation was shown by area 3 and the highest by area 1, and this difference increased as the number of launderings increased. This indicates that body wear has some effect in reducing the percent elongation of the sheets.

Chemical Damage

The analyses of variance of the fluidities and D. P.'s of the sheets are given in tables 27 and 28. For all sheets the mean differences in fluidities and in D. P.'s between the 2 locations were small and not statistically significant, showing the uniformity of chemical damage in laundering at the 2 colleges. As the number of launderings increased, the fluidity (reciprocal viscosity) values for the sheets increased and the D. P. values, which are a direct measure of the molecular length, decreased. These changes were significant for all types of sheets and for the sheets laundered only as well as those laundered and used.

The cotton sheets showed the largest and the rayon sheets the smallest change in both fluidity and D. P. as the number of washings increased (table 29). This does not necessarily mean that the cotton was more badly damaged than the rayon. From theoretical considerations, it can be shown that for the same amount of chemical damage, there should be a larger drop in the D. P. of the long cotton molecule than in the much shorter rayon molecule (*3*, *7*). Zwicky (*7*) has suggested that the calculation of the number of splits per given number of monomer units would give a better measure of damage than the D. P.'s. This would be particularly true when comparing cotton and rayon fabrics.

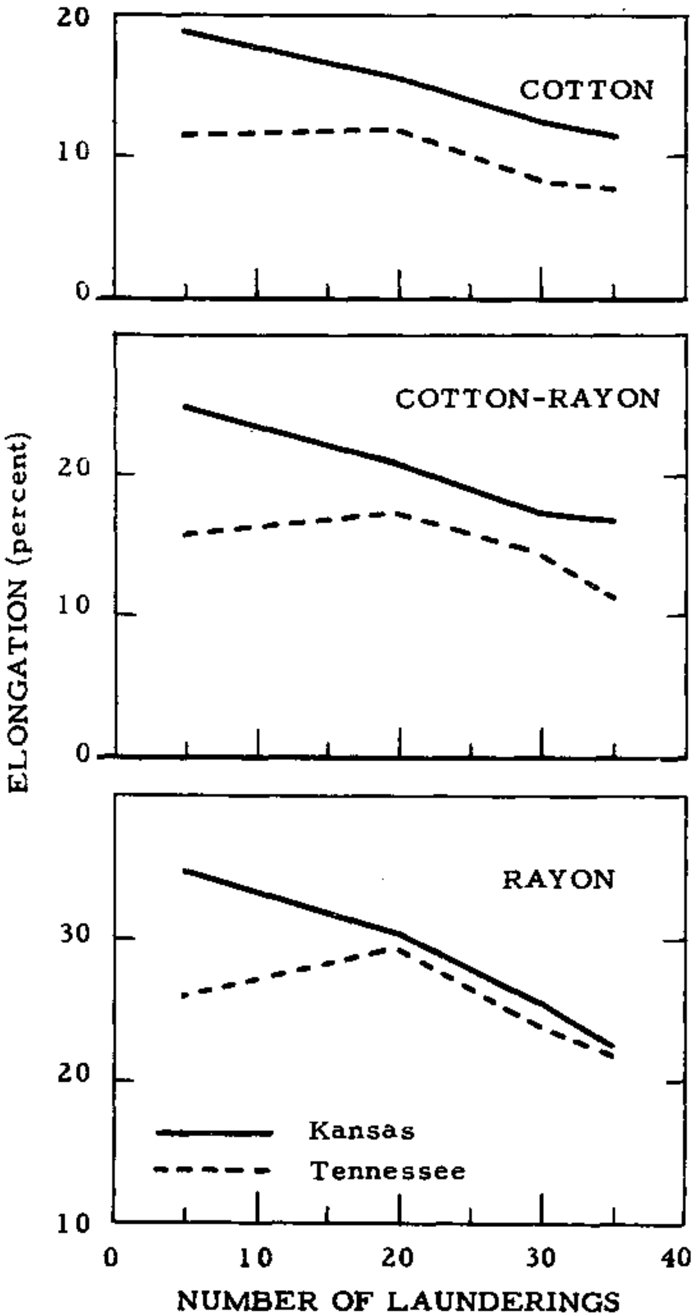

FIGURE 6.—Warp elongation, dry: All-cotton, cotton-rayon, and all-rayon sheets, laundered and used at Kansas State College and University of Tennessee.

TABLE 27.—*Analysis of variance of fluidity and degree of polymerization of sheets laundered only*

Source of variation	Fluidity		Degree of polymerization	
	Degrees of freedom	Mean square	Degrees of freedom	Mean square
Locations (L)	1	0.23	1	737,540
Types of sheets (T)	2	555.13**	2	490,977,550**
Washings (W)	3	139.73**	3	9,226,121**
LT	2	.48	2	299,892
LW	3	1.04	3	79,942
TW	6	6.38	6	1,643,826**
LTW	6	[1] 1.60	6	[1] 148,789
Areas (A)	3	2.27	3	202,296
AL	3	1.32	3	85,746
AT	6	1.42	6	219,368
AW	9	1.64	9	145,080
ALT	6	1.75	6	85,828
ALW	9	2.61	9	171,583
ATW	18	1.96	18	221,891
ALTW	18	[2] 2.16	18	[2] 129,285
Sampling error	96	.04	288	9,633
Total	191		383	

[1] Used as estimate of error a.
[2] Used as estimate of error b.
**Significant at P=.01.

TABLE 28.—*Analysis of variance of fluidity and degree of polymerization of sheets laundered and used*

Source of variation	Fluidity		Degree of polymerization	
	Degrees of freedom	Mean square	Degrees of freedom	Mean square
Locations (L)	1	1.07	1	331,503
Types of sheets (T)	2	1,166.91**	2	803,383,209**
Washings (W)	3	736.05**	3	42,320,927**
LT	2	11.09	2	999,616**
LW	3	4.41	3	203,458
TW	6	52.47**	6	10,262,040**
LTW	6	2.62	6	223,618
Sheets treated alike (error a)	24	3.54	24	155,134
Areas (A)	3	37.39**	3	1,547,509**
AL	3	3.19**	3	225,211*
AT	6	7.24**	6	690,904**
AW	9	3.56**	9	163,682*
ALT	6	2.31**	6	45,289
ALW	9	.74	9	85,814
ATW	18	1.06	18	69,502
ALTW	18	1.32*	18	68,030
Sheets treated alike x areas (error b)	72	.66	72	51,844
Sampling error	192	.05	576	6,029
Total	383		767	

*Significant at P=.05. **Significant at P=.01.

