EFFECTS OF LAUNDERING AND WASHING TEMPERATURES ON COMMERCIALLY DYED THAI SILK FABRICS

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EFFECTS OF LAUNDERING AND WASHING TEMPERATURES

ON COMMERCIALLY DYED THAI SILK FABRICS

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PREFACE

This study is concerned with the effects of laundering commercially finished Thai silk fabrics at different temperatures. The primary purpose is to provide laboratory data which can serve as guidelines for predicting consumer satisfaction with Thai silk fabrics.

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CHAPTER I

INTRODUCTION

Hand-woven Thai silk fabric is made from yarn produced from cocoons spun by cultivated Bombyx mori silkworms (22, p. 1). The Thai silkworm spins rough, fluffy filaments with a capacity to absorb and hold more than seven hundred dye colors (21, p. 13). This unique characteristic of Thai silk is accidently produced through carelessness in reeling and winding and by the fluffy nature of the native silk filaments (13, p. 35). Thai silk yarn is generally twistless, irregular in size, bulky and slubby (13, p. 35). This peculiar textured yarn creates a pleasing appearance in the fabric and makes Thai silk different from silk of other countries.

The two main types of silk fabric produced in Thailand are silk brocades and plain woven fabrics in solid colors, plaids, stripes, border designs, and prints. When one color is used for the warp yarn and another color for the filling yarn, an iridescent effect is obtained. In printed fabrics, the iridescent background enhances the designs of the prints.

Thai silk fabric is yarn-dyed. In most Thai silk, imported yarn is used for the warp and the native silk for the weft (13, p. 35). The method of dyeing varies according to the types of dyestuffs used. Direct, acid, chrome and metal complex dyes are commonly used. These dyes are simple to apply and are suited for the available technical skills and equipment of the producers. The fastness of colors is relatively good in most cases (13, p. 36).

After the fabric has been woven it can be finished in a variety of ways to give it the desired hand and other properties. Finishing is basically the same for silk as for other fibers except that in general, fine quality silk requires very little finishing compared with most other fibers (23, p. 175). Silk can be weighted with metallic salts in order to give body and density to fabric and make heavy fabric. Apart from inspecting and mending for faults, and in some cases light pressing, Thai silk fabric is subjected to no other finishing treatment (13, p. 39).

Hand block printing is usually employed to add designs to solid color fabric. One side of the wooden block has the design either cut out in relief or produced by embedded copper strips. The printer inks the block from a pad or color holder, and then presses it on to the surface of the cloth which is stretched on a padded table (23, p. 452). The number of the blocks used corresponds to the number of colors in the designs. Great skill is required to stamp each portion of the design accurately so that all designs will be clean in outline and without a change in the depth of the color. Hand block printing gives a greater variety of design and color effects than roller printing (25, p. 211). One way to detect hand block printing is to look along the selvage for the regularity of the repetition of the design. In hand block printing, the design is not repeated at regular intervals as in the roller method (25, p. 211). Another way is to observe edges of the designs; most invariably one color runs into another in at least a few places. The quality of the workmanship may be determined by the clearness of each color, the sharpness of the outline, and the regularity of the colors in the designs (25, p. 212).

The brilliantly colored, textured and designed Thai silk fabric is well known and is being accepted in more and more countries. More than 55 countries import Thai silk (21, p. 1). Projects promoting sericulture have been undertaken. The result has been increased production of silk in Thailand. Much care is taken in checking thickness, plies per warp thread, picks and ends per inch. Control procedures in the dyeing processes have improved considerably. Continuing research and accurate recording of dye bath formulas allow a precise matching of more pleasing color combinations (21, p. 14).

The Problem

Since no research related to color loss or other physical changes due to repeated laundering of finished Thai silk fabrics was found in the literature reviewed, it appeared appropriate to investigate physical changes, resulting from washing Thai silk fabrics. The experimental data and the statistical analysis resulting from the study provide information concerning physical changes and expected performance of Thai silks. The findings should also serve as guidelines for predicting potential consumer satisfaction with Thai silk fabrics.

This investigation was designed to study dimensional stability, appearance of smoothness and retention of the original appearance, and colorfastness of two commercially dyed and printed Thai silk fabrics. Specific objectives of this research were as follows:

1. To determine thread count and fabric width of two plain woven Thai silk fabrics.

2. To determine the dimensional stability of specimens from two Thai silk fabrics after 5, 10, 15, and 20 launderings at each washing temperature of 85°F, 120°F, 160°F, and 180°F.

3. To evaluate the appearance of smoothness and retention of original appearance of the fabric specimens after each designated number of launderings and washing temperatures.

4. To evaluate the colorfastness of the fabric specimens after each designated number of washings at each designated washing temperature by the following methods:

    (a) evaluation of color changes by the use of AATCC Gray Scale for Color Change.

    (b) evaluation of color staining on the multifiber test cloth attached to the specimens by using the AATCC Color Transference Chart.

Limitations of the Study

This study was confined to two yarn-dyed, hand-woven Thai silk fabrics of medium weight with plain weave construction. The experimental fabrics were commercially dyed and printed with unidentified dyestuffs. The laundering of the specimens was limited to a maximum of 20 launderings for each set of specimens at four different washing temperatures. Since neutral soap chips, rather than a synthetic detergent were used in this study, findings may differ from those in studies in which a synthetic detergent is used.

Assumption

It was assumed that each specimen was treated equally and uniformly under each washing condition in the Launder-Ometer. Therefore, the difference in evaluated results of the specimens would result from individual characteristics of each specimen.

Definition of Terms

AATCC Gray Scale for Color Change: An American Association of Textile Chemists and Colorists standard for evaluating change in color. The standard is composed of nine pairs of standard gray chips with each pair representing a difference in color or contrast (shade and strength) corresponding to a numerical fastness rating.

AATCC Color Transference Chart: An American Association of Textile Chemists and Colorists standard for evaluating color staining. The standard consists of four horizontal rows with the lightest colors on the top row and the heaviest colors on the bottom row. The rows of colors are designated numerically for rating purposes.

Colorfastness: The ability of a color to resist color destroying agents, such as sunlight, washing, dry cleaning and rubbing.

Detergent: A soap or synthetic substance which possesses cleansing or purging properties. It is used to rid yarns and fabrics of dirt and soil.

Hand-woven: Fabric which results when all steps of weaving are done by hands with the aid of simple equipment.

Neutral soap: A cleansing substance with a characteristic pH of 10 or less.

Launder-Ometer: A standard laboratory washing machine.

Metallic weighting: Techniques of increasing the weight and density of silk fabric by means of soaking the fabric in the metallic salt solution.

Pick counter: A double lens glass used in analyzing and dissecting cloth.

Pure silk: Fabric made exclusively from silk yarns containing no metallic salt.

Soap: A detergent made by action of an alkali on a fat or fatty acid.

Synthetic detergent: A cleaning agent derived from petroleum; can be made stable to acids and metallic salts.

CHAPTER II

REVIEW OF LITERATURE

There are many reasons why the consumer does not find satisfaction with the textile material he buys and uses. Denny (7, p. 139) mentioned the following: (a) shrinkage or stretch due to various causes, (b) slippage due to loose construction or unevenly matched warp and filling, (c) flaws in weaving, (d) flock and lacquer prints which are not always durable when subjected to washing and dry cleaning, and (e) non-penetration of dyes.

