

THE EFFECT OF HEAT-TREATMENT ON DIMENSIONAL STABILITY
OF COTTON/POLYESTER KNITTED FABRICS

A THESIS

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Approved:

Chairman

Date approved by Chairman: March 4, 1968

DEDICATED

to my

MOTHER, FATHER AND GRANDMOTHER

for their love, confidence and encouragement.

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NOMENCLATURE

The specimens studied in Parts 1 and 2 of this investigation encompassed a wide and varied range of heat-treatment conditions of fabric surface temperature, retention time and tension. To facilitate a concise and effective means of designating each individual type of specimen in an illustration, table or in the text itself, two special notation systems were devised and applied. Both systems, one used in Part 1 and the other in Part 2, are based on distinguishing fabric conditions during heat-treatment as follows:

Part 1 - Where fabric tension during heat-treatment remained constant with a 15 per cent overfeed in the length and the specimen held to the greige width, and where:

Fabric Surface Temperature Range -

A = 280-293°F

B = 316-333°F

C = 365-385°F

Fabric Retention Time -

180 = 180 Seconds

60 = 60 Seconds

30 = 30 Seconds

10 = 10 Seconds

N.H.T. = No Heat Treatment

Part 2 - Where fabric surface temperature range remained at 365-385°F and fabric retention time remained constant at 60 seconds and where:

L = Length, W = Width,
 '0' = Overfeed, (+) = Elongation,
 No Frame = Specimen Placed Flat and Left
 Tensionless in Oven.
 N.H.T. = No Heat Treatment.

The following nomenclature are used throughout the text:

A.S.T.M.	American Society for Testing Materials
all cotton	100 per cent cotton
cotton polyester	50 per cent cotton/ 50 per cent polyester
heat-treatment	Heat-setting
length	Walewise direction of knitted fabric
MW-TD	Machine Wash- Tumble Dry
overfeed	Additional fabric beyond relaxed dimen- sions of fabric specimen incorporated in heat-treatment of fabric
relaxed heat-treatment	No tension exerted on fabric in heat- treatment
restored dimensional change or restored shrinkage	Dimensional changes measured after fabric is restored on knit shrinkage gauge.

S.E.P.A.	Specimen Elongating and Preparatory Apparatus
total dimensional change or total shrinkage	Dimensional changes measured while fabric is in un- restored state.
width	Coursewise direction of knitted fabric

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SUMMARY

Cotton yarn manufacturers have been seeking means of improving the dimensional stability of fabrics composed of their yarns. A program was designed to determine the effect of a greige hot-air treatment on the dimensional stability of plain knit fabrics composed of 50 per cent cotton/50 per cent polyester yarn. Results were compared with non heat-treated cotton polyester and all cotton replicate specimens.

In Part 1 a series of cotton polyester specimens were subjected to a relaxed heat-treatment at a range of fabric surface temperatures and retention times and the resultant fabrics were given a boil-off treatment. The heat-treatment conditions which yielded the least restored residual shrinkage to boil-off, as indicated by a knit shrinkage gauge, were determined.

In Part 2 a series of cotton polyester specimens were subjected to heat-treatments at 365-385°F for 60 seconds, as determined in Part 1, under a range of magnitudes of tension in the length and width. The resultant heat-treated specimens along with non heat-treated and all cotton replicate specimens were then separated into two groups which were respectively bleached with and without tension. All specimens were then subjected to five cycles of machine washing-tumble drying. Total and restored dimensional changes were measured at strategic points by the knit shrinkage gauge.

Relaxed heat-treatment enabled a significant reduction of residual shrinkage, but was accompanied by additional yarn and fabric

shrinkage. Heat-treatment under a range of magnitudes of tension in the length and width did not significantly reduce distortion and wet-relaxation in wet-processing nor residual shrinkage in laundering. Maximum reduction of restored shrinkage of the specimens heat-treated under tension was obtained from heat-treatment conditions of biaxial stress.

Conditions of tension during heat-treatment did influence the final loop shape, aiding recovery to stresses in wet-processing.

The experimentally determined fully relaxed values were not found applicable to the heat-treated specimens. All finished specimens which were heat-treated under tension indicated approximately one-third less elongation in the width than the related greige values.

CHAPTER I

INTRODUCTION

1.1. Statement of the Problem

Weft knitted fabrics are a rapidly growing segment of the textile industry and all indications predict that the expansion will continue. It was not, however, until the last decade that these types of constructions began to be used more extensively for applications other than those based on their unique mechanical properties. The prime property emphasized was the relatively high extensibility in all directions, particularly the width, to small stresses. This characteristically high dimensional instability to stress has, however, also been a definite limitation in processing and in many end use applications. This has been further complicated by an instability to wet-processing and laundering referred to respectively as relaxation and residual changes. Within the last two decades, much effort has been directed in controlling these specific problems and the considerable success has directly contributed to the dynamic progress of the knitting industry. The present methods however, which include various shrinkage control resins and a number of mechanical preshrinking machines have certain limitations. In particular the search still continues for an ideal of maximum yield with minimum shrinkage, with important fabric properties undiminished.

It has only recently been fully appreciated that to guarantee the production of a finished garment that will perform within acceptable

limits of dimensional stability, cooperation is required between fiber producer, spinner, knitter, finisher and cutter. Each can maximize his contribution to the final result. Yarn manufacturers supplying cotton yarn to the knitting industry would ideally like to be able to construct their yarns with the optimum capability of insuring that these yarns would be used in garments that would perform well in consumer laundering. This might be particularly advantageous where facilities are not available for use of such shrinkage control methods as mentioned earlier, or in the case where a minimum of processing is desirable, such as for ecru* fabrics.

Circular cotton knit fabrics are often wet-processed in rope form where tension is exerted on the length of the fabric. These stresses cause the knitted loop to take a length-strained configuration, which often requires a subsequent normalizing process. A normalizing process returns the loops to a more stable shape preventing major redistribution of dimensions from ensuing in consumer laundering, notably in the form of length shrinkage. Any reduction of distortion in such wet-processing would be advantageous in the finishing process and to fabric performance in consumer use.

Polyester fibers have the property that they can be heat-treated to potentially stabilize the configuration of a yarn or dimensions of a fabric of which they are a part. It was thought by using yarns composed of an intimate blend of cotton and polyester, the greige dimensions of a plain knit fabric could be stabilized by heat-treatment.

* Fabrics whose finishing sequence does not include wet-processing.

Recent establishment of certain experimentally derived and industrially applied relationships between yarn, fabric and knitting machine have promoted the scientific approach to knitted fabrics. These relationships, which define stable states of plain knit constructions have been successfully applied and developed for use with fabrics composed of cotton, wool or acrylic fibers. Information relating to the application of these recent findings to cotton polyester plain knit fabrics, specifically those heat-treated, which is presently not available, would provide insight into the fundamental dimensional changes considered in this study.

1.2. Purposes of the Research

The purpose of this research include the following: To determine under existing test conditions of heat-treatment by hot air, a suitable combination of fabric surface temperature and retention time that would provide a 50 per cent cotton/50 per cent polyester plain knit fabric with a significant reduction of shrinkage in subsequent processing.

To determine the extent that it is possible to stabilize the greige and experimentally distorted dimensions of the cotton polyester fabric by heat-treatment. This would be studied at the greige dimensional state and at a range of tensions in the length and width, during a heat-treatment at the selected conditions of fabric surface temperature and retention time.

To study any dimensional changes in subsequent wet-processing and laundering and to compare results with cotton polyester specimens not receiving a heat-treatment and an all cotton replicate.

To compare the effect on the final dimensional properties of the cotton polyester fabric by heat-treatment under relaxed versus restrained conditions of tension.

To evaluate the effect of heat-treatment of the cotton polyester fabric on minimizing the distortion due to wet-processing under wale-wise tension and to the rearrangement of dimensions during subsequent cycles of laundering.

To consider the effect of heat-treatment on important physical properties of a knitted fabric.

To evaluate the application of experimentally derived values of K_1 and K_4 , which define stable states of plain knit fabrics based on knit geometry relationships, to the results of this study.

1.3. Survey of the Literature

The dimensional stability of a fabric is closely tied to the geometry of the type of fabric. Investigations into the causes of shrinkage had been attempted at least thirty years ago. Collins (1) attributed the principal cause of shrinkage in woven cotton fabrics to yarn swelling which activated an interchange of crimp, while yarn shrinkage was found negligible. The study of the geometry of knitted fabrics has been based on the analysis of the nature and geometry of the basic structural unit or cell, the knitted loop. This has been found to be a complicated matter because of the complex three dimensional shape of the loop and the difficulty of deciding upon the stable state of the fabric (2). Nutting and Leaf (3) considered the high internal viscosity of weft knitted fabrics to be a major deterrent in realizing a true

stable state in practice. They suggested that reliable results could be obtained only by a statistical analysis of a large number of experimental observations.

Peirce (4) was one of the first to attempt a study of the geometry of a knitted fabric. He developed equations based on relationships of yarn and fabric variables which could be used to predict properties of the knitted fabric. His geometry, which was published in 1947, was further developed and simplified by Chamberlain (5) and Shinn (6) in the early 1950's. The actual basis for the establishment of a workable knit geometry, however, is widely credited to the disclosure of findings by Doyle (7) in 1952. Doyle revealed that the length of yarn knitted into each loop uniquely determined the relaxed dimensions of a plain knitted fabric and was unaffected by other yarn and knitting variables. Doyle also proposed the use of stitch density, $N = C.P.I. \times W.P.I.$, in place of separate linear parameters of wales and courses per inch, because knitted fabrics were easily distorted.

The loop shape of an elastica was shown to be independent of loop size or material by Leaf (8).

Munden (9) developed a theory for knit fabric distortion based on the findings of Doyle and Leaf. Munden viewed the loop as attempting to attain a state of "minimum potential energy", so long as plastic deformation does not occur. He defined two distinguishable "minimum energy" or equilibrium states for cotton and wool fabrics. These were a "dry-relaxed" state and a state obtained by immersion in water referred to as the "wet-relaxed" state. Munden established four equations for the states of equilibrium relating the plain knitted structure by means of the

stitch length:

$$1. K_1 = N(\text{Stitch Density}) \times L^2$$

$$2. K_2 = \text{Courses per Inch} \times L$$

$$3. K_3 = \text{Wales per Inch} \times L$$

$$4. K_4 = (\text{Poisson's Function or Loop Shape Factor}) =$$

$$\frac{\text{Courses per Inch}}{\text{Wales per Inch}}$$

Where:

$K_1 - K_4$ are constants

L = stitch length

Munden experimentally determined values for these constants, which he found depended on yarn type, such as wool, cotton or hydrophobic, and the state of relaxation. From these equations and derived values, many fabric properties including shrinkage could be predicted. Nutting and Leaf (10) by means of experimental studies emphasized the importance of fiber type on the resultant values of Munden's constants.

Knapton (11) had experimentally explored Munden's findings and reported that "K" values in the dry and wet relaxed states were not necessarily constant but could be affected by processing variables. He suggested the use of a "fully relaxed" state, which included adequate tumble drying, to produce a true "minimum energy" state. Knapton also found

that cover factor was not a significant variable affecting this state of "minimum energy."

In a later work Munden (12) described two categories of fabric shrinkage related to cotton knit fabrics. Relaxation shrinkage was described as the shrinkage measured when the fabric is wetted out due to the release of strains imparted to the yarn in spinning and fabric in knitting and by inherent molecular changes in hydrophilic yarns. Consolidation shrinkage was described as further shrinkage after wet-relaxation, and is associated with laundering. Munden claimed that this is produced by the agitation in washing whereby frictional retarding forces in the fabric are overcome.

Munden reported that yarn shrinkage for the range of fabrics he studied was less than one and half per cent. He concluded that fabric shrinkage was a function of changes in the configuration of the knitted loop which causes adjacent loops and rows of loops to take up a more compact structure.

Suh (13) had attempted to geometrically investigate the actual phenomena associated with the shrinkage of a knit fabric by means of a new three-dimensional loop model. He found that length shrinkage of a plain knitted cotton fabric depended upon loop migration and changes in course curvature. Width shrinkage was found to be affected by the void space in a wale after accommodating four yarn diameters. Suh concluded that the major part of shrinkage occurred in the wetting process with the drying process always promoting further length shrinkage and possibly an extension in width.

Hurley (14) considered Munden's model for shrinkage of cotton and

wool with respect to plain knit acrylic staple fabrics. He experimentally determined that Munden's findings could be applied to the acrylics with two modifications. The first was that the glass transition temperature of the polymer needed to be reached before appreciable shrinkage could occur. The second was that the equilibrium loop shape factor of 1.3 for cotton and wool knits became a function of the thermal history of the acrylic knit fabric. In another study Hurley (15) revealed the significance of fabric compaction in tumble drying, which promoted longitudinal loop slippage. Hurley considered this phenomenon responsible for considerable length shrinkage in tumble drying.

Fletcher and Roberts (16) investigated, experimentally, the geometry of plain and rib knit cotton fabrics and its relation to shrinkage in laundering. They found that shrinkage in area increased as stitch length increased. In a later study Fletcher and Roberts (17) found that shrinkage in area of acetate and nylon knit fabrics usually decreased as the stitch length increased. Fletcher and Roberts (18) confirmed that distortion in knit fabrics was inherent from the knitting process and additional strains imparted from finishing processes resulted in changes, sometimes excessive, upon wetting out and agitation of the fabric. From experimental investigations of cotton, acetate, viscose and nylon knit structures, they concluded that structures which were given a wet-relaxation treatment to remove distortion, exhibited negligible rearrangement during laundering. Fletcher and Roberts (19) reported that laundering, particularly tumble drying, reduced stretching in width, but increased shrinkage in length. In a recent study, Fletcher and Roberts (20) evaluated the performance of knit fabrics composed of several

different types of cotton and of cotton-nylon blends. It was found that shrinkage of plain knits decreased with finishing and that restoration on the knit shrinkage gauge gave lower values of shrinkage than unre-stored measurements for all fabrics tested.

Schmidlin (21) listed the advantages of heat-setting woven and knitted goods as follows:

- (a) good dimensional stability in both warp and weft on boiling;
- (b) stability of shape on boiling, less creasing;
- (c) less curling of selvages with knitted and woven goods;
- (d) good handling which can be modified by the method of setting.

Mecklenburgh (22) considered the capability of imparting permanent shape to a fabric or garment a primary advantage of heat-setting.

Certain other advantages have been associated with heat-setting of polyester blend fabrics (23): Dry-heat stability to temperatures below the heat-setting temperature is improved; crease resistance can be improved, specifically preventing cracks and rope marks from forming during preparation or dyeing in rope form; resistance to pilling can be improved; variations in the previous thermal history of the yarn or fabric which would cause problems in exhaust dyeing can be evened out. Certain disadvantages have been attributed to heat-setting fabrics (24): In exhaust dyeing of polyester fabrics, dyeability and dye rate are reduced at temperatures from 275°F to 410°F; Uneven heat-setting can result in non-uniformity of dyeing by exhaust methods; Fibers can become stiff at higher temperatures.

Fabrics can be heat-set by various means. Schmidlin (25) has classified and listed the following means:

1. Setting with swelling agents:
 - (a) in boiling water at 100°C;
 - (b) with saturated steam at 110-135°C;
 - (c) with super-heated steam at 190°C;
 - (d) with aqueous solutions of organic or inorganic swelling agents at 20-110°C.
2. Setting without swelling agents:
 - (a) with hot air, hot gases, hot metal surfaces, liquor metal alloys at temperatures of 180-220°C;
 - (b) by infra-red radiation at temperatures of 180-220°C (at 90-100°C selective radiation).

Mecklenburgh (26) investigated the heat-setting of nylon locknit fabrics by hot-air. He found that the degree of stability obtained depended to some extent upon the degree of shrinkage allowed during setting and conversely the amount of subsequent yarn shrinkage after setting depended on the severity of setting conditions. He reported that treatments at temperatures as low as 140° and 212°F under tension had little stabilizing effect. He observed that if the fabric was allowed complete relaxation during setting, when shrinkage could freely take place than even oven temperatures of 212°F began to have a stabilizing effect. Mecklenburgh concluded that the degree of set increased and the per cent shrinkage decreased linearly with increases in oven temperature and retention time.

Marvin and Carlene (27) studied the stabilization of Terylene polyester staple fabrics. Heat-setting was considered essential for Terylene plain knit fabrics to prevent excessive shrinkage in dyeing and finishing due to the shrinkage of the fibers. They also found that in blending Terylene with wool, effective heat-setting was dramatically reduced when the level of Terylene fell below 60-50 per cent. Marvin and Carlene (28) reported that Terylene fabrics which are heat-set on hot air

tenter frames at 428 to 446°F yield fabrics which are dimensionally stable up to 385-392°F and which may be dyed with good results.

Heat-setting is usually accomplished at one of three different stages; in the greige off the knitting machine, in an intermediate stage before dyeing, but after some wet-processing or an after setting operation after dyeing. Schmidlin (29) summarized the positive and negative aspects peculiar to a greige heat-treatment. Some of the considerations he mentioned were the following:

Advantages --

- (1) Eliminates an additional drying operation required in the intermediate stage;
- (2) Enables the fabric to be less prone to creasing in subsequent wet-processing.

Disadvantages --

- (1) Risks the possibility of fixing impurities such as spinning oils, knitting lubricants and processing stains in the fabric.
- (2) Dyeing problems are associated with polyester fibers.
- (3) Knitted goods are not allowed to shrink freely before heat-setting.

Schmidlin(30) also listed the methods of heat-setting knit fabrics as hot-air, saturated steam and more recently, infra-red radiation.

Cotton that is in a fabric blend which is subject to heat-treatment would therefore be exposed to high temperatures. Dorée (31) reported that 284°F was the temperature up to which cotton was not measurably affected by heat.

1.4. Design of the Research Program

To effectively investigate the dimensional characteristics of heat-treated knitted specimens, it was necessary in a study of this kind, to limit the number of variables involved. This was from a point of view of both clarity in analyzing the results obtained and with respect to time requirements. It was decided to study only one type of knitted construction, composed of yarn of the same count, which would be knitted on the same machine, using identical machine organizations. In addition, in order to study dimensional changes due to stitch distortion in the knitted specimens during heat-treatment, it was necessary to maintain constant heat-treatment conditions of fabric temperature and retention time for all specimens.

A 50 per cent cotton/50 per cent polyester (cotton polyester) 60/2 yarn was selected for this study because it fulfilled the requirements of being an intimately blended yarn of polyester and cotton fibers and was a type of yarn that was becoming more commercially available to the knitting industry. In addition, this particular yarn as described in Chapter II, was a recent development by the sponsor of this project, specifically engineered for the knitting trade. More knowledge about this yarn, particularly about its behavior in fabrication and in end use was considered of great interest (32). A 100 per cent cotton (all cotton) 60/2 replicate yarn was incorporated into the study for comparisons with the blended yarn, both in processing and in final properties.

A plain knit construction was selected as the structure into which all the yarns would be fabricated. This construction has the

simplest knit geometry and is therefore more suited for studying dimensional properties. Plain knit is also a construction quite prone to industrial and consumer problems related to dimensional stability to stress and laundering. Finally, it was a suitable choice for the commercial yarns that were to be used, for such end uses as underwear and polo shirts.

Stitch uniformity in the knitted specimens was essential to obtain accurate and consistent measurements of dimensional changes. In "Survey of the Literature," the stitch length of a knitted fabric was pointed out as the unique variable that determines the dimensional properties of the fabric. Optimum control of the quality of a knitted fabric has been found possible by utilizing a positive feed system, whereby the yarn is fed to the needles at a controlled rate (33). At the time of this study, the knitting machines in the knitting laboratory at the A. French Textile School were not equipped with positive feed systems. Therefore arrangements were made for the knitting phase of this study to be accomplished at the knitting laboratory of the Philadelphia College of Textiles and Science where suitable equipment was available. A Wildman Spring Body Machine Model FBSS was selected for knitting the fabrics to be studied. The reasons for its selection and its particular specifications are described in Chapter II.

Heat-treatment in the greige state was selected in order to determine the degree that the greige or the experimentally distorted greige state could be stabilized. Selection of specifications for retention time and oven and fabric temperatures for heat-treatment conditions depends on the type and composition of the fabric to be treated, subsequent

fabric properties desired, equipment and method used and other existing conditions. Although some specifications are publicly available for standard heat-treating procedures for commonly processed fabrics, very often trial and error approaches are required for the variables involved. This was particularly true for this study, being somewhat of a laboratory simulation of an industrial tenter frame heat-treating operation. Therefore it became necessary to heat-treat sufficient preliminary specimens at various likely combinations of time and temperature, to obtain the most favorable conditions for heat-treating the knitted specimens to be studied. This phase was designated as Part 1, "Selection of Heat-Treatment Conditions of Fabric Surface Temperature and Retention Time." Specimens in Part 1 were to be given a relaxed heat-treatment so the results of this phase could be compared with those obtained from heat-treatments under tension.

The main purposes of this investigation were largely considered in Part 2, "A Study of Dimensional Changes From Greige to Finished of Cotton Polyester Specimens Heat-Treated at a Range of Conditions of Tension."

To facilitate an efficient means of recording data, a special form was developed and used for each specimen in Parts 1 and 2.

