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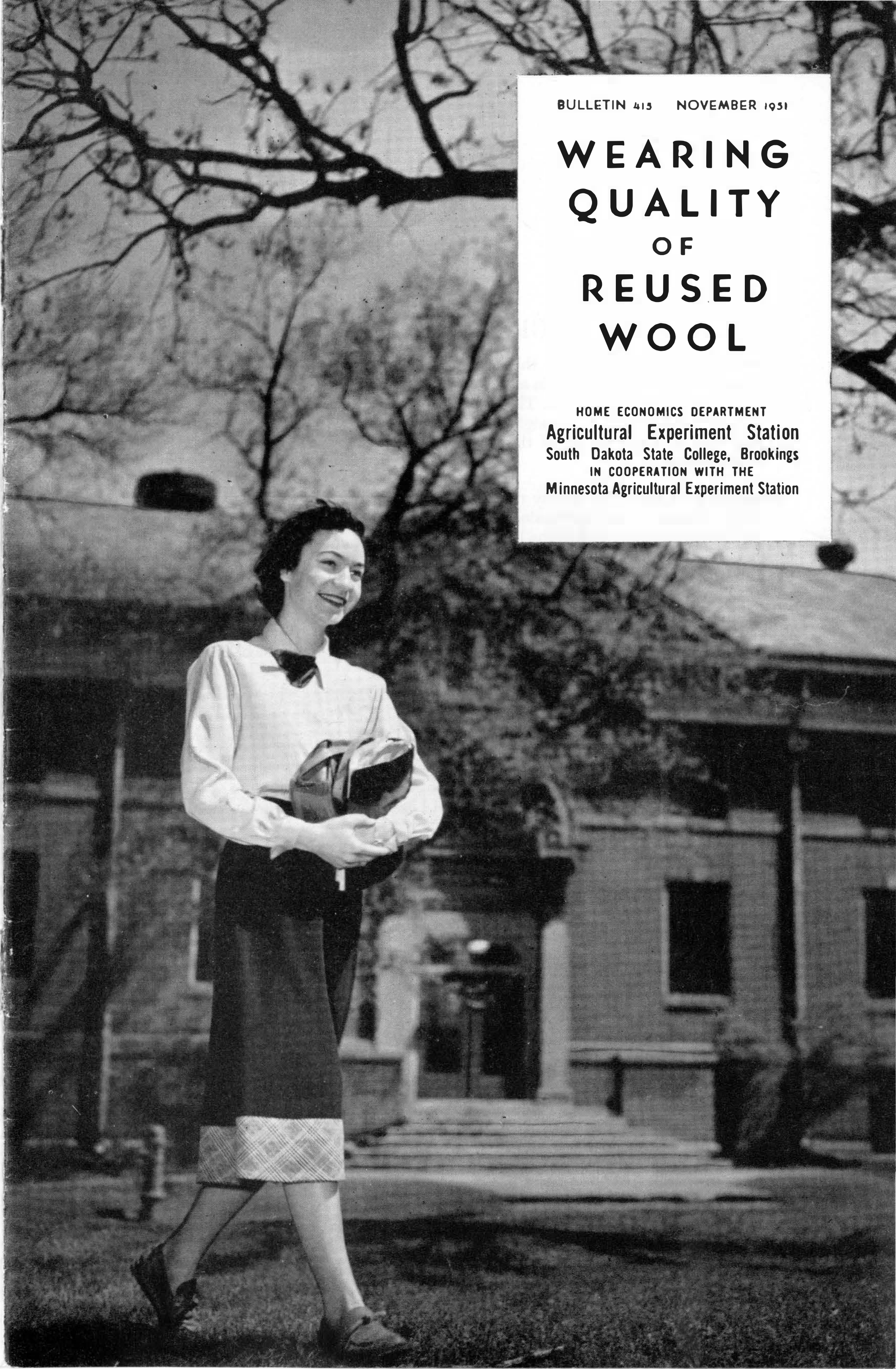
Wearing Quality of Reused Wool

L. O. Lund

E. L. Phelps

H. W. Norton



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WEARING QUALITY OF REUSED WOOL

HOME ECONOMICS DEPARTMENT
Agricultural Experiment Station
South Dakota State College, Brookings
IN COOPERATION WITH THE
Minnesota Agricultural Experiment Station

Glossary of Terms

Bow—The term used when the filling yarn in a fabric does not lie in a straight line from selvage to selvage. The maximum deflection from the straight line is expressed as a percentage of the width of the fabric.

Breaking Strength—The ability of a material to resist rupture by tension. Often called tensile strength, it is the breaking load of the material, when measured under specified conditions.

Bursting Strength—The ability of a material to resist rupture by pressure. The force required to rupture the fabric, when applied at right angles to the plane of the fabric, under specified conditions.

Decating—A finishing process applied to wool fabrics to set the fiber and develop the luster of the material. The cloth is wound tightly on a perforated roller, thoroughly saturated with either hot water or steam and then cooled while still under tension.

Elongation—The increase in length or width of the fabric, or length of the yarn, resulting from the tensile force which was applied at the time of break. This is usually expressed as a percentage of the original width or length.

Filling—The yarn which interlaces with the warps and runs from selvage to selvage at right angles to the warp in a woven fabric.

Fine—A wool grading term used in the American, or "blood," system. In the numerical grading system fine wool is designated as 64's, 70's and 80's.

Grex—A unit of yarn measurement used to express the relative fineness of yarns; the weight in grams of 10,000 meters of yarn.

Hand, Handle—The "feel" of fabrics, as harsh, soft, rough, smooth, etc.

Three-Eighths Blood Wool — A wool grading term in the "blood" system used to denote fineness and has no reference to the breeding of sheep. It is equivalent to 56's in the numerical system.

Warp—The yarns that run lengthwise in a woven fabric.

Yarn Strength—The ability of a single yarn to resist breaking by tension.

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WEARING QUALITY OF REUSED WOOL

A Study of The Physical Characteristics of New and Worn Flannels Containing New and Reused Wool

LILLIAN O. LUND[1], ETHEL L. PHELPS[2], and HELEN WARD NORTON[3]

Blending remanufactured wool with new wool has been a common practice for many years. However, only since 1941, when the Wool Products Labeling Act became effective, have labels been required to designate the percentages used in such blends. The labeling act defines three classes of wool: (1) new wool—wool not previously woven or felted; (2) reprocessed wool—wool recovered from woven or felted materials but not previously used by the ultimate consumer; (3) reused wool—wool recovered from spun, woven, knitted, or felted products which have been used in any way by the ultimate consumer.

Learning from the label that a garment contains reprocessed or reused wool, the consumer wants to know what effect this may have upon its service. This is a difficult question to answer since valid bases for predicting the durability of any fabric have not yet been established, and a blend of fibers makes the problem even more complex.

The process of reconverting a finished fabric into a fibrous state involves rigorous mechanical treatment, which may result in breaking the fiber into shorter lengths or causing other damage to the fiber. If, in addition, the fabric had received considerable wear before the reclamation process, the percentage of damaged fibers could be still higher. The extent to which the quality of a fabric may be impaired by blending reclaimed fiber with new wool has not been determined, although it is generally believed that reclaimed wool is not as satisfactory as new wool.

Many laboratory measurements can be made on fabrics, but no single measurement, or combination of measurements, has been proved to be an accurate guide for predicting serviceability. Up to the present, in order to determine the effects of actual wear, garments must be made and worn to supplement the laboratory measurements.

This cooperative study between the South Dakota and Minnesota stations, was undertaken to determine the effect of combining various amounts of reused wool with new wool upon the serviceability of wool flannels made of these two types of fiber. Since the wear life of a garment necessarily must include cleaning and aging as well as wear, the study was designed to measure the physical changes in these flannels which resulted from those three factors.

[1]Assistant Professor, textiles research in home economics, South Dakota Agricultural Experiment Station.
[2]Professor, textiles and clothing in home economics, Minnesota Agricultural Experiment Station.
[3]Formerly research assistant, textiles research in home economics, South Dakota Agricultural Experiment Station.

Description of the Materials

In order to obtain fabrics of known fiber blend, new and reused wools were bought, from which five flannels were manufactured of specified fiber content, as follows:

100 per cent new wool
75 per cent new wool plus 25 per cent reused wool
50 per cent new wool plus 50 per cent reused wool
25 per cent new wool plus 75 per cent reused wool
100 per cent reused wool

The fiber was purchased and the fabrics constructed by the Lowell Textile Institute. They were made with a four-shaft, even twill weave, weighed 11 to 12 ounces per linear yard of 54-inch width, and in all respects were similar to a commercial flannel of comparable type and weight. For convenient identification, each fabric was numbered according to the percentage of its new wool content; that is, the flannel which contained 100 per cent new wool was numbered "100" and that containing 0 per cent, "0."

The new wool fiber was white, undyed, and a blend of three parts 3/8 blood with two parts of "fine" wool. The reused wool, designated on the market as "old knits," likewise was "fine" in quality and was royal blue in color. Therefore fabric No. 100, made of 100 per cent new wool, was white, while fabrics No. 75, 50, 25, and 0 varied from light to dark blue as the amount of blue reused wool was increased and the amount of white new wool proportionately decreased. In order that the fabric and yarn properties might be studied before dyeing, the finished flannels were not dyed immediately. After they had been received at the laboratory, swatches were removed for study. The balance of the five materials were then sent to a commercial dye house and all were dyed navy blue.

Although all five fabrics were the same color after they had been dyed, it was not difficult to distinguish between them by visual observation and hand or handle. All new wool in No. 100 produced a soft smooth fabric, the weave was close and even, and there was practically no bow. With the addition of increased amounts of reused fiber the handle became less soft, the weave less regular, and the bow more pronounced. Fabric No. 0 was harsh to the touch, irregular in weave, and showed thin spots interspersed with thick matted areas. The bow was 6 per cent for this fabric. The extremes of these differences in appearance are shown in Fig. 1.

