RESEARCH AND DEVELOPMENT REPORT

*TEXTILE SERIES - REPORT NO. 66*



# EFFECT OF CONSTRUCTION ON THE LAUNDERING SHRINKAGE OF KNITTED WOOLENS



Prepared jointly by the staff of the Harris Research Laboratory, Washington, D.C. and the Textile Finishing Research Laboratory of the Research & Development Branch located at the Philadelphia Quartermaster Depot.



DEPARTMENT OF THE ARMY
OFFICE OF THE QUARTERMASTER GENERAL

# DOCUMENT DATA WORKSHEET

| AD— / ATI | Date Initiated: | Security Information: |
|---|---|---|
| STI-ATI 207 485 | 22 July 54 ems | |

**Originating Agency:**

Military Planning Div., Office of the Quartermaster General, Wash., D. C.

**Title:**

EFFECT OF CONSTRUCTION ON THE IAUNDERING SHRINKAGE OF KNITTED WOOLENS

**Foreign Title:**

——————

| Author(s): | Translator(s): |
|---|---|
| ——— | ——— |

**Type, Series, Number and Period of Report covered:**
Textile Series

| Date of Report: | Number of Pages: | | | |
|---|---|---|---|---|
| Apr 51 | 16 | Incl | x | Illustrations |
| | | | x x | Tables |

| OA No.: | PA No.: | Others |
|---|---|---|
| Rept. no. 66 | ——— | ——— |

**Translation No. and Foreign Source:**
————

**Contract No.:** ———

**Tracings:**
———

| Division(s): | Section(s): |
|---|---|
| | |

**Distribution Note:**

| TAB: | Special Instructions: |
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Office of The Quartermaster General
Military Planning Division
Research and Development Branch

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Released for Public Information
by
The Office of Technical Services
U. S. Department of Commerce

# FOREWORD

Previous work done in the Quartermaster Laboratories and reported in Textile Series Report No. 57, pointed out the importance of constructional factors on the relaxation shrinkage of knitted materials. These investigations emphasized the role of knitting stiffness, stitch type and yarn size on relaxation shrinkage and suggested means of improving the design and functional performance of knit structures through application of the principles developed.

Further work, reported herein, shows that the knitted structure has a profound effect on felting as well as relaxation shrinkage. This observation is of considerable significance at the present time because of the critical shortage of wool for military and civilian purposes. The introduction of anti-felt processes has already contributed to the current wool conservation program; it is expected that a reduction in wool consumption will also be effected by the adoption of knit structures designed on the basis of the principles discussed in this report.

This report was prepared by Mr. Herman Bogaty, Mr. Arnold Sookne and Dr. Milton Harris, of the Harris Research Laboratories, Washington, D.C., and Mr. Louis I. Weiner, Manager of the Shrink Resistant Project, Textile Finishing Research Laboratory, at the Philadelphia Quartermaster Depot.

In submitting this report, I should like to express our appreciation to Messrs. John Gardiner and Fritz Kobayashi, of the Ames Worsted Company, who arranged for treatment of the wool top. Acknowledgment is also made of the assistance of Mr. William Gosch, of the Nolde & Horst Company, who furnished advice on the construction of the experimental fabrics and arranged for the knitting that was done in his mill and the Chancellor Hosiery Mills, Reading, Pa.

Many of the measurements were performed by Mrs. Virginia G. Moran, Harris Research Laboratories, and Miss Gertrude Ardis, Quartermaster Research and Development Laboratories.

S. J. KENNEDY
Research Director for
Textile, Clothing and Footwear

April 1951

This work constitutes a part of the Army Quartermaster program on shrink-resistant wool, which is under the supervision of the National Research Council Advisory Committee on Textile Finishing Research.

# I. INTRODUCTION

In the fabrication of knitted garments, it is well known that the tightness of the structure affects the laundering behavior in use. Furthermore, it is generally understood in the industry, and by most consumers, that a loose, fluffy lady's sweater, for example, must be handled more carefully than a pair of machine-knit socks. While the pioneering work of W. A. Dutton[3] has provided the first quantitative approach to the role of knitting stiffness in shrinkage, the factors constituting "tightness of structure" are not yet precisely understood.