Standard test procedures conducted in the labroatory provide reliable data which may be used to evaluate and predict fabric performance. Scientific studies of textiles provide quantities of information, but there still are many questions that cannot be simply answered. Joseph (15, p. 420) says, "What is adequate for one end-use may be inadequate for another. What pleases one consumer could displease another." Test results serve only as guidelines for evaluating fabric behavior.

Physical characteristics of textile fabrics are described by indicating the average width, length, number of yarns per inch in warp and filling directions, and the weight in ounces per square inch or linear yard (15, p. 421). This information provides a basis for price comparison and for determination of suitable end-use.

The fabric width is important in determining how much cloth must be purchased by the consumer for intended end-use. During manufacturing and finishing processes, the fabric is subjected to various strains. The width of the fabric, when removed from the loom, may not be the same as when it reaches the consumer. The loom state of the fabric may undergo ordeals by water, heat, pressure and tension. Some processes cause contraction in width (wet treatment) and some may stretch the cloth. Textile materials possessing the power of recovery from imposed strain may contract when allowed to relax free from tension (4, p. 256).

Potter (20, p. 65) describes thread count of the fabric as "the number of warp yarns and filling yarns in a square inch of fabric." Thread count determines the compactness of the construction and density of the cloth. A fabric is said to have well-balanced construction if the number of warp yarns and filling yarns are almost equal (20, p. 65). Balanced thread count is often considered to offer better wearing qualities than unbalanced counts (15, p. 421). However, this is also influenced by yarn size. If the yarn in one direction has a very small diameter and the yarn in the filling direction has a thicker diameter, the number of threads per inch may vary considerably and still provide a satisfactory fabric (15, p. 422).

The process of laundering subjects the fabric to the combined action of detergent, water, temperature and friction (11, p. 480). If the fiber is noticeably weakened by the water, a specific problem arises. If the fabric shrinks to a marked extent under the process of laundering, then a problem of another type is encountered. Hess (12, p. 481) stated that all fabrics which have been over-stretched in finishing, shrink when wet. Cohen (5, p. 13) points out that shrinkage of textile materials in laundering is influenced chiefly by water, temperature and degree of mechanical action, and is affected by the type of detergents. Harvey (10, p. 16) mentioned the importance of the hardness of water as follows:

> One of the most important things to bear in mind is the fact that the hardness of the water is very active towards soap, which means to say, that when a hard water comes into contact with a soap solution a chemical change takes place, resulting in the production of new substances. In the case of calcium or lime salts there are formed lime soaps, while magnesium compounds produce magnesium soaps. These soaps are insoluble and therefore come out in the form of a characteristic sticky deposit or sludge, and incidentally is one of the main causes of streakiness in finished goods.

Hess recommended that 100°F is the optimum temperature for laundering wool, silk, synthetic fabrics, and some fabric containing dyes that might be adversely affected by high temperature (12, p. 488). Cook suggested that silk should be laundered with soap flakes or a mild detergent, rinsed thoroughly in soft water, dried gently and ironed while damp (6, p. 141). Wringing or strong agitation in the washing machine should be avoided since silk weakens slightly when wet (25, p. 272).

Silk combines high strength and flexibility with good moisture absorption, softness, warmth, excellent wearability, and luxurious appearance (6, p. 140). Silk can absorb moisture up to 30% of its weight and still feel dry; it absorbs perspiration without becoming clamy (23, p. 163). This ability to absorb liquid readily gives silk a great affinity for dyestuffs at low temperature (23, p. 163).

Hummel explained the phenomenon of dyeing silk as follows:

> An examination of sections of dyed silk reveals the fact that the coloring matter (or the mordant) penetrates the substance of the silk fiber to a greater or less degree, according to the solubility of the coloring matter, the duration of the dyeing process, and the temperature employed. If silk is dyed only for a short time, a section of the fiber shows an external concentric zone of color, while if the dyeing operation is continued sufficiently long, it is colored to

> the center. If a mixture of two coloring matters are to be applied, either simultaneously or successively, both are absorbed, the more soluble or that which has been allowed to act longest, penetrating the fiber most deeply (14, p. 69).

Most synthetic dyestuffs today are made from coal tar derivatives (23, p. 469). Dyestuffs used in dyeing silk include acid, basic, direct, mordant, naphthol, and vat dyes (23, p. 472). Basic dyes were the first synthetic dye type. As textile dyes, they were largely replaced by the later development of other types of dyes such as naphthol and chrome dyes. Basic dyestuffs were originally used to color wool, silk, and linen without using mordants; they produce brilliant color but have poor fastness to light and have a tendency to crock due to inadequate penetration of the dyestuff (23, p. 469).

The colors derived from direct dyes are not as brilliant as those from basic dyes, but they have better fastness to light and washing. Acid dyes form a very large and important group of dyestuffs; their colorfastness has been increased by adding a metallic salt, usually chrome, to the dyestuff (23, p. 469). The naphthol group is particularly noted for brilliant reds which are colorfast (23, p. 469). The vat dyes are the best known group of dyes in use today for their fastness in both washing and sunlight (23, p. 470). Chrome dyes are special types of acid dyes; this group of dyes provides high lightfastness and washfastness (23, p. 471).

The term <u>fastness</u> applied to a dye is explained by many authors as the resistance to the action of various agencies to change the color appearance. The fastness of dyes differs widely even among the same dye group. Matthews explains the fastness of a dye as follows:

> The fastness of a dye is more or less a relative term, as no color is absolutely fast to all agencies; therefore, fastness becomes a matter of comparison with some standard which represents a satisfactory and high degree of resistance to change. Furthermore, fastness is a rather variable term and may be differently interpreted depending upon conditions.
>
> It must be borne in mind in judging the value of a dye with respect to its qualities to fastness that the degrees of fastness to different agencies are not equally important under different conditions. The kinds of fastness to be sought for depend on the use and the manner of wear to which the dye material is to be subjected (19, p. 608).

Whittaker also pointed out the meaning of fastness of a dye as a relative value. He explained it as follows:

> There is no such thing as absolute fastness as applied to dyestuffs. Fastness is purely relative, not absolute. If experience has proved that a dyestuff during the lifetime of a fabric withstands all influence to which that fabric is subjected, then the dyer designates that dyestuff as fast for that particular class of goods (24, p. 17).

In considering the fastness of dyestuffs, Whittaker concluded that two considerations are necessary: (a) the purpose for which the dyed fabric will be used, and (b) the degree of fastness of the dyestuff for resistance to different conditions (24, p. 48).

It is usually more difficult to identify the dye on the fiber than the dyestuff in substances because there is only a small amount of the commercially dyed sample available for testing. There are variations in properties in individual dyestuffs belonging to the same dye class. The ready identification of a dyestuff on a textile is a problem which at present is associated with difficulties (8, p. 2).

Vickerstaff explained the dyeing process as a manner of placing a textile material in an aqueous solution of dyestuffs which is preferentially absorbed by the material. If the dye solution is merely absorbed in a sponge-like manner, with no change in the concentration of the external solution, and if the color can be washed out by the water, then the process is inhibited, and true dyeing does not occur. True dyeing occurs when coloring matter is absorbed with the decrease in concentration of dye in the dye bath; when the resulting dyed material possesses some resistance to the removal of dye by water washing (26, p. 62).

Some researchers (17, 18) have investigated the effects of laundering on fabrics made from fiber other than silk, and in a variety of fabric constructions. These studies showed that all fabrics shrank in washing. Lord (17, p. 307) discovered that the most shrinkage occurred in the warp direction.