TABLE 29.—*Fluidity and degree of polymerization of all-cotton, cotton-rayon, and all-rayon sheets laundered only and sheets laundered and used at Kansas State College and the University of Tennessee*

Type of sheet and number of launderings	Fluidity						Degree of polymerization					
	Laundered and used			Laundered only			Laundered and used			Laundered only		
	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average	Kansas	Tennessee	Average
Cotton:	*Rhes*	*Rhes*	*Rhes*	*Rhes*	*Rhes*	*Rhes*						
5	8.37	7.76	8.06	8.54	9.42	8.98	5492.3	5554.6	5523.5	5408.6	5349.1	5378.8
20	12.23	13.49	12.86	10.15	9.74	9.95	4449.0	4142.7	4295.9	4457.4	4880.6	4669.0
30	15.72	17.62	16.67	12.58	12.13	12.35	3896.0	3544.6	3720.3	4388.1	4541.6	4464.8
35	16.77	17.37	17.07	14.18	13.40	13.79	3621.4	3482.3	3551.9	4054.9	4308.0	4181.5
Average	13.27	14.06	13.67	11.36	11.17	11.27	4364.7	4181.1	4272.9	4577.3	4769.8	4673.5
Cotton-rayon:												
5	4.85	4.62	4.74	4.53	4.16	4.34	2830.8	2903.6	2867.2	2911.9	3069.4	2990.7
20	7.48	7.48	7.48	5.95	6.06	6.00	2215.2	2291.7	2253.4	2361.5	2458.2	2409.9
30	9.61	9.46	9.53	7.64	7.60	7.62	2005.5	2113.9	2059.7	2352.7	2343.4	2348.1
35	10.15	9.82	9.98	8.37	8.10	8.24	1942.2	1889.8	1916.0	2164.9	2194.8	2179.9
Average	8.02	7.85	7.93	6.62	6.48	6.55	2248.4	2299.7	2274.1	2447.8	2516.5	2482.1
Rayon:												
5	10.32	9.87	10.09	10.37	10.00	10.13	868.0	899.7	883.8	858.9	895.9	877.4
20	12.46	12.03	12.24	11.79	12.40	12.09	709.4	726.2	717.8	729.5	699.0	714.2
30	13.43	13.41	13.42	12.22	13.06	12.64	706.8	700.8	703.8	753.4	729.6	741.5
35	14.15	13.90	14.02	13.23	12.77	13.00	660.8	648.8	654.8	719.2	743.4	731.3
Average	12.59	12.30	12.45	11.90	12.03	11.97	736.2	743.9	740.1	765.3	767.0	766.1

Calculated by Zwicky's formula $\left(\text{Number of splits per 100,000 monomer units} = \frac{1000 \times \text{percent decrease in D. P.}}{\text{D. P. at end}}\right)$ the laundered only cotton sheets show 8 splits per 100,000 monomer units between 0 and 35 washes, while the blended sheets show 14 splits and the rayon sheets 37. For the used sheets the corresponding figures are 13, 20, and 53

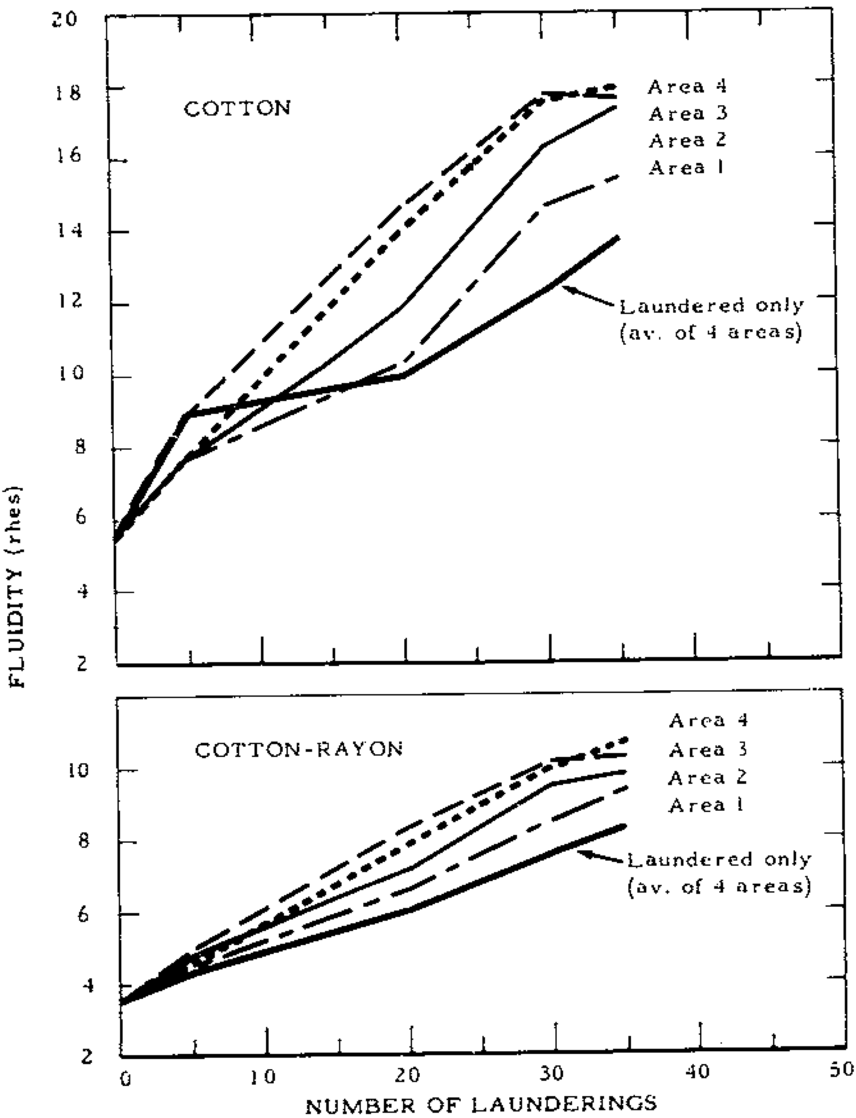

FIGURE 7.—Fluidity: Four areas of all-cotton and cotton-rayon sheets, laundered and used. Average of two locations.

splits per 100,000 monomer units. Similarly, the fluidity values, which are also a measure of molecular length, might be expected to show a more rapid rise for the cotton than for the rayon sheets for the same amount of chemical damage.

