THE RELATION OF YARN STRUCTURE OF SELECTED COTTON FABRICS TO ABRASION RESISTANCE

by

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A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Home Economics

Greensboro
June, 1966

Approved by

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ACKNOWLEDGMENT

I would like to express my appreciation to those who have given so graciously of their time and energy in helping me with the preparation of this study.

Sincere gratitude is expressed to Dr. Pauline Keeney, director of this thesis, for her invaluable assistance; to Miss Louise Lowe, Dr. Hildegarde Johnson, Dr. Anna J. Reardon, and Mrs. Frances Buchanan, members of the thesis committee, for their helpful suggestions; and, to Dr. Aden Magee for his assistance with the photography.

KENNEDY, GERALDINE. The Relation of Yarn Structure of Selected Cotton Fabrics to Abrasion Resistance. (1966) Directed by: Dr. Pauline E. Keeney. pp. 56

The objectives of the study were to determine after use and laundering the yarn characteristics of yarn number and diameter and to determine the effect of changes in these characteristics on abrasion resistance.

Yarn number measurements were made using the Suter Yarn Numbering Balance. Yarn diameter measurements of longitudinally mounted specimens were made using the Visopan Microprojector. Abrasion resistance measurements were made using the occurrence of yarn breakdown method with the Taber Abraser.

The sample of this study consisted of the experimental sheetings used at the North Carolina station for Phase I of the Southern Regional Research Project SM-18. Measurements were made on specimens from sheets withdrawn following zero, thirty and sixty periods of use and laundering.

An analysis of variance was made to determine the relationship between the yarn characteristics and abrasion resistance of the low and high fiber elongation cottons after each use and laundering period and over all periods of use and laundering. Correlation coefficients were computed comparing results of the abrasion test to the results of yarn number and the yarn diameter tests.

The results indicated (1) there were highly significant differences in yarn number between low and high fiber elongation cottons before laundering but little or no significance following use and laundering, (2) no statistical significance between the warp yarn diameter of low and high elongation cottons but

there was a significant difference between filling yarn diameters of low and high elongation cottons following use and laundering, (3) differences in abrasion resistance between the low and high elongation cottons were significant throughout the study, (4) changes in yarn characteristics were not closely related to the abrasion resistance of the fabric.

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CHAPTER I

INTRODUCTION

The slogan, "Cotton is King," may still be used today, for cotton is the most universally used of all fibers.

According to the Textile Organon, for the last cotton season (August, 1964-July, 1965), the world production of cotton was at a record high of 52,000,000 bales, as was consumption of cotton at 49,800,000 bales.[1] Despite this, cotton continues to feel the competition of the man-made fibers and the cotton textile industry is making every effort to meet this competition.

> Cotton fiber properties and their relation to the utilization of products made from cotton will be important areas of investigation as long as cotton continues to be one of our most important agricultural commodities. While there has been extensive research directed toward the properties of raw cotton, the investigation of the relationship between cotton fiber properties and in-service performance of products has been fragmentary. Cotton breeders, manufacturers and consumers would benefit from research indicating a means of selecting cottons for specific end uses.[2]

To this end the Southern Regional Research Project SM-18 was begun by Home Economics Research Personnel of six Southern states in cooperation with the Agricultural Experiment Stations in these states and under the sponsorship of the United States Department of Agriculture.

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[1] Textile Organon, XXXVI, 10 (October, 1965), p. 169.

[2] Technical Committee Project SM-18, "The Relation of Selected Properties of Raw Cotton to Product Quality and End Product Performance," (Manual of Procedures, Southern Regional Research Project SM-18).

The purpose of the Regional Project SM-18 was to investigate the properties of selected types of raw cotton and to determine the relationship between the property of fiber elongation, the product quality, and the end use of the fabrics made from the selected types of cotton.[3]

Experimentation, completed earlier in the Project, using two methods of abrasion to evaluate the performance of high and low elongation fibers, produced results indicating considerable variation within the two methods of abrasion. It seemed that some of the differences might be caused by changes in yarn structure.

The purpose of this thesis is to continue to study differences in the wearing characteristics between the high and low elongation cottons used at the North Carolina Station in Phase I of the Southern Regional Research Project. These differences will be determined by measuring changes in abrasion resistance using a third method of abrasion and by measuring changes in yarn structure. Evaluations will be made following 0, 30, and 60 intervals of use and laundering.

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[3]Ibid.

CHAPTER II

REVIEW OF LITERATURE

I. STUDIES OF ABRASION RESISTANCE

"Abrasion resistance" and the related topics of "wear" and "serviceability" are subjects which have gained considerable attention from textile technologists.

Definitions of "Abrasion", "Wear", and "Serviceability"

Ball defines "abrasion" as follows:

> Abrasion, derived from the verb 'to abrade', very distinctly suggests a 'rubbing off'. The word 'abrasion' as an adjective might properly be applied therefore to those machines or tests in which rubbing is the only, or at least the major characteristic.[1]

Kaswell believes wear to be a more confining word which "describes the ability of a fabric to withstand the effects of abrasion (as defined above) concomitant with stressing, straining, laundering, dry cleaning, pressing, creasing, etc."[2] Ball believes "wear" to be more closely associated with the thought of the conditions surrounding everyday use and service and combines the effect of

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[1]Ernest R. Kaswell, Textile Fibers, Yarns, and Fabrics, (New York: Reinhold Publishing Corporation, 1953), p. 299, citing H. J. Ball, "Problems Which Abrasion and Wear Testing Present," Textiles Research Journal, Vol. 8, 1938, p. 134.

[2]Kaswell, op. cit.

several factors of which abrasion or rubbing is only one. Ball suggests therefore:

> . . . that 'wear' be considered as a broader scope than 'abrasion' and be used to apply wherever other important destructive actions, with or without abrasion, are existent or are intentionally introduced by the machine or test method.[3]

> A fabric which serves the functions for which it is intended may be defined as being 'serviceable'. When it ceases to perform such functions, it is no longer serviceable. The word is a broad one and encompasses all those criterion [sic] of performance which permits [sic] a fabric to be accepted or rejected for use.[4]

"The Serviceability of Fabrics for Clothing" was the subject chosen for the 1937 Annual Conference of the British Textile Institute. In one of a series of papers presented at the conference, Peirce points out that "'serviceability is not concerned only with the formation of holes in the fabrics.'"[5] He also says that wearing into holes, and threadbareness are causes of loss of serviceability in shirts, sheets, hose and upholstery.

The problem of relating abrasion, wear and serviceability is summed up by Zook in the review, "Historical Background of Abrasion Testing." The basic question is 'To what extent should the laboratory wear test approximate

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[3]Kaswell, citing Ball, op. cit.

[4]Kaswell, op. cit., p. 298.

[5]Ibid., citing F. T. Peirce, "The Serviceability of Fabrics in Regard to Wear: Testing Fabrics to Foretell Serviceability," Journal of the Textile Institute, Vol. 28, Proceedings, 1937, p. P181.

service during wear?'[6] Of the two philosophies, H. DeWitt Smith, in 1934, expressed the philosophy held by many in the textile field at a conference of the U. S. Institute of Textile Research:

> I should like to see fabrics classified as to use, the most important classes in which wearability is a factor grouped, the cause of wear determined, machines designed to duplicate service results, and properties which affect wearability determined.
>
> The duplication of service wear, however, has been complicated by the fact that the essential factors in service life are not known to an exact degree.[7]

Skinkle believes that service life depends on the personal factors of size, weight and occupation of the wearer of the fabric, on the climate and its effect on the wearer, on the fit of the garment, and on the laundry methods used, together with mechanical details in an infinite variety which are involved in the motion of a fabric while being worn ". . . ---all at low standard rates---mostly slower than laboratory abrasion tests."[8]

Peirce denounces imitative tests and adds:

> Tests should be devised to measure characteristics defined by behaviour under the simplest conditions. Their validity depends not on imitative features in the testing procedure, but on intelligent interpretation, based on empirical correlation with service experience.[9]

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[6] M. H. Zook, "Historical Background of Abrasion Testing," American Dyestuff Reporter, Vol. 39, 1950, p. 625.

[7] Kaswell, op. cit., p. 300, citing H. DeWitt Smith, "Wear and Wear Testing," U. S. Institute of Textile Research Conference, Textile World, Vol. 84, 1934, p. 852.

[8] J. H. Skinkle, Textile Testing, (New York: Howes Publishing Company, 1940), p. 97.

[9] Kaswell, citing Peirce, op. cit.