CHAPTER III

MATERIALS, APPARATUS AND PROCEDURES

Materials

Fabrics

Two medium weight, hand-woven, yarn-dyed Thai silk fabrics were chosen for this study. One fabric was a solid color and the other had a printed design. These two plain woven fabrics were constructed from imported pure silk warp yarns and native pure silk filling yarns. The solid color fabric had warp and filling yarns of the same color. The patterned fabric was hand block printed on an iridescent background achieved by the use of different colored yarns in the warp and filling directions. Both fabrics were commercially finished.

For this study the solid color fabric was designated as "S" and the print fabric as "P." Table I describes the experimental fabrics.

Soap

A neutral soap[1] was used in this study. The soap solution was prepared by dissolving the soap in warm tap water. The concentration of soap solution was 0.5%.

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[1]Obtained from AATCC, P. O. Box 12215, Research Triangle Park, N.C. 27709.

TABLE I

DESCRIPTION OF THE TWO EXPERIMENTAL FABRICS

Fabric	Fiber Content		Construction	Thread Count		Mean Width (in.)
	Warp	Filling		W/in.	F/in.	
P	100% imported silk	100% native Thai silk	plain	94	54	39.9
S	100% imported silk	100% native Thai silk	plain	108	66	40.1

Multifiber Test Cloth

Multifiber test cloth[2] was used to determine the color stain taken up from the experimental fabrics. The multifiber test cloth was constructed from 13 different fiber contents in a striped pattern with each fiber stripe taking up dye differently. The fiber content of the various stripes was: (1) Acetate (dull); (2) Acrilan 1656; (3) Arnel (dull); (4) Cotton (bleached); (5) Creslan 61; (6) Dacron 54; (7) Dacron 64; (8) Nylon 66; (9) Orlon 75; (10) Silk; (11) Verel A; (12) Viscose; (13) Wool.

[2]Obtained from AATCC, P. O. Box 12215, Research Triangle Park, N.C. 27709.

Apparatus

Launder-Ometer

An Atlas Launder-Ometer was used to launder the specimens. A gas burner was a source of heat used for raising and maintaining the temperature of the water in the Launder-Ometer. A standard combination Fahrenheit and Centrigrade thermometer was used to indicate the temperature of the bath water.

The AATCC Standards for Evaluation

1. AATCC Three Dimensional Plastic Replicas for Wash-n-Wear Fabric (2, p. 181) were used to evaluate the appearance of smoothness of the specimens after a designated number of launderings. The plastic replicas have been designated numerically for rating purposes as follows:

Class 5 - negligible or no change as shown in standard #5, considered as "very good"

Class 4 - a change in appearance equivalent to standard #4, considered as "good"

Class 3 - a change in appearance equivalent to standard #3, considered as "fair"

Class 2 - a change in appearance equivalent to standard #2, considered as "poor"

Class 1 - a change in appearance equivalent to standard #1, considered as "very poor"

Standard #5 represents the best retention of the original appearance while standard #1 demonstrates the poorest appearance.

2. AATCC Gray Scale for Color Change was used to evaluate changes in the color of the specimens. This standard consists of nine pairs of standard gray chips which represent a difference in color or contrast (shade and strength) corresponding to a numerical fastness rating. The results of the colorfastness tests were rated by comparing the difference in the color of the tested specimens and the original (control) sample with the differences represented by the scale.

3. AATCC Color Transference Chart was used for evaluating the color loss of the specimens. The color absorbed by fibers of the multifiber test cloth attached to the specimens was evaluated by comparing color stain on the multifiber test cloth with the standard color chart. The Color Transference Chart consists of four horizontal rows of colors with the lightest colors on the top row and the darkest colors on the bottom row. The rows of the standard colors are designated numerically for rating purposes as follows:

Rating 5 - practically unstained, considered as "very good"

Rating 4 - stain equal to row 4, considered as "good"

Rating 3 - stain equal to row 3, considered as "fair"

Rating 2 - stain equal to row 2, considered as "poor"

Rating 1 - stain equal to row 1, considered as "very poor"

Rating 5 represents the least amount of color teansfer, while Rating #1 indicates the greatest amount of color transfer.

Fabric Width

ASTM Designation: D1910-64 (3, p. 420) was followed to determine the width of the experimental fabrics. The fabric samples were laid out flat on a smooth table and were free from tension in any direction.

The measurements were made perpendicularly to the selvages with a measuring stick.

Three measurements, evenly spaced in each yard of the experimental fabric, were taken. An average of these measurements was calculated to the nearest 0.1 inch, and reported as mean width of the experimental fabrics.

Thread Count

ASTM Designation: D1910-61 (3, p. 423) was followed to determine the thread count of the experimental fabrics. No counts were taken closer to the selvage than one-tenth of the width of the fabric.

Five counts were taken in one inch of the fabric at five different places in the warp and filling directions. The means were calculated and reported as warp and filling thread count respectively (Table I). The Alfred Suter pick counter was the device used in this process. The fabric areas counted in each direction were calculated and reported as mean thread count to the nearest 0.1 of the yarn for each test fabric.

Laundering

All test specimens were laundered in an Atlas Launder-Ometer. The AATCC washing condition of each designated test number was followed except for the fourth test condition in which the soap volume and time of washing were modified to meet the criteria of this study. The present study was designed to investigate physical changes resulting from a number of washings and different washing temperatures. The laundering conditions are shown in Table II.

TABLE II

SUMMARY OF LAUNDERING CONDITIONS USED TO TEST THE TWO EXPERIMENTAL FABRICS*

Test number	Temperature °F	Temperature °C	Soap concentration	Soap volume ml.	Time in min.
I	85	29	0.5	100	10
II	120	49	0.5	100	10
III	160	71	0.5	100	10
IV	180	82	0.5	100	10

*AATCC Method 4-1957 with some variations.

The first set of specimens from each group was laundered under the condition of Test I. The second, third, and fourth sets of specimens of each group from each experimental fabric were subjected to the laundering under the condition of Test II, Test III, and Test IV respectively.

After each laundering cycle, specimens were removed from the glass jars, rinsed in cold tap water, and wrapped in a white terry cloth towel. Excessive water was removed by blotting. In order to evaluate and compare effects of washing and drying procedures on appearance, specimens from Group I were dried flat and left unironed, while Group II specimens were damp dried and ironed at approximately 275°F.

The launderings were repeated 20 times for each test condition. After the designated number of launderings for each test, the specimens were evaluated to determine dimensional stability, appearance of smoothness and colorfastness.

Evaluation for Appearance of Smoothness

After 5, 10, 15, and 20 launderings at each washing temperature, the specimens of Group I were compared with the AATCC Standard plastic replicas for wash-n-wear fabric according to the AATCC Method 124-1967 (1, p. 181) for the evaluation of the appearance of smoothness. Three trained observers rated each specimen independently for the appearance of smoothness. The mean of the rated scores for classification of each specimen after each designated number of launderings and specified washing temperatures as identified by the observers was then calculated.

Determination of Dimensional Stability

The dimensional stability of the specimens was determined by measuring the shrinkage in both warp and filling directions. Three trained observers measured three distances between the three evenly spaced marks in the warp and the filling directions of each specimen after 5, 10, 15, and 20 launderings. The mean of the three measurements in both warp and filling directions of each specimen was calculated for each observer (Appendix A, Table VIII). The three means obtained for each specimen were then calculated after the designated number of launderings. The percentage of shrinkage in the warp and filling directions was calculated by the following equation:

$$\% \text{ Shrinkage} = \frac{\text{Original measurement} - \text{Final measurement}}{\text{Original measurement}} \times 100$$

A gain in size after laundering in which the final test specimen measurement is larger than the original measurement was expressed by the use of a + sign (Appendix A, Table XI).