Differences between areas for all sheets laundered only and for the laundered-and-used rayon sheets were very small. The laundered-and-used all-cotton and cotton-rayon sheets showed the greatest chemical damage in areas 3 and 4 and the least in area 1 (figs. 7 and 8).

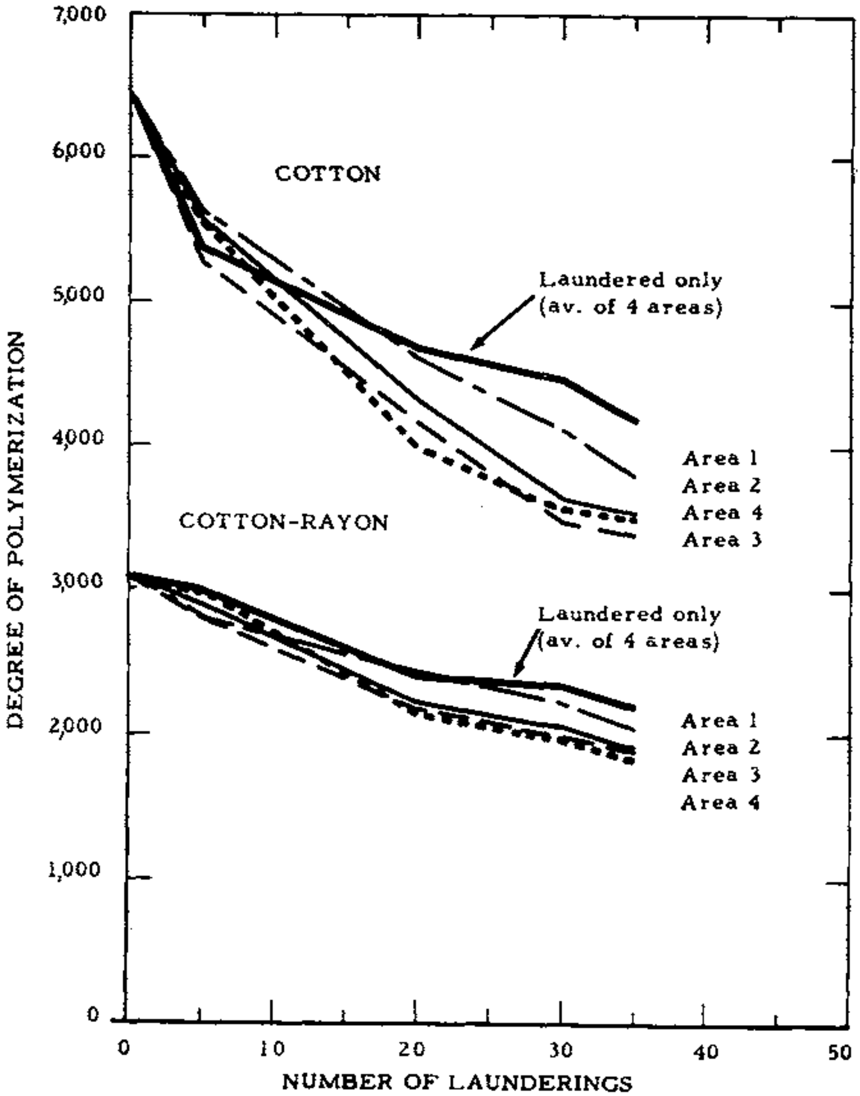

FIGURE 8.—Degree of polymerization: Four areas of all-cotton and cotton-rayon sheets, laundered and used. Average of two locations.

The laundered-and-used sheets showed a greater increase in fluidity and decrease in D. P. than those laundered only. Even in the used sheets, however, laundering accounted for a large part of the total chemical damage (table 30).

TABLE 30.—*Changes in the fluidity and degree of polymerization of sheets between 0 and 35 launderings*

Type of sheet	Fluidity			Degree of polymerization		
	Increase due to laundering	Increase due to laundering and use	Proportion of total increase due to laundering	Decrease due to laundering	Decrease due to laundering and use	Proportion of total decrease due to laundering
	Rhes	*Rhes*	*Percent*			*Percent*
Cotton	8.22	11.50	71	2274	2904	78
Cotton-rayon	4.67	6.41	73	931	1195	78
Rayon	3.69	4.71	78	276	352	78

After 35 washings the chemical damage was much greater than after 75 washings in the preliminary investigation. Since the two laundry procedures were essentially the same except for the omission of the bleach and sour in the preliminary investigation, it seems evident that one or both of these factors were responsible for most of the chemical damage.

In general, good agreement was found between the results obtained by the two methods for measuring chemical damage. The linear relationship shown in figure 9 is obtained when the fluidities are plotted against D. P.'s. These results show that either method could be used equally well for determining chemical damage due to laundering and wear in cellulose fabrics.

MICROSCOPIC STUDY OF FIBER DAMAGE

Photomicrographs of typical examples of damaged cotton and rayon fibers from the Kansas sheets are shown in figures 10 and 11. The rayon fibers usually began to split on the convex side of a curve and this splitting became progressively deeper until a complete break occurred, leaving typical frayed or sharp pointed ends. The breaks in the cotton fibers were not as sharply defined as in the rayon. In general, a higher proportion of the cotton fibers showed ragged peeling and fraying of the cuticle rather than the deep splitting of the main body of the fiber found in the rayon.

The average number of damaged fiber areas counted per slide and the percent of the damaged areas classified as having low, medium, and high damage are given in tables 31 and 32 for the three types of sheets after various periods of laundering and use. As is evident from these tables, the number of damaged areas and the percentage of highly damaged areas increased in both cotton and rayon fibers as the number of launderings increased. The increase, however, was much more rapid in the rayon than in the cotton fibers. Thus, after 45 washes, 51 percent of the damaged areas in the rayon fibers were classified as having high damage as compared to 13 percent in the cotton fibers.