Further work in this field was prompted by the recognition by the Army Quartermaster Corps that replacement of wool service clothing was, in a large fraction of cases, due to shrinkage in washing under field and other conditions. While anti-felting treatments have contributed greatly to amelioration of this problem, it is becoming clear that specification of the use of shrink-resistant wool of itself, in the absence of construction limits, provides only a partial solution to the problem. It was, therefore, with the practical goal in mind of providing a basis for modification of procurement specifications, with respect to construction, that this investigation was undertaken, in the hope that improvement in laundering stability might be achieved and that some insight into the quantative factors contributing to it might be gained.

# II. MATERIALS AND METHODS

## A. Materials

Six-hundred pounds of 64's grade Australian wool top was obtained and divided into four parts. One-fourth was set aside and the remainder treated in the mill by a commercial, continuous, top-treating process employing alkaline wet chlorination.[5] The treatment used was at three different levels, as judged by the top shrinkage test;[1] the latter measures the length change of top specimens subjected to wet mechanical action and has been shown over a long period of use to correlate well with the shrinkage behavior of garments made from the top. The top shrinkage values of the four groups of top were: Untreated - 35 to 40 per cent; "mild" treatment - 15 per cent; "optimum" treatment - 7 per cent; "severe" treatment - 2 per cent. The adjectives describing the level of chlorination are based on the experience of processors in relating top shrinkage values to the performance of Army fabrics; a 7 to 12 per cent top shrinkage is considered "optimum" for most Army constructions; a 12 to 20 per cent top shrinkage, while adequate for many civilian consumer applications, may be too mild for vigorous Army laundering methods; while a 2 to 7 per cent top shrinkage generally indicates a more severe treatment than is required for most uses.

The wool was top dyed with chrome colors and then spun into the following yarns:

1. 15/1 Bradford, normal knitting twist.
2. 15/1 Bradford, higher than normal twist.
3. 15/2 Bradford, normal knitting twist.
4. 15/2 Bradford, higher than normal twist in singles.
5. 26/1 Bradford, normal knitting twist.
6. 26/1 French, normal knitting twist.
7. 26/2 Bradford, normal knitting twist.
8. 26/2 French, normal knitting twist.
9. 36/1 French, normal knitting twist.
10. 36/2 French, normal knitting twist.

This spinner's judgment as to "normal" or "higher than normal" twists was followed; actual values of the twists in the yarns are presented below (Tables III and IV).

The yarns, now representing ten types at four levels of treatment, were fabricated into socks or tubing on commercial scale knitting machines, using either flat or 1 by 1 rib stitches.

With each knitting machine, that number of loops was used which would produce a commercially acceptable fabric with a given type of yarn. The knitting stiffness was varied above and below this value to give a tight and a loose or sleazy construction, in addition to the "normal" texture.

B. Methods

The knit fabrics were relaxed by submerging them in water at 80 degrees F. for 2 hours, followed by hydroextraction and tumble drying. The laundering procedure used for most of the data reported here was similar to that known as the Army wool mobile laundering, except that the load used was increased from 20 to 23-1/2 pounds, in order to accommodate all of the specimens in a single run. The wash cycle comprised two 5-minute suds, using Igepon T as detergent, followed by three 3-minute rinses, extraction, and tumble drying; water temperature was maintained at 100 degrees F. Five wash cycles was the maximum used, since it resulted in severe felting of most of the untreated fabrics.

In order to resolve differences in felting behavior of some of the treated samples, a milder laundering procedure was also used in some cases. This comprised a 4-minute suds, followed by two 2-minute rinses at high water level. This latter test will be referred to below as the mild laundering. Measurements were made after 5, 10 and 20 mild launderings of this type.

## III. RESULTS AND DISCUSSION

In view of the large mass of data obtained, the effect of each factor of construction is isolated where possible, and the results are presented in separate tables. While the results for a given sample may thus be used in several places, it is believed that this method of presentation is justified because it greatly facilitates comparison.

A. Effect of Knitting Stiffness

With any given yarn, the tightness of knit or density of the fabric appears to be the most important variable of construction, from the point of view of effect on felting shrinkage. Data illustrative of the effect of this factor on untreated wool are presented in Table I.