The subject matter in this investigation involved several areas of study, each requiring virtually an independent review of the literature. The dimensional stability of weft knitted fabrics, specifically fabric shrinkage in laundering, was a central subject. This required an understanding of essential related aspects of knit geometry. Heat-setting or heat-treatments of synthetic fabrics and synthetic fabric blends was another central theme. This required consideration of the

thermal properties of fibers, heat-measurement and industrial heat-treatment methods. In addition, the relatively unstandardized subject of the testing of weft knitted fabrics required exploration.

CHAPTER II

MATERIALS, EQUIPMENT AND INSTRUMENTATION

2.1. Materials

The types of yarn used in this study to knit the fabric specimens were 50 per cent cotton/50 per cent polyester 60/2 and 100 per cent cotton 60/2. Plied yarns were used to obtain a balanced twist necessary for stitch shape stability.

The polyester fiber used in the blended yarn was a Kodel type IV of 1.5 denier per filament cut 1-1/2 inch staple. The cotton was an Egyptian cotton of the Menoufi strain with a staple length of 1-3/8 inches to 1-7/16 inches. The yarn was prepared for knitting by an application of a disc wax finish which was primarily paraffins with a relatively high melting point (34).

Both yarn types were tested for significant physical properties relevant to a study of this kind. The results of these tests on yarn count, twist, breaking strength and elongation are listed in Table 1. The blended yarn exhibited a slightly greater breaking strength and an elongation of almost two and a half times that of the 100 per cent cotton yarn. Other than these differences, in addition to the dissimilarity in yarn composition, the yarns were quite comparable.

The yarns were knitted into a plain knit construction, the face and back of which are illustrated respectively in Figures 1 and 2. The average greige dry relaxed properties of the specimens used in this study are shown in Table 1. These and other additional greige properties

Table 1. Physical Properties of Yarns
Used in Knitting Specimens

Property	50% Cotton 50% Polyester	100% Cotton
Labeled Yarn Number (Cotton Count)	60/2	60/2
Measured Yarn Number (Singles Equivalent Cotton Count)	30.13	30.23
Measured % Coefficient of Variation Yarn Count	4.13	1.54
Measured Turns Per Inch Plied	17.8	16.5
Tested Direction of Twist Plied	S	S
Measured % Coefficient of Variation Turns Per Inch Plied	6.40	4.63
Measured Turns Per Inch Singles	27.8	29.4
Tested Direction of Twist Singles	Z	Z
Measured Coefficient of Variation Turns Per Inch Singles	6.18	2.38
Measured Breaking Strength (grams)	351.6	327.6
Measured % Coefficient of Variation Breaking Strength (grams)	16.13	8.52
Measured % Elongation	15.44	6.97
Measured % Coefficient of Variation Elongation	40.3	8.13

Table 2. Greige Dry Relaxed Properties* of Fabric Specimens, Parts 1 and 2

Fabric Type	C.V.		C.V.		C.V.		Stitch Density Per Cent	Stitch Length (Inches)	Bursting Strength (Pounds)	Weight (oz./sq.yd)	Elongation, Per Cent		
	Wales Per Inch	P.I. Cent	Courses per Inch	W.P.I. Cent	Per Cent	Stitch Den- sity (WPIXCI)					Length 20g	Length 50g	Width 75g
50% Cotton/ 50% Polyester	31.9	.82	36.8	2.15	1174	.34		.1238	119.0	3.4	3.6	7.8	9.0
Cotton	30.4	.46	40.2	1.00	1222	1.03		.1239	120.7	3.5	2.4	6.1	5.9
													16.7

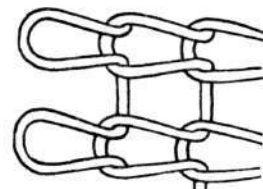


Figure 1.
Face of Plain
Knit Construction

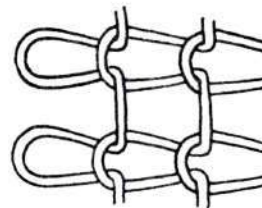


Figure 2.
Back of Plain
Knit Construction

*All properties determined at Standard Conditions of 70°F and 65 per cent Relative Humidity.

are listed and discussed in Chapter IV, Experimental Results and Discussion.

2.2. Equipment and Instrumentation

Existing Equipment

The fabrication and finishing phases of this study involved the use of the following items of existing equipment:

1. Wildman Spring Needle Body Machine Model FBSS.
2. Blue M "Power-O-Matic 60" Mechanical Convection Oven, Model POM 256C."
3. Smith-Drum Rotary Dye Machine.
4. James Hunter Dye Beck.
5. Cylindrical, Reversing Wash-Wheel.
6. Centrifuge Hydro-Extractor.
7. Cylindrical, Rotary-Tumble Type Drier, "Hy Dry" Model.
8. Jacketed Steam Kettle.

Constructed Equipment

In addition it was necessary to construct the following equipment:

1. Fabric Specimen Elongating and Preparatory Apparatus.
2. Custom-Made Heat-Treatment Pin Frame.

Physical Testing Instruments

To conduct the physical testing of the experimental yarns and resultant fabric specimens, the following laboratory items were used:

1. Uster Automatic Yarn Tester.
2. Alfred Suter Twist Tester.
3. Standard Cotton Yarn Reel.
4. Analytical Balance.

5. U.S. Testing Knit Shrinkage Gauge, Model No. 7374.
6. Instron Electronic Tensile Tester, Model TT-C.
7. Mullen Diaphragm - Type Burst Tester.
8. Hunterlab, Model D25 Color and Color Difference Meter.
9. Linen Prover.
10. Pick-Out Needle.
11. Steel Tempered Ruler.

Existing Auxiliary Items

1. Heat-Sensitive Paper Strips.
2. Stop Watch.
3. Fisher-Johns Melting Point Apparatus.
4. Lockstitch Sewing Machine.
5. Microscope.

Constructed Auxiliary Items

1. Copper-Constantan Thermocouple System.
2. Specimen Marking Templates.
3. Elongation Test Template.
4. Photomicrograph Specimen Holders.

Wildman - Spring Needle Body Machine

A Wildman Spring Body Machine Model FBSS, 16 inch diameter, 8 feeds and 24 cut (needles per inch) equipped with an IRO tape positive yarn feeding system was used to knit all fabric specimens. It was a revolving cylinder - revolving take-up machine with a ball-bearing take-up. It was considered a standard machine used in industry for such fine plain knit constructions as used in underwear and polo-shirts. The furnishing wheels, normally an integral part of the machine, were not

used in view of the use of the positive yarn feed system.

This machine was chosen particularly because of its suitable cut for the fine yarns that were knitted, based on the Law of Four-to-One; Yarn Cut Relationship, as supported by Shinn (35) to obtain a "normal jersey fabric construction". It also had a positive yarn feeding system, produced an acceptable fabric width (36-40") and possessed a relatively low number of feeds. It has been observed that usually many feeds produce a fabric having a pronounced spiral (36). The machine operated at a speed of 28 revolutions per minute and is illustrated in Figure 3.

Blue M "Power-O-Matic 60" Mechanical Convection Oven, Model POM 256C

All specimens that were subjected to a heat treatment were processed in a Blue M "Power-O-Matic 60" Mechanical Convection Oven, Model POM 256C. The proportionately controlled system and horizontal air flow assisted in providing a uniform working temperature over the range of temperatures used (284°-410°F). Thus when the door was opened to insert the framed specimen, all parts of the oven were used to bring the oven to the desired temperature as rapidly as possible. However, initial tests indicated additional insulation was needed to minimize heat loss when the door was open because of the short retention times involved. Fiberglass sheeting was used for this purpose, with a small curtain slot of the same material to allow efficient movement of the frame into and out of the heated area. The "insulated" oven is shown in Figure 4.

A multi-blade dynamically balanced turbo blower propelled the air horizontally across the shelves and the specimen at a velocity of up to 250 feet per minute. A mercury-in-glass thermometer was positioned

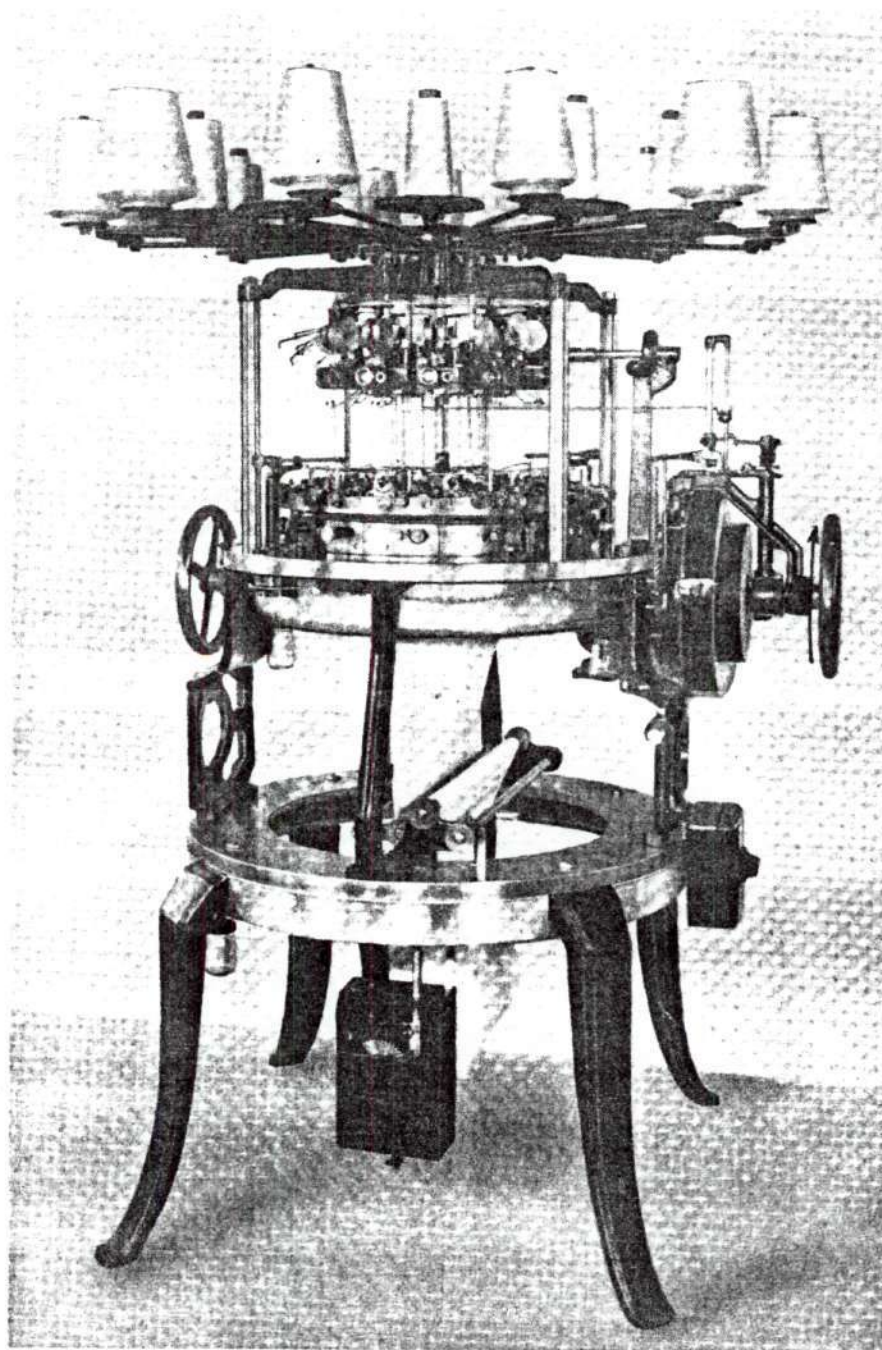


Figure 3. Wildman Spring Needle
Body Machine, Model FBSS.



Figure 4. Blue M "Power-O-Matic
60" Mechanical Convection Oven,
Model POM 256C

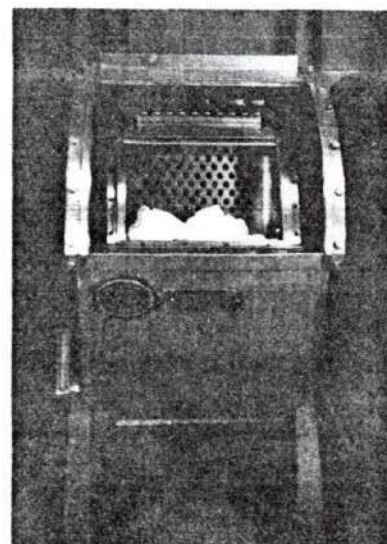


Figure 5. Smith Drum Rotary
Dye Machine.

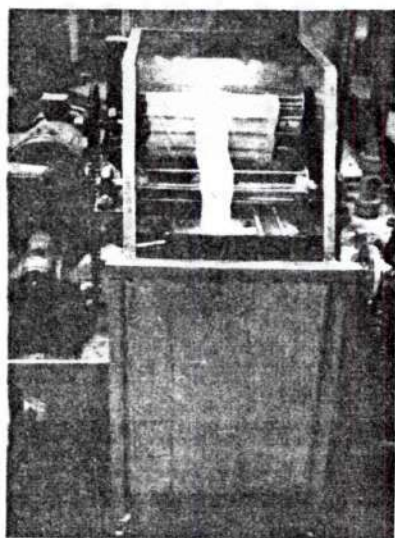


Figure 6. James Hunter
Dye Beck.



Figure 7. Cylindrical Re-
versing Wash-Wheel.

through the top of the oven, so that its bulb remained just above the framed specimen which was supported by the top shelf. The thermometer reading at this point was considered the temperature of the air to which the specimen was exposed. A copper-constantan thermocouple, which had been calibrated to the oven temperature, was attached to the top shelf and positioned so that its measuring junction remained just below the center of the heated specimen. In conjunction with a manual compensation-millivolt potentiometer, the thermocouple system was also used to monitor the temperature of the air to which the specimen was exposed ($\pm 5^{\circ}\text{F}$). It was most useful where the retention time intervals were so small that the time lag of the mercury thermometer was a limitation.

Smith-Drum Rotary Dye Machine

A conventional ten pound Smith-Drum Dyeing Machine was used for all specimens in Part 2 which were bleached without tension. The machine consisted of a two foot diameter drum composed of four compartments. The drum had a speed of six revolutions per minute and reversed direction every two revolutions. Heat was supplied by live steam through an open coil. (See Figure 5).

James Hunter Dye Beck

All specimens in Part 2 that were finished with lengthwise (walewise) tension were processed in a James Hunter Dye Beck. The elliptical fabric drive wheel, running at its minimum velocity revolved with an average fabric velocity of five yards per minute. Although for best results on these types of fabrics, a circular reel is recommended (37), it was thought that the use of an elliptical wheel would emphasize some of the limitations of wet-processing with tension. Heat for the bath was

supplied through an open steam coil. (See Figure 6).

Cylindrical, Reversing Wash-Wheel

A standard cylindrical, reversing wash-wheel was used in Part 2 in the washing phase of each laundering cycle. The wheel was 20 inches in diameter and 20 inches in length. The wheel rotated at a speed of 42 revolutions per minute and reversed directions every three revolutions. Heat was supplied to the load by injecting live steam through a pipe. The machine was equipped with a thermometer to measure the temperature of the water and an outside water gauge that indicated the level of the water in the wheel. (See Figure 7).

Cylindrical Rotary-Tumble Type Drier

A standard cylindrical, rotary tumble type drier, "Hy Dry" Model was used to tumble dry all knitted specimens from Part 1. The tumble drier also was essential in its use in the drying phase of the laundering procedure used for all knitted specimens in Part 2. The drier rotated at 54 revolutions per minute. The tumble drier's temperature selector lever was set so that temperatures of 120°-160°F were recorded at the exhaust vent. It has been observed that the temperature inside the drier will normally fluctuate around the control temperature (38). (See Figure 8).

Jacketed Steam Kettle

All specimens in Part 1 were subjected to a relaxed boil-off in a jacketed steam kettle. Heat was supplied to the bath by the circulation of live steam through the jacket of the kettle.

Fabric Specimen Elongating and Preparatory Apparatus (S.E.P.A.)

The A.S.T.M. standards on textile materials (39) specify the use of a restorative procedure as part of a complete test for the measurement

Figure 8.
Cylindrical
Rotary-Tumble
Drier, "Hy Dry"
Model.

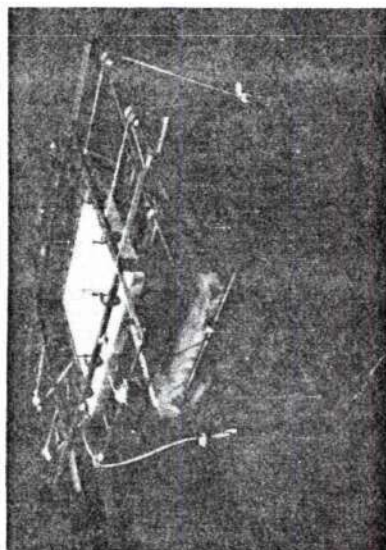
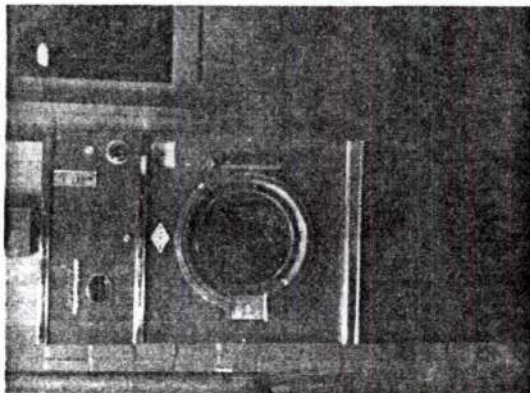


Figure 9. Fabric Specimen Elongating and Preparatory Apparatus.



Figure 10. U.S. Testing Co.
Knit Shrinkage Gauge,
Model No. 7374

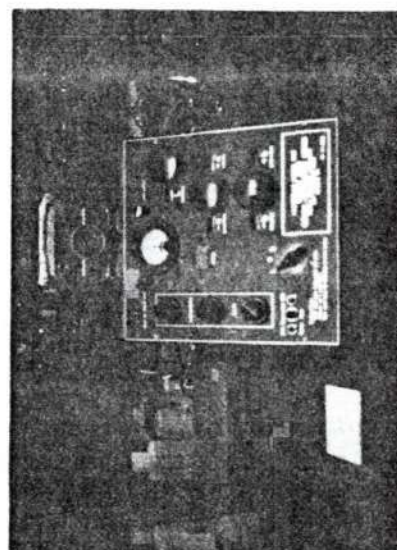


Figure 11. Hunterlab Color and
Color Difference Meter, Model D25.

of dimensional changes of knitted textiles which have been subjected to laundering. The particular restorative procedure recommended for weft knitted plain knit constructions, such as the one studied requires the use of the knit shrinkage gauge. A.S.T.M. standards also specify that a specimen so tested with a knit shrinkage gauge be approximately 16 inches square. In order to provide finished specimens of this size it was necessary to start with an even larger specimen, allowing for the probable shrinkage from the original state. Thus, a specimen size was to be determined with respect to the requirements of such subsequent testing procedures, including intermediary destructive tests and to the maximum dimensional limits of the oven used in heat-treatments. The resultant dimensions, approximately 18" x 23", required a preparatory apparatus of even greater dimensions. An apparatus that could uniformly elongate and then hold a fabric of that size was not commercially available. It was thus necessary to construct such a piece of equipment. When Fletcher, Hansen and Duensing (40) studied the elastic properties of knitted fabrics they built on apparatus with some of the features that were needed in this study. Also, the tension presser described in A.S.T.M. standards (41) on restoring procedures for evaluating dimensional changes in warp knitted or woven fabrics provided useful suggestions. The resultant apparatus was a product of such previous efforts and some features designed especially for the requirements of this study.

The apparatus, as shown in Figure 9, was composed of a foundation framework which supported two guide rails for each of the four sides. The two guide rails on either side allowed a movable clamp to be drawn by dead-weight loading by means of an attached wire rope pulley system.

Thus the movement of a clamp and consequent specimen elongation in that direction would vary directly with the amount of stress applied. The clamps were composed of sets of long metal bars which gripped the specimen by means of small 'c' clamps. Pulley systems were also incorporated in such a manner that both movable clamps in either the wale or course direction could be activated simultaneously on their low friction guide rails by the addition of weight to only one side. In addition it was possible for one operator to activate all four clamps simultaneously. Within the framework there was a movable platform, upon which the heat-treatment pin frame was positioned. It could be made to rise to allow the pin frame to puncture and hold the specimen after the specified dimensional state was obtained.

The type of apparatus just described was not recommended for a study of the actual nature of instability of knitted fabrics (42). This was because the fabric did not react uniformly, particularly when under biaxial stress. However, it was the purpose of this apparatus to simulate stresses experienced by similar fabrics on an industrial pin tenter frame. To improve uniformity, based on prior laboratory tests, two simultaneously activated movable clamps in each direction were used, rather than one movable clamp and one fixed clamp as was the choice in most other previous studies.

Custom-Made Heat-Treatment Pin Frame

In order to heat-treat a specimen of the size that was required, as previously explained, a special pin frame was made. The frame (outside dimensions $19\frac{5}{8}'' \times 24\frac{3}{8}''$) was composed of pin tenter frame clips (6 pins/inch), which assured adequate dimensional control of the

finely knit specimens.