Ball has suggested that wear-testing machines be planned to reproduce these influences which account for the major part of the destructive effort.[10]

Lomax further has suggested that:

> . . . it is not required that service life be forecast in some unit of time, but rather that the problem should be one of comparing one fabric with another. This reduces the requirements of the apparatus and the selected procedure need not, then, duplicate the actual conditions of use, but only rank fabrics in order of merit.[11]

Kaswell in a report of his work with the Quartermaster Depot, agrees with this latter philosophy when he makes the statement that:

> . . . a laboratory test need not duplicate an actual set of service conditions, if wear produced by the abrasion machine can be correlated with service wear in such a way as to predict the abrasion resistance of a fabric.[12]

Stoll suggests that:

> . . . numerically, the mechanical factors involved in normal wear can be assumed approximately as '30 per cent plane abrasion, 20 per cent edge and protection abrasion, 20 per cent tear, and 10 per cent other mechanical action.'[13]

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[10]Kaswell, citing Ball, op. cit.

[11]Kaswell, op. cit., p. 300, citing J. Lomax, "The Serviceability of Fabrics in Regard to Wear: Testing Fabrics to Foretell Serviceability," Journal of the Textile Institute, Vol. 28, Proceedings, 1937, p. P218.

[12]Kaswell, Ibid., citing Kaswell, E. R., "Wear Resistance of Apparel Textiles," Textiles Research Journal, Vol. 16, 1946, pp. 413 and 502.

[13]Kaswell, Ibid., p. 301, citing P. G. Stoll, "An Improved Multipurpose Abrasion Tester and Its Application for the Evaluation of the Wear Resistance of Textiles," Textiles Research Journal, Vol. 19, 1949, p. 394.

Abrasion has been cited by Mann and by Tait as the most important single factor in wear. For this reason, many textile technologists have simplified the problem by studying the resistance of fabrics to abrasion rather than to wear in general.[14]

Service Wear and Laboratory Abrasion Tests on Shirt Type Fabrics

ASTM Committee D-13 initiated a program of study in June, 1952, to determine the correlation between the results of laboratory abrasion tests on cotton fabrics of different constructions and the durability in wear of shirts made from these fabrics.[15]

Shirts were supplied to each of the five laboratories participating in the service wear tests. The shirts were worn and laundered until failure.

A sample of each of the fabrics was supplied to each of the eleven laboratories participating in the laboratory abrasion tests. Each laboratory chose its own method and procedure for the abrasion testing.[16]

> . . . It is remarkable that these different shirts, which were representative of rather widely varying commercial qualities, yielded essentially equal and satisfactory performance under widely different conditions of use and laundering. In view of this versatility of the shirt fabrics to accommodate and adapt themselves to such widely varying conditions of use, the quality of shirt fabrics must be chosen to vary much more than is usual

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[14]Kaswell, op. cit., p. 301.

[15]Charles Simon, Chairman, Task Group on Abrasion, ASTM Committee D-13, "Results of Service Wear and Laboratory Abrasion Tests on Seven Shirt Type Fabrics," p. 1.

[16]Ibid., p. 3.

> in commercial shirt production in order to yield results in service tests which differ clearly and distinctly without excessive overlapping. Only in this way is there hope of obtaining clear-cut correlations between the results of service tests and those of accelerated laboratory abrasion tests.[17]

II. SYSTEMS FOR NUMBERING YARNS

Definition of Yarn Number

The definition of "yarn number" as accepted by the ASTM Committee D-13 on Textile Materials states that:

> Yarn number is a measure of linear density (weight per unit length) of yarn and hence a conventional relative measure of fineness or dimension. It may be expressed in a direct system where the number increases as the yarn becomes coarser, or in an indirect system where the number decreases for coarser yarns. The units of length and weight vary among the many existing systems.[18]

The principle for determining yarn number consists of measuring a length of yarn and weighing it. Simple as this seems, complications arise from what is meant by "length" and "weight" of a specimen of yarn.[19]

Introduction of the Tex System

Grover and Hamby comment that "there exists an unfortunate condition in that so many systems are in use for numbering yarns.[20] In 1960, they

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[17]Ibid., pp. 8 and 9.

[18]ASTM Committee D-13 on Textile Materials, ASTM Standards on Textile Materials, 34th Ed., 1963, p. 807.

[19]Ibid.

[20]Elliot B. Grover and D. S. Hamby, Handbook of Textile Testing and Quality Control, 1960, p. 317.

stated that:

> Despite the activity of national and international groups who are endeavoring to correct this situation by the adoption of a universal system, it is feared that it shall be some time before any relief materializes.[21]

> A plan for the orderly introduction of the single system of numbering yarns made from all types of fibers is being introduced to the textile industry in most of the countries of the world.[22]

After extensive study by the Technical Committee on Textiles of the International Organization of Standardization the tex system has been chosen as replacement for the many conflicting systems now used. This proposal was unanimously adopted by delegates representing the textile industries of twenty-one nations including the United States and four international textile associations who participated in the study.[23]

The changeover to the tex system will be made in three easy stages over a period of years. The first stage began in 1960 and is to run until the trade is completely familiar with the new system. When the trade is ready, the dates for the second and third stages will be set.[24]

Three Stages of Changeover to Tex System

> First Stage. This stage is designed to familiarize everyone working in the textile industry with tex numbers. The existing yarn count systems will continue in use, but a corresponding rounded tex number will be given in

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[21] Ibid.

[22] ASTM Committee D-13 on Textile Materials, op. cit., p. 359.

[23] Ibid.

[24] Ibid.

parentheses after the traditional yarn count or yarn number--for example: 18 cotton count (32 tex), 48 worsted count (18 tex), 100 denier (11 tex).

During this stage the rounded tex numbers in parentheses are illustrative or explanatory and have no legal standing. They cannot be used as the basis of claims or other disputes, which must be based on the traditional yarn numbers. A note to this effect may be stamped on contracts or other documents where this is felt to be desirable.

Second Stage. Commercial transactions and manufacturing operations will be shifted to tex numbering. The equivalent traditional yarn number or count will be given in parentheses after the tex number--for example: 32 tex cotton yarn will be written 32 tex (18.5 cotton count); 18 tex worsted yarn will be written 18 tex (48 worsted count).

Third Stage. The traditional yarn number in parentheses will be deleted; only tex numbers will be given.[25]

English System for Numbering Cotton Yarns

The English system used for numbering cotton yarns is in widest use today and is the system used in this study. It is a direct system based on length per unit weight and is limited in application to roving and yarn.

For yarn . . . in the English system, the yarn number is measured by the number of 840-yard hanks in one pound of material. Expressed as an algebraic relationship, this is:

Yarn number . . . = $\frac{\text{Hanks}}{\text{Pound}}$ in which the ratio of yards to hanks is 840.[26]

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[25] Ibid.

[26] Ibid.

III. MICROSCOPIC STUDIES OF YARN

A most valuable tool in the study of fibers is the microscope. Microscopic analysis of surface characteristics of cotton and measurements of length, diameter, and area may be made with great accuracy.

> . . . With the aid of unique methods it is possible to examine the cotton fiber from all perspectives: longitudinally for width and convolutions and for surface features; transversely for shape, wall thickness, and lumen size. These various characteristics can be emphasized by choice of the proper technique--staining, swelling, cross-sectioning, mounting, or lighting.[27]

In the study of cotton, transmitted light is generally used because the cotton fiber is both colorless and transparent. "By reflected light, however, the surface characteristics can be observed more clearly and irregularities of shape and form studied to better advantage."[28]

Pillay of The South India Textile Research Association, Coimbatore, India, studied the length, nature, and distribution of protruding fibers causing hairiness in cotton yarns using a combination of singeing and microscopic techniques. He developed a method of expressing hairiness as the loss in weight after singeing per unit weight of yarn. The results indicated that torsional and flexual rigidity, fiber length, and fineness of cottons are significantly correlated with yarn hairiness.[29]

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[27] Herbert R. Mauersberger, (ed.), Matthews' Textile Fibers (New York: John Wiley and Sons, Inc., 1947), p. 198.

[28] Ibid.

[29] K. P. T. Pillay, "A Study of Hairiness of Cotton Yarns Part I: Effect of Fiber and Yarn Factors," Textile Research Journal, Vol. 34, 1964, p. 663.

> Microscopic Techniques Used. In the first technique the yarns under study were passed under the Projectina and examined on the screen under a magnification of 50X. The portion of yarn appearing between two lines on the screen (corresponding to a 3-mm length of yarn) was carefully examined for (i) the number of protruding fiber ends, (ii) the number of looped fibers, and (iii) the diameter of yarn. Two hundred random places were examined for determining the above properties for each sample of yarn.[30]

The mean was used to represent the sample.

The second technique used involved the mounting of ten yarns parallel on a glass plate using cellophane tape at the edge of the plate to hold them in place for dyeing and examining under the microscope.[31]

"A positive correlation (r = 0.4 to 0.5) between the number of projecting fibers and yarn diameter was obtained . . . ."[32]

Photoelectric Measurement of Yarn Diameter

Onions and Yates used Chamberlain's photometer to determine the diameter of worsted yarn. Results of the study by Onions and Yates showed:

> . . . that when a yarn is measured photometrically for irregularity, the protruding fibres have an appreciable effect upon the results obtained. Both the coefficient of variation and the "diameter" are dependent upon the width of the slit used to confine the shadow of the yarn being measured.[33]

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[30] Ibid., p. 666.