TABLE I

Laundering Shrinkage of Untreated Knitted Fabrics as a Function of Knitting Stiffness

| Fabric | Yarn No. | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Shrinkage in 5 Army Mobile Launderings Wales* % | Shrinkage in 5 Army Mobile Launderings Courses** % |
|---|---|---|---|---|---|
| Flat knit tubing | 15/1 | 19 | 22 | 24 | 15 |
| | 15/1 | 20 | 25 | 22 | 11 |
| Flat knit tubing | 15/2 | 13 | 16 | 24 | 14 |
| | 15/2 | 14 | 18 | 20 | 11 |
| Rib knit tubing | 15/2 | 8 | 13 | 32 | 12 |
| | 15/2 | 12 | 18 | 14 | 0 |
| Flat knit tubing | 26/1 | 25 | 28 | 24 | 13 |
| | 26/1 | 27 | 33 | 16 | 8 |
| Flat knit socks | 26/2 | 17 | 20 | 28 | 19 |
| | 26/2 | 18 | 22 | 24 | 14 |
| Flat knit tubing | 26/2 | 11 | 13 | 46 | 38 |
| | 26/2 | 14 | 20 | 35 | 26 |
| Rib knit tubing | 26/2 | 11 | 17 | 35 | 25 |
| | 26/2 | 15 | 23 | 21 | 11 |
| Flat knit tubing | 36/1 | 25 | 30 | 33 | 24 |
| | 36/1 | 30 | 46 | 12 | 6 |
| Rib knit tubing | 36/1 | 22 | 27 | 21 | 21 |
| | 36/1 | 22 | 36 | 11 | 11 |
| Flat knit tubing | 36/2 | 18 | 23 | 29 | 19 |
| | 36/2 | 20 | 26 | 22 | 13 |

*By wales shrinkage is meant shrinkage in the length dimension.
**By courses shrinkage is meant shrinkage in the width dimension.

As shown by these results, the tighter construction in each case resists felting to a greater extent than does the slack knit made with the identical yarn. By increasing the knitting stiffness to a fairly high level, a substantial improvement in fabric stability is attained.

That the effect of knitting stiffness is not limited to untreated wool can be seen from the data in Table II, in which are summarized results of laundering shrinkage measurements on treated wool fabrics.

TABLE II

Shrinkage of Knitted Fabrics Made From Chlorinated Wool as a Function of Knitting Stiffness

| Fabric | Yarn No. | Level of Treatment | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Shrinkage in 5 Army Mobile Launderings Wales % | Shrinkage in 5 Army Mobile Launderings Courses % |
|---|---|---|---|---|---|---|
| Rib knit tubing | 15/1 | Optimum | 13 | 18 | 13 | 8 |
| | 15/1 | Optimum | 16 | 20 | 10 | 8 |
| Flat knit tubing | 15/1 | Optimum | 20 | 20 | 11 | 6 |
| | 15/1 | Optimum | 21 | 24 | 7 | 2 |
| Flat knit tubing | 15/2 | Optimum | 7 | 8 | 34 | 8 |
| | 15/2 | Optimum | 8 | 10 | 21 | 12 |
| | | | 11 | 14 | 14 | 9 |
| Flat knit tubing | 15/2 | Vigorous | 6 | 8 | 10 | 3 |
| | 15/2 | Vigorous | 8 | 10 | 1 | 2 |
| Rib knit tubing | 15/2 | Optimum | 7 | 13 | 16 | -4 |
| | 15/2 | Optimum | 13 | 18 | 7 | -4 |
| Rib knit tubing | 26/2 | Optimum | 11 | 18 | 17 | 5 |
| | 26/2 | Optimum | 14 | 23 | 9 | 3 |
| Rib knit tubing | 26/2 | Vigorous | 11 | 17 | 6 | -4 |
| | 26/2 | Vigorous | 13 | 19 | 1 | -5 |
| Flat knit tubing | 26/2 | Optimum | 10 | 12 | 19 | 6 |
| | 26/2 | Optimum | 14 | 17 | 10 | 1 |
| Flat knit tubing | 26/2 | Vigorous | 10 | 13 | 10 | -1 |
| | 26/2 | Vigorous | 14 | 18 | 4 | 2 |

The decrease in feltability, with increasing knitting stiffness, is again noted, this result showing good general agreement with the conclusions of Dutton on the role of knitted fabric texture in shrinkage.(3,4) The results in Table II indicate that the manufacture of a satisfactory shrink-resistant garment depends on a judicious combination of a proper level of treatment with a sufficiently firm construction. Thus, while a shrink-resistant garment can be made from untreated yarns knitted extremely tightly, such a garment would suffer a loss of the desirable softness and extensibility which are among wool's chief virtues. Conversely, a sleazy construction can be made quite shrink-resistant by overtreatment, but only with resulting loss of soft hand and good wearing qualities.