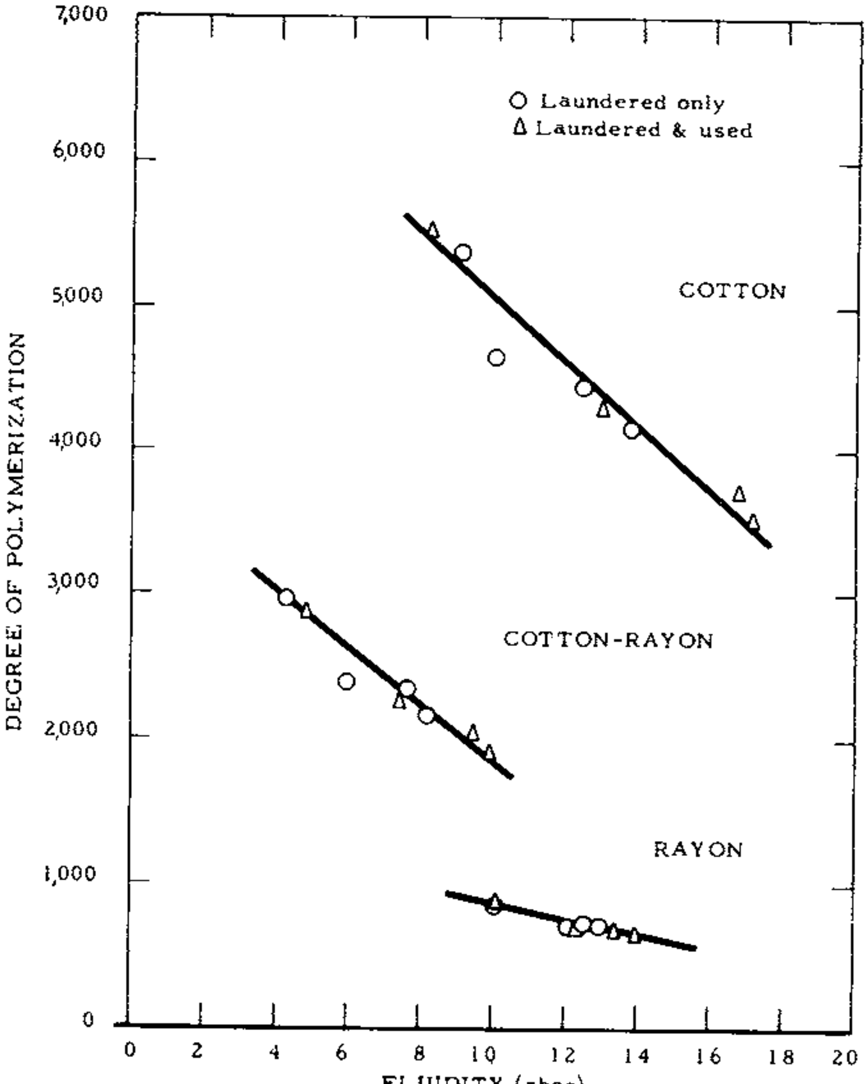

FIGURE 9.—Relationship between fluidity and degree of polymerization: All-cotton, cotton-rayon, and all-rayon sheets, laundered only and laundered and used 5, 20, 30, and 35 times. Average of two locations.

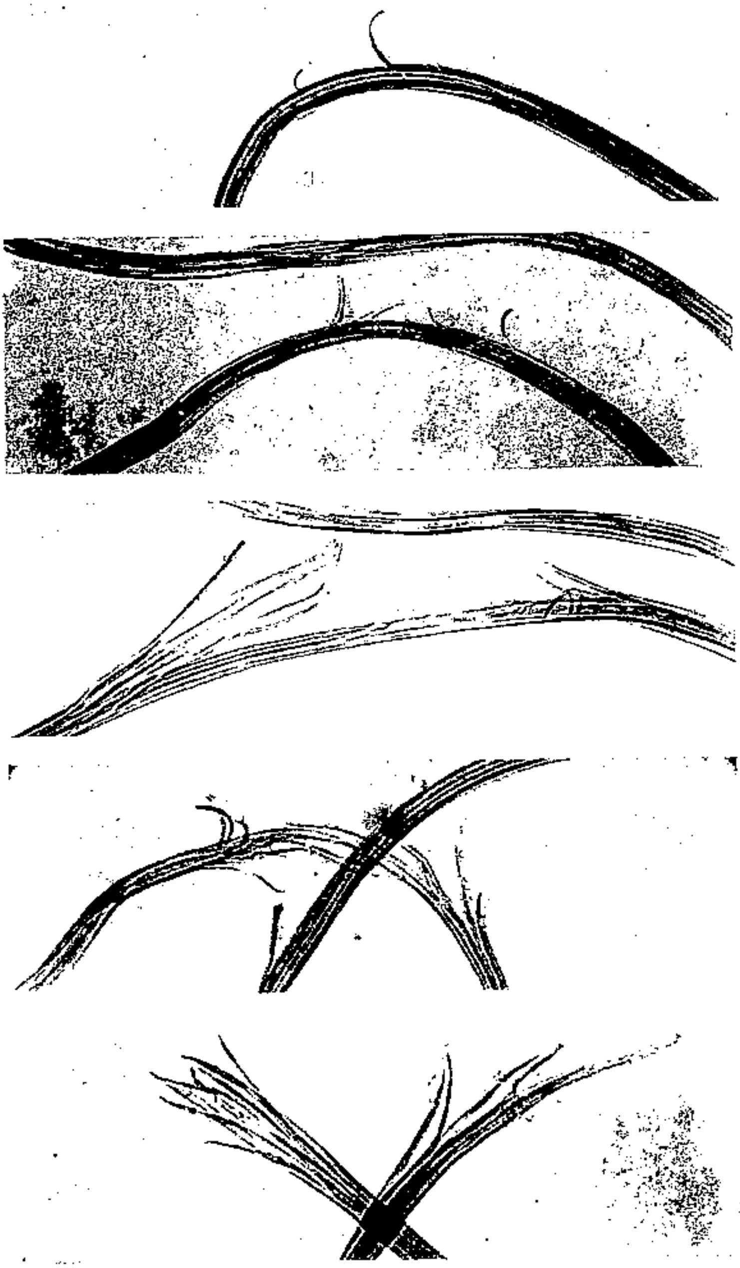

FIGURE 10.—Photomicrographs of rayon fibers with varying degrees of damage.