[31] Ibid.

[32] Ibid., p. 672.

[33] W. J. Onions and Madeline Yates, "The Photoelectric Measurement of the Irregularity and the Hairiness of Worsted Yarn," Journal of the Textile Institute, Vol. 45, Transactions, 1954, p. T885.

Quality Measurements Used in Evaluating Yarns

Sixty-one combed yarns from thirty-two different mills were studied to determine levels of quality measurements normally used in evaluating yarns. It was found that the over-all coefficient of variation averaged 2.7 per cent and with the exception of one yarn, ranged from 0.5 per cent to 4.5 per cent. The between-package coefficient of variation averaged 2.2 per cent and the within-package, 1.6 per cent.[34]

IV. SUMMARY

A review of the literature showed that very little has been done to study yarn number and yarn diameter in wear life of fabric studies. Nothing was found that related yarn number or yarn diameter to abrasion resistance in serviceability testing.

A review of the literature did, however, prove helpful in establishing procedures to use for the testing in this study.

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[34] D. S. Hamby, W. C. Stuckey, B. Gast, and R. J. Hader, "The Analysis of Variations for Certain Physical Properties of Combed Cotton Yarns," Textile Research Journal, Vol. 30, 1960, p. 438.

CHAPTER III

PROCEDURE

Summary of Regional Project SM-18 Procedures

The purpose of Regional Project SM-18 was to investigate the properties of selected types of raw cotton and to determine the relationship between the property of fiber elongation, the product quality, and the end use of the fabrics made from the selected types of cotton.[1]

Four bales of experimental cotton were selected which were similar in length, fineness and strength but differing in fiber elongation. Cottons one and two were of low fiber elongation and cottons three and four of high fiber elongation. All cotton was processed into type 140 muslin sheets, single bed size. The sheets were distributed to four of the stations participating in the project to be used in women's dormitories.[2]

To de-size the sheets, all were laundered once by the commercial laundry which would launder the sheets after each weekly use. Following this de-sizing, the sheets were coded and six sheets of each cotton type were withdrawn to be used as controls. These twenty-four were designated the

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[1]Technical Committee Project SM-18, "The Relation of Fiber Properties to End-Product Performance," (Manual of Procedures, Southern Regional Research Project SM-18).

[2]*Ibid.*

"0-laundering" interval. The remaining sheets were used as bottom sheets in women's dormitories and laundered weekly by the commercial laundry. Four nights were accepted as minimum for a week of use.

Sampling Plan

The same sheets were used for this study as for Phase I of the Southern Regional Research Project SM-18 at the North Carolina Station.

The sheets to be sampled were those which were withdrawn from the Regional Project after zero, thirty, and sixty periods of use and laundering.

A standard testing area, which was the area receiving the most wear in use, was marked on each of the sheets used in Project SM-18. The samples to be used to test abrasion resistance were taken as close as possible to this designated area of greatest wear. In some instances the samples were completely within this area and in others only partially within this area. Figure 1 shows the placement of three samples to be used for abrasion resistance (A) and four samples from which warp and filling yarns were taken to be used for determining changes in yarn characteristics (B).

Abrasion Resistance Testing Using Taber Abraser with Rotary Platform Double-Head to Determine Occurrence of Yarn Breakdown

The Taber Abraser Model E-4010 with vacuum pick-up attachment was used in this study. The Taber Abraser is a precision instrument designed for measuring abrasion resistance of materials and surface coatings. The Abraser incorporates the Taber rotary rub-wear principle of abrasion. Of the two abrading wheels, the right wheel rubs the specimen from the inside, outward,

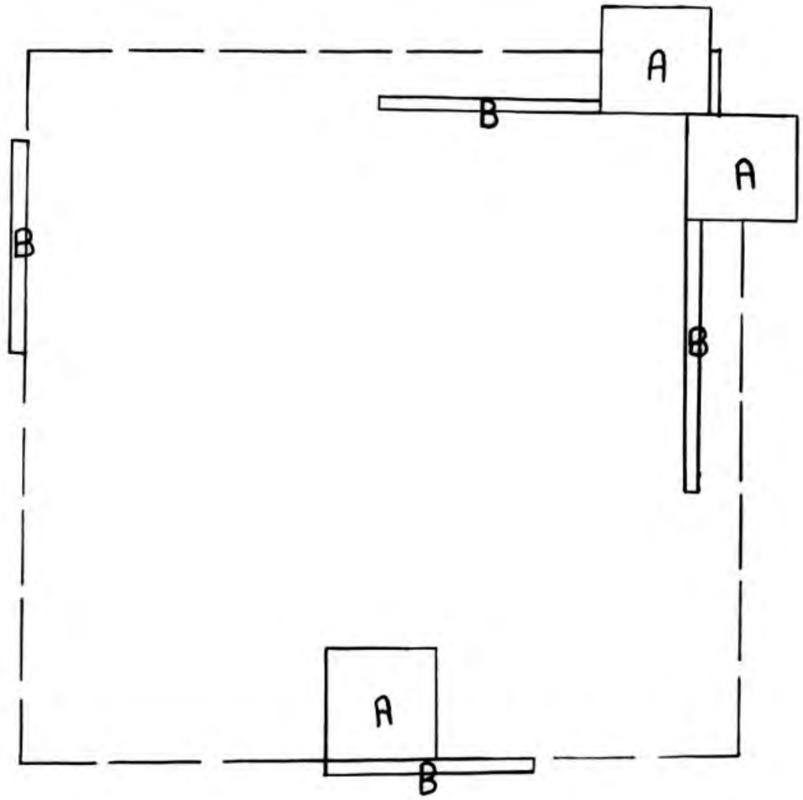

FIGURE 1

DIAGRAM OF PLAN USED FOR ABRASION AND YARN SAMPLING

Key:

Worn Area Sampled for other Tests _______ _______ _______

Abrasion Samples = A

Yarn Samples = B

and the left wheel, from the outside toward the center so the abrasion lines criss-cross their abrasion paths. The abrasion is continuous in the 360° rotation of the specimen and closely parallels abrasive wear found in actual use.

The rotary platform, double-head abraser is comprised of a removable flat circular specimen holder, a pair of pivoted arms to which the abrasive wheels are attached, a counter for indicating the revolutions of the specimen holder, and a vacuum attachment for removing abraded particles from the abrasion path.

Each of the pivoted arms exerts 500 grams of weight on the specimen. To these are attached a pair of vitrified-base wheels of calibrade H-38 type. Two pairs of wheels were used alternately so that one-half of the sample was abraded with one pair of wheels and the other half with the second pair of wheels.[3]

The samples were conditioned for twenty-four hours in a controlled atmosphere at 65 ± 2 per cent relative humidity and 70 ± 2° F.

A one-fourth inch hole was cut in the specimen which was then placed face up over the rubber mat on the specimen holder. The specimen was secured in place with the ring clamp, washer and nut.

The specimen was abraded at 70 revolutions per minute to the occurrence of yarn breakdown which is defined as the occurrence of a break in adjacent warp and filling yarns. Specimens were checked frequently during the test

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[3]Taber Abraser Manual, (New York: Taber Instrument Corporation, 1953), p. 3.

for the break. The number of revolutions required to cause the break was read from the counter and recorded.

Three samples from each sheet were tested and the average result used to represent the sample.[4]

Determining Yarn Number

The Suter Universal Yarn Numbering Balance and Ruler were used to determine yarn number in this study. In using this balance the specimen is completely housed so as to guard it from drafts.

To prepare specimens, the ruler was opened and laid flat on the table. One end of the yarn was held against the proper mark with the left hand. With the right hand, the yarn was stretched lightly until crimp and kinks were eliminated. The yarn was brought against the cutting edge and cut. The length of the specimen, made of several shorter lengths, totaled 36 inches. The specimen was then twisted into a knot to hang on the hook of the balance.[5]

The specimens were conditioned for twenty-four hours at 70 $\pm$ 2°F and 65 $\pm$ 2 per cent relative humidity. The beam of the balance was clamped before loading and the specimen hung on the hook by one yarn. The beam was unlocked; the lever rotated to balance the beam; and, the reading taken directly from the

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[4]ASTM Committee D-13 on Textile Materials, ASTM Standards on Textile Materials, (Philadelphia: American Society for Testing and Materials, October, 1962), pp. 473-478.

[5]"Universal Yarn Numbering Balance Instruction Sheet," (New York: Alfred Suter Textile Engineer).

balance and recorded. The beam was locked and the specimen removed.[6]

The yarn numbers for five warp and five filling yarns were determined and the average taken as the yarn number for the sample.