B. Effect of Yarn Twist

The shrinkage in laundering of untreated fabrics in which the yarns differed in twist is shown in Table III. Since the previous section has confirmed the importance of knitting stiffness, comparisons are made only between fabrics which are similar in this latter respect.

TABLE III

Shrinkage of Knitted Fabrics Made From Untreated Wool as a Function of Yarn Twist

| Fabric | Yarn No. | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Yarn Twist Singles tpi | Yarn Twist Ply tpi | Shrinkage in 5 Army Mobile Launderings Wales % | Shrinkage in 5 Army Mobile Launderings Courses % |
|---|---|---|---|---|---|---|---|
| Flat knit tubing | 15/1 | 19 | 24 | 6.7 | — | 23 | 13 |
| | 15/1 | 19 | 24 | 8.1 | -- | 20 | 11 |
| Rib knit tubing | 15/1 | 14 | 18 | 6.7 | -- | 28 | 18 |
| | 15/1 | 14 | 18 | 8.1 | -- | 27 | 18 |
| Flat knit tubing | 15/2 | 14 | 17 | 3.9 | 7.0 | 26 | 17 |
| | 15/2 | 14 | 17 | 7.7 | 5.1 | 23 | 13 |
| | 15/2 | 7 | 10 | 3.9 | 7.0 | 52 | 39 |
| | 15/2 | 7 | 9 | 7.7 | 5.1 | 47 | 33 |
| | 15/2 | 11 | 16 | 3.9 | 7.0 | 33 | 25 |
| | 15/2 | 11 | 15 | 7.7 | 5.1 | 34 | 25 |
| Rib knit tubing | 15/2 | 8 | 13 | 3.9 | 7.0 | 39 | 15 |
| | 15/2 | 8 | 13 | 7.7 | 5.1 | 32 | 12 |
| | 15/2 | 10 | 13 | 3.9 | 7.0 | 33 | 10 |
| | 15/2 | 9 | 15 | 7.7 | 5.1 | 30 | 7 |

TABLE IV

Shrinkage of Knitted Fabrics Made From Shrink-Resistant Wool as a Function of Yarn Twist

| Fabric | Yarn No. | Level of Treatment | Fabric Texture | | Yarn Twist | | Shrinkage in 5 Army Mobile Launderings | |
|---|---|---|---|---|---|---|---|---|
| | | | Wales/inch | Courses/inch | Singles tpi | Ply tpi | Wales % | Courses % |
| Flat Knit Socks | 15/1 | Optimum | 20 | 24 | 6.7 | - | 10 | 5 |
| | 15/1 | Optimum | 20 | 24 | 8.1 | - | 8 | 4 |
| Flat Knit Socks | 15/2 | Optimum | 13 | 16 | 3.9 | 7.0 | 12 | 4 |
| | 15/2 | Optimum | 13 | 16 | 7.7 | 5.1 | 9 | 4 |
| | 15/2 | Optimum | 14 | 17 | 3.9 | 7.0 | 10 | 4 |
| | 15/2 | Optimum | 14 | 17 | 7.7 | 5.1 | 9 | 2 |
| | 15/2 | Optimum | 7 | 8 | 3.9 | 7.0 | 34 | -8 |
| | 15/2 | Optimum | 6 | 8 | 7.7 | 5.1 | 22 | 3 |
| Flat Knit Socks | 15/2 | Vigorous | 6 | 8 | 3.9 | 7.0 | 10 | -3 |
| | 15/2 | Vigorous | 7 | 7 | 7.7 | 5.1 | 7 | -2 |

The results indicate a small but consistent trend towards lower shrinkage values for the fabrics made with the higher-twist yarns. It is to be noted that the single yarns differed to a rather minor degree in twist, and the differences in the felting of fabrics knitted from the 15/1 yarns, for example, are quite small.