The Wear Study

Each of the five fabrics was made into plain, four-gore skirts which were worn by students at the South Dakota State College. This type of skirt was chosen to facilitate sampling and to avoid as far as possible localized wear due to details of construction and design. Nine such skirts were made from each of fabrics No. 100, 75, 50, and 25, but only

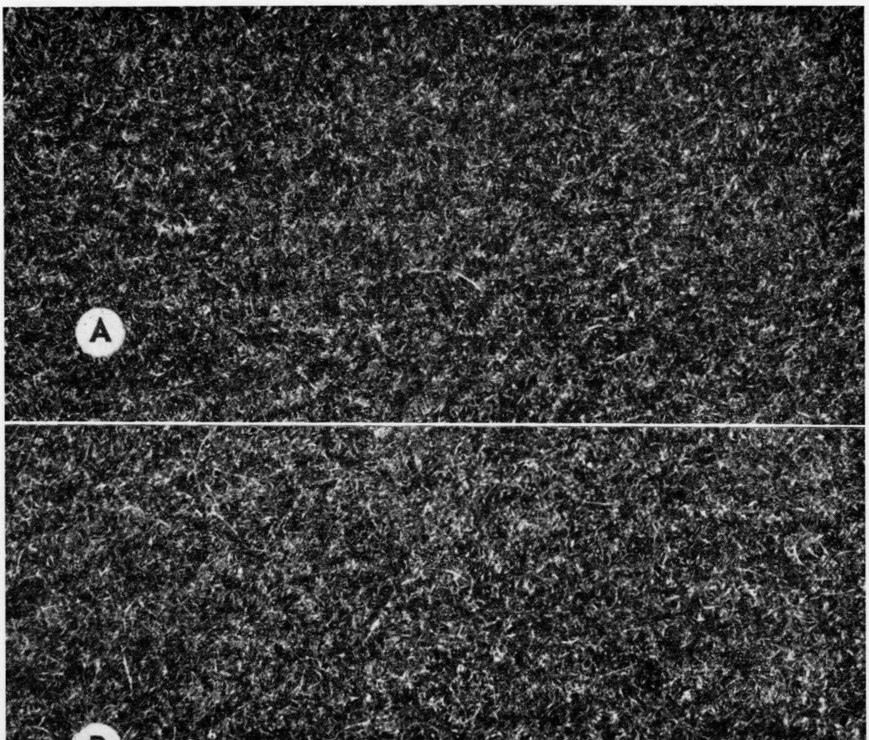


Fig. 1. The Dyed Fabrics
(A) 100 per cent new wool (B) 50 per cent new and 50 per cent reused wool
(C) 100 per cent reused wool

six garments were made from fabric No. 0 due to the smaller amount of material available. Three skirts from each of the first four fabrics were worn 1000 hours; three, 2000 hours; and three, 3000 hours. Fabric No. 0 was not subjected to 3000 hours of wear since only six garments were available.

After 200 hours of wear each garment was returned to the laboratory. It was then inspected for evidences of wear after which it was sent to a commercial dry cleaner. After dry cleaning it was again inspected and any necessary repairs were made before returning it to the wearer for another 200 hours of service. Records were kept by the wearer of the number of hours the garment was worn, type of activity during wear, and special care given, such as pressing, mending, and spot removal.

Three skirts of each fabric were used for every wear period so as to diminish any variation which might occur from individual wearing habits. Some of the skirts were worn by more than one individual, which also tended to decrease individual differences. Some of the girls left college before the wear period was over; others outgrew the garments; and for various other reasons many of the skirts had to be reassigned more than once.

During the time that the experiment was in progress, changes in fashion made it necessary to lengthen some of the skirts. For this purpose harmonizing plaids and checked flannels were purchased, bias bands of which were added to the bottom of the skirts which needed lengthening. This did not in any way alter the experimental fabrics themselves, but it did add interest to the garments and the skirts were worn for the remaining portions of the final wear period without protest.

Laboratory Procedures

In order to observe the effect of the dyeing process upon the new fabrics, swatches from each material were removed before and after dyeing. Measurements were made on these two sets, those for the dyed fabrics also being used as a basis for comparison with other measurements throughout the experiment. All statements of comparisons among the findings of this study have been verified by statistical analyses.

During the service life of a garment it is exposed to many conditions other than wear alone. To permit the measurement of some of these effects independently, three sets of control swatches were dry cleaned to parallel the dry cleaning of each of the three groups of skirts. Another set was laid aside and stored for the duration of the experiment. At the end of the first wear period 15 skirts, which had been worn 1000 hours, together with control swatches which had been dry cleaned five times, were sampled and laboratory measurements were made. Similar measurements were made at the end of the second wear period. When the third period had been completed, the stored swatches were measured together with the dry cleaned control samples and the worn fabrics. These measurements were used in making adjustments for the influence of storage and dry cleaning when determining the effect of wear alone.

The physical measurement of fabric and yarn properties, as well as the types of equipment used, conformed with methods established by the American Society for Testing Materials and The American Association of Textile Chemists and Colorists. All of these yarn and cloth measurements were made in the textiles laboratory at the University of Minnesota, where standard atmospheric conditions are maintained. Samples were cut from the same location in all skirts in order to be certain that like samples would fall within the same area for all garments.

The number of different measurements which could be made on a single skirt was limited. Only those properties which were expected to yield the most useful information concerning the effects of wear were selected. These are listed in Table 1.

Inasmuch as the quality of a fabric is the result of the combination of yarns, and they in turn are made of fibers, it was necessary to investigate the character of the yarns and fibers as well as that of the fabric. Yarn characteristics were measured for the new materials before and after dyeing, for the control swatches which were dry cleaned, and for

Table 1. Physical Characteristics of Undyed and Dyed New Wool Flannels

		Percentage of new wool in fabrics									
	Unit of	100		75		50		25		0	
Property measured	measure	W*	F†	W	F	W	F	W	F	W	F
Fabric count	No./in.										
Undyed		37.3	25.6	35.9	24.5	37.3	25.5	36.7	25.0	37.3	25.3
Dyed		37.2	27.6	36.6	26.4	36.6	27.1	36.7	26.9	35.4	26.8
Thickness	1/1000 inch										
Undyed		51.8		50.9		52.2		53.7		52.6	
Dyed		44.8		45.0		46.0		45.2		44.8	
Weight per sq. yd.	ounces										
Undyed		8.2		8.0		8.2		8.1		7.7	
Dyed		9.3		9.0		9.0		8.8		7.8	
Breaking strength‡	pounds										
Undyed		34.2	17.7	25.4	13.2	22.6	11.6	18.1	10.4	14.4	6.8
Dyed		32.6	17.6	23.2	12.2	20.4	12.3	17.6	10.9	14.4	7.5
Bursting strength§	pounds										
Undyed		63.2		47.4		44.0		38.4		26.0	
Dyed		63.7		49.6		47.3		42.0		32.8	
Breaking elongation‡	per cent										
Undyed		25.3	37.3	22.7	38.3	23.0	41.7	20.3	40.7	16.3	40.0
Dyed		28.0	35.0	24.3	35.7	23.3	35.7	23.3	36.3	19.7	32.3
Bursting elongation§	per cent										
Undyed		28.6		26.3		24.0		24.0		24.0	
Dyed		40.0		32.6		25.1		24.6		22.3	

*Warpwise
†Fillingwise
‡Raveled strip method.
§Steel ball method.

those which were stored. Samples of fiber, both new and old, were studied to determine length (4),[4] diameter (5), contour index, and evidences of fiber damage (8).

Ten replicate samples were used for all fabric and yarn measurements with the exception of yarn strength and elongation, for which 50 determinations were made. Five and six hundred fibers were used for each of the fiber measurements.

The Effect of Dyeing

The dyeing process resulted in some changes (Table 1). The effects of tension on the warps during weaving are removed by the thorough wetting involved in dyeing. The consequent shrinkage of warp yarns pulled the fillings closer together and increased the filling count. In addition, in fabric No. 0, the filling yarns actually stretched so that the warp count was decreased. The undyed fabrics had come directly from the decating process, hence the decreases in thickness may have resulted from pressing after dyeing. Increases in weight were highest for fabric No. 100 and became less as the percentage of new wool decreased. Further, the unchanged weight of No. 0 after dyeing could be expected, since the increase in number of fillings per inch was practically balanced by the decrease in number of warps.

Also following dyeing, the warpwise breaking strength decreased in the three fabrics having the greatest proportions of new wool. At the same time bursting strength increases after dyeing became greater as the proportion of reused wool increased. Measurements of fabric elongation which were associated with breaking strength showed marked increases in the fillingwise direction for the fabrics containing the largest proportions of reused wool. In the warpwise direction all of the fabrics gained in elongation after dyeing. Measurements of elongation made when a bursting force was applied showed increases after dyeing for all of the fabrics which contained new wool, while fabric No. 0 showed a decrease. These increases in elongation which resulted from dyeing dropped steadily as the proportion of new wool was decreased. Dyeing appears to have been responsible for some changes in fabric properties when comparing the undyed and dyed fabrics.

Properties of the Dyed Fabrics Before Wearing

It was intended that all five fabrics should vary only in fiber content, and that fabric count and yarn number should be as nearly alike as possible. In the finished materials both of these properties closely approached these specifications (Tables 1 and 8).

Many of the laboratory measurements supported observations of differences in hand and in appearance which have been discussed. The averages for thickness measurements did not show differences among the

[4]Figures in parentheses refer to "Literature Cited."

five fabrics. However, when examining individual values for each of the fabrics studied, greater variation among thickness measurements was found for No. 0 than for No. 100, where little variation among these measurements was observed.

Weight tended to decrease somewhat as the proportion of new wool decreased, flannel No. 0 being 1.5 ounces per square yard lighter in weight than No. 100. This appears to have been due to the greater loss of fiber during manufacture which is characteristic of reused wool.

Both breaking and bursting strength decreased with increased reused wool content. These changes are especially marked in the case of bursting strength. As shown in Fig. 2, the greatest losses in strength were found when comparing the 100 per cent new wool fabric with those fabrics containing reused wool. Increasing reused wool content diminished warpwise breaking and bursting elongation (see Fig. 3). Fillingwise elongation measurements did not vary with the exception of that for the No. 0 fabric.

Among the dyed fabrics, thickness, weight, strength and elongation values tended either to be more variable or to decrease as the proportion of reused wool increased.