Determining Yarn Diameter

The Visopan Microprojector was used to view the yarns for determining yarn diameter. The "Visopan" is made by Reichert and has a built-in low voltage illuminator "Lux FM" with adjustable collector, condenser with aperture iris diaphragm and swing-out widefield optics. The Microprojector has a built-in ground glass screen.

> The desk-like arrangement of the instrument ensures fatigue-free observation on the large screen (8 inch, 200 mm dia.), with the body in a natural and comfortable position. The built-in Fresnel lens provides completely uniform illumination of the screen. The clear vibration-free image on the screen can also be seen without difficulty by observers wearing spectacles.[7]

The "Visopan" is a convenient instrument for measuring yarn diameter. The yarn is projected in silhouette and the diameter can easily be measured using the transparent rule which is attached to the screen.

Ten warp and ten filling yarn samples were mounted, five yarns to a slide, for each sheet. The researcher held the yarns in position over the slide while an assistant placed a piece of transparent tape over the yarns to hold them in place against the slide while the measurements were being made. Three

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[6] Ibid.

[7] "Visopan" Instruction Sheet, (West Caldwell, New Jersey: William J. Hacker and Co., Inc.).

measurements were taken for each of the ten yarn samples and the mean of these used to represent the yarn diameter of warp and filling for each sheet. A total of one hundred eighty measurements were taken in each direction for each cotton type.

Analysis of Data

The analysis of variance was one statistical procedure used for this study. The computer program developed for the Southern Regional Research Project was used to analyse the data and determine the F ratios. These were compared with the F ratios at the .05 and .01 levels in an F table. The .05 per cent level was selected as the point beyond which findings would be considered significant.

Correlation coefficients between the abrasion test and the corresponding yarn number and yarn diameter were calculated by means of the formula

$$r_{x_1 x_2} = \frac{\Sigma x_1 x_2}{\sqrt{(\Sigma x_1^2)(\Sigma x_2^2)}}$$

Tests of significance of the correlation coefficients were determined using the t statistic. The formula for this statistic is

$$t = \frac{r_{x_1 x_2}\sqrt{N-2}}{\sqrt{1 - r^2_{x_1 x_2}}}$$

CHAPTER IV

PRESENTATION OF DATA

The major objective of this thesis was to determine the effect of yarn characteristics on the abrasion resistance of four cottons selected to show differences in high and low fiber elongation. The yarn characteristics studied were yarn diameter and yarn number. The occurrence of yarn breakdown was used to evaluate abrasion resistance.

I. PROPERTIES OF THE FIBERS AND SPECIFICATIONS FOR YARN AND MUSLIN

For the Southern Regional Research Project SM-18, two hundred and two bales of cotton (Classer's samples) were screened and tested. Four bales were selected from these and paired on the basis of close similarity in the properties of length, fineness and strength, but with a wide range in fiber elongation between the pairs.[1]

The four bales of cotton were grown in 1957. They were American Upland type, Strict Middling by color measurement, and 1 1/16 inch staple according to Classer's quality evaluation. Three bales were of unknown variety

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[1] Performance of Sheets Made From Low and High Elongation Cottons (Southern Cooperative Series, Bulletin No. 108, August, 1965), p. 8.

and were designated as "Magnolia". One bale was Stardel, a registered variety.[2]

Fiber Properties

The results of physical measurements of the cotton fibers verified the closeness in similarity of the physical properties except for fiber elongation. Cottons I and II were low fiber elongation cottons and averaged 6.6 and 6.4 per cent elongation, respectively. Cottons III and IV were high fiber elongation and averaged 10.1 and 9.9 per cent fiber elongation, respectively.[3]

Specifications for Yarns and Muslin

Specifications for the yarn and the muslin were as follows:

Weight of Muslin------------------------4.6 ounces per square yard

Count of Yarns------------------------140 (approximately 68 by 72)

Yarn Number---------------------------22's in both warp and filling

Twist Multiplier (Yarn)--------------------- 4.50 warp; 3.50 filling

Width of Muslin--------------------------------------- 72 inches

Different color yarns were woven into the selvage of the muslin to identify the cotton in the sheets.[4]

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[2]Ibid.

[3]Ibid., p. 28.

[4]Ibid., p. 9.

The procedure for finishing the fabric was one commonly used on type 140 sheeting. It included continuous peroxide bleaching, sizing with a solution of 1 to 2 percent starch, and the addition of a wetting agent and whitener. The fabric was also Sanforized. The finished fabric, 63-inch width, was torn into 108-inch lengths and hemmed with 3-inch and 1-inch hems.[5]

II. DISCUSSION OF RESULTS OF TESTING

Sheets sampled for this study were those used at the North Carolina Station for Phase I of the Southern Regional Research Project. Six sheets from each of the four cotton types which had been withdrawn from the Project following 0, 30, and 60 intervals of use and laundering were used for testing.

Measurements of both warp and filling yarns were obtained in the tests for yarn diameter and yarn number. The abrasion resistance test using the occurrence of yarn breakdown resulted in a single measurement representing the destruction of both warp and filling yarns.

Yarn Number

The mean yarn number and percentage change according to cotton type and laundering interval are presented in Table I, and are presented graphically in Figure 2.

Yarn number is the number of 840 yard hanks per pound thereby indicating the size of the yarn. The specification for the spinning of the cotton into yarn was for twenty-two hanks per pound in both warp and filling. Results of

---

[5] *Ibid.*

TABLE I

MEAN YARN NUMBER AND PERCENTAGE CHANGE OF FOUR COTTONS AT THREE INTERVALS FOR BOTH WARP AND FILLING YARNS

Intervals	Cottons							
	I		II		III		IV	
	Yarn number	Per cent change	Yarn number	Per cent change	Yarn number	Per cent change	Yarn number	Per cent change
0 Interval								
Warp	23.8	---	23.1	---	23.5	---	22.7	---
Filling	24.4	---	22.2	---	22.1	---	22.5	---
30th Interval								
Warp	22.9	-3.8	24.0	+3.9	23.9	+1.7	23.6	+ 4.0
Filling	22.0	-9.8	24.4	+9.9	23.3	+5.4	23.6	+ 4.9
60th Interval								
Warp	25.2	+5.9	25.1	+ 8.7	25.3	+ 7.7	25.6	+12.8
Filling	26.3	+7.8	28.0	+26.1	27.7	+25.3	26.2	+16.4

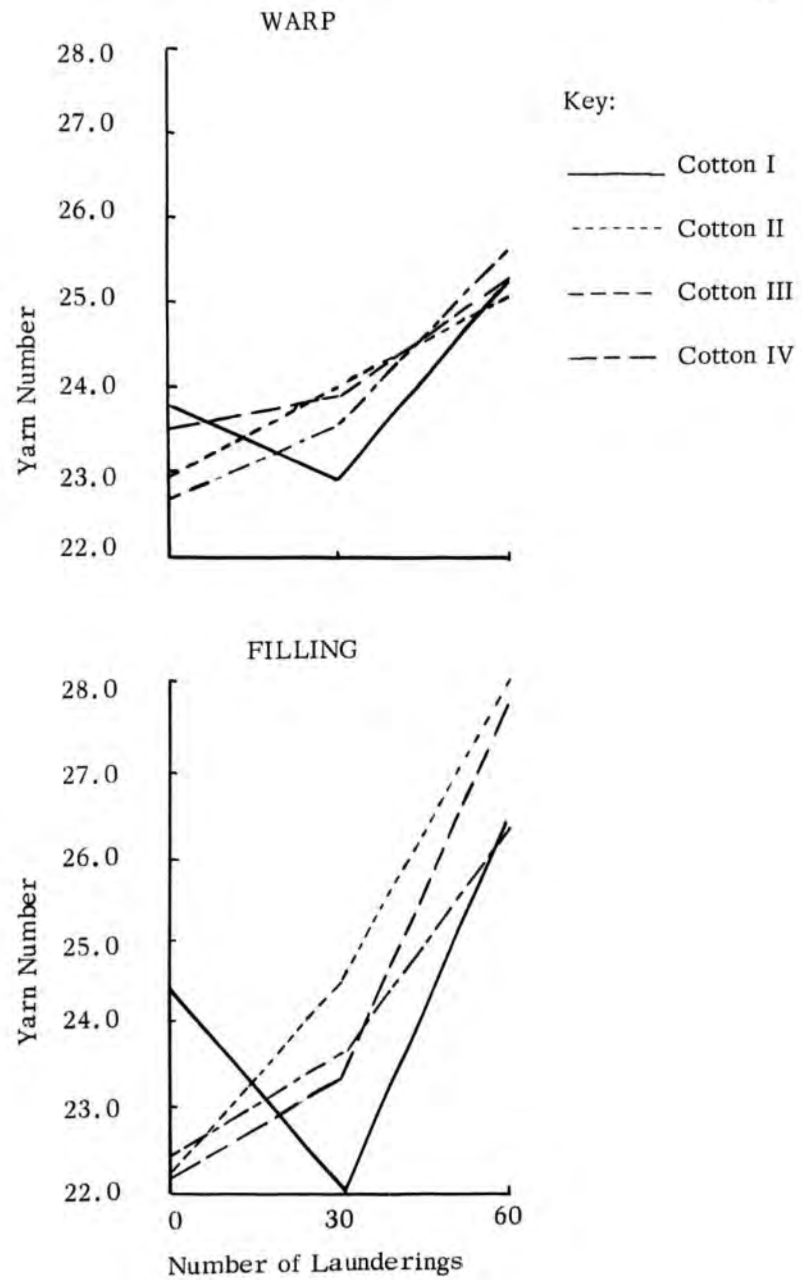


FIGURE 2

MEAN YARN NUMBERS OF FOUR COTTONS AT THREE INTERVALS

FOR BOTH WARP AND FILLING YARNS

the test for yarn number of the control sheets showed that Cotton I in both warp and filling varied most from the specification and was a much finer yarn than specified. The filling of Cotton III and the warp of Cotton IV were nearest to specification.