Similar data are presented in Table IV for the fabrics knitted from shrink-resistant wool, in which similar small improvements in felt-resistance accompany the use of higher twist yarns. It is observed that the improvement tends to be greater for the slacker knit fabrics, an effect which can be seen in some of Dutton's work as well.(4)

## C. Effect of Plying of Yarns

The role of plying in felting behavior was studied by laundering knitted fabrics made from 15's single ply yarns compared with those made from 26's and 36's, two ply. Such fabrics of similar texture were considered to be substantially the same with respect to weight. The results of wash tests are given in Table V for both untreated wool and for top subjected to the "optimum" chlorination treatment.

TABLE V

Shrinkage of Knitted Fabrics as a Function of Plying of Yarns

| Fabric | Yarn No. | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Shrinkage in 5 Army Mobile Launderings Wales % | Shrinkage in 5 Army Mobile Launderings Courses % |
|---|---|---|---|---|---|
| Flat Knit | | | | | |
| Untreated | 15/1 | 20 | 25 | 22 | 12 |
| | 36/2 | 20 | 26 | 22 | 13 |
| | 15/1 | 19 | 22 | 28 | 14 |
| | 26/2 | 18 | 22 | 25 | 14 |
| | 36/2 | 18 | 23 | 29 | 19 |
| Flat Knit | | | | | |
| Optimum Treatment | 15/1 | 20 | 24 | 8 | 4 |
| | 36/2 | 20 | 24 | 3 | 3 |
| | 15/1 | 20 | 20 | 11 | 6 |
| | 26/2 | 18 | 21 | 9 | 8 |
| | 36/2 | 19 | 22 | 3 | 3 |

Plying is seen to produce no effect on the laundering shrinkage of untreated fabrics. On the other hand, the data in Table V suggest that with shrink-resistant wool, plying may result in superior resistance to felting. This is, however, believed to result from the differences in yarn twist in the samples available for comparison. The singles twist of the 15's, 26's and 36's yarns used in the treated fabrics were respectively 8.2, 8.8 and 11.6 turns per inch. The felting of the samples made from the 26/2 yarn is similar to that knit from the 15/1 yarn whereas the felting of the 36/2 yarn with higher twist is lower. The decrease in felting observed with the 36/2 higher twist yarn is similar to that given in Table IV and may therefore be attributed to the twist rather than to the plying. It is concluded that plying results in little effect on felting in the absence of other interactions.

D. Type of Spinning

Comparisons for feltability of untreated fabrics made from yarns which were spun on the French or on the Bradford system are shown in Table VI. The results indicate negligible difference in felting behavior.

TABLE VI

The Effect of Bradford vs. French Spinning on Shrinkage in Laundering of Untreated Wool

| Fabric | Yarn No. | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Type of Spinning | Shrinkage in 5 Army Mobile Launderings Wales % | Shrinkage in 5 Army Mobile Launderings Courses % |
|---|---|---|---|---|---|---|
| Flat Knit | 26/1 | 27 | 35 | Bradford | 18 | 13 |
| Tubing | 26/1 | 27 | 33 | French | 18 | 8 |
| Flat Knit | 26/2 | 17 | 20 | Bradford | 27 | 19 |
| Socks | 26/2 | 16 | 20 | French | 28 | 16 |
| Flat Knit | 26/2 | 11 | 13 | Bradford | 46 | 38 |
| Tubing | 26/2 | 11 | 13 | French | 50 | 36 |
| Rib Knit | 26/2 | 12 | 20 | Bradford | 29 | 16 |
| Tubing | 26/2 | 13 | 19 | French | 30 | 17 |

E. Effect of Yarn Number

It was considered of interest to compare the feltability of fabrics of as nearly identical texture as possible but made from different untreated yarns. This in effect constitutes a different way of changing the weight of the cloth than through varying the knitting stiffness. The comparisons are shown in Table VII.