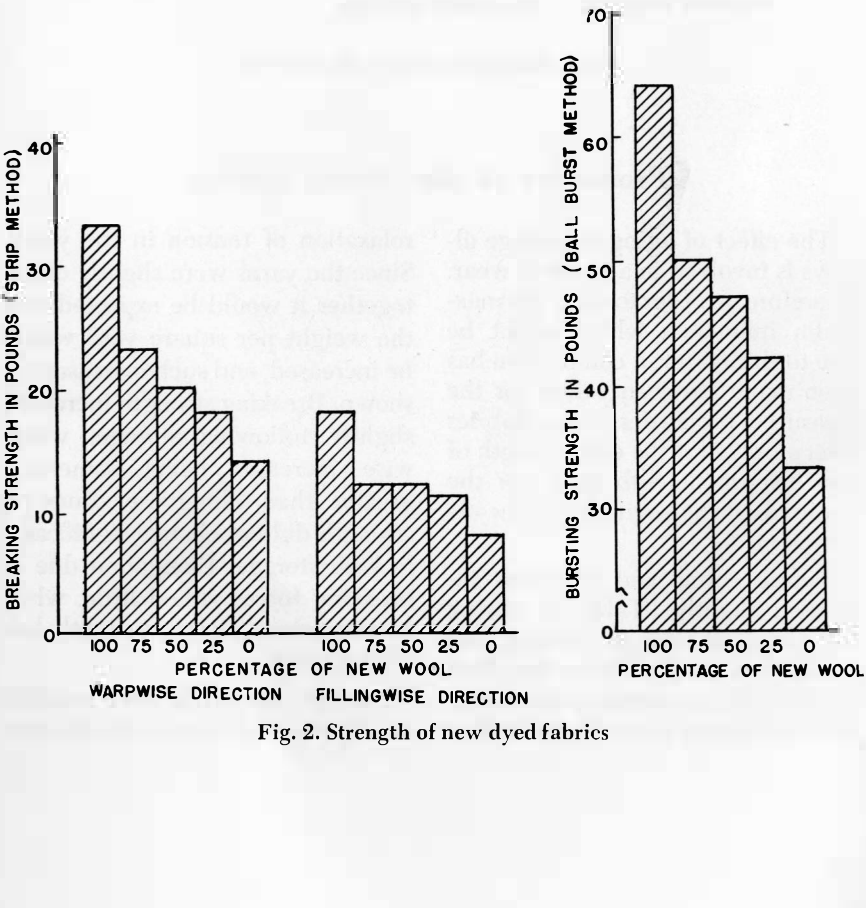


Fig. 2. Strength of new dyed fabrics

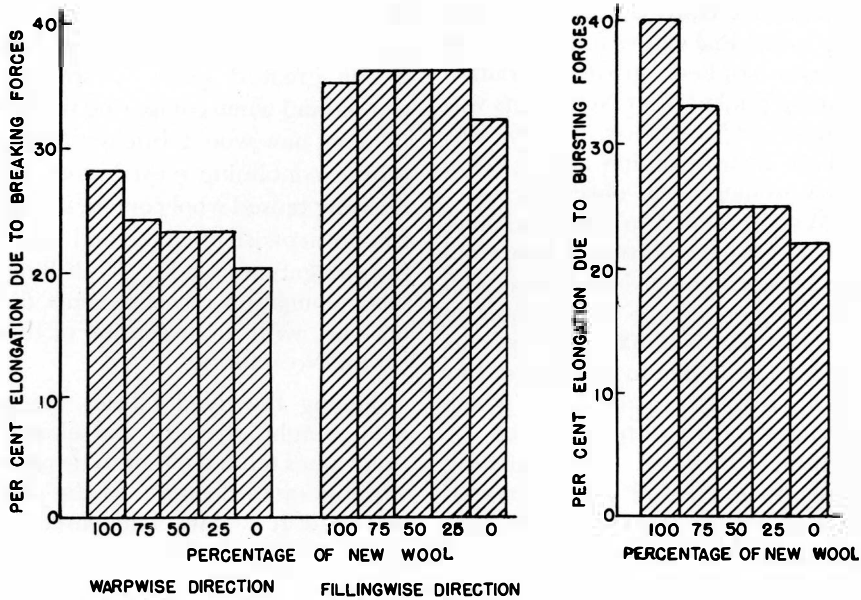


Fig. 3. Elongation of new dyed fabrics

Properties of the Stored Fabrics

The effect of aging or storage always is involved in a study of wear. Therefore, in order to show the maximum influences which might be due to this factor, a comparison has been made between values for the measured properties of the fabrics after storage for the entire length of the experiment with those for the materials at the beginning of the experiment.

Fabric count and thickness increased slightly (Table 2) during the period of storage. Possibly this could have resulted from the effect of atmospheric moisture, which may have facilitated somewhat a further relaxation of tension in the yarns. Since the yarns were slightly closer together it would be expected that the weight per square yard would be increased, and such increases are shown. Breaking strength increased slightly following storage, warpwise increases being somewhat greater than fillingwise. Bursting strength did not change significantly with storage. Elongation due to breaking forces varied little, while bursting elongation was slightly less after storage.

Storage appears to have resulted in only minor changes in the fabrics.

Table 2. Physical Characteristics of Flannels after Storage Alone

Property measured	Unit of measure	Percentage of new wool in fabrics: 100	75	50	25	0
Fabric count	no./inch					
Warps		37.6	37.3	37.5	37.4	36.9
Fillings		27.9	26.8	27.4	28.4	26.6
Thickness	1/1000 in.	49.2	48.7	49.5	48.5	49.2
Weight per sq. yd.	ounces	9.5	9.3	9.2	8.9	8.0
Breaking strength*	pounds					
Warpwise		33.2	24.6	21.5	18.6	13.8
Fillingwise		17.4	13.1	13.2	11.0	8.1
Bursting strength†	pounds	63.7	46.9	46.5	42.7	36.6
Breaking Elongation*	per cent					
Warpwise		24.0	23.0	25.7	22.7	19.7
Fillingwise		31.7	34.0	38.7	36.3	38.0
Bursting elongation†	per cent	23.4	22.9	22.3	22.3	26.9

*Raveled strip method.
†Steel ball method.

Table 3. Physical Characteristics of Flannels after Dry Cleaning

Property measured	Unit of measure	No. of cleanings	100 W*	100 F†	75 W	75 F	50 W	50 F	25 W	25 F	0 W	0 F
Fabric count	no./inch	5	36.7	29.0	36.6	27.8	37.5	27.5	37.2	28.3	36.1	27.1
		10	36.0	29.3	36.4	27.8	36.4	28.3	37.0	28.4	35.7	27.1
		15	36.6	28.9	36.8	27.5	37.7	28.1	37.1	28.4	—	—
Thickness	1/1000 in.	5	50.7		49.9		51.0		49.5		49.2	
		10	49.6		50.1		49.5		48.6		46.6	
		15	51.9		51.8		52.7		50.7		—	
Weight per sq. yd.	ounces	5	9.5		9.0		8.9		8.7		7.8	
		10	10.0		9.5		9.6		9.2		7.8	
		15	9.7		9.3		9.4		8.9		—	
Breaking strength‡	pounds	5	31.8	18.7	23.0	13.3	20.8	12.2	17.2	10.6	13.2	7.4
		10	30.6	19.2	23.4	13.7	21.3	13.4	17.8	12.0	12.5	8.3
		15	34.3	20.2	25.3	12.8	22.2	12.7	19.6	11.8	—	—
Bursting strength§	pounds	5	63.2		47.8		45.0		40.0		31.8	
		10	63.0		47.8		46.7		41.4		30.8	
		15	60.1		48.6		48.1		43.0		—	
Breaking elongation‡	per cent	5	29.0	36.0	24.7	36.0	23.0	35.3	21.7	34.7	20.0	33.0
		10	29.3	38.0	27.7	41.0	25.3	42.7	24.7	43.3	23.3	39.7
		15	31.0	35.0	26.7	33.0	23.0	29.7	23.0	32.7	—	—
Bursting elongation§	per cent	5	22.3		21.7		24.0		21.1		20.0	
		10	21.7		18.3		19.4		19.4		18.3	
		15	36.6		28.6		22.9		18.3		—	
Shrinkage	per cent	5	3.17	+1.22	3.27	+0.72	2.35	+1.25	1.96	+0.49	2.73	+2.50
		10	3.21	+1.05	2.85	+0.30	2.41	+0.80	2.00	+0.08	2.63	+3.30
		15	3.54	+0.16	2.90	0.06	3.05	+0.74	3.44	+1.89	—	—

*Warpwise
†Fillingwise
‡Raveled strip method.
§Steel ball method.

Properties of the Dry Cleaned Fabrics

The dry cleaning process itself might be a source of part of the differences observed for the fabrics which were worn and dry cleaned. Comparing measurements for fabrics which have been dry cleaned only (Table 3) with those for new fabrics, it is observed that fabric count decreases slightly in the warpwise direction and increases somewhat in the fillingwise direction. Dimensional changes also followed dry cleaning and included some cases of shrinkage and some where stretching occurred. It is possible that changes in fabric count resulted from changes in dimensional stability.