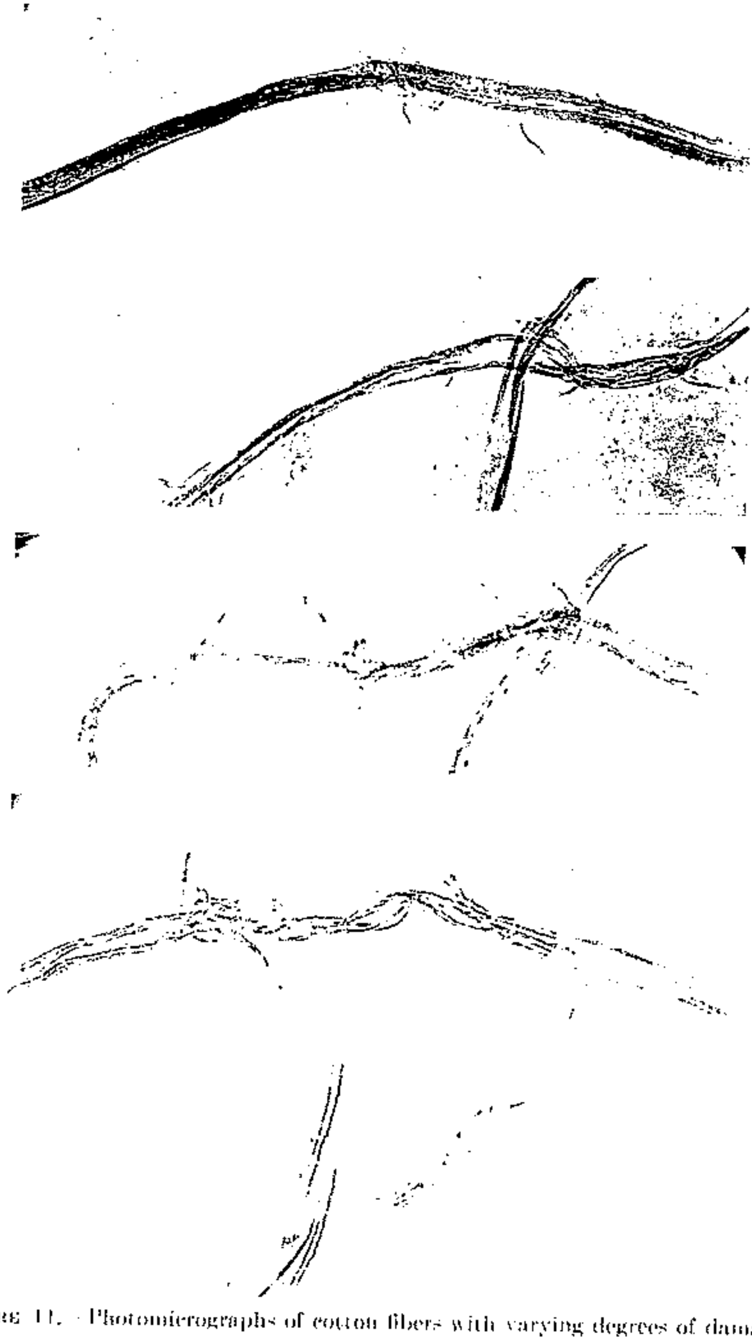

FIGURE 11.—Photomicrographs of cotton fibers with varying degrees of damage.

TABLE 31.—*Damaged areas of cotton and rayon fibers on a microscopic slide, by type of sheet and amount of laundering and use*

Amount of laundering and use	Cotton fibers from—			Rayon fibers from—		
	All-cotton sheets	Cotton-rayon sheets	Average	All-rayon sheets	Cotton-rayon sheets	Average
Unlaundered	33	34	34	9	22	16
5 launderings:						
Unused	58	67	62	37	46	42
Used	66	93	80	54	53	54
Average	62	80	71	46	50	48
20 launderings:						
Unused	112	93	102	110	120	115
Used	118	109	114	108	99	104
Average	115	101	108	109	110	110
35 launderings:						
Unused	130	124	127	178	156	167
Used	113	143	128	183	176	180
Average	122	134	128	180	166	174
45 launderings:						
Unused	141	135	138	229	160	194
Used	119	120	120	230	192	211
Average	130	128	129	230	176	203

TABLE 32.—*Percentage of total damaged areas of cotton and rayon fibers that show low, medium, or high damage after laundering or laundering and use*

Amount of laundering and use	Degree of damage	Cotton fibers			Rayon fibers		
		From all-cotton sheets	From cotton-rayon sheets	Average	From all-rayon sheets	From cotton-rayon sheets	Average
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Unlaundered	Low	84.2	88.4	86.3	96.8	84.2	90.5
	Medium	12.4	6.2	9.3	.8	10.8	5.8
	High	3.4	5.4	4.4	2.4	5.0	3.7
5 launderings:							
Unused	Low	87.6	86.2	86.9	83.0	84.4	83.7
	Medium	8.2	9.4	8.8	11.8	11.4	11.6
	High	4.2	4.4	4.3	5.2	4.2	4.7
Used	Low	83.0	88.0	85.5	71.6	80.2	75.9
	Medium	12.0	9.4	10.7	20.0	14.6	17.3
	High	5.0	2.6	3.8	8.4	5.2	6.8
Average	Low	85.3	87.1	86.2	77.3	82.3	79.8
	Medium	10.1	9.4	9.8	15.9	13.0	14.4
	High	4.6	3.5	4.0	6.8	4.7	5.8
20 launderings:							
Unused	Low	82.6	79.0	80.8	49.0	51.6	50.3
	Medium	13.0	12.8	12.9	26.0	21.0	23.5
	High	4.4	8.2	6.3	25.0	27.4	26.2

TABLE 32.—*Percentage of total damaged areas of cotton and rayon fibers that show low, medium, or high damage after laundering or laundering and use*—Continued