Investigation for Colorfastness

The colorfastness of the tested fabric specimens was investigated by the evaluation of color change and color staining on the multifiber test cloth attached to the specimens. After 5, 10, 15, and 20 launderings at each washing temperature, the colors of the washed specimens were compared with the colors of the control specimens. The difference in color or contrast between the washed specimens and the controlled sample (original sample) was compared with the differences represented by the AATCC Gray Scale for Color Change. Three trained observers rated color changes of each specimen independently by comparing the difference of the tested specimens with the controlled set with the Gray Scale according to the recommended procedure of the AATCC Method 4-1957.

Color staining on the multifiber test cloth attached to the fabric specimens was evaluated by the observers by comparing the color stained on the multifiber test cloth with the AATCC Color Transference Chart. The AATCC recommended procedure was followed to rate the colorfastness of each specimen by scoring it. The mean of the scores rated by the three trained observers was then calculated.

CHAPTER IV

PRESENTATION AND DISCUSSION OF FINDINGS

The descriptive and statistical findings presented in this chapter and in the Appendix report results of the determination of fabric width and thread count, evaluation of dimensional stability, appearance of smoothness and colorfastness of the specimens from the two experimental fabrics.

Determination of Fabric Characteristics

Fabric Width

Three yard lengths of the two experimental fabrics were measured according to ASTM Designation: D 1910-64, to calculate the mean width of each fabric. The print fabric ranged in width from 39.725 inches to 40.0 inches, whereas the solid color fabric ranged from 40.0 inches to 40.187 inches in width (Appendix B, Table VI).

Thread Count

Thread counts were made in both warp and filling directions for the two experimental fabrics according to ASTM Designation: D 1910-61. The thread count mean was calculated for each fabric (Appendix B, Table VII). The print fabric was found to vary more in the thread count than the solid color fabric. Both warp and filling thread counts were lower for the print fabric than for the solid color fabric. The warp yarn counts for the print fabric varied from 90 to 112 yarns per inch, while the warp yarn counts for the solid color fabric ranged from 107 to 112 yarns per inch. The print fabric revealed filling yarn counts ranging from 48 to 70 yarns per inch, while the filling yarn counts for the solid color fabric varied from 60 to 73 yarns per inch (Appendix B, Table VII). Higher thread counts were observed in the printed areas than in the solid background areas of the print fabric. This was assumed to be caused by the printing process with the dyestuffs used in printing affecting the closeness of the yarns.

Evaluation of Test Specimens

Specimens from the two experimental fabrics were subjected to 5, 10, 15, and 20 launderings at each of the washing temperatures of 85°F, 120°F, 160°F, and 180°F in order to determine dimensional changes, to evaluate the appearance of smoothness and colorfastness of the specimens. All specimens were evaluated independently by three trained observers by comparing the specimens with the recommended AATCC standard procedures.

Dimensional Change

The average percentage of shrinkage occurring in the warp and filling directions of each specimen from each experimental fabric after 5, 10, 15, and 20 launderings at each designated washing temperature was calculated and has been presented as the mean percentage of the experimental fabrics (Table III). All specimens tested for dimensional change shrank after the first five launderings at each washing temperature. Greater shrinkage occurred in the warp direction.

Specimens displayed a higher percentage of shrinkage when washed at higher washing temperatures. The number of launderings also affected the shrinkage of the experimental fabrics, but this effect was less than that of the washing temperatures.

After five launderings at 85°F, the print fabric showed 4.22% shrinkage in the warp direction, while shrinkage in the solid color fabric was 3.99%. In the filling direction, the print fabric displayed 0.65% shrinkage, whereas the solid color fabric revealed 0.67% shrinkage. When the washing temperature was increased to 120°, the print fabric shrank 4.51% in the warp direction. Filling shrinkage in the print fabric was 0.78%. The solid color fabric exhibited 4.01% shrinkage in the warp direction, and 0.75% in the filling direction. At washing temperature of 160°F, the print fabric showed 4.55 % of warp shrinkage, while the solid color fabric revealed 4.84% warp shrinkage. In the filling direction, the print fabric showed shrinkage of 1.29%, whereas the solid color fabric displayed filling shrinkage 0.92% after five launderings. At the severest washing temperature of 180°F, the print fabric shrank 6.12% in the warp direction after five washings, while the solid color fabric shrank 4.25% in the warp direction. The filling shrinkage of the print fabric and the solid color fabric were 0.55% and 0.62% respectively after they had been washed for five times.

After 10, 15, and 20 launderings at 85°F, the print fabric displayed the warp shrinkages of 3.52%, 4.97%, and 5.51% respectively, while the solid color fabric revealed percentages of warp shrinkage at 3.31%, 3.92%, and 4.54% after 10, 15, and 20 launderings respectively. The filling shrinkages of the print fabric after 10, 15, and 20 washings were 0.66%, 0.78%, and 1.04% respectively. The solid color fabric revealed the filling shrinkages at 0.65%, 0.66%, and 1.13% after 10, 15, and 20 launderings respectively.

After 10, 15, and 20 launderings at 120°F, the print fabric shrank 4.76%, 4.95%, and 5.59% respectively, in the warp direction, while the solid color fabric shrank 4.51%, 4.55%, and 4.59% respectively. The print fabric displayed the filling shrinkages of 0.95%, 1.06%, and 1.36% after 10, 15, and 20 launderings respectively, whereas the solid color fabric exhibited 0.95%, 1.14%, and 1.43% filling shrinkages respectively.

After 10, 15, and 20 launderings at 160°F, the print fabric showed the warp shrinkages of 4.29%, 5.09%, and 6.09% respectively, whereas the solid color fabric exhibited warp shrinkages of 5.01%, 5.02%, and 5.82% after 10, 15, and 20 launderings respectively. The filling shrinkages of the print fabric after 10, 15, and 20 washings were found to be 0.84%, 1.08%, and 1.57% respectively, while the filling shrinkages of the solid color fabric after 10, 15, and 20 launderings at 160°F were 1.16%, 1.16%, and 1.92% respectively.

At the severest washing temperature of 180°F, the print fabric showed the warp shrinkages of 6.13%, 7.10%, and 7.29% after 10, 15, and 20 launderings respectively, while the solid color fabric displayed shrinkages of 5.09%, 5.51%, and 5.51% in the warp direction after 10, 15, and 20 washings respectively. The print fabric shrank 0.62%, 0.88%, and 2.02% in the filling direction after 10, 15, and 20 launderings respectively, whereas the solid color fabric displayed the filling shrinkages of 1.65%, 1.22%, and 1.89% after 10, 15, and 20 launderings at 180°F respectively.