Since the dry cleaned swatches showed evidence of shrinkage, it is to be expected that thickness would increase and such was the case. The plus values for these data in Table 4 indicate that the dry cleaned values were higher than those for the new fabric. Numbers 100, 75, and 50 gained four to seven thousandths of an inch in thickness; No. 25 gained three to six thousandths, and No. 0, two to four thousandths of an inch. Weight likewise increased for the fabrics with large proportions of

Table 4. Changes Due to Dry Cleaning as Shown by Comparison of Values for New and Dry Cleaned Fabrics (Gains Indicated by +)

Property measured	Unit of measure	No. of cleanings	Percentage of new wool in fabrics 100	75	50	25	[illegible]
Thickness	1/1000 in.	5	+ 5.9	+ 4.9	+5.0	+4.3	+4.4
		10	+ 4.8	+ 5.1	+3.5	+3.4	+1.8
		15	+ 7.1	+ 6.8	+6.7	+5.5	—
Weight per sq. yd.	ounces	5	+ 0.2	0.0	−0.1	−0.1	0.0
		10	+ 0.7	+ 0.5	+0.6	+0.4	0.0
		15	+ 0.4	+ 0.3	+0.4	+0.1	—
Breaking strength*	pounds						
Warpwise		5	− 0.8	− 0.2	+0.4	−0.4	−1.2
		10	− 2.0	+ 0.2	+0.9	+0.2	−1.9
		15	+ 1.7	+ 2.1	+1.8	+2.0	—
Fillingwise		5	+ 1.1	+ 1.1	−0.1	−0.3	−0.1
		10	+ 1.6	+ 1.5	+1.1	+1.1	+0.8
		15	+ 2.6	+ 0.6	+0.4	+0.9	—
Bursting strength†	pounds	5	− 0.5	− 1.8	−2.3	−2.0	−1.0
		10	− 0.7	− 1.8	−0.6	−0.6	−2.0
		15	− 3.6	− 1.0	+0.8	+1.0	—
Breaking elongation*	per cent						
Warpwise		5	+ 1.0	+ 0.4	−0.3	−1.6	+0.3
		10	+ 1.3	+ 3.4	+2.0	+1.4	+3.6
		15	+ 3.0	+ 2.4	−0.3	−0.3	—
Fillingwise		5	+ 1.0	+ 0.3	−0.4	−1.6	+0.7
		10	+ 3.0	+ 5.3	+7.0	+7.0	+7.4
		15	0.0	− 2.7	−6.0	−3.6	—
Bursting elongation†	per cent	5	−17.7	−10.9	−1.1	−3.5	−2.3
		10	−18.3	−14.3	−5.7	−5.2	−4.0
		15	− 3.4	− 4.0	−2.2	−6.3	—

*Raveled strip method.
†Steel ball method.

new wool, but remained constant for those with the lowest percentages of new wool.

Changes in fabric count and thickness could influence strength to some extent. Breaking strength values show increases and decreases. Some losses of strength occur in the first few dry cleanings, but apparently increases in shrinkage associated with continued dry cleaning cause increases in fabric count, and consequently increased strength. Again, those blends having the largest proportions of reused wool showed little change in properties.

The elongation associated with strip strength showed numerous gains after dry cleaning, but elongation resulting from bursting forces showed a definite loss in all cases.

During dry cleaning some small increases in thickness, weight, breaking strength, and elongation have been observed. In numerous cases these appear to have been less marked for those fabrics with larger proportions of reused wool. In contrast, elongation due to bursting forces showed marked losses.

Properties of the Worn Fabrics

Common experience tells that wear will cause changes in the properties of fabrics and such are shown to have occurred during the wear life of these flannels (Table 5). Although the three skirts of each group were worn by different girls, no significant difference was found among replicate skirts for any of the physical properties measured.

Thickness measurements for the worn fabrics varied little among the four materials containing new wool. After the first wear period, values for the worn fabrics were greater than those for the new dyed materials. These increases could have resulted from differences in the pressing processes used. When a piece of flannel many yards in length is pressed, the method used applies a pressure which is considerably greater than that exerted when an individual garment is pressed. As wear proceeded, fabrics No. 100, 75, 50, and 25 all decreased in thickness at approximately the same rate, while No. 0, which was thinner at the beginning of the study, had suffered a marked loss by the end of the second wear period.

Weight measurements were similar for the four fabrics containing new wool, but No. 0 weighed less than the other four. With increased amounts of wear the fabrics showed small losses in weight, varying from 0.2 ounces per square yard for No. 100 to 1.3 ounces for No. 0 after the final wear periods.

The strength of these flannels diminished markedly with each decrease in new wool content (see Fig. 4). This was true for both breaking and bursting strength (Fig. 5). At the end of the final wear periods those fabrics containing less than 50 per cent of new wool showed losses in strength. This decrease was evident in the values for bursting strength for all five fabrics. However, fabric No. 100 showed remarkably little change due to wear and dry cleaning. Although all of the

Table 5. Physical Characteristics of Worn Flannels

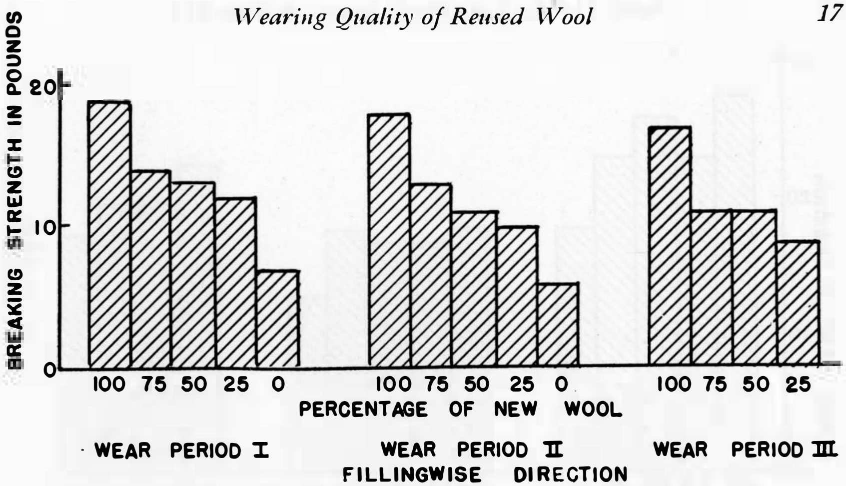
			Percentage of new wool in fabrics									
	Unit of		100		75		50		25		0	
Property measured	measure	Period	W*	F†	W	F	W	F	W	F	W	F
Fabric count	no./in.	I	37.3	28.2	37.1	27.2	37.2	27.8	37.2	27.9	35.3	26.2
		II	36.7	28.6	36.2	27.3	37.1	28.1	37.3	28.3	34.9	26.6
		III	37.0	28.5	36.9	27.3	37.0	27.9	37.0	28.2	—	—
Thickness	1/1000 in.	I	49.5		49.2		49.7		48.3		45.8	
		II	48.4		47.6		46.5		46.1		40.2	
		III	46.5		46.0		46.2		44.5		—	
Weight per sq. yd.	ounces	I	9.4		8.9		9.0		8.6		7.4	
		II	9.4		9.0		8.8		8.6		6.5	
		III	9.1		8.6		8.4		8.2		—	
Breaking strength‡	pounds	I	33.1	19.4	24.1	13.8	21.4	13.2	18.5	11.6	12.4	7.2
		II	31.9	18.0	22.8	12.9	19.6	11.1	16.4	10.2	11.0	5.5
		III	32.4	17.3	22.6	11.1	20.8	11.0	16.5	9.0	—	—
Bursting strength§	pounds	I	61.0		46.9		45.2		40.2		27.6	
		II	60.1		44.5		38.2		34.5		18.4	
		III	59.7		42.6		39.9		31.7		—	
Breaking elongation‡	per cent	I	28.2	35.9	26.4	45.7	24.8	47.4	23.9	47.6	22.7	42.3
		II	29.5	35.6	26.3	40.1	25.5	41.3	22.7	40.8	18.1	26.7
		III	29.7	32.6	23.4	29.4	22.8	31.6	19.7	30.1	—	—
Bursting elongation§	percent	I	28.0		22.7		25.9		23.2		18.1	
		II	17.5		17.3		17.0		17.5		12.6	
		III	22.7		20.4		19.8		17.7		—	

*Warpwise. ‡Raveled strip method.
†Fillingwise. §Steel ball method.

skirts were still wearable, most of them were at the point where they probably would have been discarded for their shabby appearance, under usual conditions. Many of the waist bands had holes where they fastened, and for No. 0, one waist band needed replacement before the end of the second wear period (Fig. 6).

Warpwise elongation values (see Fig. 7), as well as strength values, showed definite decreases when the amount of new wool was decreased. During the wear life of the garments these elongation values exhibited a downward trend for fabrics with less than 50 per cent new wool and for all five in the filling-wise direction. Flannel No. 0 showed a marked drop in elongation. Furthermore this fabric tore easily, which could result not only from lack of ability to stretch but also from its lower residual strength.

Wear combined with dry cleaning can be said to have resulted in progressive losses in strength and elongation as the proportion of reused wool increased. Successive increments of wear and dry cleaning resulted in decreased thickness and weight for fabric 0; decreased bursting strength for all fabrics containing reused wool; and decreased elongation for all five materials after the first wear period.