After thirty periods of use and laundering, all yarns from each type, except Cotton I, increased in yarn number (yarns were finer) in both warp and filling. The per cent change from the control sizes ranged from +9.9 per cent in the filling of Cotton II to -9.8 per cent in the filling of Cotton I.

All cottons showed increased yarn numbers (yarns were finer) after sixty periods of use and laundering in both warp and filling. The per cent change ranged from +5.9 per cent finer to +26.1 per cent finer after the sixtieth period of use and laundering.

The statistical procedure developed for the Southern Regional Research Project was used to analyse the data and determine the F ratios for an analysis of variance (See Appendix A for example of analysis of variance model used). The results of the analysis are shown in Table II.

The variance among all the cottons was highly significant through the thirtieth period of use and laundering and became less significant after sixty.

Differences between the yarn number means of low and high fiber elongation cottons were highly significant in the control specimens but generally not so after use and laundering.

Differences between Cottons I and II, the low fiber elongation cottons, were highly significant in the warp direction after thirty periods of use and

TABLE II

SIGNIFICANCE OF VARIANCE OF YARN NUMBER MEANS OF FOUR COTTONS AT THREE PERIODS FOR BOTH WARP AND FILLING YARNS

Cottons	Number of times laundered					
	0		30		60	
	Warp	Filling	Warp	Filling	Warp	Filling
I	23.8	24.4	22.9	22.0	25.2	26.3
II	23.1	22.2	24.0	24.4	25.1	28.0
Difference	0.7	2.2**	1.1**	2.4**	0.1	1.7*
III	23.5	22.1	23.9	23.3	25.3	27.7
IV	22.7	22.5	23.6	23.6	25.6	26.2
Difference	0.8*	0.4	0.3	0.3	0.3	1.5
Mean Low	23.4	23.3	23.4	23.2	25.2	27.2
Mean High	23.1	22.3	23.8	23.4	25.4	27.0
Difference	0.3**	1.0**	0.4	0.2	0.2	0.2*
Mean of cottons	23.3**	22.8**	23.6**	23.3**	25.3	27.0*

*F value is significant (.05 per cent level).

**F value is highly significant (.01 per cent level).

laundering and highly significant in the filling direction at both the control and thirtieth intervals and significant at the sixtieth interval. Differences between the high fiber elongation cottons were not generally significant.

Over-all-periods Analysis of Variance

There was no significant variance ratio among the means of the cottons over the three testing periods in either warp or filling (See Appendix B for example of model used). Highly significant differences between the washing periods were found in both warp and filling. In the filling the interaction between the cottons and the washing intervals was highly significant.

Yarn Diameter

Means of yarn diameter measurements and the per cent change are presented in Table III and shown graphically in Figure 3.

The results of yarn diameter, reported in millimeters, indicated considerable difference within the low and within the high elongation cottons. In the control sample, Cotton III in the warp direction had the greatest diameter and Cotton I, the smallest. In the filling direction, Cotton IV had the greatest diameter and Cotton II, the smallest diameter.

Results of the test for yarn diameter after thirty periods of use and laundering showed variation in the ranking of the yarns when compared to the ranking of the control cottons. In the warp, Cotton IV had the greatest diameter with Cotton III, Cotton I, and Cotton II ranking respectively smaller. Cottons I and IV increased in the warp yarn diameter at this interval while Cottons II and

TABLE III

YARN DIAMETER MEANS OF FOUR COTTONS AT THREE INTERVALS FOR BOTH WARP AND FILLING YARNS AND PERCENTAGE CHANGE AFTER USE AND LAUNDERING

Intervals	Cottons							
	I		II		III		IV	
	Yarn diameter*	Per cent change	Yarn diameter	Per cent change	Yarn diameter	Per cent change	Yarn diameter	Per cent change
0								
Warp	10.2	---	10.8	---	11.5	---	10.9	---
Filling	12.2	---	11.8	---	12.1	---	13.0	---
30th								
Warp	10.9	+5.9	10.4	-3.7	10.9	-5.2	11.0	+0.9
Filling	12.1	-0.8	11.3	-4.2	12.5	+3.3	12.4	-4.6
60th								
Warp	10.2	0	10.5	-2.8	10.4	-9.6	10.8	-0.9
Filling	11.0	-9.8	10.6	-10.2	10.9	-9.9	12.1	-6.9

*Yarn diameters are expressed in millimeters

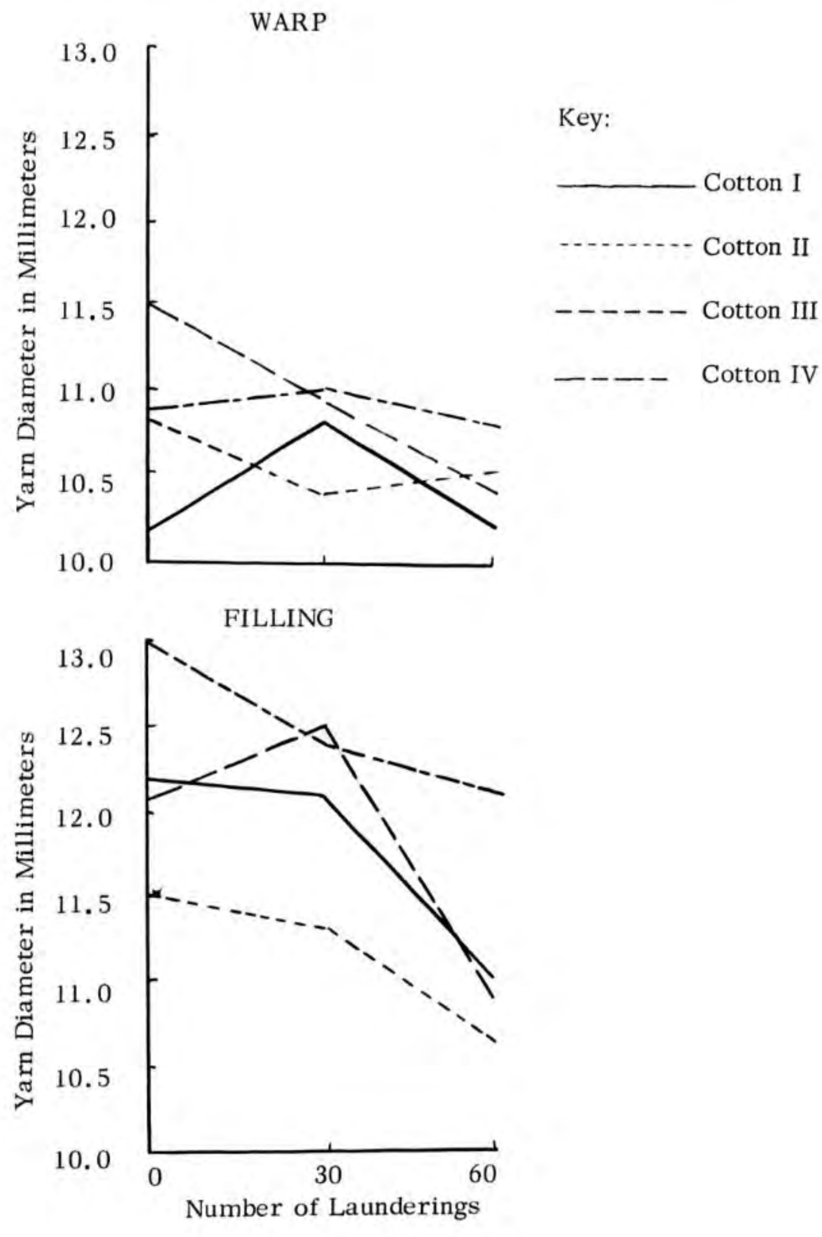


FIGURE 3

MEAN YARN DIAMETERS OF FOUR COTTONS AT THREE INTERVALS FOR BOTH WARP AND FILLING YARNS

III decreased. The per cent change ranged from +5.9 per cent to -5.2 per cent. In the filling direction, Cotton III had the greatest yarn diameter and Cotton I, the smallest. Only Cotton III increased in filling yarn diameter at this interval. The per cent change ranged from -4.6 per cent to +3.3 per cent.