Uster Automatic Yarn Tester

A Uster Automatic Yarn Tester was used for the measurement of breaking strength and elongation of all yarns used in knitting fabric specimens.

Alfred Suter Twist Tester

An Alfred Suter Twist Tester served two purposes. It was used in the standard manner in the evaluation of twist of the yarns used in knitting fabric specimens, according to A.S.T.M. standard procedures (43). It was also utilized in the evaluation of stitch length as a means of holding an unravelled yarn under a tension constant of 10 grams and in measuring the resultant length. (See Figure 19).

Knit Shrinkage Gauge

A U.S. Testing Knit Shrinkage Gauge, Model 7374 (see Figure 10) was used according to A.S.T.M. standard methods (44) to measure the dimensional changes in all knitted specimens in Parts 1 and 2. The gauge consists of a set of 20 mounting pins set in guides in radial slots. Each pin is connected to an individual calibrated spring through which tension is exerted on the specimen. The tensioning members have a common drive to allow restorative forces to take place simultaneously in all directions of the plane of the test specimen. The pins make a circle with a diameter of eleven inches when in their innermost position and a diameter of fourteen inches when in the outermost or restored position. The gauge when holding the specimen in its outermost position, allowed the shrinkage that could not be restored in both the length and width. In addition, the direct reading scale which is used for all readings on

the gauge was used to measure the dimensional state of all marked specimens that required the application of the S.E.P.A. Appendix A describes the principle of operation of the knit shrinkage gauge and illustrates its application.

Instron Electronic Tensile Tester

An Instron Electronic Tensile Tester, Model TT-C was used to measure elongation in all knitted specimens in Parts 1 and 2. It is a constant-rate-of-extension type tester.

Diaphragm-Type Burst Tester

A Mullen Burst Tester, a diaphragm type of tester, was used for all those knitted specimens tested for bursting strength.

Hunterlab, Model D25 Color and Color Difference Meter

To evaluate the permanence of fabric discoloration due to heat-treatment, a Hunterlab Model D25 Color and Color Difference Meter was used. It is shown in Figure 11.

Linen Prover, Pick-Out Needle and Steel Tempered Ruler

It was necessary to record the greige dry relaxed stitch counts of all specimens in Parts 1 and 2. A linen prover, pick-out needle and steel tempered ruler were used for this purpose.

Heat-Sensitive Paper Strips

Fabric temperature is a topic of much concern to most textile finishing operations. At this time there are still widely divergent opinions on what actually can be measured and how it can be best accomplished.

Many heat-treatment operations today are based on trial and error with regard to exposure conditions rather than on any knowledge of the

state of the fabric. It was the author's intent to obtain at least some indication of the relationship of the temperature of the fabric to the conditions of heat-treatment. Initial efforts were made to incorporate the reference junction of a thermocouple within a yarn of a fabric being heat-treated. This method was found to be impractical because the various heat gradients, thermocouple-fiber, thermocouple-air and air-fiber would be virtually impossible to control. The use of heat-sensitive paper strips, which change color at specified temperatures, had been recommended for the simple testing of fabric temperature (45). Such indicators were obtained and calibrated for actual values by the use of a Fisher-Johns Melting Point Apparatus. The paper strips were utilized in heat-treatment as described in Chapter III and did indicate the approximate temperature range of the surface of the fabric.

Specimen Marking Templates

In order to accurately and efficiently mark all knitted greige specimens that required the use of the S.E.P.A., including an allowance for overfeed, special marking templates were constructed and used as shown in Figure 12.

Elongation Test Template

In studies of the elongation of weft knitted fabrics, both Fletcher (46) and Shinn (47) modified the dimensions of the specimen in order to minimize curling of the specimens under load. A template was constructed as shown in Figure 18 similar to that used by Shinn, and was used for marking all specimens subjected to elongation tests.

Photomicrograph Specimen Holders

Samples of both yarns and fabrics from knitted specimens selected

for photomicroscopy studies required protection from any alteration due to handling. In addition, a technique was needed in order to effectively remove a sample from a specimen under tension while it was in the S.E.P.A. A Photomicrograph Specimen Holder was developed in conjunction with the Optical Laboratory of the Engineering Experiment Station at the Georgia Institute of Technology. It was composed of a two part slide, the rear section having a three-quarter inch diameter opening enabling light to pass through the specimen, and using double-sided tape and small staples to maintain the dimensional characteristics of the specimen.

CHAPTER III

EXPERIMENTAL PROCEDURE

3.1. Knitting of Specimens

As discussed in Chapter II, the knitting phase of this study was accomplished on a Wildman Spring Needle Machine in the Knitting Laboratory of the Philadelphia College of Textiles and Science. Knitting set-up and the knitting of all specimens was conducted by Dr. Thomas Edman, Director of the Knitting Laboratory, and his staff. The author observed and approved the initial set-up.

Both the 100 per cent cotton 60/2 and 50 per cent cotton/50 per cent Kodel 60/2 yarns were supplied prewaxed and on cones. The yarn was allowed to condition in the knitting laboratory, which maintained standard conditions of 70°F and 65 per cent relative humidity, before the knitting set-up began.

Only four of the eight feeds of the machine were used to knit the specimens. The knitting set-up began with the 100 per cent cotton 60/2 yarn. The IRO Tape Positive Feed System was utilized. It was the author's intent to select the knitting organizations in such a manner so as to produce a fabric whose stitches would have a minimum of readjustment upon removal of the fabric from the machine. Shinn (48) had proposed mathematical formulas based on relationships between machine gauge yarn count and stitch length for the selection of knitting organizations, in order to produce what he termed a "normal jersey fabric". In particular he suggested a relationship between stitch length and yarn diameter

to obtain this "normal state" based on his theoretical loop model and experimental studies:

$$\text{Stitch Length} = 16.66d \quad (\text{where } d = \text{yarn diameter})$$

This formula was applied to the yarn count used in this study and a comparison was made with results calculated from readings taken from several yarn speed meters during knitting and results from the unraveling method. The high correlation between theoretical value and the actual results obtained are shown below in Table 3.

Table 3. Stitch Length of Cotton Polyester
Test Fabric as Determined by
Alternate Methods

<u>Instrument or</u> <u>Method Used</u>	<u>Average Reading</u> <u>During Knitting</u>	<u>Calculated</u> <u>Stitch Length</u>
Shinn's Formula	-----	.1250
Zivy Yarn Meter	345 ft./min.	.1245
Hamilton Yarn Meter	448.6 in./3 rev.	.1259
*Unravelling Method	-----	.1238

*Average obtained from 75 individual measurements of greige fabric.

Tension during knitting was maintained at 4-1/2 - 5 grams, as measured by a Kidde-Sipp Tensometer. The cloth take-up tension was considered average. Ten yards of 100% cotton were knit. The cotton cones were then replaced by cones of 50 per cent cotton/50 per cent polyester, all knitting organizations being maintained and approximately 100 yards

were subsequently knitted. Sufficient yarn was left on those cones used in knitting to provide samples for yarn testing.

3.2. Preparation of Greige Fabric

Upon arrival at the A. French Textile School, the knitted fabric rolls were rerolled for cloth inspection. The 100 per cent cotton fabric was approximately 39" wide and the 50 per cent cotton/50 per cent polyester was approximately 36.5" - 37.75" wide. The large cloth rolls were rerolled onto several small rolls in such a manner as to allow the cloth to remain smooth and free from excess tension. The resultant rolls remained for several days in the Physical Testing Laboratory of the A. French Textile School, which continuously maintains standard conditions of 70°F and 65 per cent relative humidity, before they were used.

3.3. Part 1. Selection of Heat-Treatment Conditions of Fabric Surface Temperature and Retention Time

3.3.1. Method of Approach

Both fabric temperature and retention time of heat-treatment can be varied to yield a wide range of results. A fabric can be given a mild heat-treatment (low fabric temperature and short retention time) so that virtually no beneficial results are obtained. It can also be treated so severely (high fabric temperature and long retention time) that excessive shrinkage and permanent damage to the fabric will occur (49). It was the purpose of Part 1 to find a combination of fabric temperature and retention time which would provide the fabric with considerable dimensional stabilization to further processing and laundering, without largely diminishing favorable fabric properties. This task was

not the main purpose of this investigation and certainly could have been an extensive study in itself. Thus it was decided to evaluate a range of values based on available industrial specifications and on other heat-treatment studies (50, 51). Three fabric temperatures, 380°F, 325°F and 284°F and retention times of 10, 30, 60 and 180 seconds were selected as a result of expected requirements based on industrial information, previous studies and results from preliminary heat-treated specimens under test conditions. It was considered that these ranges would provide the maximum information from a minimum number of specimens.

Fabric temperature is a very difficult variable to measure precisely. Heat-sensitive paper strips provided only a range of temperatures, approximately 20°F per strip, for measuring the temperature of the surface of the fabric. Therefore the particular measurable ranges that included the specific temperatures chosen were considered the fabric surface temperature parameters during heat-treatment and they were as follows:

284°F; 280-293°F

325°F; 316-333°F

380°F; 365-385°F.

The procedure used to select the conditions for heat-treatment involved the relaxed heat-treatment of a series of cotton polyester specimens at various combinations of fabric surface temperature and retention time. The treated specimens were then tested for dimensional changes from the greige state and subsequently given a boil-off treatment as a means of evaluating the effectiveness of the heat-treatment. The specimens were then remeasured for dimensional changes and other relevant

properties. The selection of conditions for heat-treatment were then determined by the combination of variables which resulted in the greatest dimensional stabilization after subsequent wet-processing as represented by the boil-off test. It should be mentioned that the boil-off test was selected because it was the simplest successful technique used in previous investigations of heat-setting. The dimensional state in which the specimen was heat-treated was considered a significant factor in determining the results and was considered in depth in Part 2 of this study.

It was thought that this variable should not only remain constant throughout this phase of the study, but also have a minimum effect on the results. Relaxed heat-treatment using industrial specifications was considered to be the best approach. A 15 per cent overfeed in the length with the specimen held to the open greige width was selected according to industrial recommendations (52). The overfeed would allow freedom for shrinkage in the length during heat-treatment, which would then ideally limit the walewise distortion and shrinkage during subsequent processing. Although 15 per cent overfeed was more than necessary for the fabric involved, some overfeed loss due to manual overfeeding was expected. Some restraint was required in the width to preserve the greige width dimension and to prevent excessive yarn shrinkage. Therefore the specimens were heat-treated while at the greige width. Two specimens, each with a 15 per cent overfeed and at the greige width, were processed for each of the following heat-treatment conditions:

280-293°F; 10, 30, 60 and 180 seconds,

316-333°F, 10, 30, 60 and 180 seconds,

365-385°F; 10, 30, 60 and 180 seconds,

No Heat-Treatment.

3.3.2. Temperature Controls

The first matter that required attention, was the accurate calibration of the copper-constantan thermocouple to the Blue M "Power-O-Matic 60" oven. A manual compensation type potentiometer was used to monitor the temperature indicated by the thermocouple in the oven in millivolts. Cold junction compensation was accomplished by using a commercial laboratory mercury-in-glass thermometer to determine the temperature at the cold junction. The cold junction temperature in terms of millivolts was then compensated for by appropriately adjusting the potentiometer. Five copper-constantan thermocouples were constructed and then individually calibrated by placing a thermocouple centrally in the oven and taking readings of the thermocouple versus a commercial laboratory mercury-in-glass thermometer over a range of applicable oven temperatures and cold junction compensations. The error in oven temperature measurement was $\pm 5^{\circ}\text{F}$ which was considered largely a combined result of using a potentiometer of this type, $\pm 2^{\circ}\text{F}$ (53), the human error involved in manual cold junction compensation and any inconsistencies in the thermocouple used.

3.3.3. Preparation and Marking of Specimen

The cloth roll from which a specimen was to be cut was unrolled onto a hard, smooth formica table in the Physical Testing Laboratory. Approximately a 44 inch length was cut and the tubular piece was then

split open lengthwise (walewise) and carefully laid flat without tension with the face of the fabric up. The specimen was allowed to further condition and dry relax for a minimum of six hours. The conditioning time and all subsequent data for that specimen were entered on an individual form for each specimen.

A template representing the "zero biaxial elongation" dimensions of the S.E.P.A. was placed on the specimen. A special template was then attached to the first template, adding the 15 per cent overfeed in the length specified for all heat-treated specimens in Part 1. Weights were then placed strategically on the edges of the specimen to reduce curling, and on the templates to discourage movement of the specimen during marking. The outside dimensions of the templates were then marked onto the specimen by a fine point waterproof marking pen, to indicate the area that was to be held within the clamps of the S.E.P.A. Markings were then required so that dimensional changes could be measured by the knit shrinkage gauge after each stage of processing the specimen. The knit shrinkage gauge marking ring was placed centrally on the specimen. The set-up at this point is illustrated in Figure 12. The ten inch inner circle of the marking ring and the 20 equidistant dots composing the eleven inch outside diameter were then traced from the marking ring. The knit shrinkage gauge direct reading scale ruler, which was used for direct readings of dimensional changes in per cent, was placed on the specimen with its engraved arrow lying on the inner circle and with the edge of the scale passing roughly through the center of the circle. Three lines were drawn in the walewise direction. The middle line was drawn parallel to the central wale in the inner circle, with each of the

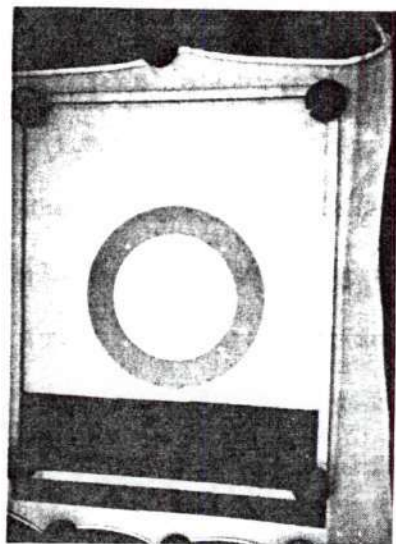


Figure 12. Fabric Specimen in Position for Marking with Marking Ring, S.E.P.A. Template and 15 Per Cent Overfeed Template in Place.

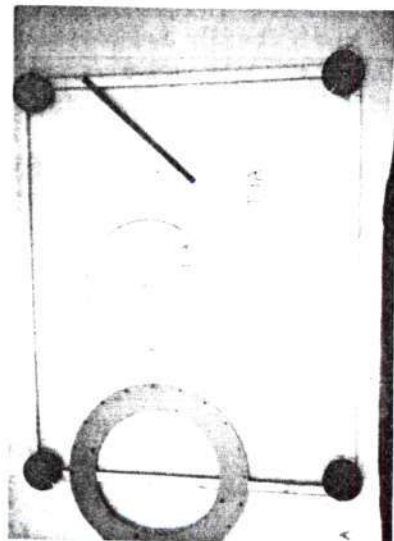


Figure 13. Marked Greige Fabric Specimen to Allow Subsequent Measurement of Dimensional Change

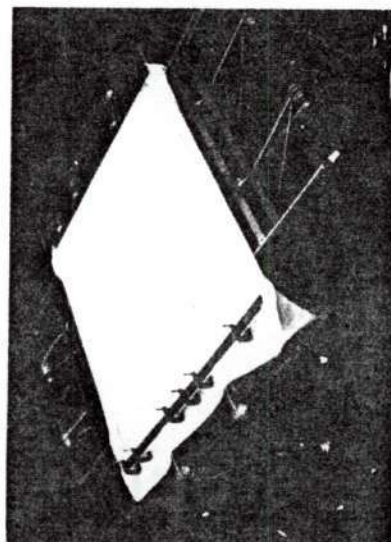


Figure 14. Fabric Specimen Elongated in Width on Fabric Specimen Elongating and Preparatory Apparatus.



Figure 15. Fabric Specimen in Fabric Specimen Elongating and Preparatory Apparatus after Pin Frame has Gripped Specimen.

other lines, approximately three-quarters of an inch away along the circumference of the circle. Similarly three lines were drawn in the coursewise direction with the middle line along the central course. Ideally the inner circle should have been ten inches in diameter. An error introduced by the width of the marking pen line was accounted for by an adjustment factor of up to two and half per cent. This was considered in all further calculations. Each specimen was clearly marked with its own code designation, according to its processing plan. (See Figure 13).

A greige stitch count was then taken by the use of a linen counter, pick-out needle and steel ruler. Readings of two consecutive inches for each of the four sectors of the inner circle were made. The average greige dry relaxed wales and courses per inch were then calculated for each specimen. With the exception of the specimens not receiving a heat-treatment all specimens required the following procedure. The S.E.P.A. which was located in the Physical Testing Laboratory was prepared for use by arranging the Custom-Made Pin Frame centrally on the movable platform and covering the pins with a protective sheeting. The platform was lowered sufficiently to insure that the pins were not above the bottom of the metal bar clamps, thereby minimizing any excess tension while placing the specimen in the clamps. The specimen was then transferred from the marking table to the framing apparatus with a minimum of handling. The edges of the walewise direction of the specimen were then placed in the two appropriate bar clamps, while distributing the over-feed within the clamps as evenly as possible. The bar clamps were then fastened with sufficient 'c' clamps to prevent slippage of the specimen

when under stress. No bar clamps were used along the coursewise direction, to allow minimum restraint in the walewise direction. To provide sufficient tension for framing the specimen, a 20 ounce load was suspended from the pulley system which was attached to the clamps holding the fabric. A general view of a typical set-up in the S.E.P.A. is shown in Figure 14. The protective sheeting covering the pin frame was then removed and the platform on which it rested was raised by means of the jack system. The specimen was so pierced by the pins that the markings for subsequent dimensional analysis were centrally located. A wire brush was used to push the pierced areas of the specimen down to the base of the pins. The specimen then appeared similar to the specimen illustrated in Figure 15. The tension was then eliminated and the specimen was released from the clamps. The pin frame with the specimen was then transferred to a table where the frame was trimmed of most of all the fabric on the exterior of the pins. This cut portion of the specimen was put into a labeled envelope for later testing.

3.3.4. Heat-Treatment and Measurement of Dimensional Changes

The oven was turned on at least two hours before a specimen was heat-treated. This would allow the entire oven to reach equilibrium at the desired temperature. The oven temperature depends on the particular conditions specified for that specimen. The specific temperatures of 380°F, 325°F and 284°F, as previously discussed, were used as base figures. However, specimens having short retention times, such as 10 and 30 seconds, required elevated temperatures so that the specimens could reach the required fabric surface temperature within the specified time. The elevated temperatures were selected on the basis of preliminary

treatments of similar specimens. Several calibrated heat-sensitive paper strips were attached to the specimen to measure fabric surface temperature over a range of temperatures to which the specimen would be exposed. The strips were stapled to a piece of fabric, the same as that of the specimen, and fastened face down on the specimen to be heat-treated. A paper strip would remain white if unaffected or turn black if affected, indicating that the specified temperature to which it was sensitive had been reached. Thus a series of such strips designated the highest fabric surface temperature that had been attained. The initial oven temperature was checked and recorded from the thermometer located in the oven and a similar reading was made from the thermocouple system with appropriate cold compensation. The specimen was then ready for heat-treatment and the set-up is illustrated in Figure 16.

The oven door was opened and the specimen was passed through the insulating fiberglass curtain and was placed on the top shelf. Opening and closing of the doors and placing of the frame was done as rapidly as possible to minimize heat loss. Retention time was measured by a stop watch. Periodic readings of oven temperatures were taken first from the thermocouple, and then shortly thereafter from also the thermometer. The hot framed specimen was immediately removed from the oven at the end of the specified retention time, as indicated by the stop watch. It was placed on a sheet of masonite to cool for a minimum of 60 seconds. The specimen was then removed from the pins. The heat-sensitive paper strips were detached and the maximum fabric surface temperature was recorded.

After heat-treatment the specimen was transferred to the Physical Testing Laboratory where it was laid flat without tension on the formica



Figure 16. Framed Fabric Specimen, Before Heat-Treatment and Auxiliary Heat-Treatment Equipment; Potentiometer, Stop Watch, Insulated Glove and Form for Recording Data.

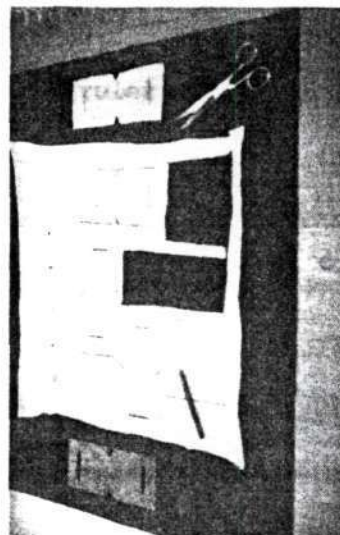


Figure 18. Finished Fabric Specimen Which Has Been Marked for Respective Fabric Tests and Special Elongation Test Template.



Figure 17. Fabric Specimens in Protective Porous Bag with Accompanying Washing Fabrics Prior to a Wash Cycle.