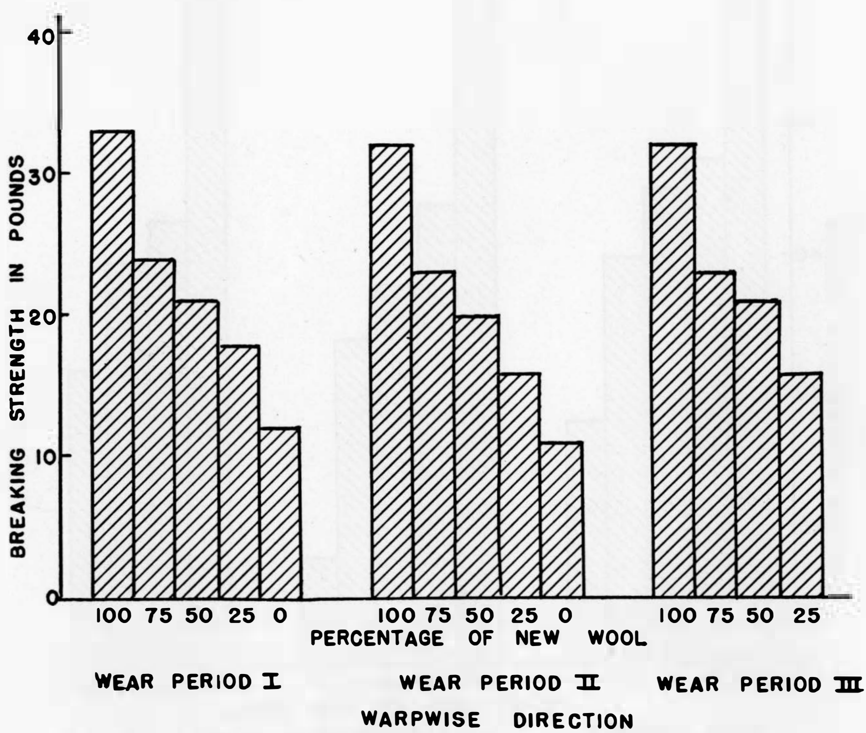


Fig. 4. Breaking strength of fabrics after wear and dry cleaning

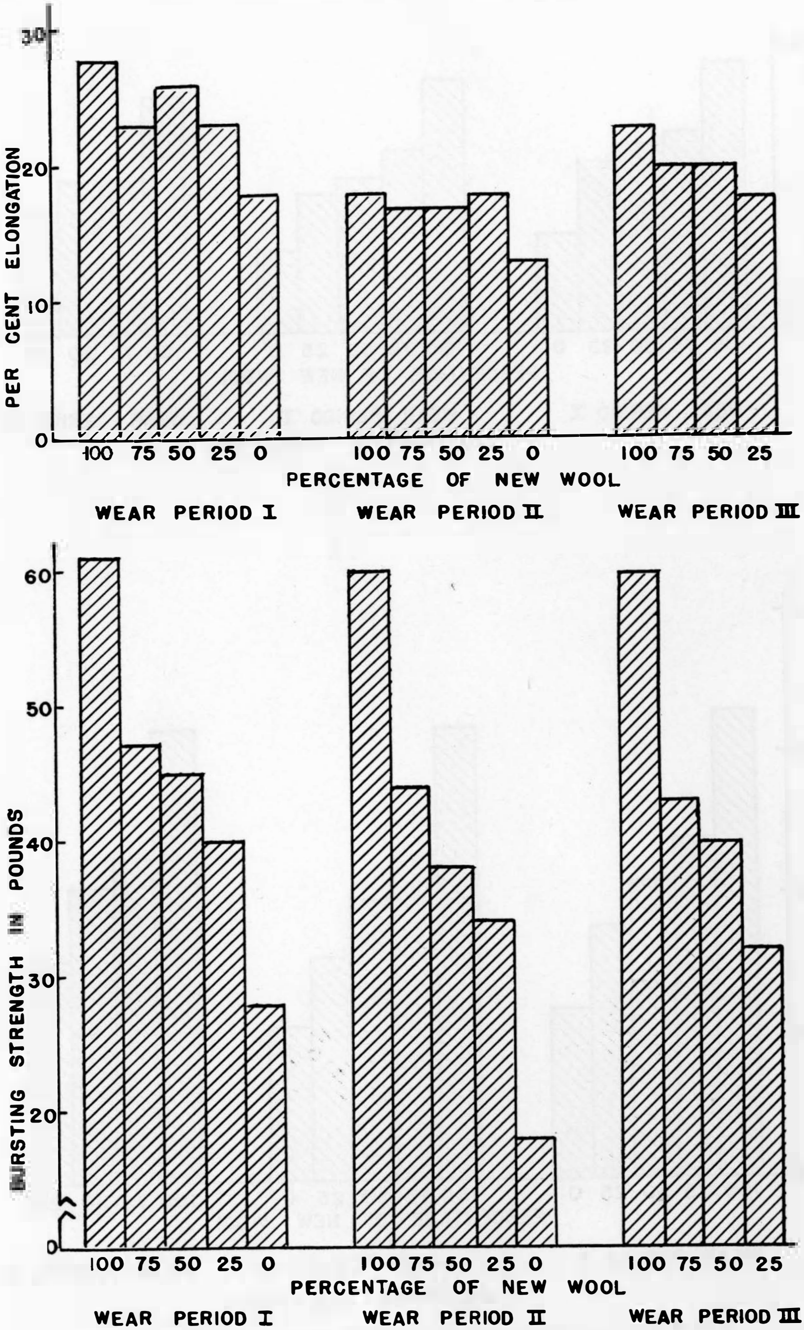


Fig. 5. Bursting strength and elongation due to bursting forces of worn fabrics

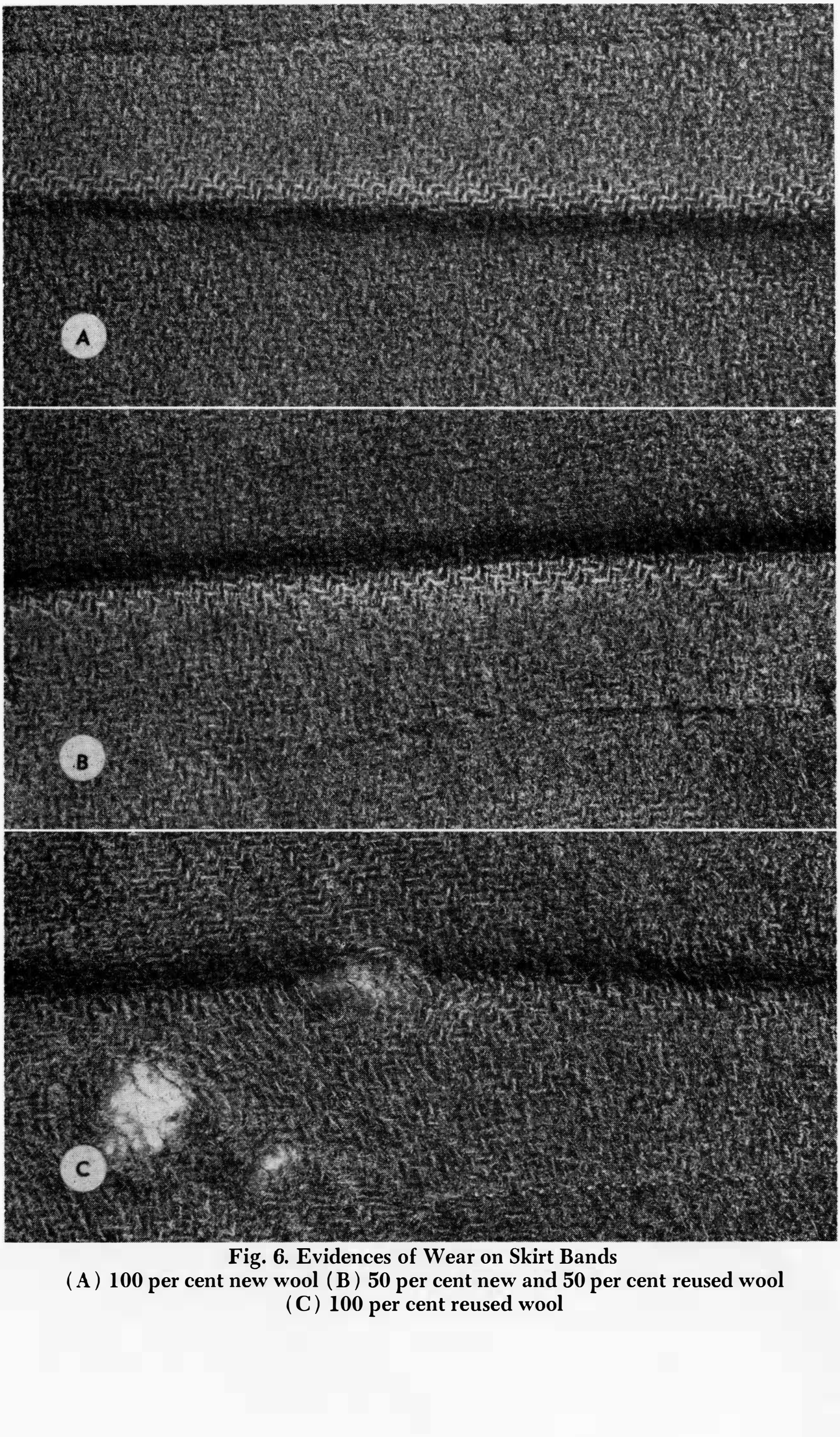


Fig. 6. Evidences of Wear on Skirt Bands
(A) 100 per cent new wool (B) 50 per cent new and 50 per cent reused wool
(C) 100 per cent reused wool