Amount of laundering and use	Degree of damage	Cotton fibers			Rayon fibers		
		From all-cotton sheets	From cotton-rayon sheets	Average	From all-rayon sheets	From cotton-rayon sheets	Average
20 launderings—Continued		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Used	Low	81.0	77.6	79.3	50.0	51.2	50.6
	Medium	13.8	12.4	13.1	26.4	21.6	24.0
	High	5.2	10.0	7.6	23.6	27.2	25.4
Average	Low	81.8	78.3	80.0	49.5	51.4	50.4
	Medium	13.4	12.6	13.0	26.2	21.3	23.8
	High	4.8	9.1	7.0	24.3	27.3	25.8
35 launderings:							
Unused	Low	76.2	77.6	76.9	35.4	46.0	40.7
	Medium	14.6	13.6	14.1	23.6	19.0	21.3
	High	9.2	8.8	9.0	41.0	35.0	38.0
Used	Low	76.8	70.6	73.7	34.8	39.4	37.1
	Medium	16.0	15.6	15.8	22.2	20.8	21.5
	High	7.2	13.8	10.5	43.0	39.8	41.4
Average	Low	76.5	74.1	75.3	35.1	42.7	38.9
	Medium	15.3	14.6	15.0	22.9	19.9	21.4
	High	8.2	11.3	9.8	42.0	37.4	39.7
45 launderings:							
Unused	Low	74.2	77.6	75.9	27.0	36.8	31.9
	Medium	15.8	15.2	15.5	19.2	16.4	17.8
	High	10.0	7.2	8.6	53.8	46.8	50.3
Used	Low	63.8	64.8	64.3	26.4	32.0	29.2
	Medium	19.2	18.0	18.6	20.4	18.2	19.3
	High	17.0	17.2	17.1	53.2	49.8	51.5
Average	Low	69.0	71.2	70.1	26.7	34.4	30.6
	Medium	17.5	16.6	17.0	19.8	17.3	18.6
	High	13.5	12.2	12.8	53.5	48.3	50.9

Microscopic examination of fiber damage showed little difference between laundered-only and laundered-and-used sheets. No consistent difference was found in the number of damaged areas or in the degree of damage of the fibers from sheets made of the 50-50 blend of cotton and rayon and the corresponding fibers from the all-cotton and the all-rayon sheets.

Comparison of Different Methods of Measuring Damage

For the deterioration due to laundering and wear that occurred in this study, a linear relationship was found between the physical and chemical measures of damage. Figure 12 shows the relationship between the percent loss in dry warp breaking strength and the increase in fluidity both for sheets laundered only and for those laundered and used.

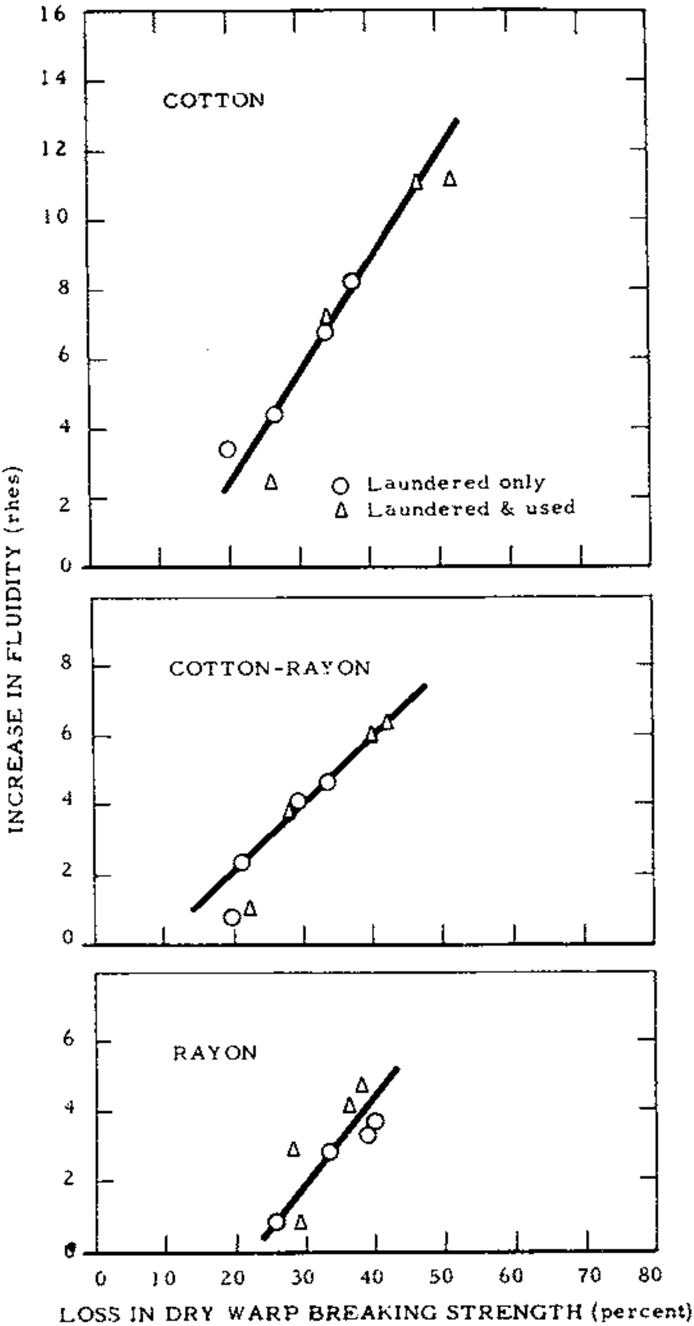

FIGURE 12.—Average of four areas, relationship between percent loss in dry warp breaking strength and increase in fluidity: All-cotton, cotton-rayon, and all-rayon sheets, laundered only and laundered and used. Average of two locations.