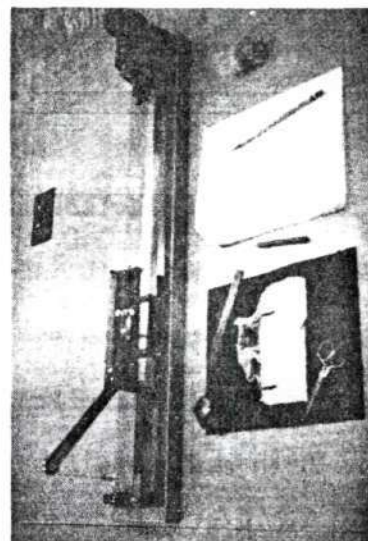


Figure 19. Technique and Apparatus Used to Measure Stitch Length of Fabric Specimens.

table and was allowed to condition in the standard conditioning environment.

After completion of the conditioning period the specimen was then ready to be measured for dimensional changes due to heat-treatment. There are no standard methods for such an analysis and in most previous studies, measurement was based on the total dimensional changes. However, it was the author's opinion that more useful results would be obtained from measurements of restored dimensional changes after wet-processing and laundering. A knit shrinkage gauge was used to determine both total and restored dimensional changes. Total dimensional changes were reported when applicable.

Total dimensional changes were first measured from the specimen as it lay relaxed and flat on the formica table. Heat-treatment had stabilized all specimens sufficiently to retard curling, eliminating the need for weights. The direct reading scale ruler was first properly placed along the middle line of the inner marked circle in the coursewise direction and a reading to the nearest half per cent change was made. Readings were then made for the two adjacent marked lines and an average total dimensional change in the coursewise direction was calculated from the three readings, including an allowance for the adjustment factor previously discussed. Similarly, the same procedure was then repeated for the walewise direction. The knit shrinkage gauge measurement tools and an illustration of their application are shown in Figure 59 which is in the Appendix. The specimen was then transferred to the knit shrinkage gauge where restored dimensional changes were recorded. The pins were brought to their innermost position by means of a handwheel. The

specimen was mounted on the gauge by properly placing each of the twenty previously marked dots over a corresponding pin. The pins were then moved to their outermost position. The instrument manufacturer commented on this state: "In this condition an equilibrium is reached between the restraining force of the fabric and the tension of the extended springs (54)." Readings were then taken for restored dimensional changes, following the same procedure used in measuring total dimensional change. The average restored dimensional change for the three measurements in each direction was calculated. The specimen was then removed from the gauge and allowed to relax without tension on the formica table in preparation for finishing.

3.3.5. Boil-Off and Tumble-Drying

A jacketed steam kettle was filled with water and all 26 specimens were immersed in the water. The temperature of the water was then raised to the boil in ten minutes. The specimens remained in the boiling water for 30 minutes. Occasional mechanical agitation was applied to insure a more uniform distribution of specimens in the bath. Upon terminating the steam and discarding the bath, the specimens were given a cold rinse. All specimens were then extracted and then tumble dried for 30 minutes at 160°F in a cylindrical, rotary-tumble type drier. Upon completion of the drying cycle, the specimens were transferred to the Physical Testing Laboratory for conditioning. As before, the specimens were laid flat, without tension, on the formica table.

3.3.6. Measurement of the Amount of Dimensional Stabilization Due to Heat-Treatment at a Range of Fabric Surface Temperatures and Retention Times.

The amount of dimensional stabilization due to various

heat-treatment conditions was derived by measuring the boiled-off specimens for additional shrinkage beyond that recorded for the heat-treated state. Those specimens not heat-treated were also evaluated. After a minimum of four hours at standard conditions, the boiled-off specimens were re-measured for dimensional changes due to heat-treatment and boil-off by the procedure just described for heat-treated only specimens. Average total and restored dimensional changes were recorded. The shrinkage due to boil-off and tumble drying, which was considered a measure of instability, was calculated for the length, width and area by the following formula:

$$\begin{aligned} \text{Residual Restored Shrinkage} &= \\ \text{Boiled-Off Restored Shrinkage} &- \\ \text{Heat-Treated Restored Shrinkage.} & \end{aligned}$$

The results are illustrated and discussed in Chapter IV, Experimental Results and Discussion.

The specimens were then subjected to various relevant fabric tests which included bursting strength, elongation, weight and stitch length. The results were compared with the information just obtained. The test methods used were identical to those used in Part 2, which are discussed at the end of this chapter and the results are shown and discussed in Chapter IV.

3.4. Part 2. A Study of Dimensional Changes From Greige to Finished of Cotton Polyester Specimens Heat-Treated at a Range of Tensions

3.4.1. General

In Part 2 most of the purposes of this study as outlined in Chapter I were considered. As will be further discussed in Chapter IV, Experimental Results and Discussion, a fabric surface temperature of 380°F (365-385°F) and retention time of 60 seconds was selected for use in Part 2. A range of conditions of magnitude and direction of tension were selected to effectively evaluate the ability of heat-treatment to stabilize the greige or distorted greige dimensions and to study the effect of the chosen parameters on subsequent dimensional changes. Specimens were designated to be heat-treated at conditions ranging from complete relaxation to very high uniaxial or biaxial stress. The conditions and specimens chosen were the following:

Cotton Polyester -

<u>Code No.</u>	<u>Length</u>	<u>Width</u>
T1.	15% Overfeed	25% Elongation
T2.	15% Overfeed	10% Elongation
T3.	15% Overfeed	5% Elongation
T4.	Greige Length	Greige Width
T5.	5% Overfeed	5% Overfeed
T6.	No Frame	No Frame
T7.	5% Overfeed	5% Elongation
T8.	5% Overfeed	10% Elongation
T9.	5% Overfeed	15% Elongation
T10.	4% Stretch	4% Elongation

Cotton Polyester (Continued)

<u>Code No.</u>	<u>Length</u>	<u>Width</u>
T11.	No Heat-Treatment	
All Cotton -		
T12.	No Heat-Treatment	

The selected range included combinations which were in the scope of industrial application (No.'s 2, 3, 4, 5, 7, 8, 10, 11 and 12) and also several of primarily academic interest (No.'s 1, 6, and 9). It was decided that three specimens of each combination would provide results indicative of a satisfactory average of performance with respect to the variability involved and the time required per specimen.

3.4.2. The Preparation and Marking of a Specimen

The procedures for the preparation and marking of specimens in Part 2 were precisely the same as in Part 1. Appropriate overfeed templates were used in marking as needed. A special code designation for individual specimens was used:

T1 to T12; Groups based on heat-treatment
conditions of tension just listed,
A, B, or C, for individual specimens within
each group.

3.4.3. Framing the Specimen and Measurement of Dimensional Changes

The same procedure was also used in Part 1 for framing the specimens, with some additions as required for those specimens specified for framing (T1, 2, 3, 4, 5, 7, 8, 9 and 10). Those specimens requiring elongation were placed in the frame in the same manner as usual.

Appropriate stress (20 to 106 ounces) was applied, utilizing the pulley system, to elongate the specimen the required amount. The direct reading scale ruler was used in conjunction with the original ten inch inner circle marked on the specimen to determine the dimensional state. A slight manual adjustment of the bar clamps was occasionally required to overcome effects due to friction. Specimens T-10A-C which required bi-axial stress were elongated in both directions simultaneously. After a specimen was in its specified state to be framed, 'c' clamps were applied strategically to clamp the bar clamps onto the stationary frame to prevent their movement as the pin frame was raised into the specimen. The framed specimen was removed from the S.E.P.A. and placed on a table in the laboratory, and the excess fabric was cut away. In addition, the specimen's dimensional state was measured with the direct reading scale ruler.

3.4.4. Heat-Treatment and Measurement of Dimensional Changes

Specimens requiring heat-treatment were processed following the same procedures outlined for Part 1. All heat-treatments were administered to allow a maximum fabric surface temperature of 380°F (365-385°F) and a retention time of 60 seconds. The oven was brought up to an initial temperature of 387-388°F, which was required to bring the fabric up to a surface temperature of 380°F (365-385°F) and allow exposure for several seconds in this range. This elevated temperature included compensation for the 6 to 8°F heat loss indicated at the end of the 60 second period due to the initial opening of the oven door. After heat-treatment and cooling were complete the specimen was removed from the frame and transferred to the Physical Testing Laboratory. The specimen

was laid flat, without tension on the formica table and allowed to condition for a minimum of six hours. The specimen was then measured for total dimensional changes only, by the same procedure as described in Part 1.

The procedures for framing, heat-treatment and measuring were repeated for all 36 specimens, according to specifications in the planned procedure listed earlier.

3.4.5. Bleaching and Measurement of Dimensional Changes

All specimens were given a bleaching treatment to simulate a standard wet-processing step in a typical commercial knitgoods finishing cycle. Although the polyester in the blend does not normally require bleaching, such a treatment is common in commercial finishing to obtain a good white on the cotton in the blend. Bleaching also served as an intermediate means of wet-relaxation between heat-treatment and laundering. It was important to separate dimensional changes due to wet-relaxation which normally occur in wet-processing from the residual changes that occur in laundering. In addition, wet-processing on equipment such as a beck quite often tends to exert a lengthwise tension on the fabric. To study the dimensional stability of the heat-treated specimens to stresses in processing such as these, groups A and B of Part 2 were bleached on a beck with lengthwise tension. Group C was used as a control group and was bleached with no tension in a hosiery dyeing machine.

To prepare specimens for bleaching in the beck the specimens were tacked end to end on a lockstitch sewing machine. A James Hunter Dye Beck was filled to its 30 gallon capacity by the preparation of the

following:*

1.5 % Hydrogen Peroxide

.8 % Sodium Silicate

.25% Soda Ash

A pH of 11 was indicated by a universal indicator. The tacked specimens were loaded onto the beck and the two free ends were joined. The elliptical fabric drive wheel was started and the temperature was raised to 180°F in 30 minutes. The bath was maintained at 180°F for 30 minutes. The bath was then discarded and the specimens were given several cold rinses. The fabric was rinsed to a neutral pH in a weak solution of acetic acid. The beck was unloaded and the tacked length of specimens were extracted. The specimens were then transferred to the Physical Testing Laboratory and laid flat, without tension on the formica table to dry and condition.

For bleaching without tension a four-compartment Smith-Drum Hosiery Dye Machine was filled with a 10 gallon bath consisting of the same chemicals and in the same amount as in the beck bleaching procedure. Likewise the liquor to cloth ratio was approximately 100:1 and a pH of 11 was obtained. The twelve loose specimens were separated into groups of three, and each group was placed in one of the compartments of the machine. Bleaching, extraction, and drying procedures were followed similarly to those applied for specimens which were bleached with tension. The specimens were allowed to condition overnight. The specimens which had been bleached in the beck were untacked. The wet relaxation during

*All percentages are based on weight of the solution. The liquor to bath ratio was approximately 100:1.

the bleaching operation was sufficient to allow the application of the knit shrinkage gauge to obtain values for restored dimensional changes. Following the procedure described in Part 1, values were acquired for total and restored dimensional changes.

3.4.7. Laundering and Measurement of Dimensional Changes

Laundering of the specimens was accomplished by following A.S.T.M. standard method D1905-60T-E-2(55) with some modifications. The method involved a washing procedure with a suds cycle at 140°F (56), a tumble-drying procedure and a restorative procedure using the knit shrinkage gauge. The 36 specimens were separated into small groups and placed in several nylon mesh bags for washing, to protect the specimens from excess distortion. A total wash load including several dissimilar fabrics is illustrated in Figure 17. Sufficient water softener (.016 oz./gal.) was added to the washing bath, to counteract any effects of hard water. Five grams of a recognized commercial detergent was used in the washing cycle.

Upon completion of the tumble drying cycle the specimens were transferred to the Physical Testing Laboratory where they were laid flat without tension to condition overnight.

Upon completion of the conditioning period the specimens were measured for total and restored dimensional and the dimensional changes inclusive of the first cycle of laundering were recorded.

The specimens were then all subjected to four additional consecutive laundering cycles of machine washing and tumble drying. The procedures used were identical to those just outlined for the first cycle, however, measurement of dimensional changes was only executed after the

completion of the fifth cycle.

3.5. Yarn and Fabric Testing

Yarn and fabric tests other than for fabric dimensional changes, consisted of the evaluation of those significant properties which contribute largely to the overall performance of a knitted fabric. All specimens used in both yarn and fabric testing were first conditioned in the Physical Testing Laboratory for a minimum of four hours. All testing was conducted in the same laboratory with the exception of the bursting strength tests which were run in the standard conditioned Physical Testing Laboratory of Fulton Industries of Atlanta, Georgia. Specimens for testing fabric elongation and weight were cut from full fabric specimens which were appropriately marked with templates. During marking, the full fabric specimens were restrained by resting on an abrasive sheet. This technique is illustrated in Figure 18. Lengthwise specimens were cut parallel to the wales and widthwise specimens were cut parallel to the courses.

One third of the greige specimens from Part 1 and Part 2 were chosen randomly for greige fabric tests. The number of greige specimens tested and the procedures used were the same as for the finished specimens. Greige dry relaxed specimens are referred to as greige specimens, and specimens which had completed boil-off and tumble drying operations in Part 1 and five cycles of MW-TD in Part 2, are referred to as finished specimens.

A.S.T.M. standard methods were used where applicable to test both the cotton polyester and all cotton experimental yarns for yarn number,

singles and plied twist, breaking strength and elongation. All tests were made from the four cones of all cotton yarn and nine cones of cotton polyester yarn that were used to knit the experimental fabrics.

Five determinations were made from each cone to determine yarn number, using the cotton yarn reel and analytical balance. The method and formula used to arrive at average yarn numbers were based on the standard A.S.T.M. procedure (57).

Three determinations were made from each cone to determine singles and plied twist using the Alfred Suter Twist Tester. The methods and formulas used to arrive at an average turns per inch, singles and plied were also based on the standard A.S.T.M. procedures (58, 59).

Measurements for elongation and breaking strength of experimental yarns were conducted on a Uster Automatic Yarn Tester. The length of an individual specimen was 28 inches and the complete cycle time was ± 22 seconds. Ten breaks were made from each of the cones. Calculation of average breaking strength and average elongation was based on formulas applicable to the Uster Automatic Yarn Tester (60).

Calculation of coefficient of variation for yarn number and singles and plied twist was performed by the application of the standard statistical formula:

$$\text{Per Cent C.V.} = \frac{100}{\bar{x}} \left(\frac{\sum x^2}{n} - \frac{(\sum x)^2}{n^2} \right)^{1/2}$$

Where:

Per Cent C.V. = Per Cent Coefficient
of Variation.

$\bar{x}$ = Average of Individual
Measurements.

x = Individual Measurement

n = Number of Specimens

The coefficient of variation of breaking strength was determined by the application of special templates, supplied with the yarn tester, to the frequency distribution chart obtained directly from the yarn tester.

All finished fabric specimens in Parts 1 and 2 were tested for elongation using an Instron Electronic Tensile Tester. The specimens were marked with the elongation test template to produce a specimen 3 inches by 7 inches, the longer dimension parallel to the direction being tested, with half inch notches along each edge of the center of the specimen to minimize curling. The templates and a cut specimen are shown in Figure 18.

The purpose of the elongation test was to evaluate the effect of the variables studied in this investigation on the working range of an essential property of a knitted fabric. Preliminary tests indicated that a practical working range of the fabrics studied was a 10 per cent elongation in the length and a 30 per cent elongation in the width. All elongation tests were conducted with these values as upper limits. The following settings on the Instron were used:

Load Range - (Cell B; 100, 200, 500, 1000 and 2000 grams).

Gauge Length - 5 inches

Cross Head Speed - 20 inches per minute.

Full Scale Load - 100, 200 or 500 grams.

Three specimens from the full finished specimens in Part 1 and two specimens from the full finished specimens in Part 2, from both the length and width, were cut and tested. Results were reported in terms of an average elongation for both a high and low stress within the range tested. The high stresses were 75 grams for the width and 50 grams for the length, while low stresses were 25 grams for the width and 20 grams for the length.

Bursting strength tests were conducted on a Mullen diaphragm type bursting tester. A minimum of five tests were made to determine an average bursting strength in pounds for each of the finished specimens from Parts 1 and 2 and from randomly selected greige specimens.

Fabric weight per square yard was determined by weighing, on an analytical balance, a minimum of two four inch square specimens cut from all finished full specimens from Parts 1 and 2 and from randomly selected greige specimens. The fabric weight per square yard was then calculated by the following formula:

Ounces per Square Yard =

$$\frac{\text{Weight of 4"x4" Specimen in grams} \times 1296 \text{ (sq. in./sq. yd.)}}{16 \text{ sq. in.} \times 28.35 \text{ (grams/ounce)}}$$

Stitch length measurements enabled the determination of yarn shrinkage. The method used required the cutting of approximately a six inch square sample from an area as close to the center of the full specimen as possible. Dark lines were then drawn on the cut sample along two wales which were a minimum of four inches apart. The number of stitches

between the two marks were then counted with a Linen Prover and recorded. The cut sample was then unravelled with a minimum of tension exerted on the yarn. An unravelled yarn containing the two distinct marks was then mounted on an Alfred Suter Twist Tester. One end was fastened in the fixed rotatable clamp so that its black mark was just within the edge of the clamp. The free end was then fastened under the movable pre-tensioning assembly so that the black mark was within the assembly. The tension assembly lock was then released, causing the yarn to extend and remain under a tension of ten grams, to remove knitting crimp without causing yarn extension (61). The distance between the inside edges of the clamps were then measured. The preparation of marked yarn specimens and a specimen under tension in the twister is illustrated in Figure 19. Stitch length was calculated from the following formula:

$$\text{Stitch Length (Inches)} = \frac{\text{Measured Distance Between Clamps, Tension Applied (in.)}}{\text{Total Number of Stitches Between Marks}}$$

Ten specimens from one of the two finished full specimens in each group of Part 1 were measured to obtain an average finished stitch length for each combination of fabric surface temperature and retention time. Ten specimens from one of each of the three fabric specimens in each group of Part 2 after both heat-treatment and final MW-TD were measured to obtain an average heat-treated and finished stitch length for each group.

3.6. Experimental Values for K_1 and K_4

To determine dry relaxed values for K_1 and K_4 the average dry

relaxed values for stitch density and the average greige stitch length of all the cotton polyester and all cotton specimens in Parts 1 and 2 were used. Wet-relaxed values were determined by obtaining the stitch densities from small specimens which were wet-relaxed by the method described by Munden (64). In conjunction the greige stitch lengths were used. Fully relaxed values were determined from the stitch densities obtained similarly, following the full-relaxation method recommended by Knapton (65). The stitch lengths used in conjunction were obtained from measurements from the fully-relaxed specimens.

Dry-relaxed, wet-relaxed and fully-relaxed values of K_1 and K_4 for the all cotton and cotton polyester specimens were calculated by the following formulas:

$$K_1 = N \times \ell^2$$

$$K_4 = \frac{\text{Courses per Inch}}{\text{Wales per Inch}}$$

Where:

N = Stitch Density

ℓ = Stitch Length

CHAPTER IV

EXPERIMENTAL RESULTS AND DISCUSSION

4.1. Properties of Greige Test Specimens

The properties of the greige dry relaxed fabric specimens used in Parts 1 and 2 were shown in Table 2 in Chapter I. Both the all cotton and cotton polyester fabrics were quite similar, other than distinctive differences due to the presence of polyester in the blended fabric. The essential common constructional property was the stitch length, which was determined and controlled by the positive yarn feeding system during the knitting operation. While the stitch length for both fabrics remained essentially the same, the dry relaxed stitch count relationships differed. The cotton polyester fabric had a narrower loop (loop shape factor, $K_4 = 1.32$) than the all cotton ($K_4 = 1.15$) and almost a 5 per cent greater stitch density. These differences would be an example of Munden's (66) reference to the fact that the shape of knitted loops of fabrics containing thermoplastic fibers can be modified by the stresses of knitting. This effect can be illustrated by Figures 20 and 21 which show yarns unravelled from greige specimens and from specimens after wet-processing and after five cycles MW-TD. Figure 21, illustrating the cotton polyester yarn, demonstrates greater loop definition in all phases as compared to the all cotton yarn shown in Figure 20. Figure 22 illustrates the changes in loop configuration of yarns from the greige to finished state of a cotton polyester specimen which has been heat-treated. A modified configuration in the form of a wider loop with less

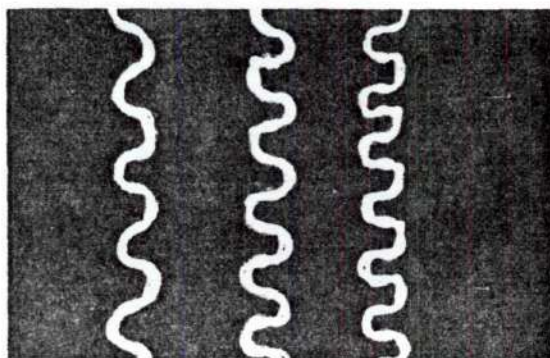


Figure 20. Unravelled
Yarns from Fabric
Specimen T-12A ("All
Cotton, N.H.T."); From
Top to Bottom; Greige,
Bleached and After
Fifth Cycle MW-TD (5X)

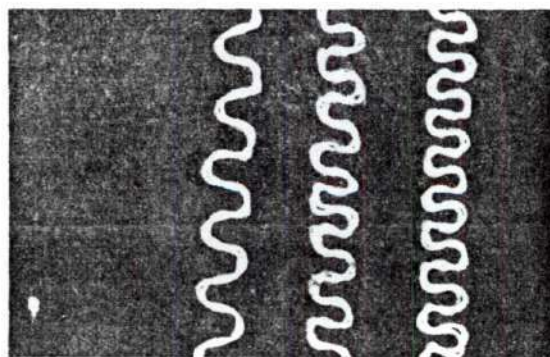


Figure 21. Unravelled
Yarns from Fabric
Specimen T-11A (Cotton
Polyester "N.H.T.");
From Top to Bottom;
Greige, Bleached and
After Fifth Cycle MW-
TD (5X)

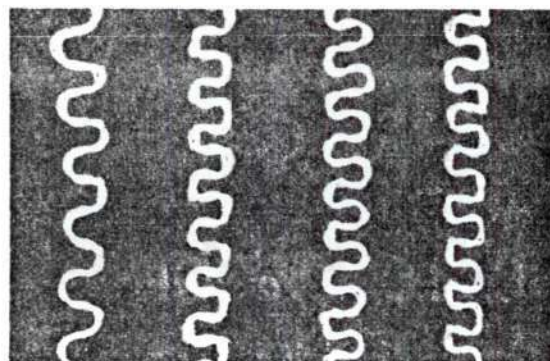


Figure 22. Unravelled
Yarns from Fabric
Specimen T-1A ("L15%O";
W+25%); From Top to
Bottom; Greige, Heat-
Treated, Bleached and
After Fifth Cycle MW-
TD (5X)

curvature is apparent due to elongation in the width during heat-treatment.