In the warp direction there was a general decrease in yarn diameter from the thirtieth to the sixtieth period with Cotton II increasing slightly. All cottons in the filling decreased in yarn diameter following sixty periods of use and laundering. The change decreased from 0 per cent for Cotton I to -10.2 per cent.

The results of the analysis of variance are shown in Table IV. There was no significant difference in yarn diameter among all the cottons in the warp direction at either interval. There was a significant difference in the means of all the cottons in the filling at the thirtieth period and highly significant differences at the sixtieth period. There were no significant differences within the low or high elongation cottons in the warp direction. Significant differences were found within the low elongation filling yarns following thirty periods and highly significant differences following sixty periods within the high elongation filling yarns. After thirty periods of use and laundering there were highly significant differences between the means of the filling yarns of the low and high fiber elongation cottons and significant differences after sixty periods.

<u>Over-all-periods Analysis of Variance</u>

There was no significant variance among the means of the warp yarns of the cottons over the three testing periods. There was also no significant

TABLE IV

SIGNIFICANCE OF VARIANCE OF YARN DIAMETER MEANS OF FOUR COTTONS AT THREE INTERVALS FOR BOTH WARP AND FILLING YARNS

Cottons	Number of times laundered					
	0		30		60	
	Warp	Filling	Warp	Filling	Warp	Filling
I	10.2	12.2	10.8	12.1	10.2	11.0
II	10.8	11.8	10.4	11.3	10.5	10.6
Difference	0.6	0.4	0.4	0.8*	0.3	0.4
III	11.5	12.1	10.9	12.5	10.4	10.9
IV	10.9	13.0	11.0	12.4	10.8	12.1
Difference	0.6	0.9	0.1	0.1	0.4	1.2**
Mean low	10.5	12.0	10.6	11.7	10.4	10.8
Mean high	11.2	12.5	11.0	12.5	10.6	11.5
Difference	0.7	0.5	0.4	0.8**	0.2	0.7*
Mean of cottons	10.9	12.3	10.8	12.1*	10.5	11.2**

*F value is significant (.05 per cent level).

**F value is highly significant (.01 per cent level).

difference at either of the washing intervals or between the interactions of the cottons and the washing interval.

Highly significant differences between the washing periods and among the means of the cottons were found in the filling yarns.

Photographic Examples of Yarns Tested for Yarn Number and Yarn Diameter

Examples of yarns which were measured for yarn number and yarn diameter are shown in photographs on the following pages. Examples of each cotton type are shown at the zero, thirtieth, and sixtieth period of use and laundering.

The photographs were made using a Polaroid MP-3, Industrial View Land Camera using a 35 mm. macro lens. The lens setting for the photographs was f/11 and the exposure time was 1/15 second. The film used was Polaroid Land Film Pack, Type 107, with 3000 ASA units speed in black and white.

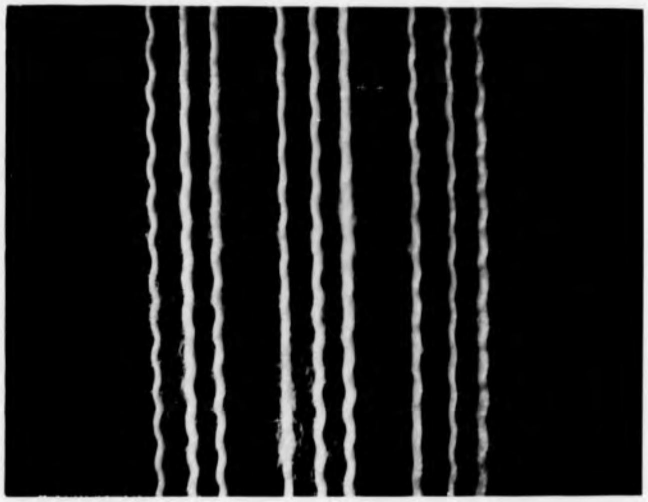
The examples of the yarns photographed do not necessarily represent the data reported in this thesis. They attempt to show only that differences in the yarns could be determined visually.

Abrasion Resistance

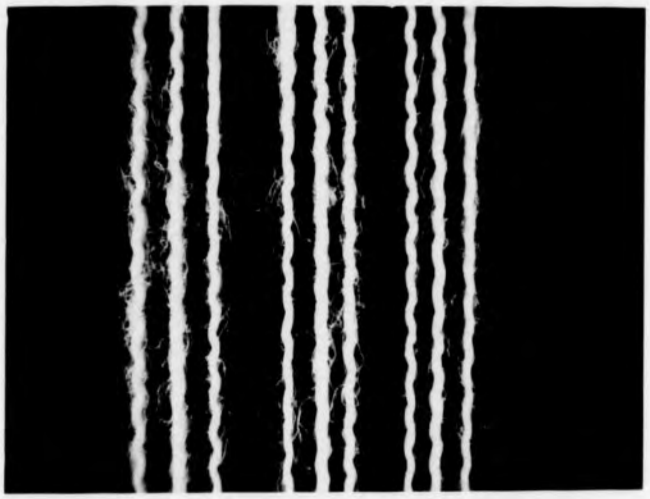
Abrasion resistance means and per cent change are reported in Table V and represented graphically in Figure 8.

Results of the abrasion resistance were reported as the number of wear cycles required to produce a hole in the specimen. Cotton III was highest in

WARP



FILLING



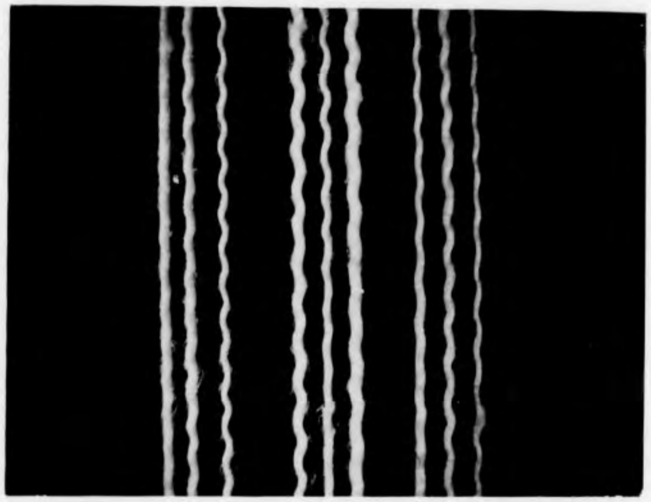
0 30 60

FIGURE 4

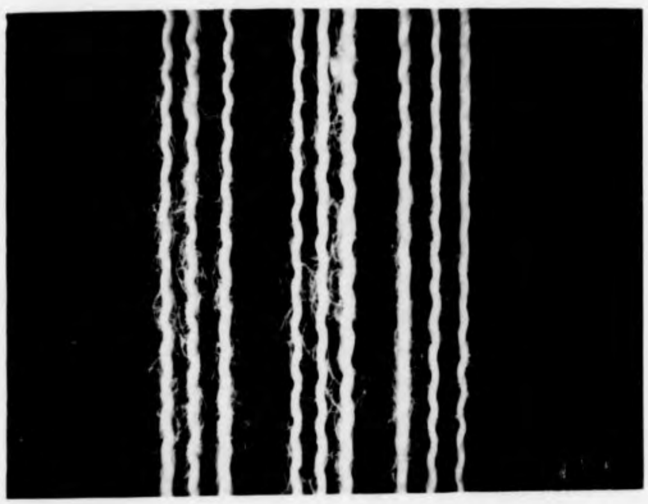
EXAMPLES OF YARNS OF COTTON I BEFORE AND AFTER