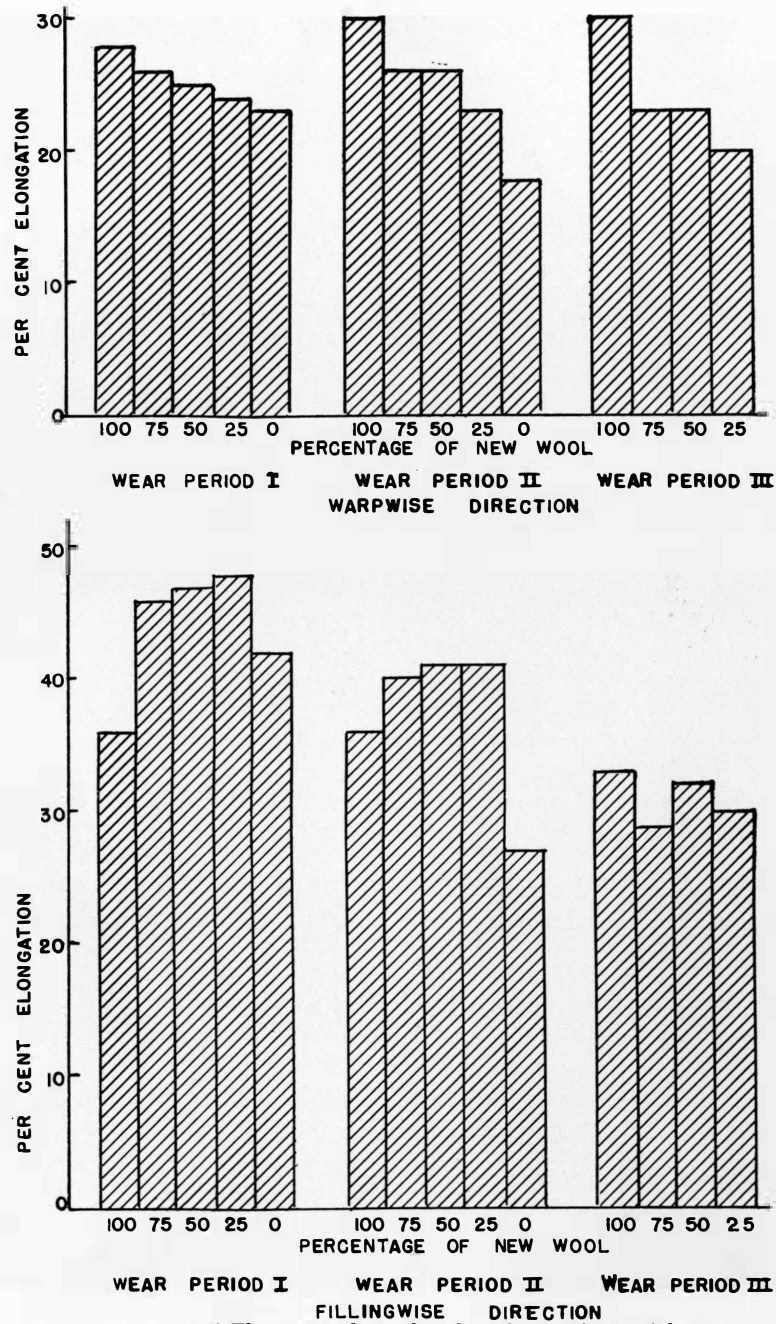


Fig. 7. Elongation due to breaking forces of worn fabircs

The Effect of Wear Alone

Values for fabric characteristics vary considerably even when measurements are made side by side on the same piece of cloth; therefore samples were scattered as far as possible over the entire area of the fabric so as to arrive at a mean value which would be as representative of the whole as possible. Despite every precaution the increases and decreases found do not always travel consistently in the same direction. However, by subtracting values for the worn and dry cleaned fabrics from those for fabrics which were dry cleaned only, the difference can be attributed to the effects of wear alone (Table 6).

Wear apparently was responsible for decreases in thickness varying from one to 6½ thousandths of an inch. The maximum loss in fabric No. 50 represents about 14 per cent of its original thickness. A marked loss in thickness for fabric No. 0 occurred after the first and second wear periods, while similar losses were observed for the four other fabrics after the third wear period. Losses of weight which can be attributed to wear were, in general, small. However, the maximum loss observed in fabric 0 after the second wear period represents a decrease of about 17 per cent.

The changes in breaking strength due to wear alone include both increases and decreases. While the five fabrics do not differ greatly with respect to loss of strength due to this factor, there was a general tendency toward decreasing strength with increasing length of service in both warpwise and fillingwise directions. The greatest change in bursting strength due only to wear is shown for fabric No. 0, although differences for fabrics 75, 25, and 0 indicate increased losses which were associated with increased wear.

After the first wear period the worn fabrics apparently stretched with greater ease than did the corresponding dry cleaned materials. The increases in breaking elongation tend to accompany increased proportions of reused wool after the first wear period. However, with increasing amounts of service, losses in extensibility are evident. The maximum loss was recorded for fabric 0 after the second wear period and in this case amounted to 26 per cent of the extensibility of the new dyed material warpwise, 40 per cent fillingwise.

Likewise, when subjected to bursting forces, all the worn fabrics show increased extensibility after the first wear period, with the exception of fabric 0. At the same time there appears to be some tendency for increasing losses in this type of elongation to be associated with increasing wear. The greatest losses after the first and second wear periods were found for fabric 0, but neither of these was as great as that suffered by the 100 per cent fabric after the third wear period.

The effects of wear alone therefore obviously are increased by increased duration of service, as would be expected. Also, in general, they appear to be increased by increasing proportions of reused wool.

Table 6. Losses Due to Wear Alone as Shown by Comparison of Values for Worn and Dry Cleaned Fabrics with Values for Fabrics Dry Cleaned Alone (Gains Indicated by +)

Property measured	Unit of measure	Period	Percentage of new wool in fabrics 100	75	50	25	0
Thickness	1/1000 in.	I	1.2	0.7	1.3	1.2	3.4
		II	1.2	2.5	3.0	2.5	6.4
		III	5.4	5.8	6.5	6.2	—
Weight per sq. yd.	ounces	I	0.1	0.1	+ 0.1	0.1	0.4
		II	0.6	0.5	0.8	0.6	1.3
		III	0.6	0.7	1.0	0.7	—
Breaking strength*	pounds						
Warpwise		I	+ 1.3	+1.1	+ 0.6	1.3	0.8
		II	+ 1.3	0.6	1.7	1.4	1.5
		III	1.9	2.7	1.4	3.1	—
Fillingwise		I	+ 0.7	+0.5	+ 1.0	+ 1.0	0.2
		II	+ 0.2	0.8	2.3	1.8	2.8
		III	2.9	1.7	1.7	2.8	—
Bursting strength†	pounds	I	2.2	0.9	+ 0.2	+ 0.2	4.2
		II	2.9	3.3	8.5	6.9	12.4
		III	0.4	6.0	8.2	11.3	—
Breaking elongation*	per cent						
Warpwise		I	0.8	+1.7	+ 1.8	+ 2.2	+ 2.7
		II	+ 0.2	1.4	+ 0.2	2.0	5.2
		III	1.3	3.3	0.2	3.3	—
Fillingwise		I	0.1	+9.7	+12.1	+12.9	+ 9.3
		II	2.4	0.9	1.4	2.5	13.0
		III	2.4	3.6	+1.9	2.6	—
Bursting elongation†	per cent	I	+5.7	+1.0	+ 1.9	+ 2.1	1.9
		II	4.2	1.0	2.4	1.9	5.7
		III	13.9	8.2	3.1	0.6	—

*Raveled strip method.
†Steel ball method.

Effect of Light

Exposure to light has been shown, in a previous report (6), to cause marked decreases in the strength of wool serge. It was not possible to keep a record of the number of hours the skirts actually were exposed to sunlight. However, the effect of light upon these five flannels can be shown after exposure of control swatches to light from an electric arc with a spectrum similar to that of sunlight.

As would be anticipated, the fabrics definitely declined in breaking strength and elongation (Table 7) with increasing exposure to light. Maximum losses occurred after 120 and 200 hours of exposure. After 680 hours, all of these fabrics had lost from 80 to 90 per cent of their original strength. Comparing these results with those noted at the end of the final wear period, it is evident that the residual strength for fabrics

No. 100 and 75, after 3000 hours of wear, is approximately equal to the strength of the same after exposure to light for 80 hours. The residual strength of worn fabrics No. 50, 25, and 0 is approximately equal to the strength values for these same fabrics after exposure to light for 120 hours.

The effect of light also varied with the fiber composition (Fig. 8). As the percentage of reused wool increased breaking strength values tended to decrease after each period of exposure. Also the rate of these decreases diminished as the duration of exposure increased.

The most marked decrease in elongation occurred after exposure to this light for 200 hours. At the end of 680 hours exposure the fabrics had lost from 74 to 80 per cent of their original extensibility. Elongation values tended to decrease as the percentage of new wool decreased (Fig. 9), but this trend was more marked before 200 hours exposure to light than after.

Although a definite portion of the losses in strength which occurred during the service life of these garments cannot be assigned to the effect of light, it is evident that light did contribute to a decrease in fabric strength and elongation, and that these decreases were associated with a decreased percentage of new wool.

Table 7. Effect of Exposure to Light for New Dyed Flannels

Property measured	Unit of measure	Hours of exposure	Percentage of reused wool in fabrics 100	75	50	25	0
Breaking strength*	pounds	unexposed	32.6	23.2	20.4	17.6	14.4
		40	34.1	22.3	23.1	18.6	14.5
		80	32.5	22.0	22.1	19.3	13.2
		120	28.0	20.6	19.9	16.3	12.4
		200	19.2	15.8	15.8	14.7	7.3
		320	14.2	8.2	9.8	8.0	5.0
		480	8.8	6.8	5.6	5.0	5.1
		680	5.5	4.7	2.4	3.1	1.4
Percentage loss after		680 hrs.†	83	80	88	82	90
Breaking elongation*	per cent	unexposed	28.0	24.3	23.3	23.3	19.7
		40	28.0	24.0	22.7	22.0	17.3
		80	24.7	21.3	21.3	19.3	14.0
		120	18.0	17.3	18.0	16.7	13.3
		200	10.0	12.0	12.7	12.7	7.4
		320	7.3	8.0	10.0	8.7	6.7
		480	8.7	8.0	9.3	8.0	6.7
		680	7.3	6.0	6.0	5.3	4.0
Percentage loss after		680 hrs.†	74	75	74	77	80

*Raveled strip method.
†Percentage loss based on values for new dyed fabrics.