The stitch densities of the 59 cotton polyester specimens used in Parts 1 and 2 indicated a coefficient of variation of 0.34 per cent as indicated in Table 2. This was lower than the coefficients of variation listed for the related wales and courses per inch. These results would then be in agreement with Doyle's (67) findings that the stitch density is less affected by the stress history of the fabric. The variability found, as represented by the coefficients of variation just discussed, was not considered uncommon. As reported earlier, Knapton (68) had found that previous processing variables could effect values obtained in the determination of stable states. The greige state variability is actually of a temporary nature, largely due to frictional restraints, and as all specimens were of constant stitch length, subsequent wet-processing would correct these differences.

Bursting strengths of the two fabric types were virtually the same.

The all cotton fabric was slightly heavier which could be attributed to both a greater stitch density and to the somewhat greater specific gravity of cotton fibers, 1.55, to that of Kodel IV polyester fibers, 1.38 (69).

The cotton polyester fabric demonstrated 35 to 50 per cent greater elongation than the all cotton in both the length and width. For example, the elongation of the all cotton fabric in the width at a stress of 75 grams was 16.7 per cent, while the cotton polyester specimen demonstrated an elongation of 24.4 per cent.

Table 4. Average Restored Dimensional Changes in Per Cent of Cotton Polyester Specimens, Part 1, as a Result of Heat-Treatment and Subsequent Boil-Off Test.

Specimen Designation	After Heat-Treatment (a)			After Boil-Off Test; Cumulative Total (b)			Residual Test Shrinkage (b-a)		
	Length	Width	Area	Length	Width	Area	Length	Width	Area
No Heat-Treatment	-	-	-	-4.5	-2.5	7.4	-4.5	-2.5	-7.4
180A	-3.0	-1.5	4.5	-3.5	-3.5	6.9	-0.5	-2.0	-2.4
180B	-3.5	-2.5	5.9	-4.5	-2.5	6.9	-1.0	0.0	-1.0
180C	-7.0	-2.0	8.9	-8.0	-2.5	10.3	-1.0	-0.5	-1.4
60A	-3.0	-1.5	4.5	-4.0	-2.0	6.0	-1.0	-0.5	-1.5
60B	-4.0	-2.0	6.0	-5.0	-2.0	7.0	-1.0	0.0	-1.0
60C	-7.5	-1.5	8.9	-7.5	-2.0	9.3	0.0	-0.5	-0.4
30A	-2.5	-1.0	3.5	-4.0	-2.0	5.9	-1.5	-1.0	-2.4
30B	-5.0	-2.0	6.9	-6.5	-2.0	8.4	-1.5	0.0	-1.5
30C	-11.0	-2.5	13.3	-11.5	-4.5	16.0	0.5	-2.0	-2.7
10A	-3.5	-0.5	4.0	-5.0	-1.5	6.4	-1.5	-1.0	-2.4
10B	-5.0	-2.0	6.9	-6.0	-3.0	8.8	-1.0	-1.0	-1.9
10C	-9.5	-3.0	12.2	-10.5	-4.5	14.5	-1.0	-1.5	-2.3

Moisture regain of the cotton polyester fabric was about three per cent, which is considered in the optimum range for heat-treatment (70).

4.2. Part 1. Selection of Heat-Treatment Conditions of Fabric Surface Temperature and Retention Time

The method of selecting the conditions for heat-treatment was based on the determination of the combination of fabric surface temperature and retention time of the parameters considered that produced a minimal residual test area shrinkage of a restored specimen. Table 4 lists the dimensional changes in length, width and area of the specimens studied in Part 1. All heat-treated specimens showed a marked improvement of 4.5 to 7 per cent less residual area shrinkage than the specimens which did not receive a heat-treatment. The non-heat-treated specimens indicated an average restored area shrinkage of 7.4 per cent, which would be at least partly a result of not having been preshrunk by a heat-treatment and also, not having previously stabilized the polyester fibers to the heat of the boiling water. These latter conditions resulted in a comparatively high yarn shrinkage of 6.9 per cent. This would be indicative of the importance of heat-treating similar fabrics, which would be subjected to boiling water in finishing.

Results obtained from specimens heat-treated at retention times of 10 and 30 seconds were erratic and inconclusive. These specimens were heat-treated at elevated temperatures in order to raise the fabric surface temperature up to the specified level within the given time interval. Excessive yarn shrinkages of up to 7.5 per cent suggest that these treatments were uncontrolled. No additional reduction in restored area shrinkage was derived from specimens which were heat-treated at retention

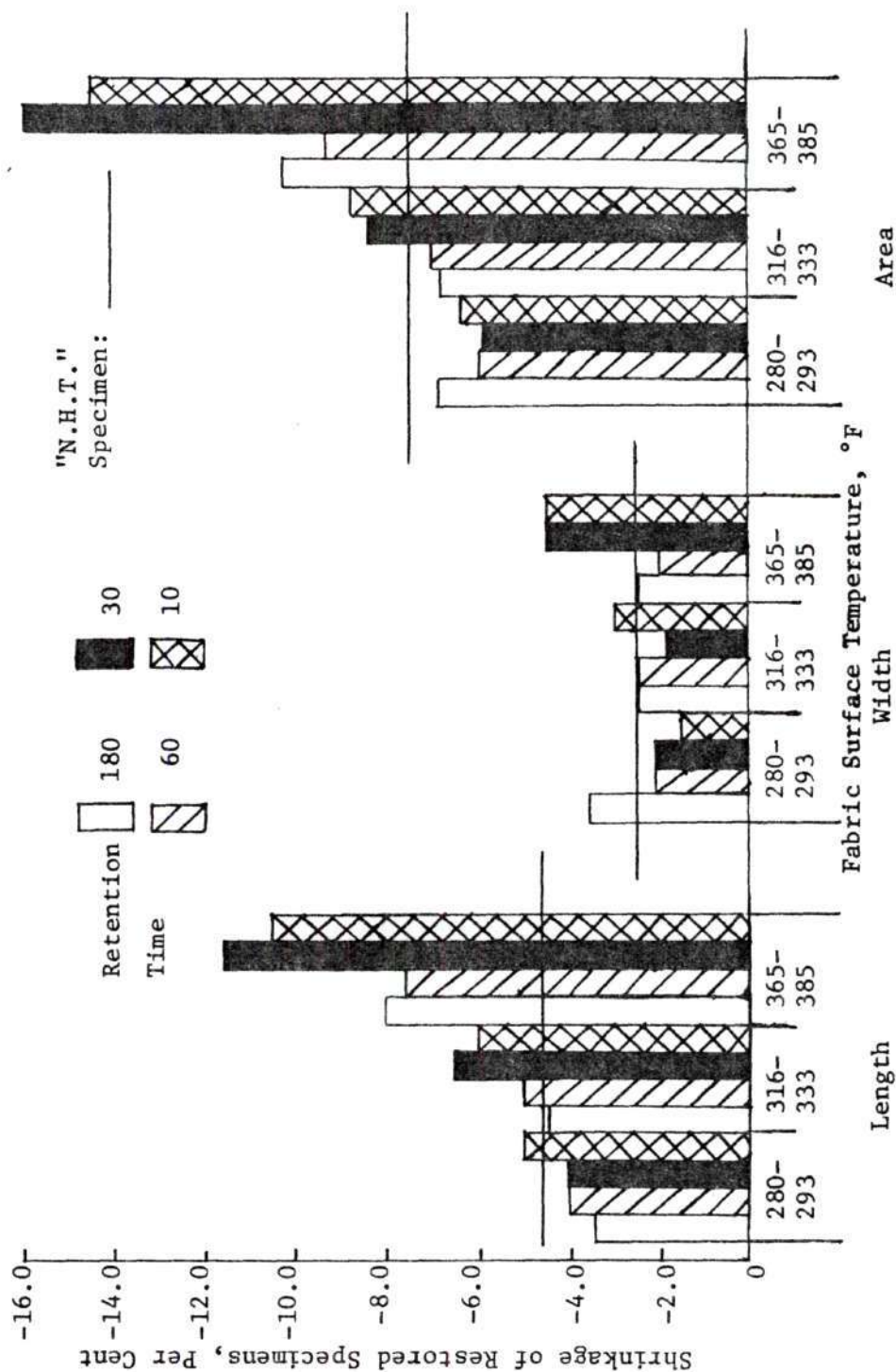


Figure 23. Restored Shrinkage of Various Heat-Treated and Boiled-Off Cotton Polyester Fabric Specimens, Part 1, and Comparison to "N.H.T." and Boiled-Off Specimens.

times of 180 seconds compared to specimens heat-treated at 60 seconds.

Heat-treatments even at the lowest temperature range of 280-293°F resulted in residual area shrinkage as low as 1.5 per cent. As pointed out earlier, Mecklenburgh (71) had experimentally demonstrated that results such as these could be expected under relaxed conditions. However, specimens would be heat-treated in Part 2, under conditions specifying a range of magnitudes of tension and so higher fabric temperature ranges would be preferable for maximum setting and shrinkage control. A fabric surface temperature range of 380-393°F with a retention time of 60 seconds indicated virtually no residual area shrinkage and was selected for use in Part 2.

Figure 23 compares the restored length, width and area shrinkages as a result of heat-treatment and boil-off. With the exception of specimens treated at short retention times, all heat-treated specimens showed a greater length shrinkage than the "N.H.T." specimen. Results for restored width shrinkage were inconclusive, but showed a number of values below the result of the non heat-treated specimen. Restored area shrinkage was lower than that of the non heat-treated specimen for all values of the lowest temperature range, but conversely was greater for all values of the highest temperature range. These results showed a direct correlation with yarn shrinkage as indicated by changes in stitch length. An excessive amount of restored fabric shrinkage accompanied with a greater yarn shrinkage at the higher temperature range indicate that the stability to residual shrinkage cited earlier for conditions in this range, would therefore be gained at a permanent loss of fabric yield.

Other than losses in fabric yield none of the heat-treated specimens

were damaged by any of the experimental conditions used, although certain properties were modified. Table 5 lists the physical properties of the physical properties of the finished specimens in Part 1. The bursting strengths of all heat-treated were greater than the strength of the untreated specimens with the bursting strength increasing slightly as fabric surface temperature increased. The range of bursting strengths, 114.9 to 125.7 lbs., was still however close to the greige strength of 119.0 lbs.

Fabric weight was dependent on final stitch density as determined by total shrinkage and ranged from 4.03 to 4.59 ounces per square yard. Yarn shrinkage as measured by changes in stitch length indicated a direct relationship with the heat-treatment variables. For values other than those heat-treated at short retention times for which the results were found inconclusive, yarn shrinkage increased as fabric surface temperature and retention time increased. The untreated specimens, as indicated previously, demonstrated a high yarn shrinkage.

Elongation in the length and width is shown graphically in Figure 24 for the tests at higher stress. A direct relationship between the fabric surface temperature and per cent elongation existed. Most noteworthy is the approximate 15 to 50 per cent loss of elongation in the width from the greige value of 24.4 per cent as fabric surface temperature increased, not considering specimens having had short retention times. Increases in retention time had a similar effect but were not as significant. Yarn shrinkage, setting of the polyester fibers and wet-processing would all reduce elongation.

All heat-treated specimens were discolored upon removal from the

Table 5. Physical Properties of Finished Fabric Specimens in Part 1.

Specimen Designation	Bursting Strength Pounds	Fabric Weight oz./sq.yd.	Stitch Length In.	Elongation, Per Cent		
				Length 20g.	Length 50g.	Width 75g.
No Heat-Treatment	114.9	4.17	.1153	4.3	9.2	10.8
180A	115.3	4.04	.1191	4.5	8.6	9.9
180B	118.3	4.14	.1184	4.2	8.0	9.2
180C	119.7	4.31	.1158	3.8	7.3	7.5
60A	118.5	4.12	.1192	4.8	9.6	10.1
60B	125.7	4.27	.1180	4.2	8.2	9.2
60C	124.6	4.41	.1164	3.6	7.3	7.6
30A	115.9	3.97	.1216	4.6	9.2	9.0
30B	118.7	4.11	.1157	3.4	8.1	8.8
30C	130.3	4.59	.1147	3.1	6.4	5.0
10A	118.0	4.03	.1198	4.2	8.8	10.0
10B	118.7	4.11	.1181	3.5	7.8	9.2
10C	121.0	4.59	.1173	3.5	7.0	7.0

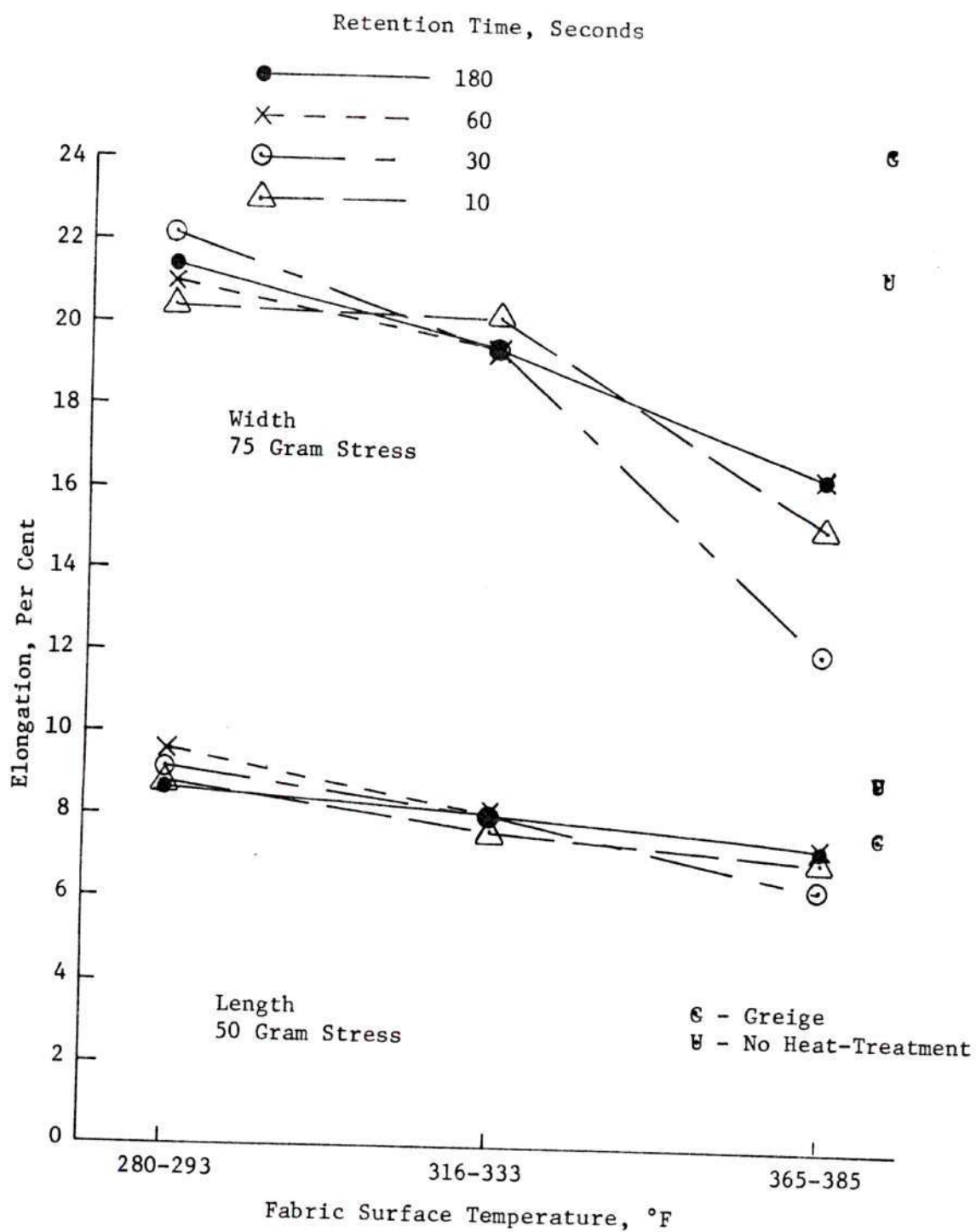


Figure 24. Per Cent Elongation of Heat-Treated Specimens Versus Heat-Treatment Conditions of Fabric Surface Temperature and Retention Time.

heat-treating oven. However, it was found that the discoloration would be effectively removed by a subsequent bleaching operation.

4.2. Part 2. A Study of the Dimensional Changes From Greige to Finished of Cotton Polyester Specimens Heat-Treated Under a Range of Tensions

Figure 25 graphically follows the total dimensional changes in the width of all specimens from their state in the frame prior to heat-treatment to their state after the final cycle of MW-TD. It is clearly illustrated that virtually all specimens had at least contracted to the original greige width upon wet-processing. Only one group of specimens, "L15%'0'; W+25%" showed any permanent degree of set in the final unre-stored state. This amounted to approximately 2 per cent in the width. The group of specimens heat-treated at the greige dimensions (L0%: W0%) indicated a restored shrinkage of approximately 8 per cent in the width demonstrating the inability to set the greige dimensions.

Because of its readily observable distortions, specimen "L15%'0'; W+25%" is illustrated in specimen form in Figures 26 through 30 as it was processed from the greige dry relaxed state shown in Figure 26 to the final state shown in Figure 30. The initial concentric ten inch circle was made oblong by the one dimensional elongation operation in the width and maintains this shape through subsequent heat-treatment, wet-processing and laundering processes. The specimen was elongated in the length by the mechanical stresses applied during wet-processing. Therefore Figure 29 indicates a more concentric shape than the one in the previous stage. But the distorted shape as a result of the heat-treatment returned during laundering as shown in Figure 30, indicating

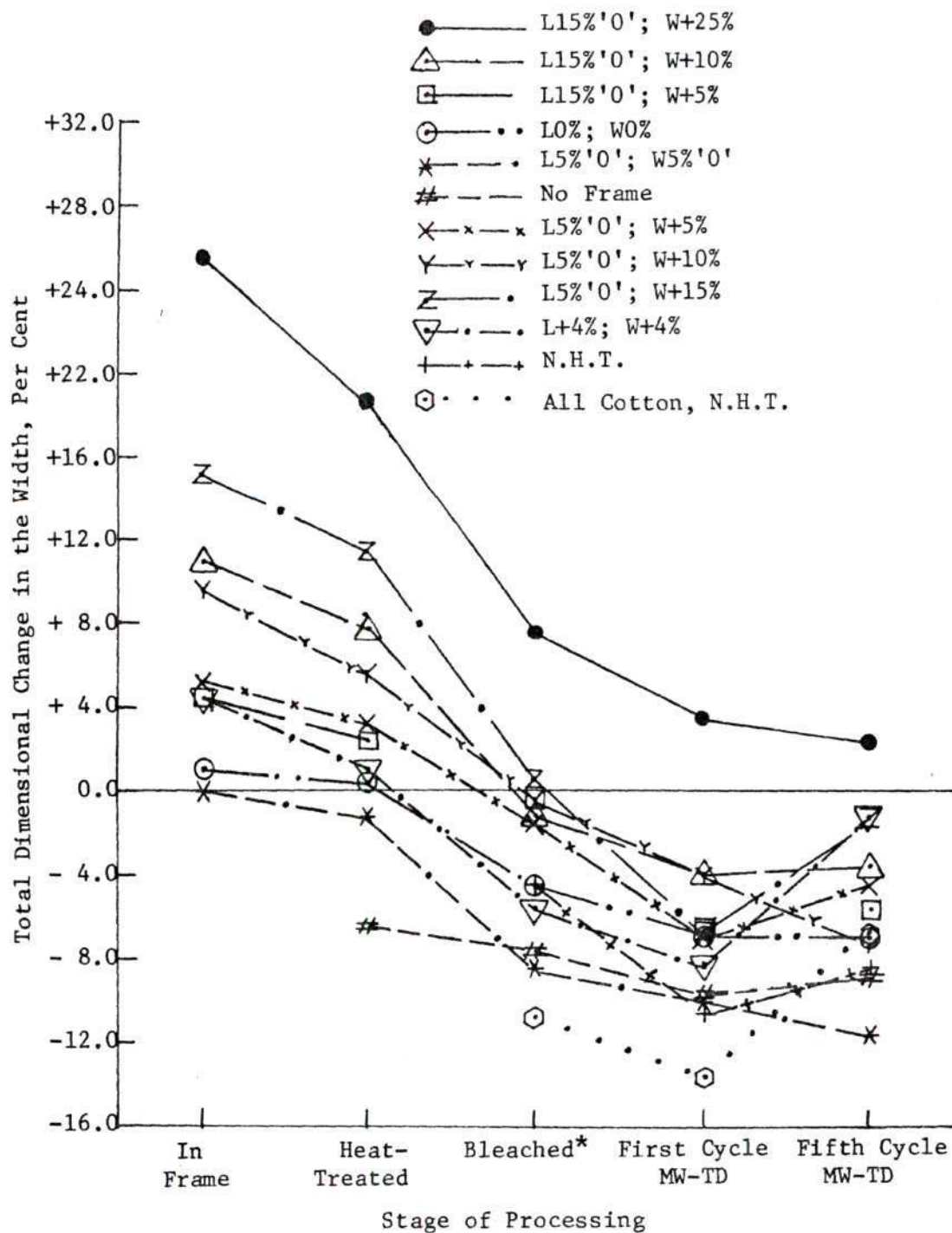


Figure 25 . Total Dimensional Change in the Width of Fabric Specimens, Part 2, As A Result of Processing and Laundering.