TABLE III

MEAN PERCENTAGE CHANGES IN DIMENSIONS OF SPECIMENS FROM TWO EXPERIMENTAL FABRICS AFTER 5, 10, 15, AND 20 LAUNDERINGS AT WASHING TEMPERATURES OF 85°F, 120°F, 160°F, and 180°F

Laundering Temperature	Number of Launderings	Experimental Fabric	Mean Percentage Change in Dimension	
			Warp	Filling
85°F	5	Print	4.22	0.65
		Solid Color	3.99	0.67
	10	Print	4.52	0.66
		Solid Color	3.31	0.65
	15	Print	4.97	0.78
		Solid Color	3.92	0.66
	20	Print	5.51	1.04
		Solid Color	4.54	1.23
120°F	5	Print	4.51	0.78
		Solid Color	4.01	0.75
	10	Print	4.76	0.95
		Solid Color	4.51	0.85
	15	Print	4.95	1.06
		Solid Color	4.55	1.14
	20	Print	5.59	1.36
		Solid Color	4.59	1.43
160°F	5	Print	4.55	1.29
		Solid Color	4.84	0.92
	10	Print	4.55	0.84
		Solid Color	5.01	1.16
	15	Print	5.09	1.08
		Solid Color	5.02	1.16
	20	Print	6.09	1.57
		Solid Color	5.82	1.92
180°F	5	Print	6.12	0.55
		Solid Color	4.25	0.62
	10	Print	6.13	0.62
		Solid Color	5.09	1.65
	15	Print	7.10	0.88
		Solid Color	5.51	1.22
	20	Print	7.92	2.02
		Solid Color	5.51	1.89

The relationship between percentages and the washing temperatures at each laundering interval is presented graphically in Figures 1, 2, 3, and 4. From these graphs it can be seen that in general, shrinkage of the experimental fabrics increased as the washing temperatures increased.

When the number of launderings were plotted against the mean percentage of shrinkage of the experimental fabrics, the graphs showed that the shrinkage of the experimental fabrics did not increase constantly with the increasing in the number of launderings. (Figures 1, 2, 3, and 4)

Appearance of Smoothness

The appearance of smoothness of the specimens after 5, 10, 15, and 20 launderings at each washing temperature of 85°F, 120°F, 160°F, and 180°F was observed and evaluated to determine the degree of retention of the original appearance of the experimental fabrics. Three trained observers rated each specimen independently by comparing it with the AATCC Standard Plastic Replicas for Wash-n-Wear Fabric according to the recommended procedure.

Individual specimens from the print fabric displayed slight differences in appearance after five launderings at 85°F, while extensive changes in appearance of the solid color fabric were observed after five washings at 85°F (Appendix B, Table IX). After five and ten launderings at 85°F, the print fabric had a "good" to "fair" retention of the original appearance, while the solid color fabric exhibited "poor" retention of the original appearance.