TABLE VII

Shrinkage of Untreated Knitted Fabrics of Approximately Equal Texture as a Function of Yarn Number

| Fabric | Yarn No. | Fabric Texture Wales /Inch | Fabric Texture Courses /Inch | Shrinkage in 5 Army Mobile Launderings Wales % | Shrinkage in 5 Army Mobile Launderings Courses % |
|---|---|---|---|---|---|
| Flat Knit Tubing | 15/2 | 13 | 17 | 25 | 11 |
| | 26/2 | 16 | 19 | 30 | 18 |
| Rib Knit Tubing | 15/2 | 12 | 18 | 14 | 0 |
| | 26/2 | 12 | 20 | 29 | 16 |
| | 15/1 | 15 | 17 | 30 | 19 |
| Flat Knit Tubing | 26/2 | 18 | 22 | 25 | 14 |
| | 15/1 | 19 | 22 | 24 | 15 |
| | 36/2 | 18 | 23 | 29 | 19 |
| Flat Knit Tubing | 15/2 | 8 | 10 | 30 | 25 |
| | 26/2 | 11 | 13 | 46 | 38 |
| Flat Knit Tubing | 36/2 | 20 | 26 | 22 | 13 |
| | 26/1 | 25 | 33 | 23 | 16 |
| | 26/1 | 25 | 28 | 24 | 13 |
| | 36/1 | 25 | 30 | 33 | 24 |

The results indicate that the heavy fabrics made with yarns of lowest yarn number are relatively less feltable. Thus, increasing the density of the fabric by using a heavier yarn or by knitting with more loops per inch tends to produce a more shrink-resistant fabric.

This result suggested that these two factors could be considered together. With woven fabrics, the parameter known as the cover factor, F, is frequently used to define the fabric density; it is given by the relationship:

$F = \frac{T}{\sqrt{Y}}$, where T is the number of picks or ends per inch

and Y is the effective yarn number, (i.e., the yarn number for singles, one-half the yarn number for 2 ply yarns, etc.). F.T. Peirce[6] has analyzed the geometry of knitted fabrics and has defined the density $\rho k$, in terms of the unit weight of the yarn, g, and the course and wale spacing, p and w, respectively. Combining several of his equations, the density is given to a first approximation by:

$$\rho k = \frac{\text{Constant x g.}}{(p + w)^2}$$

Since Peirce's weight per unit length, g, is inversely proportional to the yarn number, Y, and the course and wale spacing varies as the reciprocal of the number of courses and wales per inch, the "cover factor" as defined above can be seen to be related to the density of knitted fabrics given by Peirce. The somewhat arbitrary procedure was therefore followed of calculating a "cover factor" for the present knitted fabrics, using the relationship:

$F = \frac{T}{\sqrt{Y}}$, and taking as T the sum of the number of courses

and wales per inch. The factor so calculated is clearly related to the density of packing of wool in a given area of knitted goods, and it has the virtue of extreme simplicity.

The "cover factors" so calculated were plotted against the felting shrinkage, the curves being shown by the circles and triangles in figures 1 and 2 for the untreated flat and 1 by 1 rib knit fabrics, respectively. The correlation is seen to be quite good. One can estimate the felting for a wide variety of constructions and yarn types from the "cover factor" values.

As a matter of general interest an attempt was made to determine whether this relationship would also hold for other data. Accordingly, the data of Dutton[3] and of Cox et al[2] were calculated in this way and plotted on the same curves.

Fig. 1
SHRINKAGE OF UNTREATED FLAT KNIT FABRICS IN LAUNDERING AS A FUNCTION OF "COVER FACTOR"