* Bleaching with No Tension Only.



Figure 26. Fabric Specimen
T-1A ("L15%0"; W+25%");
Greige Dry Relaxed.

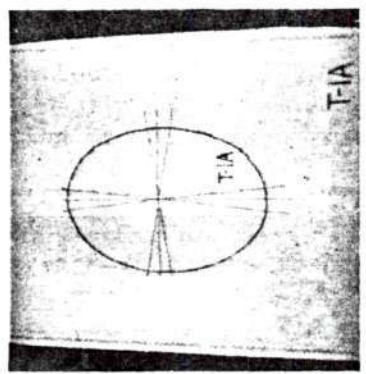


Figure 27. Fabric Specimen
T-1A ("L15%0"; W+25%");
In Frame.

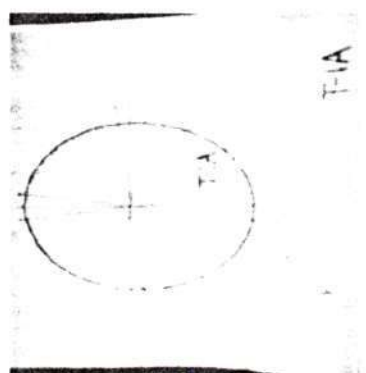


Figure 28. Fabric Specimen
T-1A ("L15%0"; W+25%");
After Heat-Treatment.

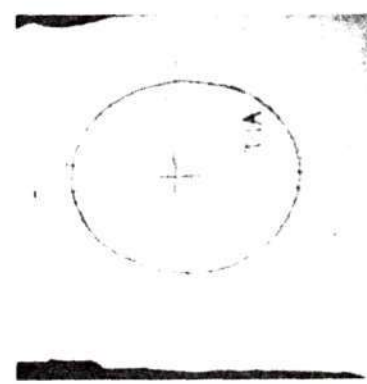


Figure 29. Fabric Specimen
T-1A ("L15%0"; W+25%");
After Bleaching.

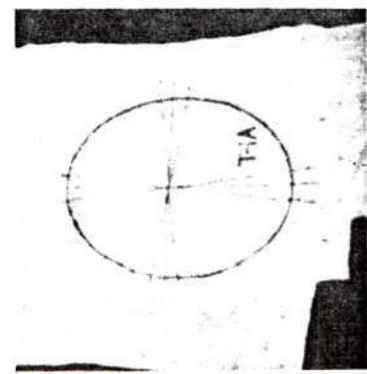


Figure 30. Fabric Specimen
T-1A ("L15%0"; W+25%");
After Fifth Cycle MW-TD.

that the heat-treatment had largely affected the permanent shape of this specimen. Figures 31 through 34 trace this specimen through some of the same stages by means of micrographs. Changes in stitch shape and density from the framed state to the state after final laundering are apparent. Changes in surface quality of the yarns may be observed, noting that stitch definition is accompanied by an increase in bulk density.

The restored shrinkages of heat-treated specimens, Part 2, after the fifth cycle MW-TD with comparisons to the non heat-treated specimens including the all cotton replicate are shown in Figure 37. Investigation of this graph readily reveals that heat-treatment did not effectively stabilize the dimensions of the greige and experimentally distorted greige specimens to prevent any sizeable reduction of fabric shrinkage from occurring. The results did vary widely as a result of the magnitude and direction of tensions during heat-treatment and wet-processing. In general, the specimens wet-processed under tension experienced less shrinkage than their counterparts which were wet-processed without tension, particularly for length and area measurements.

The only group of specimens that demonstrated any sizeable improvement over the "N.H.T." cotton polyester specimens and the all cotton specimens which were wet-processed without tension, was the biaxially stressed specimen ("L+4%, W+4%"). The specimens in this group which were wet-processed without tension had an average restored area shrinkage of 6.1 per cent and a length shrinkage of 5 per cent. These results compared to the 8.8 per cent area shrinkage and 7 per cent length shrinkage of the "N.H.T." cotton polyester specimens which had been wet-processed without tension, showed a definite improvement. This example may be

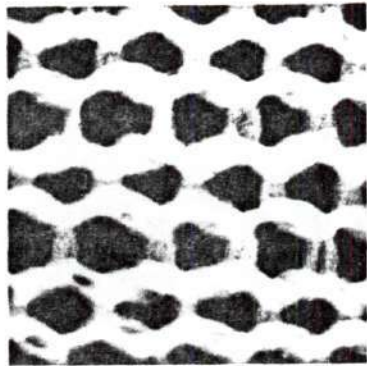


Figure 31. Fabric Specimen T-1A ('L15%'0'; W+25%"); After Framing (17X).



Figure 32. Fabric Specimen T-1A ('L15%'0'; W+25%"); After Heat-Treatment (17X).



Figure 33. Fabric Specimen T-1A ('L15%'0'; W+25%"); After Heat-Treatment and Bleaching (17X).

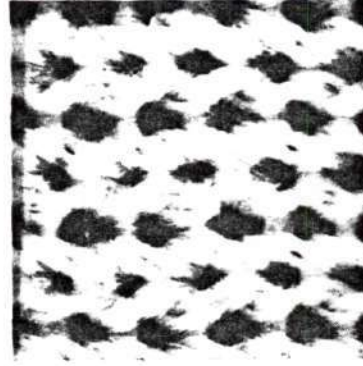


Figure 34. Fabric Specimen T-1A ('L15%'0'; W+25%"); After Heat-Treatment, Bleaching and Fifth Cycle MW-TD (17X).

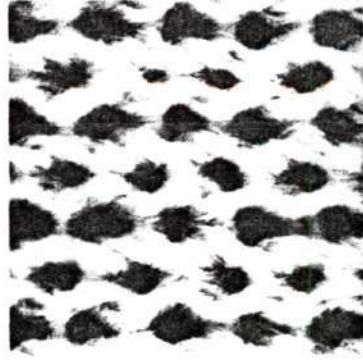


Figure 35. Fabric Specimen T-6A ('No Frame"); After Heat-Treatment (17X).

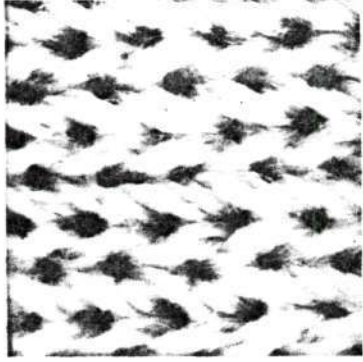


Figure 36. Fabric Specimen T-6A ('No Frame"); After Heat-Treatment, Bleaching and Fifth Cycle MW-TD (17X).

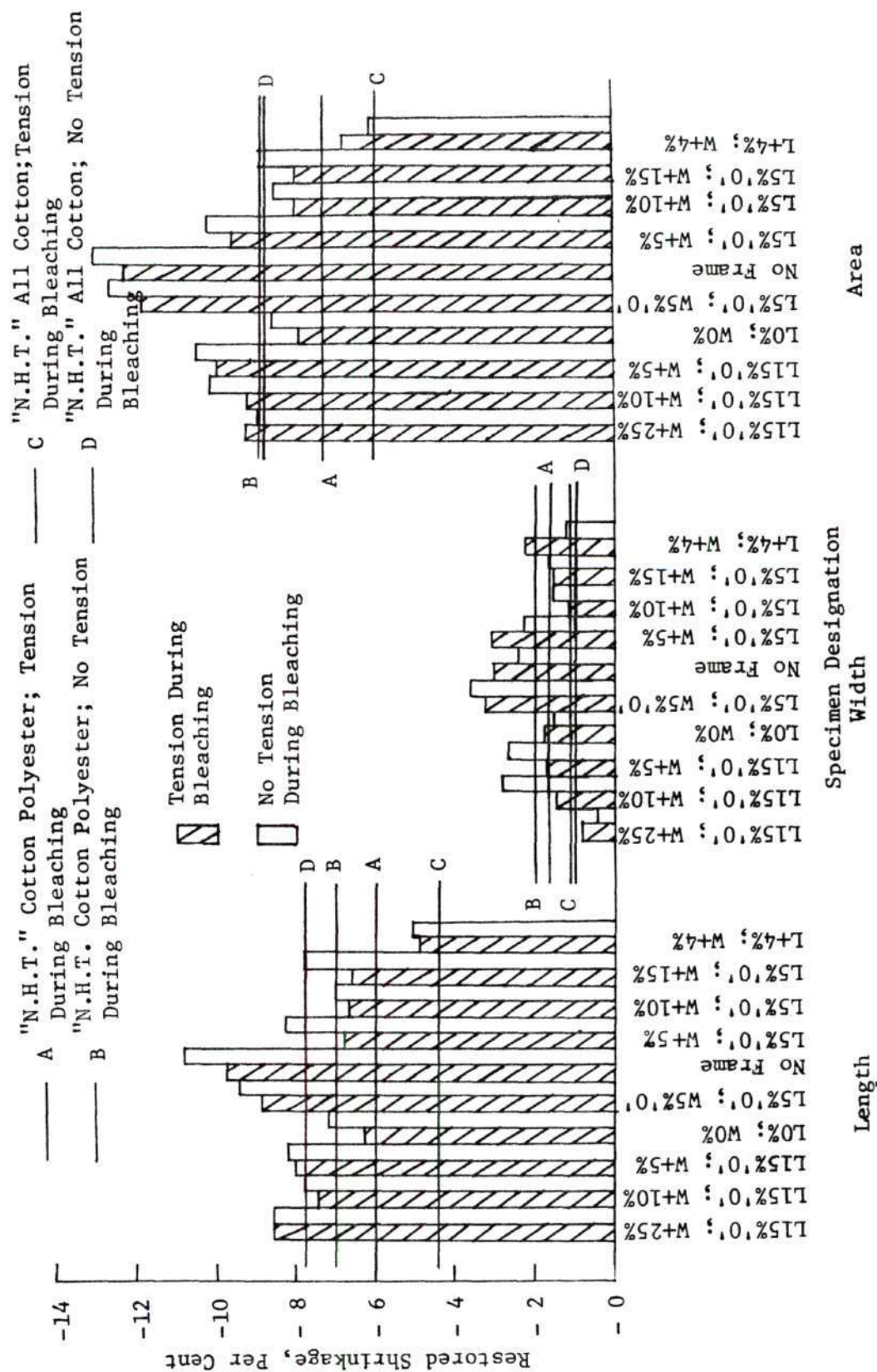


Figure 37. Restored Shrinkage of Heat-Treated Specimens, Part 2, After Fifth Cycle Machine Wash-Tumble Dry and Comparison to the "N.H.T." Specimen and the All Cotton Replicate.

illustrative of the importance of some tension in the length, rather than an overfeed, to produce any degree of stabilization when heat-treating in this manner. Figures 38 and 39 indicate the preservation of concentricity of the marked circle of the biaxially stressed specimen considered after heat-treatment and after the fifth cycle MW-TD. Figures 40 through 43, by means of micrographs show the changes of this specimen from the greige dry relaxed state to the final state. Consideration of changes in stitch shape and density is considered later in this chapter.

The specimens heat-treated at the greige dimensions ("L0%; W0%") and specimens heat-treated with low overfeed in the length and high elongation in the width ("L15% '0'; W+15%") demonstrated a slight improvement over the "N.H.T." specimens and all cotton specimens, which were wet-processed without tension. Under these conditions a reduction of up to 1.5 per cent restored length and area shrinkage were made possible.

Specimens heat-treated under little or no tension, and those treated at high overfeed (15 per cent) exhibited higher shrinkage than the non heat-treated cotton polyester and all cotton specimens. In several cases, these differences were considerable, with the greatest shrinkage exhibited by the specimens which were heat-treated without the use of a frame ("No Frame"). This group of specimens indicated approximately 50 per cent greater area shrinkage (12.58 per cent) than the "N.H.T." cotton polyester, which was wet-processed without tension. (6.11 per cent). A "no frame" specimen is illustrated by micrographs in Figures 35 and 36.

The all cotton specimen which were wet-processed with tension



Figure 38. Fabric Specimen T-10B ("L+4%; W+4%"); After Heat-Treatment.

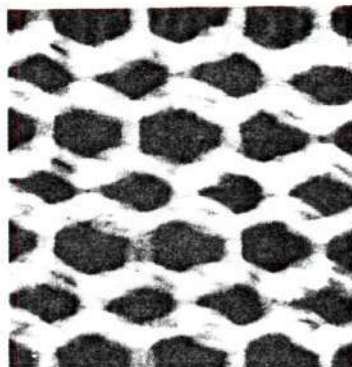


Figure 41. Fabric Specimen T-10B ("L+4%; W+4%"); After Framing (17X)

Figure 39. Fabric Specimen T-10B ("L+4%; W+4%"); After Fifth Cycle MW-TD.

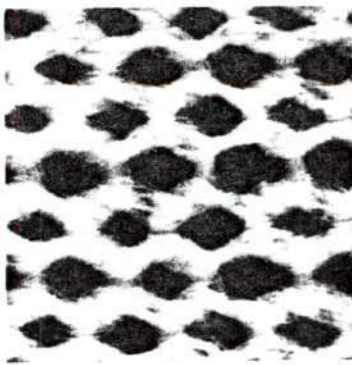


Figure 42. Fabric Specimen T-10B ("L+4%; W+4%"); After Heat-Treatment (17X).

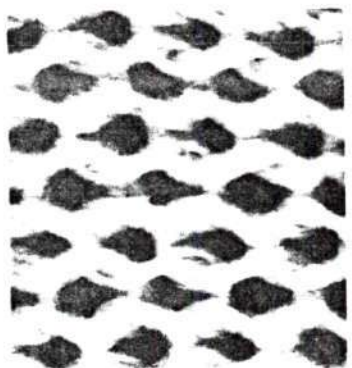


Figure 40. Fabric Specimen T-10B ("L+4%; W+4%"); Greige Dry Relaxed (17X).

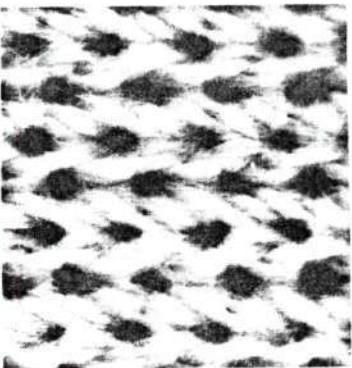


Figure 43. Fabric Specimen T-10B ("L+4%; W+4%"); After Heat-Treatment, Bleaching with Tension and Five Cycles MW-TD (17X).

demonstrated approximately 3.5 per cent less length shrinkage than similar specimens that were wet-processed without tension indicating the effect of finishing.

The previous discussion concerned the evaluation of heat-treatment in terms of stabilizing the greige heat-treated state and optimizing final fabric yield. However, this investigation was also concerned with the use of heat-treatment to reduce both distortion in wet-processing and shrinkage in laundering. Therefore it is essential to know at what stages the changes just described actually occurred. Figure 44 and Table 12, which is in the Appendix, give a breakdown of the restored area shrinkage into two components. The first component is designated "processing shrinkage" and includes dimensional changes due to heat-treatment and wet-processing (bleaching). The second component is considered "residual shrinkage" and includes all dimensional changes due to laundering. "Residual shrinkage" would therefore be representative of fabric behavior in consumer laundering.

"N.H.T." cotton polyester specimens, for both finishing techniques, indicated an average area shrinkage of 1.6 per cent. Of the heat-treated specimens, maximum stability to residual shrinkage was exhibited by most of the same specimens which were shown earlier as having the greatest stability to restored shrinkage from greige to finished. Specimen "L0%; W0%" which was wet-processed with tension exhibited a slight extension. Specimen "L+4%; W+4%", which was wet-processed without tension showed no measurable change, as did specimen L5%'0'; W+10%" which was wet-processed without tension.

Three other specimens exhibited an extension in area in laundering.

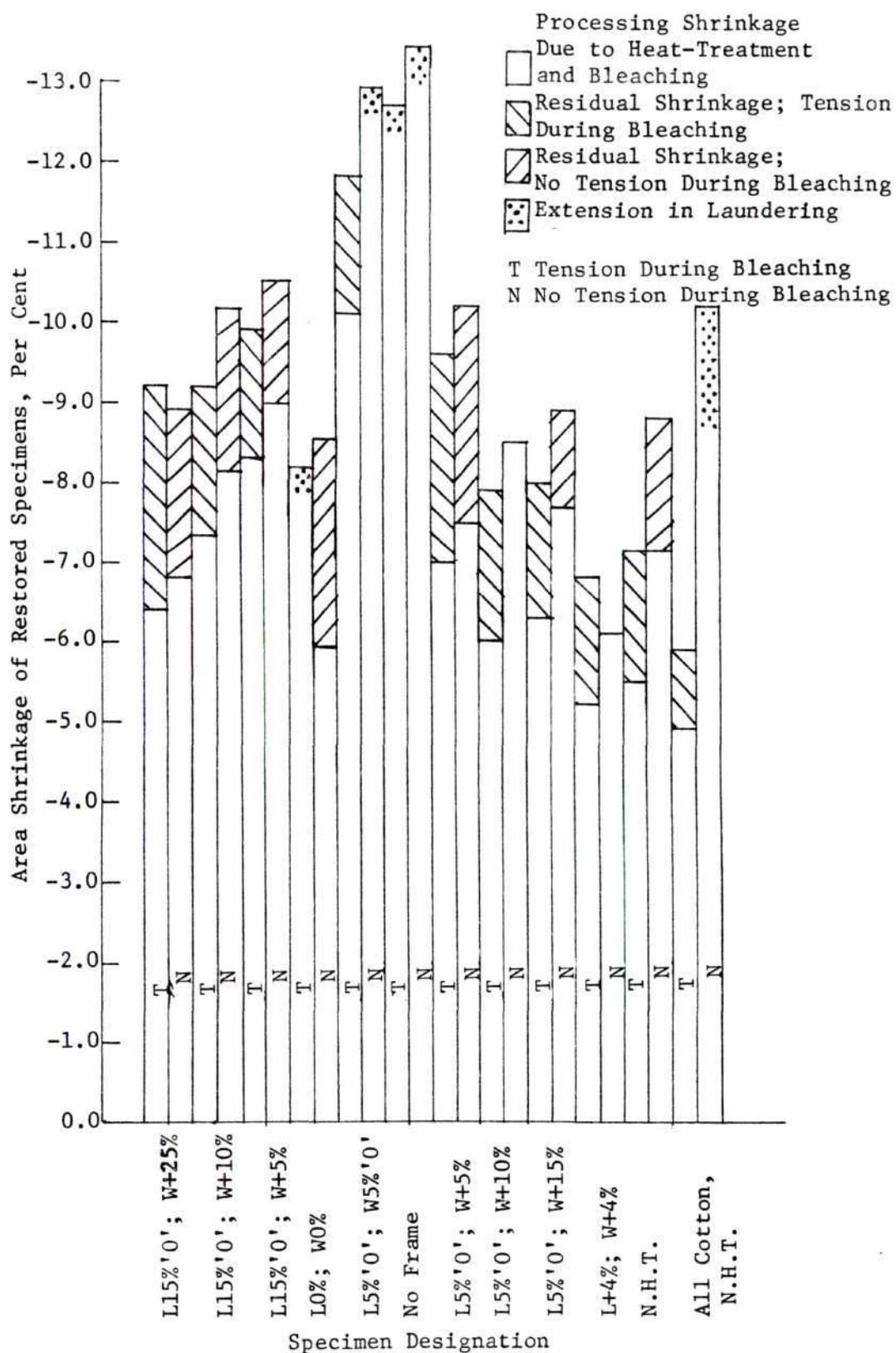
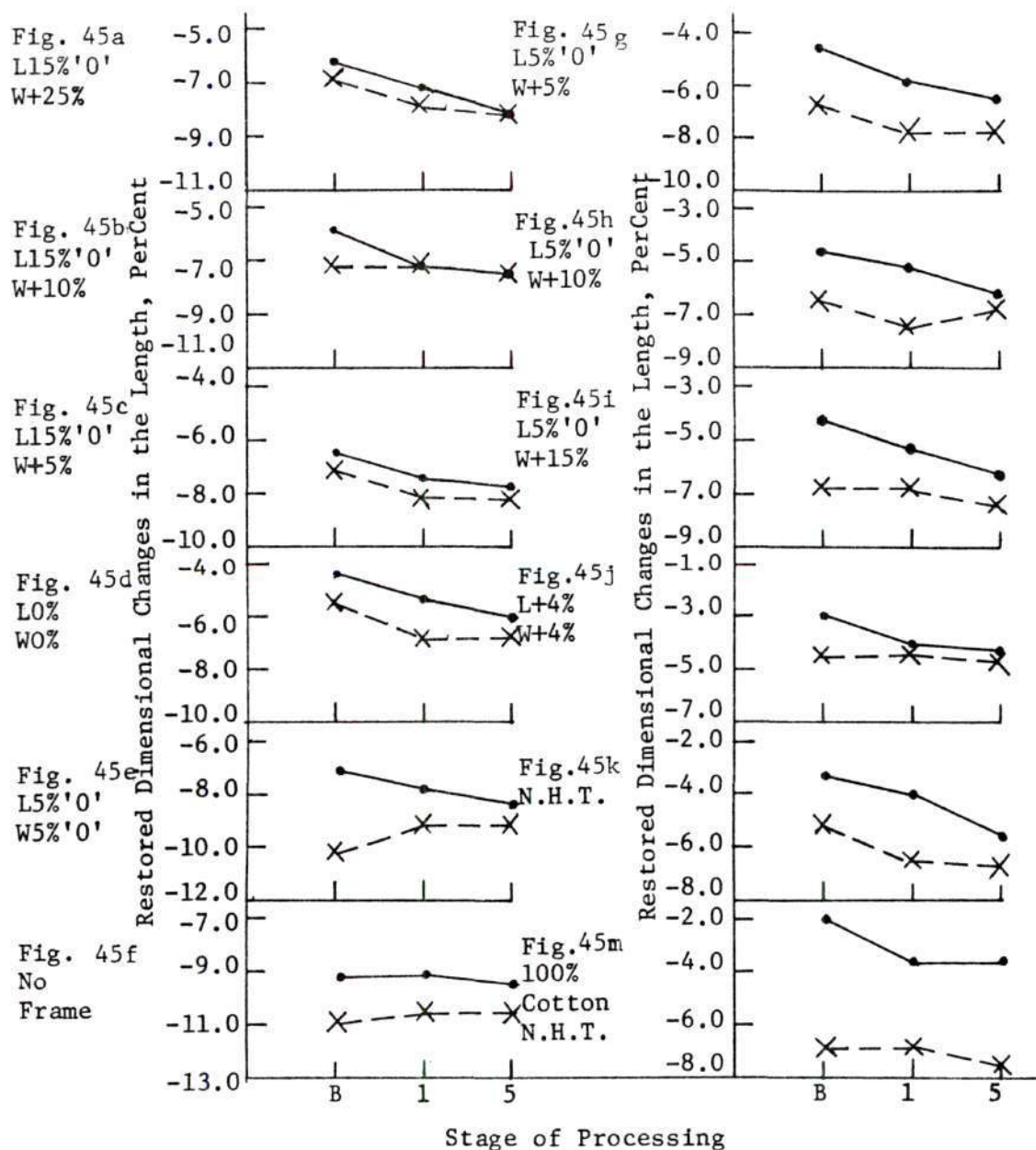