At 120°F the print fabric displayed "poor" retention of the

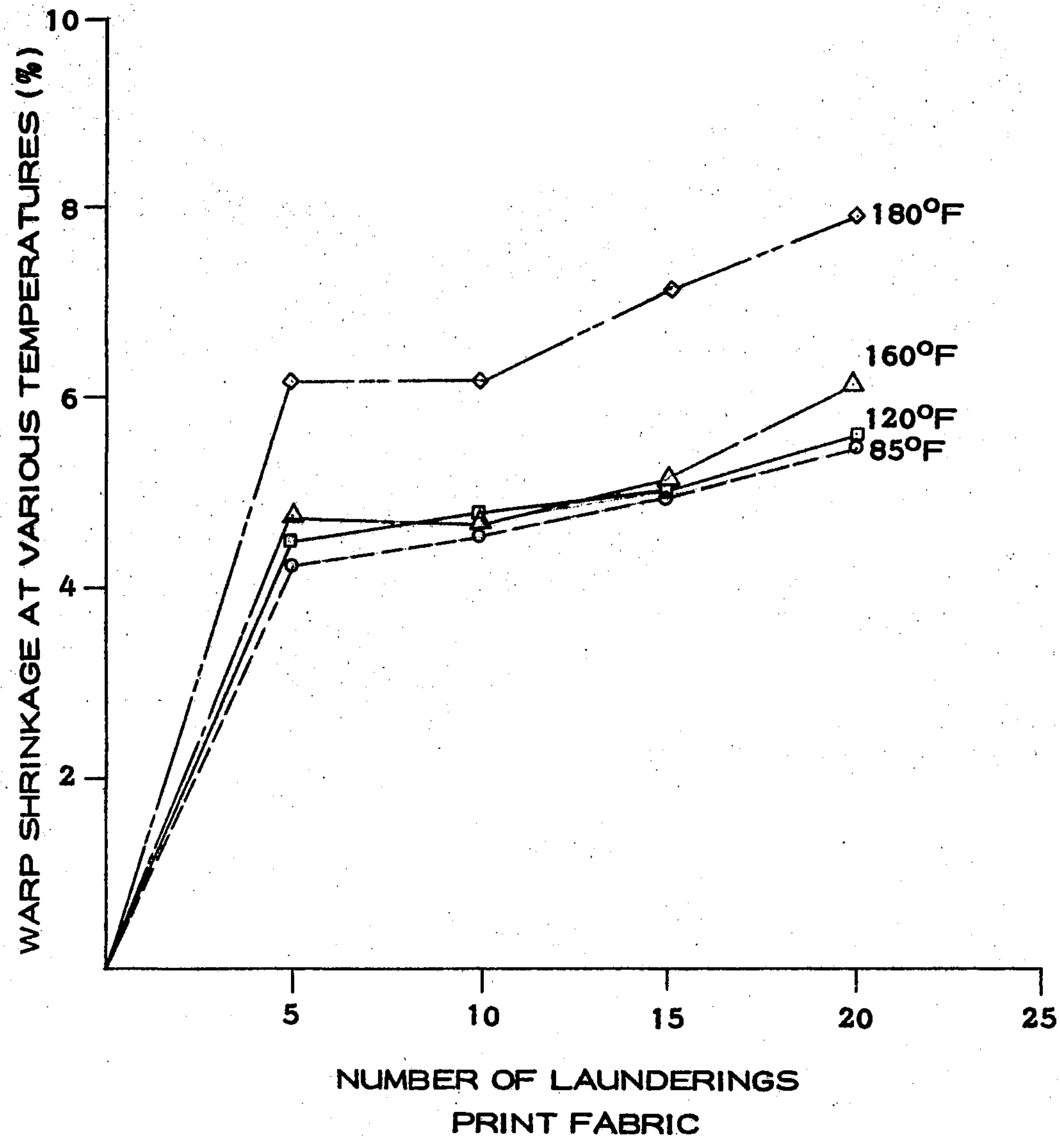

Figure 1: Warp Yarn Shrinkage of Print Fabric at Various Temperatures

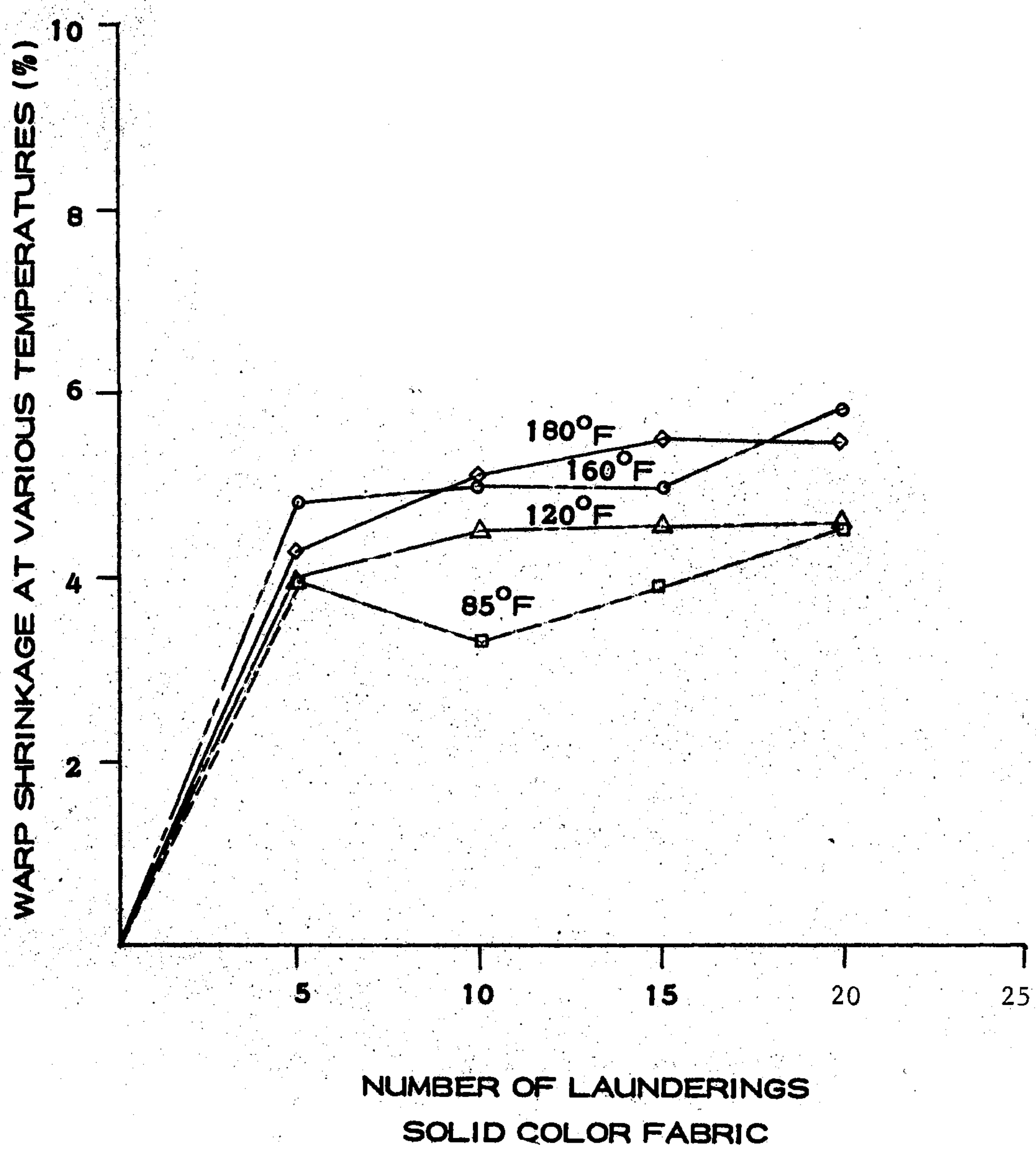

Figure 2: Warp Yarn Shrinkage of Solid Color Fabric at Various Temperatures

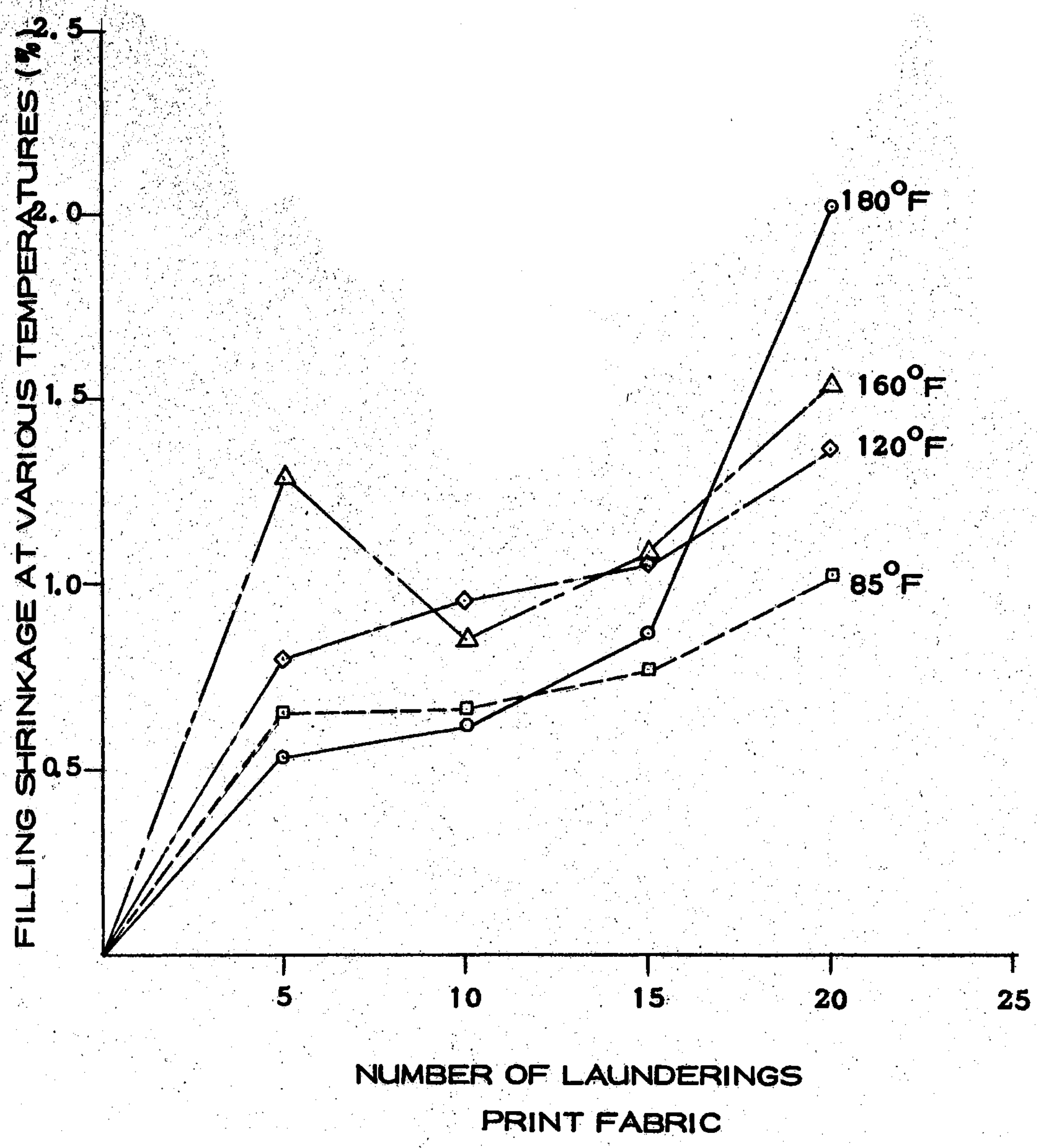

Figure 3: Filling Yarn Shrinkage of Print Fabric at Various Temperatures

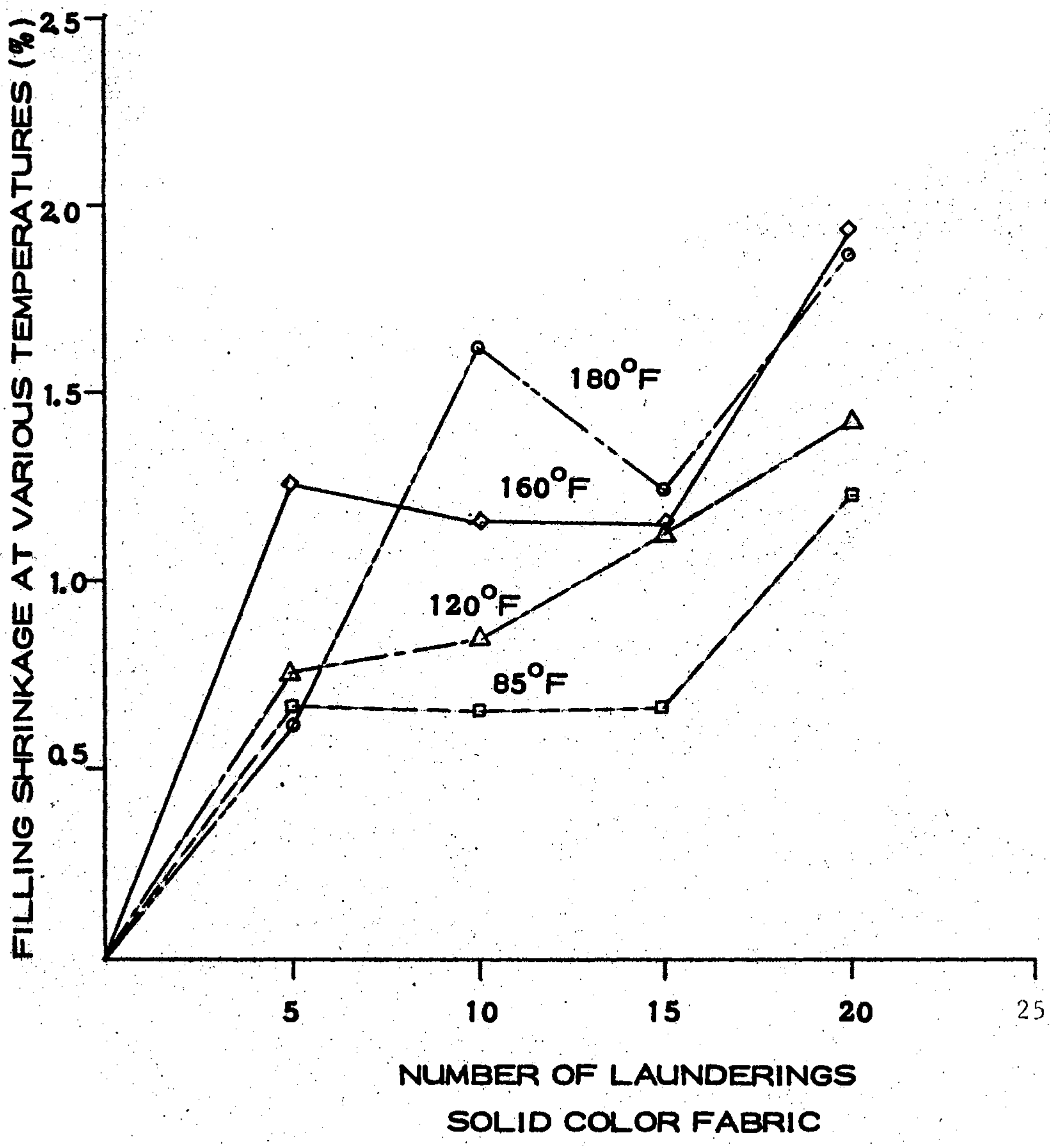

Figure 4: Filling Yarn Shrinkage of Solid Color Fabric at Various Temperatures

original appearance after 10 and 15 launderings, and displayed "very poor" retention after 20 launderings, while the solid color fabric displayed the "poorest" appearance of smoothness after only 10 launderings at 120°F (Appendix B, Table IX).

At the washing temperature of 160°F, the print fabric revealed the "poor" retention after 5 and 10 launderings, and showed the "poorest" appearance of smoothness after 15 launderings, whereas the solid color fabric exhibited the "poorest" appearance of smoothness after five washings at 160°F (Appendix B, Table XIV).

At the severest washing temperature of 180°F, both experimental fabrics exhibited the "poorest" appearance of smoothness after five launderings (Appendix B, Table XV).

The mean scores for appearance of smoothness of the fabrid specimens from two experimental fabrics as rated by three trained observers are presented in Table IV.