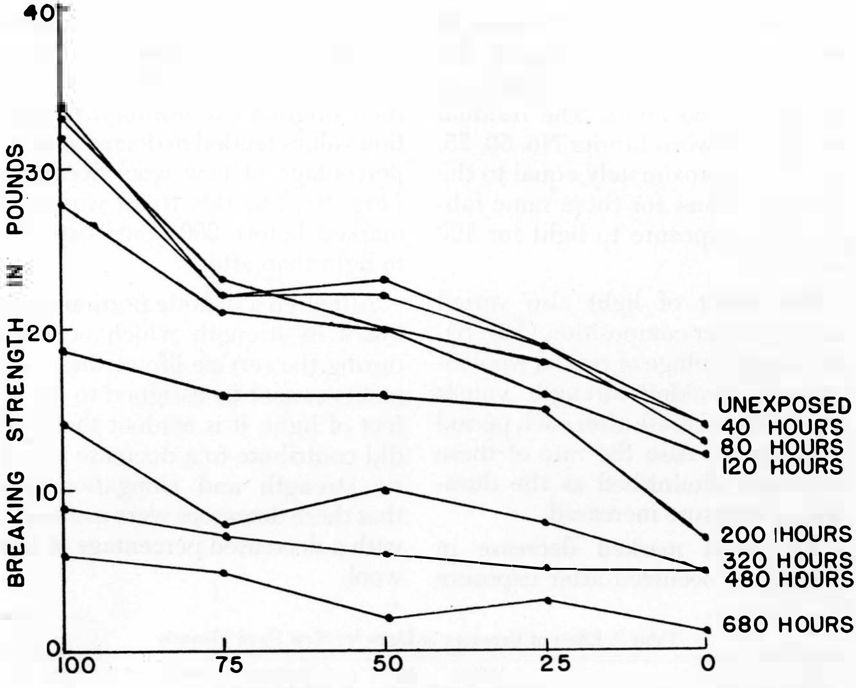


Fig. 8. Breaking strength of fabrics after exposure to light

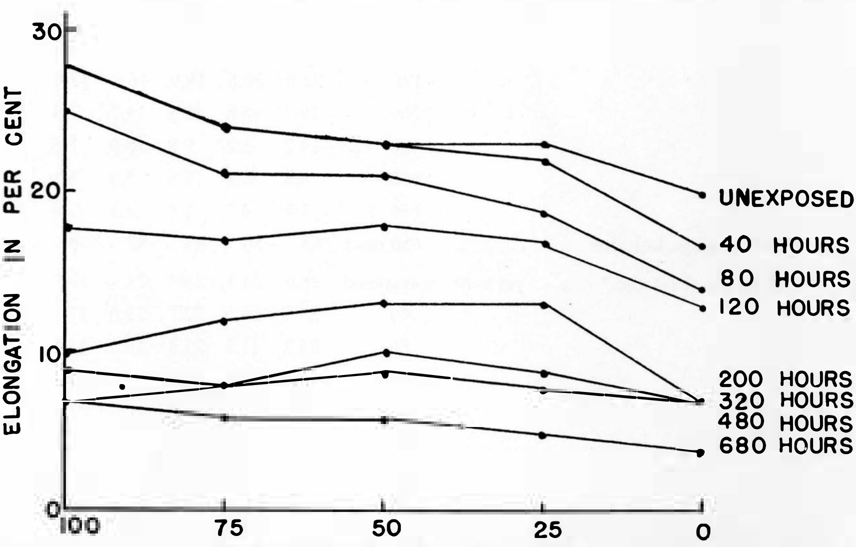


Fig. 9. Elongation due to breaking forces of fabrics after increasing exposure to light

The Character of the Yarns

The five flannels of varying fiber composition have been shown to have numerous differences in physical characteristics. Similar variation in the properties of the yarns therefore are to be expected and mean values recorded in Table 8 show such differences.

Although an effort was made to manufacture yarns as nearly alike as possible, yarn number measurements indicate that the addition of reused wool tended somewhat to result in yarns of decreasing size. The filling yarns were slightly coarser than the warps.

Twist also varied slightly with fiber blend, the yarns made of all new fiber having fewer twists per inch than those containing reused wool. Filling yarns had two or three more twists per inch than the corresponding warp yarns.

Yarn strength measurements (Fig. 10) show that, just as for fabrics, an increase in the amount of reused wool results in lower strength values. This trend is more marked for the warp yarns than for the fillings, due to the fact that the warp yarns are stronger than the corresponding filling yarns, and that this difference becomes less as the amount of new wool decreases.

Not only does the new wool provide more strength, but it also imparts greater elongation to the yarn. Increases in the proportion of reused wool are associated with lower values for elongation under stress. On the whole, the filling yarns showed a slightly greater extensibility than the corresponding warp yarns.

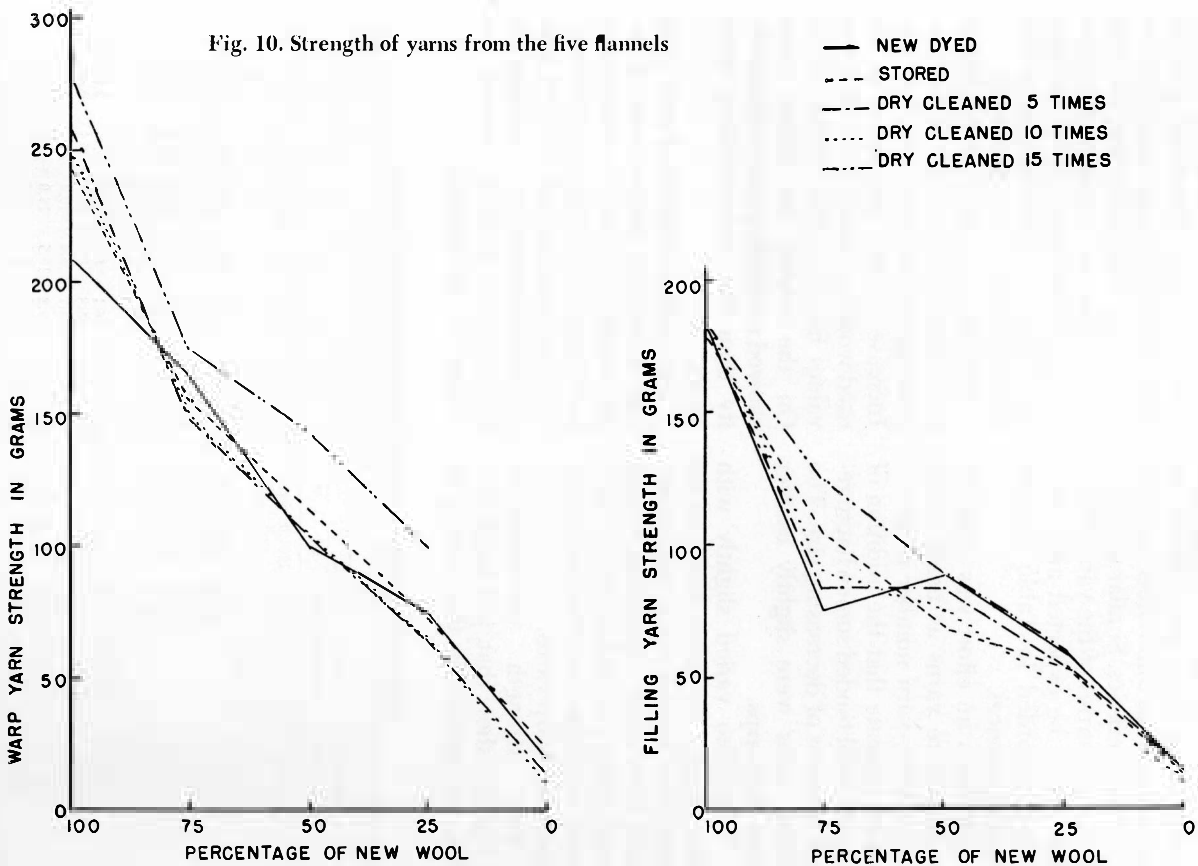
Decreasing amounts of new wool and increasing proportions of reused wool have been shown to have been accompanied by small increases in yarn number and twist, by substantial decreases in yarn elongation under stress, and by marked decreases in yarn strength.

Table 8. Physical Characteristics of the Yarns from the Flannels

Property measured	Unit of measure	Percentage of new wool in fabrics: 100 W*	100 F†	75 W	75 F	50 W	50 F	25 W	25 F	[illegible] W	[illegible] F
Number	grex	997.8	1101.0	991.0	1083.0	925.8	1089.6	912.7	1055.6	841.6	889.2
Twists	no./in.	12.1	14.2	13.8	16.4	14.0	17.4	14.6	17.4	15.2	16.8
Strength	grams										
Undyed		282.1	180.5	171.7	111.1	109.1	79.6	81.9	54.6	16.7	12.2
Dyed		209.7	186.9	164.9	74.9	99.9	89.1	77.4	59.3	20.9	14.7
Stored		243.0	180.9	154.4	105.6	115.4	70.2	73.4	53.7	23.6	16.2
DC 5x‡		258.7	187.0	150.1	86.8	104.4	85.5	67.1	53.6	16.9	17.3
DC 10x		250.2	185.0	147.8	91.0	103.7	75.6	64.8	44.5	10.5	9.1
DC 15x		282.3	186.6	176.1	123.4	147.4	88.3	97.7	59.8	—	—
Elongation	per cent										
Undyed		17.9	22.4	15.0	17.9	11.3	16.1	8.8	10.9	2.4	2.0
Dyed		15.8	20.8	15.3	17.6	12.4	16.8	10.8	15.0	6.1	10.4
Stored		15.3	16.3	12.5	14.0	11.1	13.1	8.4	10.2	4.3	6.3
DC 5x		18.2	19.4	14.7	17.6	11.1	15.8	10.5	15.0	8.4	12.8
DC 10x		15.1	15.9	11.5	12.4	10.2	13.1	8.1	9.4	3.6	4.3
DC 15x		19.0	17.0	13.7	13.5	11.7	10.9	8.5	9.7	—	—

*Warpwise.
†Fillingwise.
‡Dry cleaned 5 times.

Fig. 10. Strength of yarns from the five flannels



The Character of the Fiber

All five flannels were designed to be as nearly identical as possible with the exception of fiber content. This being a fundamental difference, the physical characteristics of these two groups of fibers were studied. Five hundred fibers were measured in each instance with the exception of the fiber length of the reused wool, for which 600 measurements were made. Group means, recorded in Table 9, show that the new wool fiber was approximately one-half inch longer than the reused fiber. From the distribution of fiber length, shown in Fig. 11, it is evident that the modal length of the new fiber is likewise one-half inch longer than that of the reused wool. Also it may be seen that about half of the reused fibers fall in the 0 to 1½ inch groups, while only 30 per cent of the new fibers fall within this length group. At the same time, the new wool contained more than twice as many fibers which were three inches or more in length than did the reused wool. The reused wool is, therefore, appreciably shorter than the new fiber. The distribution of fiber length for both groups is not a normal symmetrical arrangement; both curves are skewed to the left, that for the reused fiber being more skewed than that for the new.

Not only were the new fibers longer than the reused, but they were finer as well, the mean diameter being approximately 7 microns less than that of the reused. The new wool fibers showed considerably less variation in diameter measurements than did the reused wool as is shown by the standard deviations and coefficients of variation. Over 80 per cent of the new fibers fall in the 16 to 28 micron groups, whereas only about 40 per cent of the reused fibers fall in this group. Phelps *et al.* (7) also found that the finest fibers were the most uniform in diameter. Likewise Bosman and Botha (3) have reported that higher standard deviations were associated with coarser wool in their study of fiber from Merino lambs.