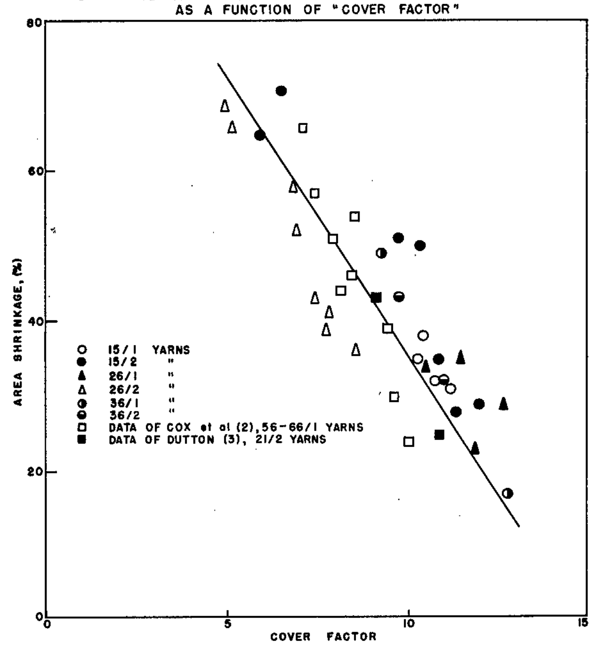
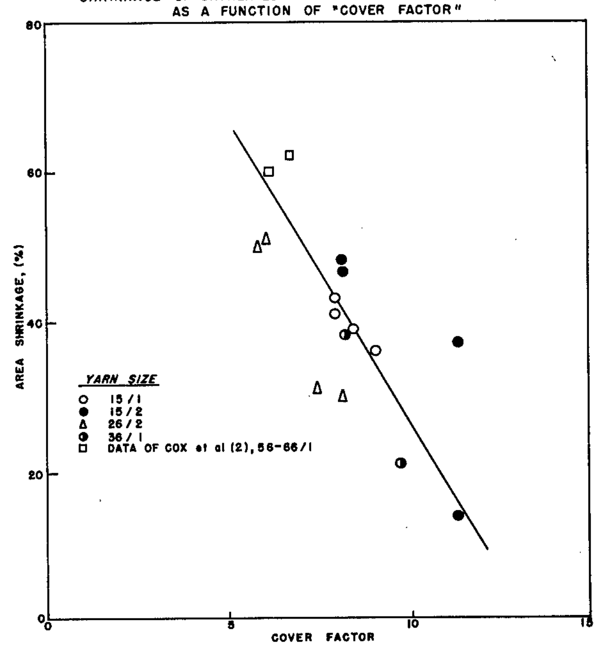



Fig. 2
SHRINKAGE OF UNTREATED RIB KNIT FABRICS IN LAUNDERING AS A FUNCTION OF "COVER FACTOR"




The points (solid squares - ■ and open squares - □, respectively) are observed to fit very well to the present data, despite the considerable difference in the felting test methods used. This result suggests that the observed relationship may be of general usefulness, although the very good agreement between the present data and those of Dutton and Cox must be regarded as partly fortuitous, probably resulting from the fact that all the shrinkage tests involved are quite severe.

F. Effect of Level of Treatment

Some data and discussion have previously been presented on the influence of the treatment of the wool. Comparison of the general shrinkage values in Tables I and II, and Tables III and IV, reveal, as one would expect, that treatment for shrink-resistance is the largest factor in lowering felt-ability. An overall view of this given in Tables VIII and IX, which in addition give a picture of the magnitudes of the felting changes with continued laundering; these results are for the mild washing procedure using low titer soap as detergent.

TABLE VIII

Shrinkage in Mild Laundering of Flat Knit Socks

| Yarn Code Number* | Length Shrinkage in Laundering** Untreated 5 Cycles % | Untreated 10 Cycles % | Untreated 20 Cycles % | Mild Treatment 10 Cycles % | Mild Treatment 20 Cycles % | Optimum Treatment 20 Cycles % | Severe Treatment 20 Cycles % |
|---|---|---|---|---|---|---|---|
| 1 - Slack Knit | 8 | 18 | 25 | 10 | 14 | 3 | - |
| 1 - Tight Knit | 7 | 15 | 22 | 10 | 8 | 3 | - |
| 2 - Slack Knit | 11 | 16 | 26 | 5 | 8 | - | 2 |
| 2 - Tight Knit | 8 | 17 | 24 | 1 | 4 | 5 | - |
| 3 - Slack Knit | 12 | 16 | 24 | 10 | 14 | 4 | 1 |
| 3 - Tight Knit | 10 | 13 | 22 | 7 | 10 | 2 | 1 |
| 4 - Slack Knit | 7 | 15 | 23 | 8 | 13 | 4 | 1 |
| 4 - Tight Knit | 6 | 12 | 18 | 6 | 6 | 2 | 1 |
| 5 - Slack Knit | 9 | 19 | 26 | 6 | 9 | - | - |
| 5 - Tight Knit | 6 | 14 | 19 | 6 | 5 | - | - |
| 6 - Slack Knit | 7 | 13 | 22 | - | - | 2 | 2 |
| 6 - Tight Knit | 6 | 7 | 16 | - | - | 2 | 2 |
| 7 - Slack Knit | 11 | 23 | 28 | 12 | 14 | 6 | 5 |
| 7 - Tight Knit | 10 | 19 | 25 | 10 | 12 | 6 | 2 |
| 8 - Slack Knit | 13 | 18 | 30 | - | - | 3 | 5 |
| 8 - Tight Knit | 9 | 13 | 25 | - | - | 1 | 2 |
| 10 - Slack Knit | 9 | 19 | 28 | - | - | 2 | 1 |
| 10 - Tight Knit | 5 | 13 | 22 | - | - | 2 | 2 |