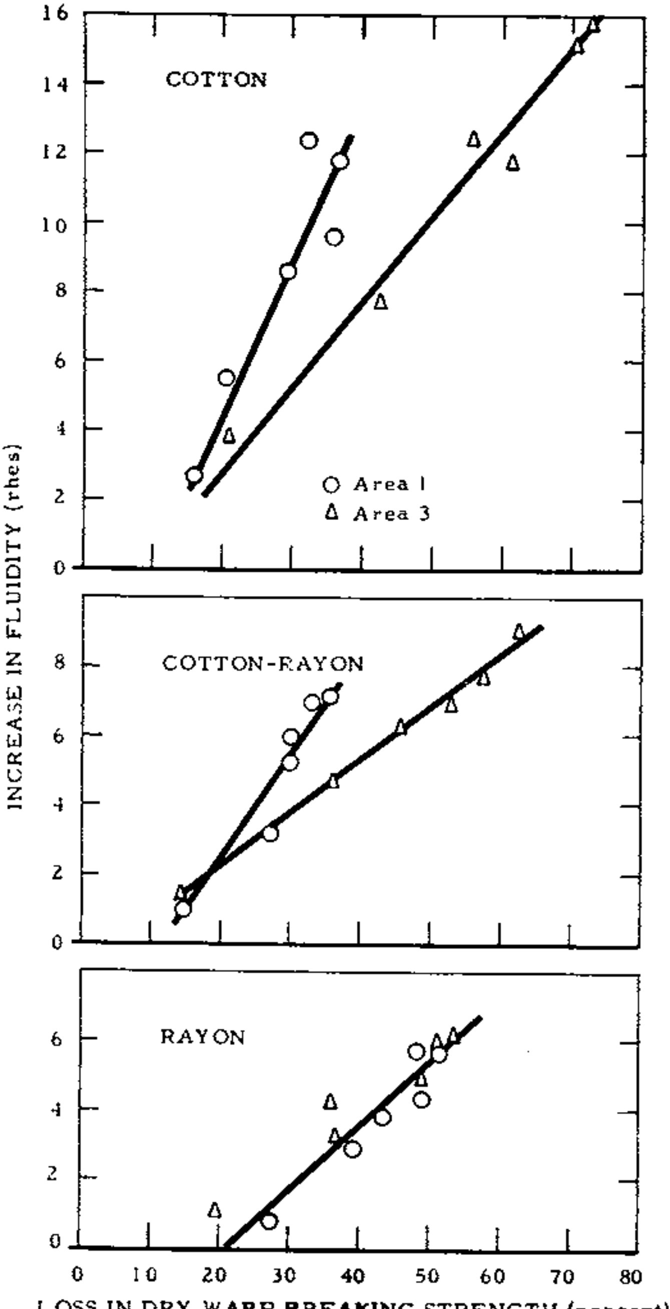

FIGURE 13.—Areas 1 and 3, relationship between percent loss in dry warp breaking strength and increase in fluidity: All-cotton, cotton-rayon, and all-rayon sheets, laundered and used at Kansas State College.

In figure 12 the average of the four areas was used for both fluidity and breaking strength. If, however, fluidity and breaking strength values for areas 1 and 3 (areas of least and greatest wear) of the laundered-and-used sheets are plotted separately, it is evident that there is a difference in the relative proportion of physical and chemical damage in the 2 areas of the cotton and cotton-rayon sheets (fig. 13). Area 3, which received the most body wear, showed a relatively greater loss in breaking strength as compared with the increase in fluidity than was found in area 1. This indicates that mechanical abrasion has a greater effect on breaking strength than on fluidity. In the all-rayon sheets, in which little difference between areas was found by either physical or chemical measures of damage, the points for areas 1 and 3 fall along the same line.

Figures 14 and 15 show the relationship between the damage as determined by the microscopic examination of fibers, the percent loss in breaking strength, and the percent decrease in D. P. for the cotton and rayon sheets used at Kansas. In the laundered-only

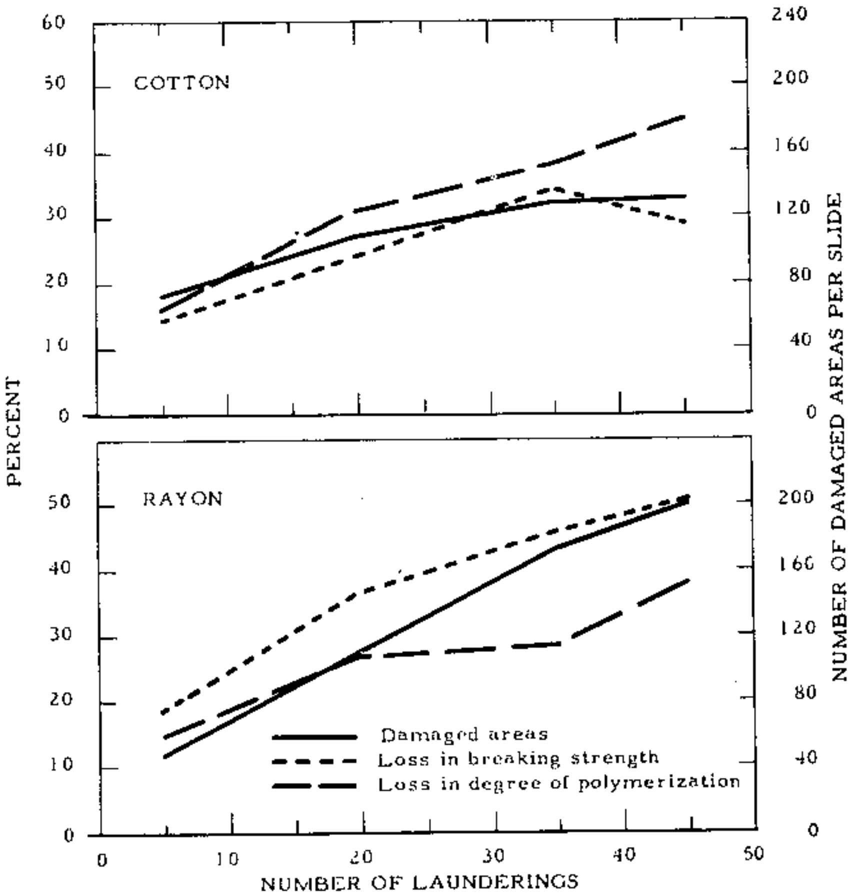

FIGURE 14.—Sheets laundered only, relationship between number of damaged areas per slide, percent loss in breaking strength, and percent loss in degree of polymerization: All-cotton and all-rayon sheets, Kansas State College.