USE AND LAUNDERING

WARP



FILLING

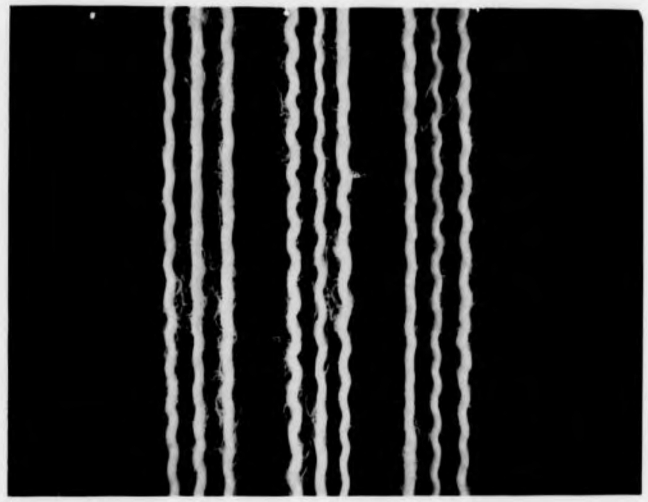


0 30 60
Number of launderings

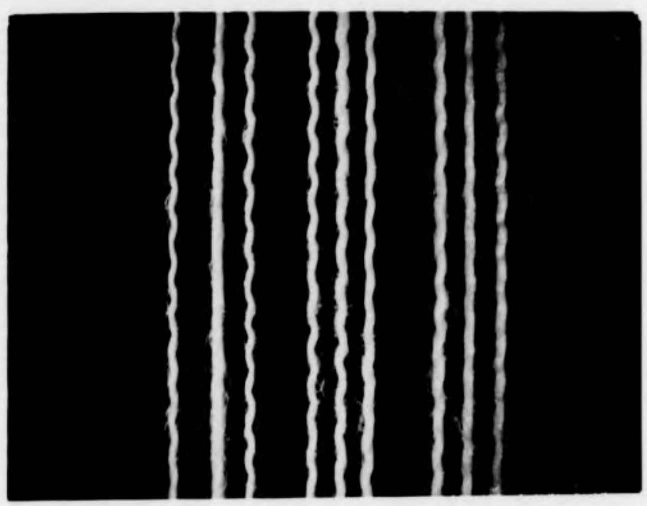
FIGURE 5

EXAMPLES OF YARNS OF COTTON II BEFORE AND AFTER USE AND LAUNDERING

WARP



FILLING

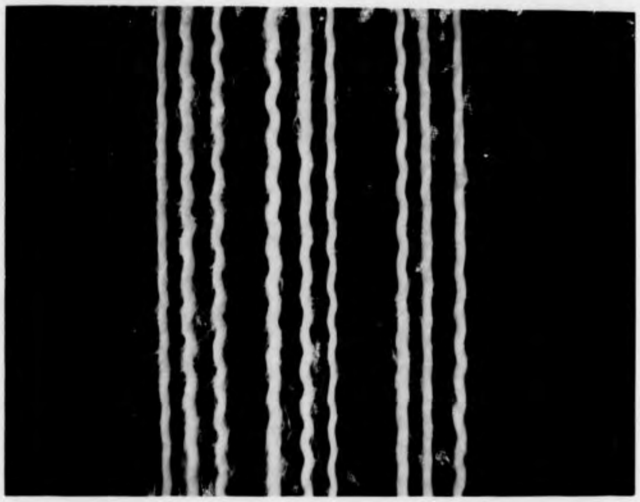


0 30 60
Number of launderings

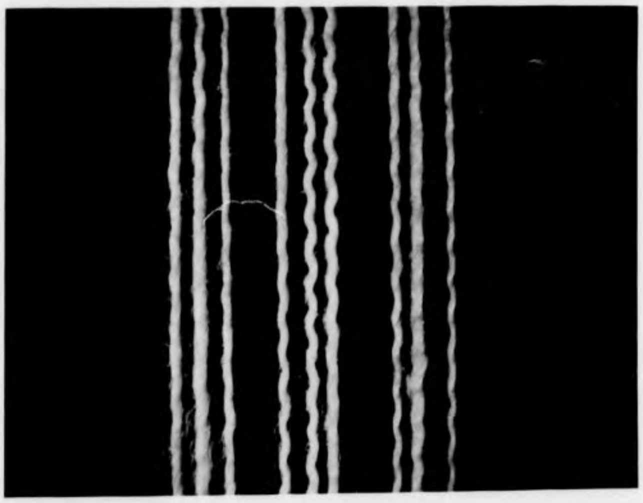
FIGURE 6

EXAMPLES OF YARNS OF COTTON III BEFORE AND AFTER USE AND LAUNDERING

WARP



FILLING



0 30 60
Number of launderings

FIGURE 7

EXAMPLES OF YARNS OF COTTON IV BEFORE AND AFTER USE AND LAUNDERING

TABLE V

ABRASION RESISTANCE MEANS AND PERCENTAGE CHANGE

OF FOUR COTTONS AT THREE INTERVALS

Intervals	Cottons							
	I		II		III		IV	
	Wear cycles	Per cent change	Wear cycles	Per cent change	Wear cycles	Per cent change	Wear cycles	Per cent change
0	876	----	637	----	2382	----	1056	----
30	419	-52.2	353	-44.6	742	-68.8	504	-52.3
60	120	-86.3	314	-50.7	339	-85.8	317	-70.0

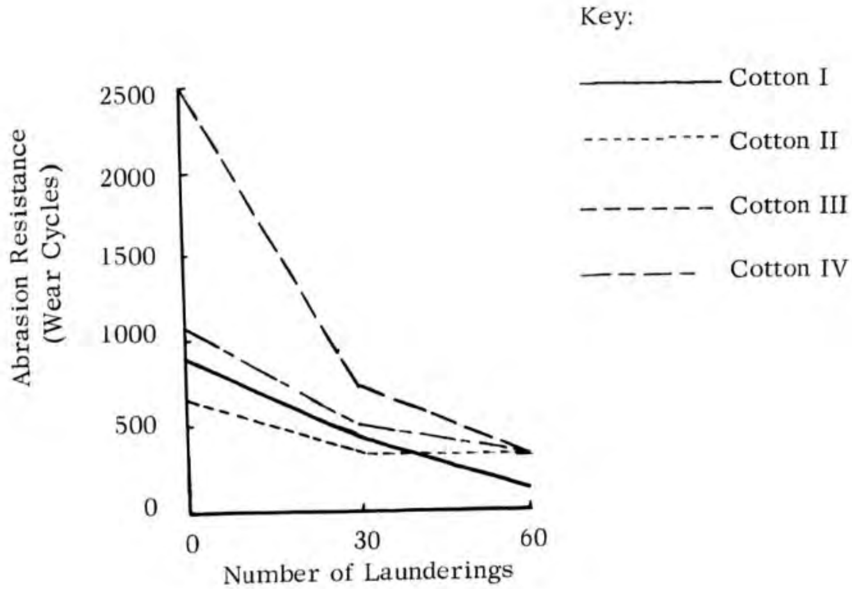


FIGURE 8

MEAN ABRASION RESISTANCE OF FOUR COTTONS AT

THREE INTERVALS

abrasion resistance and Cotton II, lowest at the control interval.

After thirty periods of use and laundering the four cottons decreased in abrasion resistance and remained in the same rank as in the controls with Cotton III having the greatest resistance; Cotton IV, second greatest; Cotton I, third; and, Cotton II having the least resistance to abrasion. After the thirtieth period the per cent change of the cottons ranged from -44.6 per cent to -68.8 per cent.

Cotton I had the least abrasion resistance at the sixtieth period and Cotton III, the greatest. All cottons decreased in abrasion resistance after sixty periods of use and laundering with a range of from -50.7 per cent to -86.3 per cent.

The results of the analysis of variance are shown in Table VI. There were highly significant differences among the four cottons in the controls and at the sixtieth period. Highly significant differences in abrasion resistance were found between the low and high fiber elongation cottons in the controls and significant differences were found after thirty and sixty periods of use and laundering. Highly significant differences were found within the high elongation cottons in the controls and within the low fiber elongation cottons at the sixtieth period.

Over-all-periods Analysis of Variance

Very high significance of variation was found with the abrasion resistance data among the means of the cottons, in the washing period, and between the interaction of cottons and washing period.

TABLE VI

SIGNIFICANCE OF VARIANCE OF MEAN ABRASION RESISTANCE

OF FOUR COTTONS AT THREE INTERVALS

Cottons	Number of launderings		
	0	30	60
I	876	419	120
II	637	353	314
Difference	239	66	194**
III	2382	742	339
IV	1056	504	317
Difference	1326**	238	22
Mean low	756	386	217
Mean high	1719	623	328
Difference	963**	237*	111*
Mean of cottons	1238**	504	272**

*F value is significant (.05 per cent level).

**F value is highly significant (.01 per cent level).

III. RELATION OF CHANGES IN YARN CHARACTERISTICS TO ABRASION RESISTANCE

Correlation Coefficients and Tests of Significance

Correlation coefficients between the number of abrasion cycles and the yarn number and yarn diameter tests were calculated. Using the *t* statistic, tests of significance of the correlation coefficients were determined. The results are shown in Table VII.

The correlation between the warp yarn diameter and the number of abrasion cycles of the control specimens was significant at the .05 per cent level. There were no other significant correlations.