The contour index, which is the ratio of the major to the minor fiber diameter axis, describes the extent of ellipticity in the cross section of the wool fiber. It has been claimed that lower contour index values are associated with better spinning quality for wool (1, 2). In this respect the new and the reused wool were not significantly different.

During manufacture and use, fiber ends may suffer varying amounts of damage. Rogers, Hays, and Hardy (8) have studied and classified the various fiber ends to

Table 9. Physical Characteristics of the New and Reused Fiber

	New Wool			Reused Wool		
Property measured	Group mean	Standard deviation	Coeff. of variation	Group mean	Standard deviation	Coeff. of variation
Fiber length in inches	2.23	1.14	51.19	1.72	0.89	52.01
Fiber diameter in microns	22.84	5.00	21.91	29.58	6.87	23.22
Contour index ratio of axes	1.23	0.14	11.62	1.22	0.15	12.20

be found in wool. These range from ends characteristic of undamaged fiber to those ends which are characteristic of extremely damaged wool, which they have designated as types 1 to 5 respectively. Fibers from both the new and the reused wool were examined and classified according to these five types. Five hundred fibers were drawn from each group and both ends examined. The distribution of the type of fiber ends found is shown in Fig. 12. In groups 1 to 3, which represent none or little damage, the new wool outnumbers the reused. However, in groups 4 and 5, representing heavily damaged fiber ends, the reused fibers are more numerous than the new. At the same time, it should be noted that undamaged fiber ends were found in the reused wool, and heavily damaged ends in the new wool. Also some similarity of distribution with respect to the character of the fiber ends appears to be shown for both the samples of wool which were studied.

The reused wool, therefore, was about equal to the new wool fiber in ellipticity of cross section, but at the same time it was shorter, coarser, less uniform, and showed evidence of somewhat greater damage.

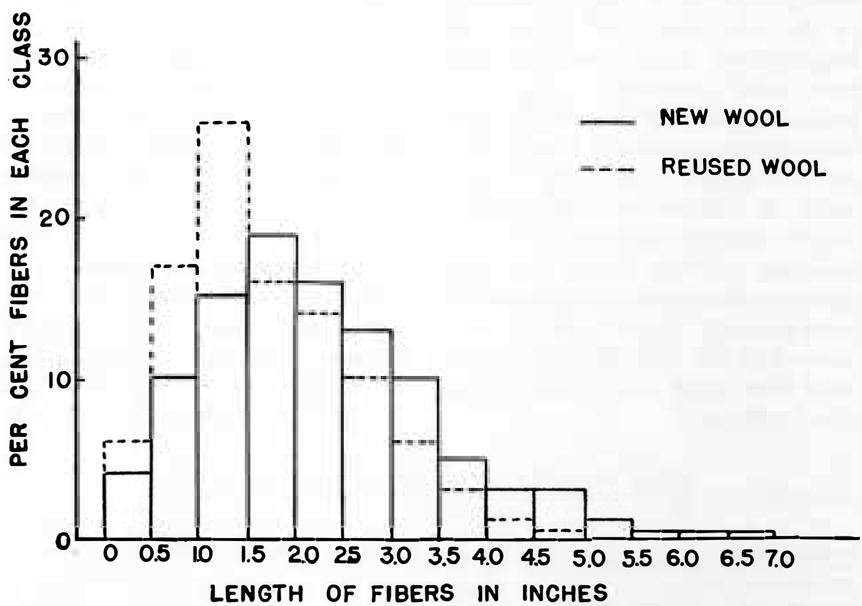


Fig. 11. Distribution of fibers measured according to length

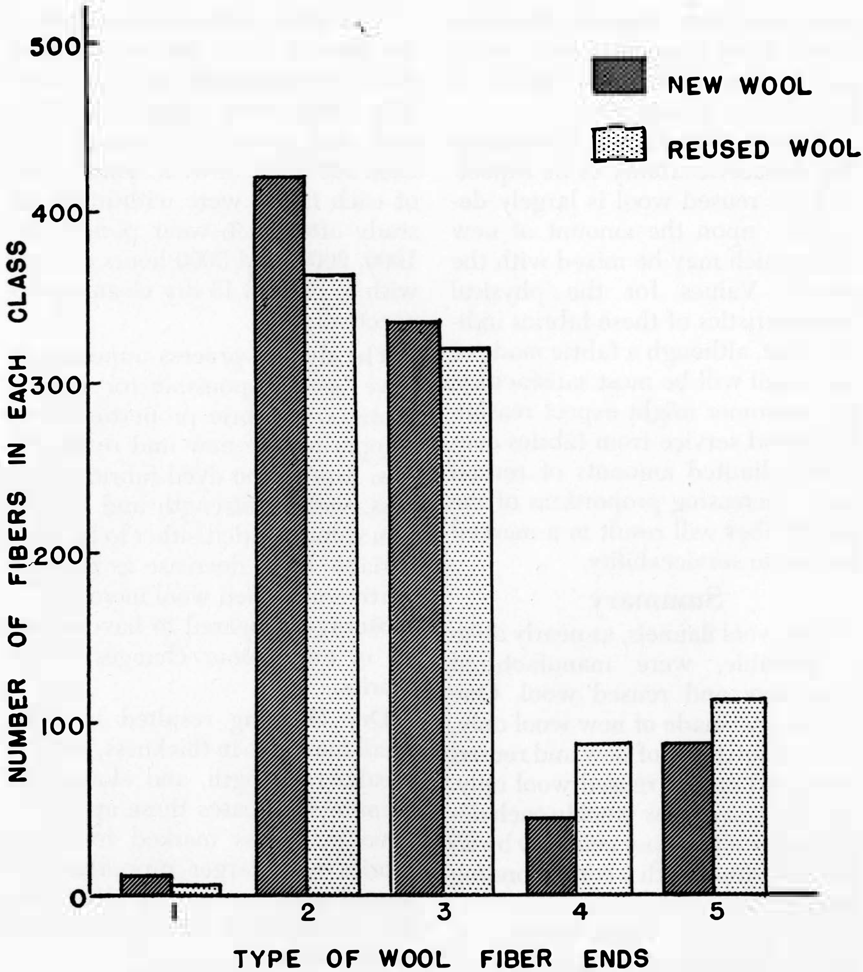


Fig. 12. Distribution of type of fiber ends in new and reused wool

Serviceability of Mixtures of New and Reused Wool

Increasing proportions of reused wool resulted in decreasing yarn and fabric strength for the dyed material before use, and also in decreasing yarn elongation as well as fabric elongation under bursting and warpwise breaking forces. After wear and the dry cleaning associated with it, decreasing strength, as well as bursting and breaking elongation, continued to be associated with an increasing percentage of reused wool. The all-new wool fabric was most uniform in thickness, while the presence of new wool appears to have retarded the loss in thickness due to wear which has been shown for the reused wool. New wool also has been shown to be somewhat more resistant to the detrimental effects of light than is reused wool.

In view of the above, it is evident that the serviceability to be expected from reused wool is largely dependent upon the amount of new wool which may be mixed with the reused. Values for the physical characteristics of these fabrics indicate that, although a fabric made of new wool will be most satisfactory, the consumer might expect reasonably good service from fabrics containing limited amounts of reused wool. Increasing proportions of the reused fiber will result in a marked decline in serviceability.

Summary

Five wool flannels, as nearly alike as possible, were manufactured from new and reused wool. One flannel was made of new wool only, three of mixtures of new and reused wool, and one of reused wool only. The amount of new wool in each decreased from 100 per cent to 0 by 25 per cent steps, with a corresponding increase in reused wool.

The physical characteristics of these materials were measured on a set of control swatches as delivered from the factory. The new wool was white and the reused blue, and all of the fabrics were dyed navy blue. Several swatches were removed from each piece after dyeing to be used as controls. One series was measured after dyeing, others after dry cleaning 5, 10, and 15 times. Another series was stored at room temperature for the duration of the experiment.

Nine skirts were made of each of the flannels with the exception of No. 0, of which only six were made. The skirts were worn by college girls and were dry cleaned after each 200 hours of wear. Three skirts of each fabric were withdrawn for study after each wear period, i.e., 1000, 2000, and 3000 hours of wear with 5, 10, and 15 dry cleanings respectively.

The dyeing process appeared to have been responsible for varying changes in fabric properties when comparing the new and dyed fabrics. Among the dyed fabrics thickness, weight, strength and elongation values tended either to be more variable or to decrease as the proportion of reused wool increased.

Storage appeared to have resulted in only minor changes in the fabrics.

Dry cleaning resulted in some small increases in thickness, weight, breaking strength, and elongation. In numerous cases these appear to have been less marked for those fabrics with larger proportions of reused wool. In contrast, elongation due to bursting strength showed marked losses.

Wear combined with dry cleaning can be said to have resulted in progressive losses in strength and elongation as the proportion of reused wool increased. Successive increments of wear and dry cleaning resulted in decreased thickness and weight for fabric 0; decreased bursting strength for all fabrics containing reused wool; and decreased elongation for all five materials after the first wear period.

The effects of wear alone were increased by increased duration of service, as would be expected. Also, in general, they appeared to have been increased by increasing proportions of reused wool in the fabric.

The effect of exposure to light could not be measured for the worn fabrics. However light did contribute to a decrease in fabric strength and elongation, and these decreases were associated with a decreased percentage of new wool.

Yarn characteristics were influenced by fiber composition. Decreasing amounts of new wool and increasing proportions of reused wool were accompanied by small increases in yarn number and twist, by substantial decreases in yarn elongation under stress, and by marked decreases in yarn strength.

The fiber characteristics of the two kinds of wool differed. The reused wool was about equal to the new wool in ellipticity of cross section, but at the same time it was shorter, coarser, less uniform, and showed evidence of somewhat greater damage.

The serviceability to be expected from reused wool, as indicated by these findings, is largely dependent upon the amount of new wool which may be mixed with the reused. Values for the physical characteristics of these fabrics indicate that, although a fabric made of new wool will be most satisfactory, the consumer might expect reasonably good service from flannels containing limited amounts of reused wool. Increasing proportions of the reused fiber will result in a marked decline in serviceability.

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