* The numbers correspond to the listing presented in the "Materials" section.

** Measured with the Schiefer device (Supplement to Fed. Spec. CCC-T-191a).

TABLE IX

Shrinkage in Mild Laundering of 1 x 1 Rib Knit Socks or Tubing

| Yarn Code Number[a] | Length Shrinkage in Laundering[b] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Untreated | | | Mild Treatment | | Optimum Treatment | Severe Treatment |
| | 5 Cycles | 10 Cycles | 20 Cycles | 10 Cycles | 20 Cycles | 20 Cycles | 20 Cycles |
| | % | % | % | % | % | % | % |
| 1 - Slack Knit | 11 | 26 | 33 | 17 | 19 | 9 | 5 |
| 1 - Tight Knit | 11 | 16 | 20 | 4 | 6 | 0 | 3 |
| 2 - Slack Knit | 14 | 23 | 32 | 9 | 13 | 5 | 5 |
| 2 - Tight Knit | 7 | 9 | 21 | 4 | 9 | 2 | - |
| 9[c]- Slack Knit | 8 | 12 | 18 | - | - | - | - |
| 9[c]- Tight Knit | 6 | 6 | 8 | - | - | - | - |

[a]The numbers correspond to the listing presented in the "Materials" section.
[b]Measured with the Schiefer device (Supplement to Fed. Spec. CCC-T-191a).
[c]Tubing specimens.

The data demonstrate the importance of wool treatment in achieving acceptable shrink-resistance. In line with the discussion in section A, there are socks (especially the slack constructions) which are unsatisfactory as shrink-resistant garments because of inadequate construction, despite the overall reduction in felting when chlorinated wool is employed. This point is of great importance and hence merits repetition: specification of shrink-resistance is of itself insufficient, and further description with respect to the construction in which the wool is to be used is required. One may thus "tailor" a treatment (within limits) to a given construction or alternatively one must provide a sufficiently tight construction for a given treatment to meet end use requirements.

## IV. SUMMARY AND CONCLUSIONS

1. Knitting stiffness, and to a much smaller extent yarn twist, contribute to the felting behavior of knitted fabrics. Increase in the wales and courses per inch and in the twist can be used to effect appreciable improvement in laundering stability.

2. As the weight of the yarn used in a knitted structure is increased, the feltability decreases.

3. The "cover factor," which is a measure of the amount of wool packed into a unit area of fabric, and proportional to the wales and courses and inversely proportional to the square root of the yarn number, correlates well with the relative shrink-resistance of a construction.

4. Plying of yarns and type of spinning (Bradford vs. French) do not appear to affect feltability, other things being equal.

5. Application of a shrink-resistant treatment to the wool produces a greater effect in reducing laundering shrinkage than any modification of construction here employed. Construction variables must necessarily be considered in relation to the level of treatment none the less, since unsatisfactory stability may be found with shrink-resistant wools if the fabric construction is sleazy.

It is to be noted that the range of constructions considered in this experiment did not deviate too far from those considered "normal" in terms of conventional commercial practice. It is quite possible that combinations of variables exist which would give considerably better felting control than was found here, and which are not now used in industry.


## ACKNOWLEDGMENTS

Grateful acknowledgment is made to Messrs. John Gardiner and Fritz F. Kobayashi of the Ames Worsted Company, who arranged for treatment of the wool top.

Many of the measurements were performed by Mrs. Virginia G. Moran (Harris Research Laboratories) and Miss Gertrude Ardis (Quartermaster Research and Development Laboratories).

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