Figure 44. Processing and Residual Area Shrinkage of Restored Specimens, Part 2.

These specimens included both the "No Frame" specimens which were wet-processed with and without tension and specimens "L15%'0'; W5%'0'" which were wet-processed without tension. However these three types of specimens were under no tension in heat-treatment, which permitted an excessive amount of fabric shrinkage, subsequently reducing any tendency of the specimens to shrink at later stages. All remaining heat-treated specimens did not indicate a lower value of residual shrinkage than the "N.H.T." specimens.

The all cotton replicates which were wet-processed with tension showed a residual area shrinkage of 1.0 per cent. This uncommonly low result would be an illustration of the effect of finishing processes on dimensional changes. The all cotton specimen which was bleached without tension indicated approximately 1.5 per cent extension in laundering. This same specimen had a relatively high area shrinkage of 10.25 per cent in processing, so an extension in laundering was quite feasible.

Figures 45a through 45m compare the restored dimensional changes in the length of all twelve types of specimens from wet-processing (bleaching) through the fifth cycle MW-TD. All specimens which were wet-processed with tension in the length were decidedly elongated in the length by the mechanical actions of the finishing process. This was reflected in the resultant restored length shrinkage measurement after wet-processing. There was 1 to 5 per cent less restored length shrinkage from the greige state for the specimens which had been wet-processed under tension as opposed to those wet-processed without tension. The "N.H.T." cotton polyester specimens which had been wet-processed under tension had considerably recovered from distortion but did indicate an incomplete



Figures 45 a-m. Comparison of Restored Dimensional Changes in the Length of Specimens Bleached with Tension Versus Specimens Bleached with No Tension.

recovery. Figure 46 illustrates a specimen of this type after the final cycle MW-TD. The all cotton specimen did not effectively recover and indicated a permanent distortion of approximately five per cent. Specimens which had been heat-treated under high tensions showed a higher recovery than those heat-treated at low tensions or those specimens receiving no heat-treatment. Figure 47 shows a cotton specimen after wet-processing under tension and Figure 48 shows a cotton specimen which had been wet-processed without tension. The high elongation in the length of the former specimen is clearly visible. Figures 49 and 50 show respectively specimen "L15% '0'; W+15% wet-processed with and without tension. Figure 51 shows the former specimen in its final state. Wet-processing under walewise tension had temporarily cancelled the shape due to coursewise elongation in heat-treatment. However as can be seen in Figure 51 after the fifth cycle MW-TD, the shape as determined by heat-treatment was recovered. This illustrates the main point of the information just presented, that heat-treatment under sufficient tension had largely influenced the final shape of the fabric, reducing potential temporary and permanent effects due to stresses introduced in wet-processing.

The properties of the finished fabric specimens in Part 2 are listed in Table 6. With the exception of stitch length and elongation in the width at high stress, all other properties were not unusually altered. Finished bursting strength was as great or greater than the greige strength. Fabric weight for the cotton polyesters ranged from 4.04 to 4.62 ounces depending largely on the final area shrinkage. Values for elongation were maintained similar to the greige fabric, with the exception of elongation in the width at high stress of the heat-treated cotton polyester specimens. These specimens lost approximately

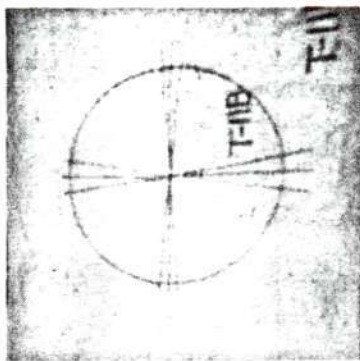


Figure 46. Fabric Specimen T-11B ("N.H.T.") After Five Cycle MW-TD.



Figure 47. Fabric Specimen T-12A ("All Cotton, N.H.T.") After Bleaching with Tension



Figure 48. Fabric Specimen T-12C ("All Cotton, N.H.T.") After Bleaching with No Tension.



Figure 49. Fabric Specimen T-9B ("L5% '0'; W+15%") After Bleaching with Tension.

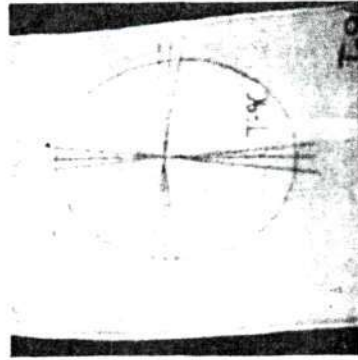


Figure 50. Fabric Specimen T-9C ("L5% '0'; W+15%") After Bleaching with No Tension

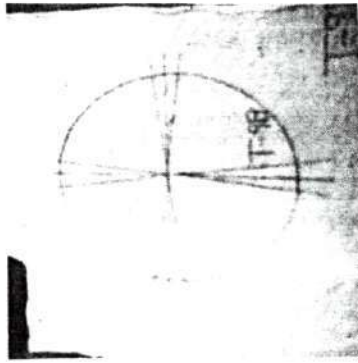


Figure 51. Fabric Specimen T-9B ("L5% '0'; W+15%") After Fifth Cycle MW-TD.

Table 6. Physical Properties of Finished Fabric Specimens in Part 2.

Specimen Designation	Bursting Strength Pounds	Fabric Weight oz./sq.yd.	Stitch Length		Elongation, Per Cent		
			After H.T.	After 5 MW-TD Inches	Length 20g.	Length 50g.	Width 75g.
1. L15'0'; W+25%	119.5	4.04	.118	.117	3.9	8.3	7.1
2. L15'0'; W+10%	125.7	4.21	.118	.116	3.8	7.8	7.5
3. L15'0'; W+5%	120.1	4.19	.117	.116	3.2	6.7	6.9
4. L0%; W0%	124.1	4.28	.117	.116	3.5	7.3	7.6
5. L5'0'; W5'0'	125.8	4.42	.117	.116	3.1	6.5	7.8
6. No Frame	128.1	4.62	.116	.114	3.3	6.8	7.3
7. L5'0'; W+5%	119.1	4.10	.117	.117	3.3	6.8	7.7
8. L5'0'; W+10%	120.1	4.04	.117	.117	3.8	7.5	7.6
9. L5'0'; W+15%	119.9	4.12	.119	.117	3.6	7.6	7.9
10. L+4%; W+4%	124.0	4.15	.120	.118	3.3	6.9	7.7
11. N.H.T.	117.9	4.29	-	.121	3.6	7.6	8.0
12. All Cotton, N.H.T.	120.5	4.23	-	.122	1.9	5.3	5.0

one third of the original elongation of 24.4 per cent. The "N.H.T." specimens were not as affected, and lost approximately 20 per cent. Yarn shrinkage, which is based on changes in stitch length, varied from 3 to 6 per cent for heat-treated specimens, depending on the magnitude and direction of tension during heat-treatment. Less restraint in heat-treatment was accompanied by greater yarn shrinkage and consequently a shorter stitch length. Yarn shrinkage increased slightly during subsequent wet-processing and laundering resulting in a final range of 5 to 8 per cent for the heat-treated specimens. The "N.H.T." specimen indicated a total yarn shrinkage of 2 per cent and the all cotton of approximately 1.5 per cent.

4.4. Evaluation of Constants K_1 and K_4

The values that were determined experimentally for K_1 and K_4 would define the stable states of the all cotton and cotton polyester specimens according to established relationships. It was one of the purposes of this study to determine whether these experimentally derived stable states were applicable to the results obtained from the heat-treated specimens. The values found are listed in Table 7. Comparison of experimental values obtained to those indicated in the literature demonstrated a high correlation.* Figures 52 through 57 show the two types of fabric in the respective three states. From these illustrations changes in stitch density which affect K_1 and in stitch shape which are reflected by K_4 , are readily seen.

*No reference values were available for the "fully relaxed state".

Tables 7 a & b. Experimentally Derived Values of K_1 and K_4 for Dry, Wet and Fully Relaxed States and Comparison to Established Values.

$K_1 = N \times \ell^2$					
Fabric Type	Dry Relaxed		Wet Relaxed		Fully Relaxed Experimental
	Experimental	Reference *	Experimental	Reference *	
100% Cotton	** 18.8	19.0 +0.8	** 22.1	22.6 +0.5	*** 22.3
50% Cotton/ 50% Polyester	*** 18.0	Orlon, Nylon; 18.5 +1.0	*** 19.0	Orlon, Nylon; 18.5 +1.0	***** 21.2
$K_4 = \frac{C.P.I.}{W.P.I.}$ (Loop Shape Factor)					
Fabric Type	Dry Relaxed		Wet Relaxed		Fully Relaxed Experimental
	Experimental	Reference *	Experimental	Reference *	
100% Cotton	1.32	1.30	1.30	1.30	1.29
50% Cotton/ 50% Polyester	1.15		1.19		1.20

* Based on values arrived at by Munden (72)

** Stitch Length = .1239 in.

*** Stitch Length = .1229 in.

**** Stitch Length = .1238 in.

***** Stitch Length = .1228 in.



Figure 52. All Cotton Test Fabric; Greige Dry Relaxed State (17X)



Figure 53. All Cotton Test Fabric; Wet Relaxed State (17X).



Figure 54. All Cotton Test Fabric; Fully Relaxed State (17X).

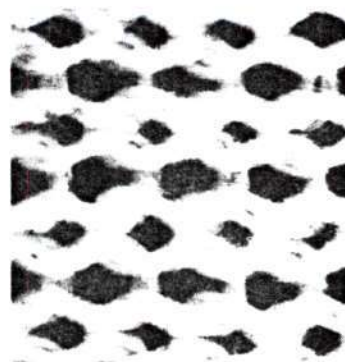


Figure 55. Cotton Polyester Test Fabric; Greige Dry Relaxed State (17X).

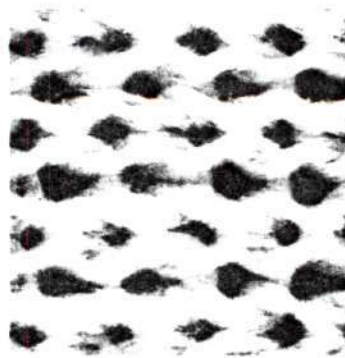


Figure 56. Cotton Polyester Test Fabric; Wet Relaxed State (17X).



Figure 57. Cotton Polyester Test Fabric; Fully Relaxed State (17X).

Table 8 lists the values of K_1 obtained from the specimens after the final cycle MW-TD and with a comparison to the fully relaxed values. First, as a check on the given values of cotton, it is seen that values obtained from the cotton test specimens were within 0.4 of the predicted value. This was considered a satisfactory check of the applicability of both the fully relaxed technique used and of the processed specimens, to the present analysis. K_1 of the "N.H.T." cotton polyester fabric was within 0.3 of the experimentally derived value, indicating the usefulness of the K_1 value for a non heat-treated cotton polyester plain knit fabric. Thus the behavior of this fabric might then be as predictable as an all cotton item. The values of K_1 for the heat-treated specimens did not exhibit the same behavior, varying widely for the range of specimens. The final values of K_1 were influenced by the previous heat-treatment conditions as evidenced by a range of stitch lengths and densities. Conditions of tension during wet-processing had a slight effect in determining the final value in most cases. Thus values of K_1 were not applicable to the specimens heat-treated in this study.

K_4 was also influenced by the conditions of heat-treatment and conditions of tension during wet-processing. Figure 58 graphically presents final values of K_4 for all specimens with a comparison to values experimentally derived. The particular value of the all cotton specimen, 1.32, approximated the experimentally derived value of 1.29. The values of the "N.H.T." cotton polyester specimens were virtually identical to the experimentally derived value of 1.20. Values of K_4 of heat-treated specimens varied widely and did not in general assume values approximating the value of 1.20. It can be observed that nearly all values obtained

Table 8. Values of K_1 of Unrestored Fabric Specimens, Part 2, After Fifth Cycle Machine Wash-Tumble Dry Compared to Values Experimentally Derived.

Experimentally Derived Fully Relaxed K_1^*				K_1^*			
100% Cotton		K_1 22.3	50% Cotton/ 50% Polyester		K_1 21.2		
K_1^* Values of Test Specimens							
Specimen Designation		K_1	Specimen Designation		K_1		
1.	L15%'0'; W+25%	T	18.7	7.	L5%'0'; W+5%	T	19.7
		N	19.0			N	19.4
2.	L15%'0'; W+10%	T	19.3	8.	L5%'0'; W+10%	T	19.1
		N	19.1			N	19.4
3.	L15%'0'; W+5%	T	19.6	9.	L5%'0'; W+15%	T	19.0
		N	19.8			N	19.3
4.	L0%; W0%	T	19.6	10.	L+4%; W+4%	T	19.7
		N	19.6			N	20.7
5.	L5%'0'; W5%'0'	T	20.4	11.	N.H.T.	T	21.1
		N	20.4			N	21.5
6.	No Frame	T	19.8	12.	All Cotton	T	21.9
		N	19.9		N.H.T.	N	22.0

Where:

T = Tension during bleaching

N = No tension during bleaching

*Based on Formula:

$$K_1 = N \times \ell^2$$

Where:

K_1 = Constant, N = Stitch Density of Unrestored Specimen after fifth MW-TD and ℓ = Stitch length of specimen after 5th MW-TD.

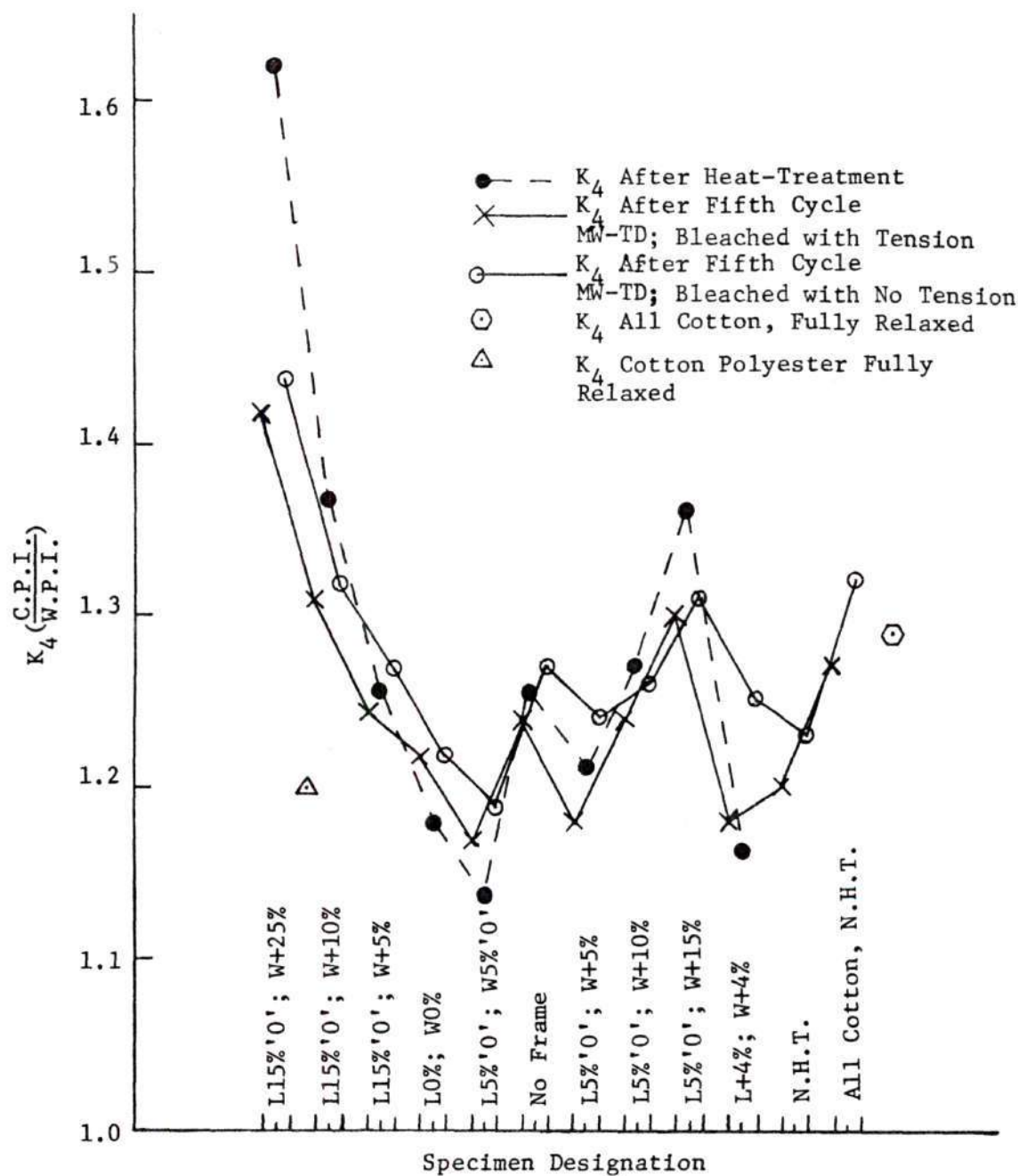


Figure 58. K_4 of Fabric Specimens Part 2, After Heat-Treatment Versus After Fifth Cycle Machine Wash-Tumble Dry.

from specimens which were wet-processed with tension were greater than the values of their counterparts which were wet-processed without tension. This indicated that heat-treatment did not prevent permanent effects from resulting from stresses during the wet-processing operation. Figure 58 shows that the plot of points of K_4 after the fifth cycle MW-TD follows quite closely the plot for K_4 after heat-treatment. This illustrates the direct influence the conditions of tension during heat-treatment on the final determination of K_4 .

Although the heat-treated cotton polyester specimens could not be effectively stabilized from dimensional changes due to wet-relaxation in wet-processing and residual changes in laundering, the polyester fibers were sufficiently affected by heat-treatment to prevent natural and predictable changes as observed in the all cotton or non heat-treated cotton polyester specimens. In particular the final loop shape was largely determined by the magnitude and direction of tension during heat-treatment.