The colors and designs in the print fabric affected the appearance of smoothness of that fabric. It was recognized that the patterns masked the wrinkled appearance of the print fabric.

Colorfastness

Color changes and color staining on the multifiber test cloth attached to the specimens were evaluated according to the AATCC Method 4-1957 to determine colorfastness to washing of the specimens from the two experimental fabrics. Three trained observers rated each specimen independently by comparing the test specimens for color change with the AATCC Color Transference Chart. The mean scores rated according to the number of classes of the standards for each specimen were calculated and are presented in Table V.

TABLE IV

MEAN SCORES FOR APPEARANCE OF SMOOTHNESS IN SPECIMENS FROM TWO EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, AND 20 LAUNDERINGS AT WASHING TEMPERATURES OF 85°F, 120°F, 160°F, and 180°F

Laundering Temperature	Number of Launderings	Mean Scores for Smoothness	
		Print Fabric	Solid Color Fabric
85°F	5	3.6	1.7
	10	3.0	1.7
	15	2.7	1.3
	20	2.3	1.0
120°F	5	2.2	1.0
	10	2.2	1.0
	15	2.2	1.0
	20	1.8	1.0
160°F	5	1.5	1.0
	10	1.5	1.0
	15	1.3	1.0
	20	1.3	1.0
180°F	5	1.7	1.0
	10	1.5	1.0
	15	1.3	1.0
	20	1.1	1.0

The comparison of the degrees of retention of original appearances at four washing temperatures between the two experimental fabrics by means of rated scores is presented graphically in Figures 5, 6, 7, and 8.

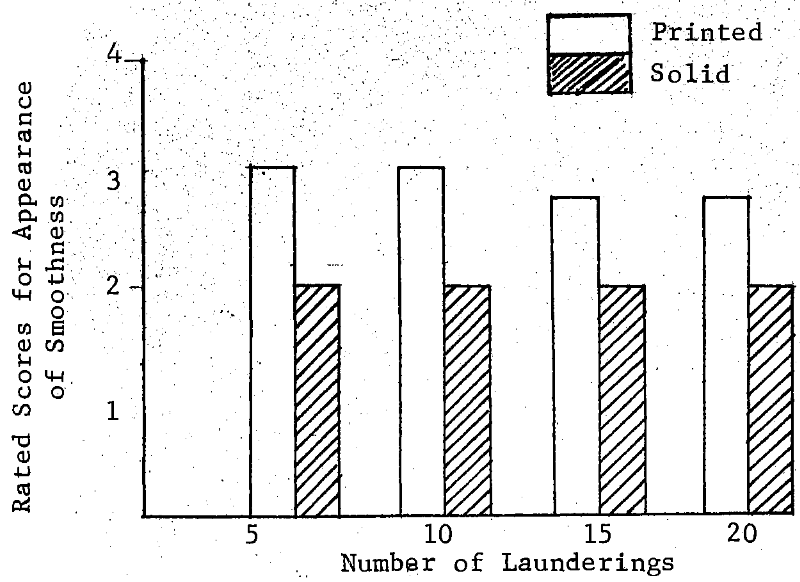

Figure 5. The Retention of the Original Appearance of the Print and the Solid Color Fabrics at 85°F