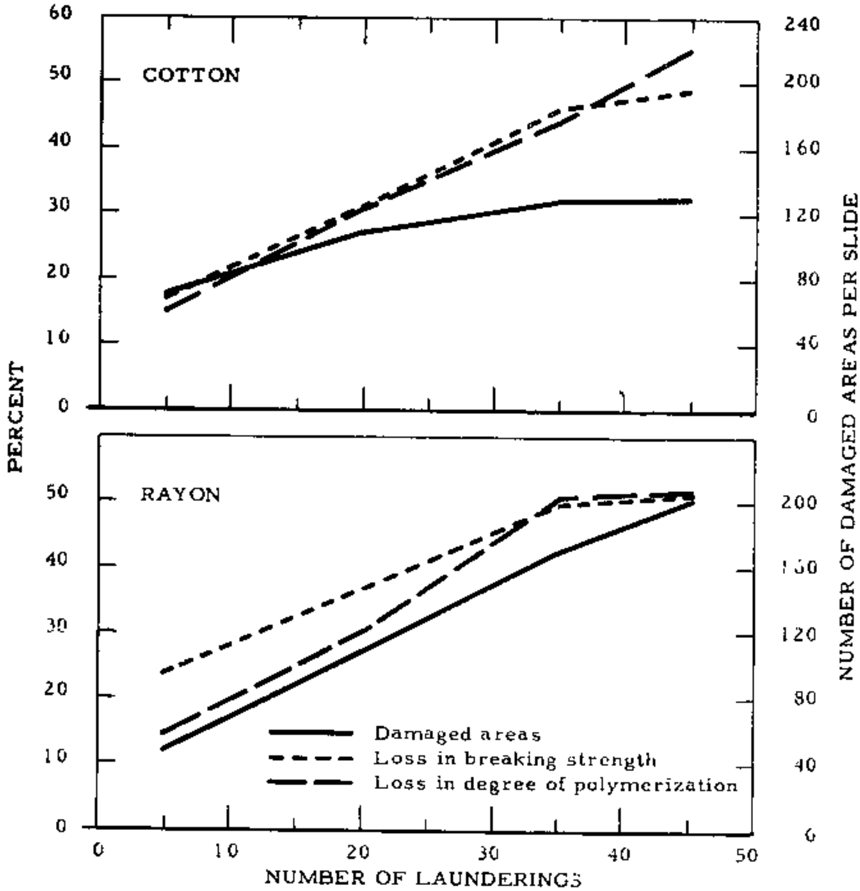

FIGURE 15.—Sheets laundered and used, relationship between number of damaged areas per slide, percent loss in breaking strength, and percent loss in degree of polymerization: All-cotton and all-rayon sheets, Kansas State College.

sheets, the increase in the number of damaged areas on the microscope slide with increased laundering followed the same general trend as the loss in breaking strength. Both microscopic examination and breaking strength measurements showed greater damage in the rayon than in the cotton sheets, while the percent decrease in D. P. was somewhat smaller for the rayon than for the cotton.

In the laundered-and-used cotton sheets, both the loss in breaking strength and in D. P. were greater than in the laundered-only sheets, while no difference was found in the microscopic examination of fibers. In the laundered-and-used rayon sheets neither breaking strength measurements nor microscopic examination of fibers showed increased damage as compared with the laundered-only sheets while there was a somewhat greater decrease in D. P. In the used sheets, the percent loss in both breaking strength and D. P. was about the same for the all-cotton and for the all-rayon sheets, while microscopic examination showed more damage in the rayon sheets.

SUMMARY

To obtain information on the durability of utility fabrics composed of different fibers, a study was made of the physical and chemical properties and the performance in actual use of sheets made entirely or in part of cotton and of rayon. Cotton of known history and typical of that used in commercial production was manufactured into sheeting in accordance with regular established mill procedures. Sheetings of the same construction were also made from staple viscose rayon and from blends of cotton with varying amounts of rayon.

In a preliminary investigation, seven sheetings varying in fiber content from all-cotton to all-rayon in steps of ⅙th were evaluated in the laboratory. In the unlaundered fabrics, the dry breaking strength of the all-cotton was greater than that of the all-rayon; both all-cotton and all-rayon were stronger than the 5 fabrics made from blends of the 2 fibers. A similar relationship was shown in the yarns used in making the sheetings. The all-rayon fabric was less resistant to laboratory abrasion than the all-cotton or the blends.

After repeated launderings, shrinkage occurred in all fabrics in both warp and filling directions with a corresponding increase in weight and in count. In most instances, the greatest shrinkage, the highest count, and the maximum weight were reached within the first 20 launderings. The all-rayon showed the greatest change in these properties and the all-cotton the least.

No appreciable chemical degradation was found in any of the fabrics, irrespective of fiber content, during 75 launderings without use of bleach or sour. The influence of fiber content, however, was evident in the physical properties. Fabrics containing 50 percent or more cotton showed little change in breaking strength after repeated laundering, while those containing less than 50 percent cotton decreased in strength.

On the basis of findings from the preliminary investigation, sheets composed of all-cotton, all-rayon, and a 50-50 blend of cotton and rayon were manufactured in sufficient quantity for study under actual use conditions. These sheets were placed in service in a men's dormitory at the University of Tennessee and in a women's dormitory at Kansas State College. Changes in the physical and chemical properties with repeated laundering and wear were determined at specified intervals.

As in the preliminary study, evaluation of the yarns and finished sheets showed the all-cotton to be the strongest, followed in order by the all-rayon and the 50–50 blend of cotton and rayon. The elongation of the cotton and of the 50–50 blend was about the same, approximately half as large as that of the all-rayon.

During the first 5 launderings, the all-rayon shrank 18 percent, the blend 12 percent, and the all-cotton 8 percent in the warp direction. With an original sheet length of 104 inches, this meant a loss of 19, 12, and 8 inches, respectively, for the 3 types of sheets. All sheets stretched approximately 5 percent fillingwise. As a result of these dimensional changes, the fabrics increased in weight and also in count and breaking strength in the filling direction, with the rayon showing the greatest increase in these properties. Between 5 and 35 launderings, some additional shrinkage occurred in the warp direction, but the change was much less pronounced than during the first 5 washes. The weight of the sheets decreased slightly as the result of repeated laundering and wear.

In general, the breaking strength of the sheets decreased progressively as the number of launderings increased, with the all-rayon showing the greatest and the all-cotton the least loss in strength due to laundering alone. The laundered-and-used cotton and cotton-rayon sheets evidenced greater damage than the corresponding sheets laundered only and damage was greatest in the area occupied by the shoulders. The used rayon sheets, on the other hand, showed no difference in damage between areas within the sheets, and little or no increase in damage as compared with the sheets laundered only. Thus, the loss in strength in the used all-rayon sheets was about the same as or, in some cases, smaller than the loss in the cotton or blend.

The percent elongation of the fabrics decreased as the number of launderings increased. In all cases, the laundered-and-used all-rayon sheets showed the greatest elongation and the all-cotton the least. In most instances, the elongation of the blend was closer to that of the cotton than to the rayon.

All sheets showed increased chemical damage with increased laundering, and the used sheets showed greater damage than those laundered only. No difference was found between the areas in the used rayon sheets, while in the cotton and cotton-rayon sheets the area occupied by the shoulders showed the greatest chemical damage. Changes in fluidity and degree of polymerization were less in the all-rayon sheets than in the all-cotton and the blends.

The microscopic examination of fibers taken from the sheets used at Kansas showed that there was a progressive increase in damage as the number of launderings increased. After the first five launderings, greater damage was found in the rayon than in the cotton fibers. No difference in damage was evident, however, between the sheets laundered and used and those laundered only.

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U. S. GOVERNMENT PRINTING OFFICE: 1953

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 30 cents

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