TABLE VII

CORRELATION COEFFICIENTS AND t-FUNCTIONS OF THE RELATIONSHIP BETWEEN ABRASION RESISTANCE AND YARN NUMBER AND YARN DIAMETER

	Yarn number		Yarn diameter	
	Warp	Filling	Warp	Filling
0 Interval				
Abrasion	.02719	- .24259	.42318	.06972
t-function	.12756	-1.1728	2.19053*	.32778
30th Interval				
Abrasion	-.01104	- .31522	-.08802	.26247
t-function	-.05178	-1.55779	-.41442	1.27570
60th Interval				
Abrasion	.12802	.22593	-.03703	.04440
t-function	.60539	1.08772	-.17378	.20844

*t value is significant (.05 per cent level).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

I. SUMMARY

The fiber properties of cotton, one of our most important agricultural commodities, and their relation to the utilization of products made from cotton are important areas of investigation. Extensive research has been directed toward the properties of raw cotton but little has been done to investigate the relationship between cotton fiber properties and in-service performance of products made from cotton. Research indicating a means of selecting cottons for specific end uses would benefit cotton breeders and manufacturers, as well as consumers.

The Southern Regional Research Project sponsored by the United States Department of Agriculture was designed to investigate the properties of selected types of raw cotton and to determine the relationship between the property of fiber elongation, the product quality, and the end use of the fabrics made from the selected types of cotton. This research was undertaken by Home Economics Research Personnel of six Southern states in cooperation with the Agricultural Experiment Stations in these states.

Four bales of American Upland type cottons grown in 1957 were selected for their similarity in properties of length, strength and fineness. The cottons differed only in fiber elongation. Two bales were of low elongation and two of high fiber elongation.

Type 140 muslin sheets were made from the cottons and the sheets distributed to four of the stations participating in the Project to be used in women's dormitories and laundered weekly in commercial laundries. At each of these stations six sheets of each cotton type were withdrawn before laundering to be used as controls and six were also withdrawn after 5, 15, 30, 45, and 60 weeks of use and laundering. Sheets serviced at the North Carolina station following 0, 30, and 60 periods of use and laundering provided data for this study.

Experimentation, completed earlier in the Project, using two methods of abrasion to evaluate the performance of high and low elongation fibers, produced results indicating considerable variation within the two methods of abrasion. It seemed that some of the differences might be caused by changes in yarn structure.

The specific objectives of this study were as follows:

1. To study yarn and abrasion characteristics of four cottons selected to show differences in high and low fiber elongation.
2. To measure changes in abrasion resistance after 0, 30, and 60 intervals of use and laundering.
3. To determine changes in yarns after 0, 30, and 60 intervals of

use and laundering.

4. To compare changes in yarn structure with changes in abrasion resistance.

The laboratory analysis of the samples consisted of the following tests which would measure changes in yarn size and abrasion resistance:

1. Changes in yarn number as determined by weight of hanks per pound using the Suter Yarn Numbering Balance. Five samples of warp and five samples of filling for each sheet were weighed. (This represented a total of 30 measurements in both warp and filling for each cotton type.)
2. Changes in yarn diameter in millimeters using the Visopan Microprojector. Three measurements for each of ten samples in both warp and filling yarns for each sheet were determined. (This was 180 measurements in each direction for each cotton type.)
3. Changes in abrasion resistance as expressed in wear cycles required to produce a break in both warp and filling yarns for each of three samples for each sheet. (This represented 18 measurements for each cotton.)

An analysis of variance was used to determine the significance of differences between cottons of high and low fiber elongation as indicated by the three measurements after 0, 30, and 60 periods of use and laundering and over all periods of use and laundering. The .05 per cent level was selected as the point beyond which findings would be considered significant.

Correlation coefficients between the abrasion test and the corresponding yarn number and yarn diameter were calculated. Tests of significance of the correlation coefficients were determined using the $\underline{t}$ statistic.

Yarn Number

Differences in yarn number between Cottons I and II, the low fiber elongation cottons, were generally significant at each period while differences between Cottons III and IV, the high fiber elongation cottons, were not generally significant.

The means of all the yarns in the control specimens were finer than 22's, the number specified for the spinning of both warp and filling yarns. The mean weight per unit length of all cottons except Cotton I decreased from 1.7 per cent to 9.9 per cent following thirty periods of use and laundering. Cotton I increased in weight per unit length from the control to the thirtieth period. After sixty periods of use and laundering the warp yarn number means for each of the cottons ranged from 25.1 to 25.6 which was approximately a 6-12 per cent loss in yarn size. The filling yarn means for all cottons were between 26.2 and 28.0 following the sixtieth period which was approximately an 8 to 26 per cent loss in yarn number from the control filling yarns.

Yarn Diameter

No significant differences were found in the warp yarns at either interval. However, significant differences were found in the filling yarns.

The yarn diameter of the low elongation cottons tended to be smaller than the high elongation cottons at the control period. Considerable variance was found after thirty periods of use and laundering with some yarns becoming smaller in diameter and some larger in diameter than in the control samples. After sixty periods the filling yarns decreased in yarn diameter from approximately 7 to 10 per cent.

Abrasion Resistance

Significant differences in abrasion resistance were found between the means of the low and high fiber elongation cottons at each interval. Highly significant differences were found between the low elongation cottons after sixty periods. Highly significant differences in abrasion resistance were also found between the high fiber elongation cottons at the control interval.

The means for all the cottons decreased in abrasion resistance following thirty and again after sixty periods of use and laundering. In general, the decrease was approximately 50 per cent after thirty periods and approximately 75 per cent after sixty periods.

In the control sheets Cotton II had the least resistance to abrasion and continued to have the least throughout the study. However, Cotton II also had the smallest per cent change throughout the study. Cotton III had the greatest resistance to abrasion at the beginning and throughout the study and it also showed the highest per cent change from the beginning to the end of the study. Though Cotton II changed the least in the study and Cotton III, the most; Cotton II was still the least resistant to abrasion and Cotton III the most resistant.

Relation of Changes in Yarn Characteristics to Abrasion Resistance

The correlation coefficient of the warp yarns in the yarn diameter and the number of abrasion cycles was significant at the .05 per cent level of probability. Though no other significant correlations were found, it was interesting to note that both negative and positive coefficients were found. Half of the correlation coefficients were negative for the yarn number-abrasion relationship which indicates that the weight per unit length of yarn does not necessarily affect the abrasion resistance of a fabric. Both negative and positive correlation coefficients were found in the yarn diameter-abrasion relationship. Four out of six correlations were positive which may indicate that a larger yarn diameter may cause greater abrasion resistance.

II. CONCLUSIONS

The results of this study indicate the following conclusions.

1. There were highly significant differences in yarn number between the low and high fiber elongation cottons before laundering but generally no significant differences following use and laundering.
2. There were no significant differences in the yarn diameter of the warp yarns between the low and high elongation cottons but significant differences were found between the filling yarn diameters of low and high elongation cottons following use and laundering.

3. There were significant differences in abrasion resistance between the low and high elongation cottons at each period of the study.

4. The changes in yarn characteristics were not closely related to the abrasion resistance of the fabric.

III. RECOMMENDATIONS FOR FURTHER STUDY

Further study is needed to determine the relationship between yarn characteristics and abrasion resistance. The following recommendations are made for further study:

1. Compare yarn characteristics to abrasion measurements made by the same method of abrasion to sheets withdrawn after fifteen and forty-five periods of use and laundering.

2. Relate yarn number and yarn diameter to data obtained using another method of determining abrasion resistance (Stoll Flex Abrasion).

3. Relate yarn characteristics to other measurements of physical properties such as tear resistance, tensile strength, elongation, and stiffness.

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APPENDIX

State North Carolina
Test Taber Abrasion
Interval 30th

APPENDIX A

ANALYSIS OF VARIANCE OF LABORATORY TESTS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	F	F at .05	F at .01
Cottons	3	521644.15	173881.38	2.46780	3.10	4.94
Low vs. high	1	337583.04	337583.04	4.79113*	4.35	8.10
Between low	1	13008.67	13008.67	0.18462	4.35	8.10
Between high	1	171052.05	171052.05	2.42764	4.35	8.10
Sheets treated alike	20	1409199.33	70459.97			

$$C.V. = \frac{\sqrt{M.S.\ \text{Sheets treated alike}}}{\bar{M}} \times 100 \text{ or } 52.61\%$$

*F value is significant.

**F value is highly significant.

State North Carolina
Test Taber Abrasion

APPENDIX B

OVER-ALL-PERIODS ANALYSIS OF VARIANCE

	Degrees of Freedom		Sum of Squares	Mean Square	F
Cottons		3	5832722.82	1944240.94	10.1719**
Low vs. high	1				
Between lows	1				
Between highs	1				
Washing Interval	(W - 1)	2	12051228.73	6025614.36	31.5249**
C X WI		6	5879715.18	979952.53	5.1269**
Sheets Treated like	CW (S - 1)	60	11468273.70	191137.90	
Total			35231940.43		

$$CV = \sqrt{\frac{MSC\ (W-1)}{\text{Total Mean}}} \times 100 = 65.07\%$$

*F value is significant at .05 per cent level.

**F value is highly significant at .01 per cent level.