CHAPTER V

CONCLUSIONS

Relaxed heat-treatment of the cotton polyester knitted fabric at a surface temperature range of 365-385°F and a retention time of 60 seconds resulted in a significant reduction of residual shrinkage as determined by a boil-off test.

Relaxed heat-treatments were associated with fabric preshrinkage and were accompanied by yarn shrinkage and a frequent loss of final fabric yield.

Heat-treatment at a fabric surface temperature range of 365-385°F and a retention time of 60 seconds with the fabric held to the greige dimensions and also at a range of tensions in the length and width did not effectively set the greige or experimentally distorted dimensions of the cotton polyester fabric. Relaxation and residual shrinkage were also not largely reduced in subsequent wet-processing and laundering.

Maximum dimensional stabilization by heat-treatment under tension was observed in specimens heat-treated under biaxial elongation of 4 per cent. Under these conditions a reduction of up to approximately 2.5 per cent restored area shrinkage was possible, when compared to the cotton polyester specimens that were not heat-treated and the all cotton specimens which were wet-processed without tension.

Specimens heat-treated under low tension indicated additional loss of final fabric yield compared to specimens which were heat-treated under

greater magnitudes of tension.

Heat-treatment did not prevent distortion due to wet-processing under walewise tension. However the magnitude and direction of tension during heat-treatment did influence the final shape of the knitted loops, aiding in the recovery of these latter distortions in subsequent laundering.

Yarn shrinkage of heat-treated specimens increased with the use of lower magnitudes of tension in the length and width of the cotton polyester specimens during heat-treatment.

All cotton polyester specimens heat-treated under tension indicated a loss of elongation in the width. The elongation in the width at a stress of 75 grams was reduced approximately one-third from the original value of 24.4 per cent.

Experimentally determined values of K_1 and K_4 for "fully relaxed" states of the cotton polyester fabric which applied to the non heat-treated specimens did not apply to the heat-treated specimens. Both K_1 and K_4 were influenced by the magnitude and direction of tensions during heat-treatment.

CHAPTER VI

RECOMMENDATIONS

It is recommended that the system devised in this study for the evaluation of the dimensional stability of weft-knit fabrics to processing and laundering, particularly with reference to heat-treatment, serve as a workable approach to future investigations in this field.

Heat-treatments with retention times of 30 seconds or less under the existing conditions described yielded inconclusive results and are not recommended for use under similar conditions.

The specimen elongating and preparatory apparatus performed well in both uniformly elongating and preparing a large knitted sample and should be considered for use wherever applicable. A roller system operating on tracks, rather than metal bars sliding along guide rails would reduce some of the frictional effects in applying tension. A more uniform method of incorporating an overfeed would produce more uniform results.

In studies involving heat-treatment of cut specimens a despatch type oven would be more efficient than the one used, to reduce heat loss and to insure more uniform results.

Some of the results of this investigation were affected to a greater extent than anticipated by excessive stresses produced during wet-processing with tension. It is recommended that in similar studies, the range of forces involved in operations such as beck processing with an oval reel, be given careful consideration.

The inability to largely set and stabilize the greige fabric by heat-treatment might be improved by increasing the polyester content of the fabric. The use of a blend of 65 per cent polyester/35 per cent cotton is suggested as an appropriate choice.

APPENDICES

APPENDIX A

PRINCIPLE OF OPERATION OF THE KNIT SHRINKAGE GAUGE

The knit shrinkage gauge is now widely recognized as a standard apparatus used in the determination of the dimensional change and restorability of knitted fabrics, which have been subjected to laundering (70).

The apparatus is based on the principle of applying a force in a concentric manner to realign the geometric structure of the knitted fabric to a restored condition, prior to measurement. This restored condition is considered representative of the fabric state that would have normally resulted from drying, pressing and wearing (71).

By this method it is possible to measure total shrinkage and to determine recoverable as well as non-recoverable shrinkage. The application of this method is illustrated in Figure 59.

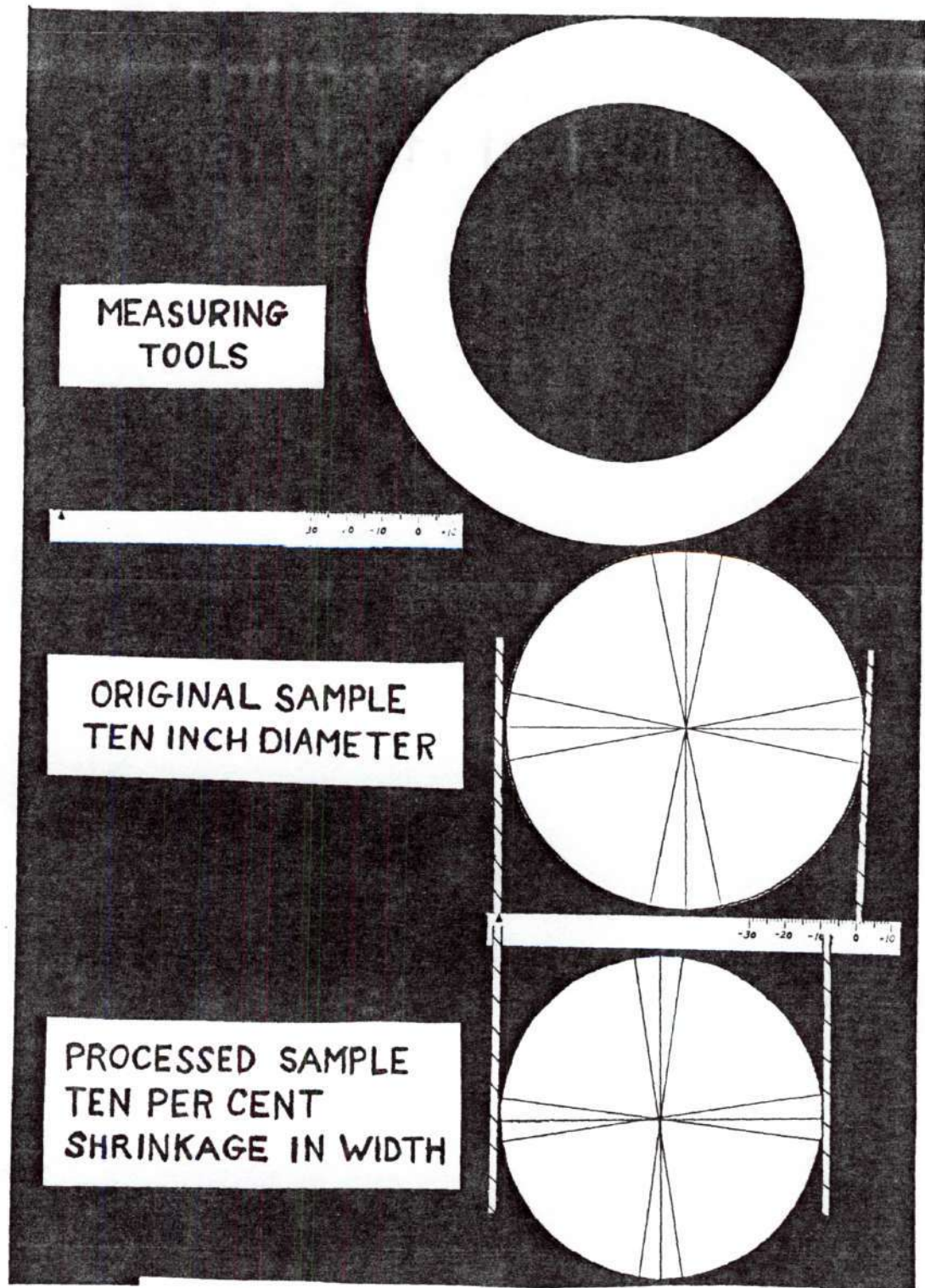


Figure 59. Knit Shrinkage Gauge Measurement Tools and Illustrated Sample Application.

APPENDIX B

TABLES WITH SUPPORTING INFORMATION

Table 9. Average Total Dimensional Changes in Per Cent of Specimens, Part 2, As a Result of Wet-Processing (Bleaching) and One and Five Cycles of Machine Washing-Tumble Drying.

Specimen Designation		Bleached			First Cycle - MW-TD			Fifth Cycle - MW-TD		
		Length	Width	Area	Length	Width	Area	Length	Width	Area
1. L15%O'; W+25%	T	-17.53	+3.59	-14.57	-20.54	+1.00	-19.75	-20.80	+2.75	-16.62
	N	-20.50	+7.58	-14.47	-22.17	+3.58	-19.03	-22.50	+2.42	-19.38
2. L15%O'; W+10%	T	-13.78	-3.67	-16.94	-16.42	-4.92	-19.70	-18.25	-4.08	-22.59
	N	-17.00	-1.17	-17.97	-17.67	-3.84	-20.83	-18.00	-3.50	-11.22
3. L15%O'; W+5%	T	-13.83	-6.80	-19.69	-17.00	-7.05	-22.85	-16.83	-5.96	-21.79
	N	-16.17	-4.58	-20.01	-18.34	-8.58	-16.20	-18.17	-5.58	-13.39
4. L0%; W0%	T	-7.21	-8.34	-11.29	-13.67	-8.75	-21.22	-14.50	-7.17	-20.63
	N	-14.83	-4.50	-18.66	-15.83	-6.83	-22.58	-14.61	-6.94	-20.54
5. L5%O'; W5%O'	T	-11.88	-12.25	-22.67	-15.63	-12.42	-26.11	-16.13	-10.59	-25.01
	N	-16.41	-8.34	-23.38	-18.08	-10.00	-26.37	-17.58	-9.50	-26.41
6. No Frame	T	-14.58	-11.71	-24.58	-17.17	-10.87	-26.17	-18.00	-9.71	-26.96
	N	-19.17	-7.58	-22.16	-21.50	-9.75	-29.15	-18.50	-8.75	-26.54
7. L5%O'; W+5%	T	-10.67	-8.63	-18.56	-15.76	-8.63	-23.13	-14.76	-7.63	-21.26
	N	-16.00	-1.84	-17.55	-18.00	-6.50	-23.33	-16.83	-4.34	-20.44
8. L5%O'; W+10%	T	-11.38	-4.46	-15.33	-15.71	-6.12	-20.87	-15.38	-6.71	-21.06
	N	-16.41	-0.17	-16.55	-17.41	-3.83	-20.57	-17.08	-7.08	-22.95
9. L5%O'; W+15%	T	-7.92	-2.67	-10.28	-17.59	-4.25	-21.09	-17.42	-1.17	-18.39
	N	-18.33	+0.67	-17.78	-19.00	0.00	-19.00	-18.83	-1.33	-19.91
10. L+4%; W+4%	T	-7.50	-9.96	-16.71	-12.00	-10.71	-21.42	-17.42	-1.17	-18.39
	N	-10.33	-5.50	-15.26	-12.66	-8.33	-19.93	-18.83	-1.33	-19.91
11. N.H.T.	T	-7.33	-9.79	-16.40	-11.88	-10.88	-11.47	-12.83	-8.88	-21.57
	N	-14.09	-5.57	-18.88	-18.40	-10.67	-18.12	-15.42	-8.33	-22.47
12. All Cotton, N.H.T.	T	-1.09	-17.42	-19.06	-7.50	-15.84	-18.79	-7.42	-12.00	-18.53
	N	-11.50	-10.82	-21.08	-13.59	-13.50	-25.26	-12.52	-7.00	-18.64

Where: T = Tension During Bleaching; N = No Tension During Bleaching.

Table 10. Average Restored Dimensional Changes in Per Cent of Specimens, Part 2, as a Result of Wet-Processing (Bleaching) and One and Five Cycles of Machine Washing-Tumble Drying.

Specimen Designation		Bleached		First Cycle -		MW-TD		Fifth Cycle -		MW-TD	
		Length	Width	Length	Width	Length	Width	Length	Width	Length	Width
1. L15%O'; W+25%	T	-6.42	0.00	-6.42	-7.71	-0.42	-8.10	-8.46	- .75	-9.15	-8.88
	N	-7.00	+0.25	-6.77	-8.00	-0.42	-8.40	-8.50	- .42	-8.88	-9.19
2. L15%O';	T	-6.25	-1.17	-7.35	-7.17	-1.42	-8.50	-7.50	-1.83	-10.14	-9.89
	N	-7.17	-1.67	-8.72	-7.17	-2.50	-9.49	-7.67	-2.67	-10.54	-7.94
3. L15%O'; W+5%	T	-6.67	-1.80	-8.35	-7.58	-2.21	-9.62	-8.00	-2.05	-10.84	-8.55
	N	-7.34	-1.75	-8.96	-8.17	-2.91	-10.84	-8.17	-2.58	-11.84	-12.58
4. L0%; W0%	T	-4.50	-3.92	-8.15	-5.51	-1.83	-7.24	-6.34	-1.71	-7.94	-8.55
	N	-5.50	-1.50	-5.93	-7.00	-1.50	-8.40	-7.16	-1.50	-8.55	-11.84
5. L5%O'; W5%O'	T	-7.30	-3.00	-10.08	-8.05	-3.34	-11.12	-8.88	-3.25	-12.58	-12.34
	N	-10.25	-3.00	-12.94	-9.25	-3.34	-12.28	-9.41	-3.50	-13.00	-9.60
6. No Frame	T	-9.25	-3.79	-12.69	-9.34	-3.88	-12.86	-9.67	-2.96	-13.00	-10.14
	N	-11.00	-2.75	-13.45	-10.84	-3.42	-13.89	-10.84	-2.42	-13.00	-9.60
7. L5%O'; W+5%	T	-5.09	-2.21	-7.19	-6.17	-2.88	-8.87	-6.75	-3.05	-10.14	-7.90
	N	-7.16	-0.34	-7.48	-8.00	-2.83	-10.60	-8.16	-2.16	-10.14	-8.47
8. L5%O'; W+10%	T	-4.88	-1.29	-6.11	-5.58	-2.00	-7.47	-6.71	-1.28	-8.00	-8.90
	N	-6.58	-1.83	-8.29	-7.58	-1.83	-9.27	-7.08	-1.50	-8.47	-8.00
9. L5%O'; W+15%	T	-4.76	-1.59	-6.27	-5.75	-1.83	-7.47	-6.60	-1.50	-8.90	-6.78
	N	-7.00	-0.83	-7.67	-7.00	-0.83	-7.77	-7.83	-1.16	-8.90	-6.11
10. L+4%; W+4%	T	-3.25	-2.04	-5.22	-4.33	-2.29	-6.52	-4.75	-2.13	-6.78	-7.15
	N	-4.64	-0.50	-6.11	-4.66	-1.33	-5.93	-5.00	-1.17	-6.11	-7.15
11. N.H.T.	T	-3.67	-1.96	-5.56	-4.33	-1.96	-6.30	-6.09	-1.13	-8.78	-5.93
	N	-5.25	-2.00	-7.14	-6.59	-2.33	-8.77	-6.92	-2.00	-8.78	-5.93
12. All Cotton, N.H.T.	T	-2.17	-2.92	-4.93	-4.09	-1.84	-6.85	-4.33	-1.67	-5.93	-8.67
	N	-7.00	-3.50	-10.25	-6.92	-2.50	-9.25	-7.75	-1.00	-8.67	-8.67

Where: T = Tension during bleaching; N = No tension during bleaching.

Table 11. Average Total Dimensional Changes in Per Cent of Specimens, Part 2,
as a Result of Framing and Heat-Treatment.

Specimen Designation	In Frame			Heat-Treated		
	Length	Width	Area	Length	Width	Area
1. L15%'0'; W+25%	-11.28	+25.72	+11.54	-14.47	+18.94	+1.73
2. L15%'0'; W+10%	- 5.00	+11.00	+5.45	-9.67	+7.83	-2.61
3. L15%'0'; W+5%	- 2.84	+4.50	+1.53	-9.39	+2.33	-7.68
4. L0%; W0%	+ 0.39	+0.96	+1.35	-3.36	+0.47	-2.90
5. L5%'0'; W5%'0'	0.00	0.00	0.00	-7.89	-5.22	-12.7
6. No Frame	-	-	-	-13.50	-6.44	-19.11
7. L5%'0'; W+5%	+ 0.45	+5.31	+5.78	-5.50	+3.14	-2.53
8. L5%'0'; W+10%	- 2.11	+9.86	+7.54	-6.67	+6.53	-0.58
9. L5%'0'; W+15%	- 6.06	+15.28	+8.29	-8.83	+11.44	+1.60
10. L+4%; W+4%	- 3.78	+4.47	+8.42	+1.28	+1.20	+2.50
11. N.H.T.	-	-	-	-	-	-
12. All Cotton, N.H.T.	-	-	-	-	-	-

Table 12. Average Restored Dimensional Changes in Area in Per Cent of Specimens, Part 2, as a Result of Processing and Laundering.

Specimen Designation	Dimensional Changes as a Result of Processing (H.T. & Bleaching)		Dimensional Changes as a Result of Laundering (Five Cycles MW-TD)	
	T	N	T	N
1. L15%'0'; W+25%	-6.42	-6.77	-2.73	-2.11
2. L15%'0'; W+10%	-7.35	-8.72	-1.84	-1.42
3. L15%'0'; W+5%	-8.35	-8.96	-1.54	-1.58
4. L0%; W0%	-8.15	-5.93	+0.21	-2.62
5. L5%'0'; W5%'0'	-10.08	-12.94	-1.76	+0.36
6. No Frame	-12.69	-13.45	+0.35	+0.45
7. L5%'0'; W+5%	-7.19	-7.48	-2.41	-2.66
8. L5%'0'; W+10%	-6.11	-8.29	-1.79	-0.18
9. L5%'0'; W+15%	-6.27	-7.67	-1.73	-1.23
10. L+4%' W+4%	-5.22	-6.11	-1.56	0.00
11. N.H.T.	-5.56	-7.14	-1.59	-1.64
12. All Cotton, N.H.T.	-4.93	-10.25	-1.00	+1.58

Where: T = Tension during bleaching; N = No tension during bleaching.

Table 13. Average Stitch Count of Unrestored Specimens, Part 2, After Fifth Cycle Machine Wash-Tumble Dry as Compared to Experimentally Derived Values.

Experimentally Derived Fully Relaxed Stitch Count					
Fabric Type	W.P.I.	C.P.I.	Stitch Density	Fabric Type	Stitch Density
100% Cotton	35.1	42.8	1477.0	50% Cotton/	1402.2
				50% Polyester	
				W.P.I.	C.P.I.
				34.2	41.0
Stitch Count of Specimens					
Specimen Designation	W.P.I.	C.P.I.	Stitch Density	Specimen Designation	Stitch Density
L15%'0'; W+25%	T 30.1	44.0	1364.4	L5%'0';	1436.6
	N 31.1	44.7	1388.8	W+5%	1417.8
L15%'0'; W+10%	T 33.1	43.2	1429.6	L5%'0';	1394.6
	N 32.7	43.1	1412.4	W+10%	1415.8
L15%'0'; W+5%	T 34.2	42.5	1452.0	L5%'0';	1389.2
	N 34.2	43.0	1468.4	W+5%	1408.0
L0%; W0%	T 34.5	42.1	1452.3	L+4%;	1418.4
	N 34.5	42.1	1450.7	W+4%	1490.8
L5%'0'; W5%'0'	T 36.0	42.0	1509.6	N.H.T.	1446.5
	N 35.6	42.5	1513.8		1472.6
No Frame	T 35.1	43.4	1522.7	All Cotton	1472.5
	N 34.8	44.0	1529.1	N.H.T.	1473.5

Where: T = Tension during bleaching; N = No tension during bleaching.

Table 14. Average Poisson's Ratio, K_4 , for Fabric Specimens, Part 2, from Greige to Finished Fabric.

Specimen Designation	Greige	In Frame	Heat-Treated	Bleached	1st Cycle MW-TD	5th Cycle MW-TD
1. L15%'0'; W+25%	1.14	1.64	1.62	T	1.39	1.42
				N	1.49	1.44
2. L15%'0'; W+10%	1.15	1.34	1.37	T	1.26	1.31
				N	1.33	1.32
3. L15%'0'; W+5%	1.13	1.20	1.26	T	1.20	1.24
				N	1.25	1.26
4. L0%; W0%	1.14	1.15	1.18	T	1.13	1.22
				N	1.25	1.22
5. L5%'0'; W5%'0'	1.11	1.11	1.14	T	1.11	1.17
				N	1.19	1.19
6. No Frame	1.15	-	1.23	T	1.18	1.24
				N	1.28	1.27
7. L5%'0'; W+5%	1.11	1.18	1.21	T	1.12	1.18
				N	1.26	1.24
8. L5%'0'; W+10%	1.11	1.26	1.27	T	1.19	1.24
				N	1.29	1.26
9. L5%'0'; W+15%	1.12	1.38	1.36	T	1.18	1.30
				N	1.31	1.31
10. L+4%; W+4%	1.14	1.36	1.16	T	1.11	1.18
				N	1.19	1.25
11. N.H.T.	1.16	-	-	T	1.13	1.20
				N	1.25	1.23
12. All Cotton, N.H.T.	1.32	-	-	T	1.14	1.27
				N	1.33	1.32

Where: T = Tension during bleaching; N = No tension during bleaching.

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^{*}The abbreviations used here follow the form employed by the Textile Technology Digest.

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