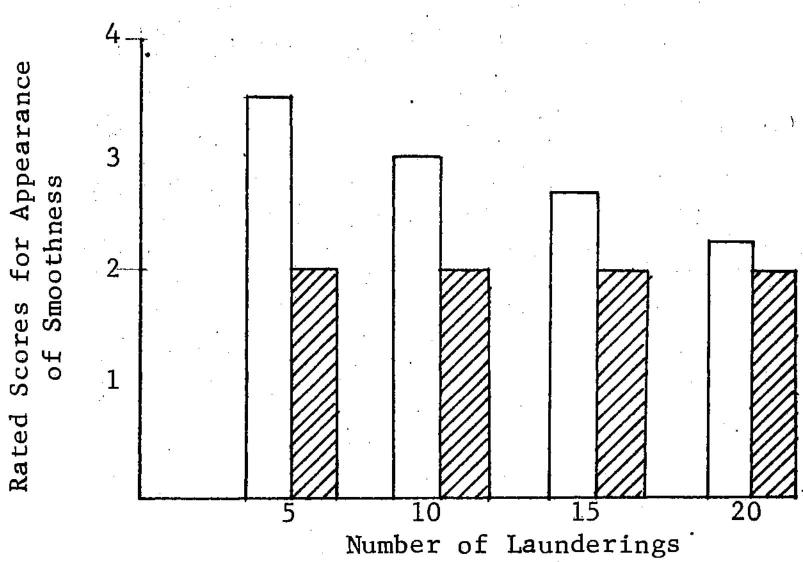

Figure 6. The Retention of the Original Appearance of the Print and the Solid Color Fabrics at 120°F

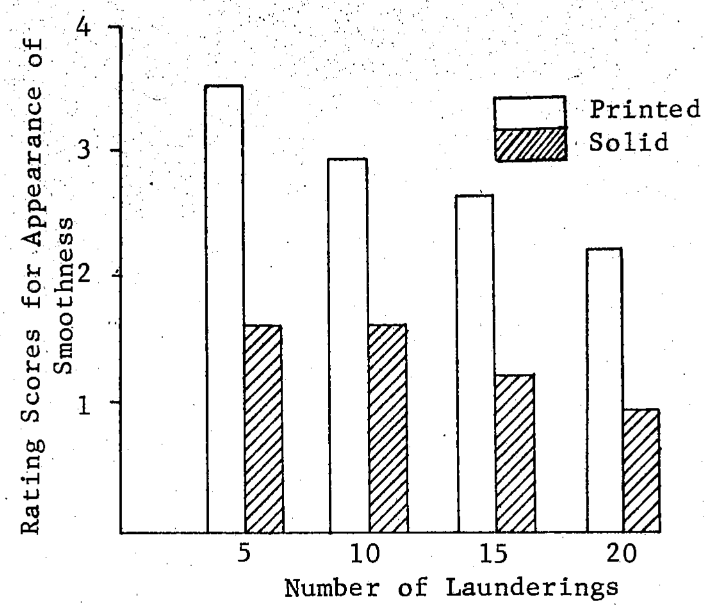

Figure 7. The Retention of the Original Appearance of the Print and the Solid Color Fabrics at 160°F

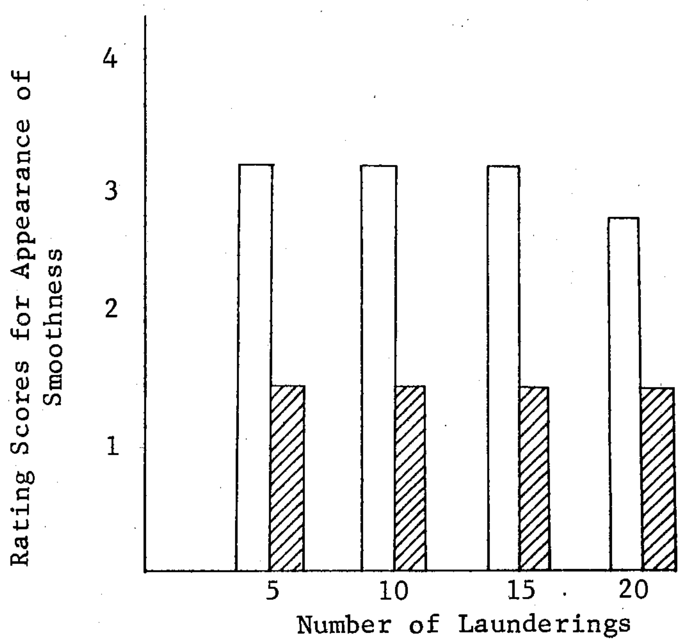

Figure 8. The Retention of the Original Appearance of the Print and the Solid Color Fabrics at 180°F

After five and ten launderings at 85°F, the print fabric was rated Class 4 according to Gray Scale while the solid color fabric was rated between Class 4 and Class 5 after five and ten launderings at 85°F. At the end of 15 and 20 launderings at 85°F, the print fabric was rated equivalent to 3.5 as well as the solid color fabric. The color transferred from the print to the multifiber test cloth attached to the specimens was rated Class 4, after 5, 10, and 15 launderings at 85°F, whereas the solid color fabric showed color transfer equivalent to Class 4 after five washings and was rated close to Class 4 of Color Transference Chart after 10, 15, and 20 launderings at 85°F.

At a washing temperature of 120°F, the print fabric specimens were rated close to Class 4 according to Gray Scale after five launderings, while the solid color fabric specimens were rated equivalent to Class 4 according to Gray Scale after five washings at 85°F. After 10, 15, and 20 launderings, the print fabric was rated equivalent to Class 3.5 according to Gray Scale at 120°F, whereas the solid color fabric was rated 3.5, 3.5, and 3.5 after 10, 15, and 20 launderings respectively at 120°F. According to Color Transference Chart, the print fabric was rated 3.0 which is equivalent to Class 3 of the scale after 5, 10, 15, and 20 launderings at 120°F, while the solid color fabric rated scores were equivalent to Class 3.5 according to Color Transference Chart after five and ten washings at 120°F. After 15 and 20 launderings the solid color fabric was rated 3.3 which was equivalent to Class 3 of the scale at 120°F.

At 160°F the print specimens were rated 3.0, 3.0, 2.7, and 2.7 after 5, 10, 15, and 20 launderings according to Gray Scale, whereas the solid color fabric was rated 3.5, 3.5, 3.3, and 2.8 after 5, 10, 15, and 20 washings at 160°F according to Gray Scale. According to Color Transference Chart, the print fabric was rated 2.5, 2.3, 2.0, and 2.0 after 5, 10, 15, and 20 launderings respectively, while the solid color fabric was rated 3.0 after 5, 10, 15, and 20 launderings at 160°F.

At 180°F the print fabric was rated equivalent to Class 2 according to Gray Scale after 5, 10, 15, and 20 launderings, whereas the solid color fabric had rated scores equivalent to Class 2.5 after 5, 10, and 15 launderings and equivalent to Class 2 after 20 launderings at 180°F. According to Color Transference Chart the print fabric specimens were rated 1.7 after 5, 10, and 15 launderings and was rated 1.3 after 20 launderings at 180°F, while the solid color fabric was rated with the scores equivalent to Class 2 after 5, 10, 15, and 20 launderings at 180°F.

Specimens in Figures 9 and 10 contain portions of the actual tested specimens and the controlled samples for color changes and for color staining after 5, 10, 15, and 20 launderings at each washing temperature of 80°F, 120°F, 160°F, and 180°F.

Statistical Analysis

The experimental data were analyzed as a complete randomized design having a factorial arrangement of three factors: fabrics, washing temperatures and number of launderings. The mean square for specimens within Number of Launderings X Washing Temperature X Experimental Fabric was used as the mean square for testing the effects due to the three factors. This mean square, a "pooled" estimate of variance, among the five specimens within the treatment combinations

TABLE V

MEAN SCORES FOR COLOR CHANGE AND COLOR STAINING OF THE SPECIMENS FROM THE TWO EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, AND 20 LAUNDERINGS AT EACH WASHING TEMPERATURE OF 85°F, 120°F, 160°F, AND 180°F

		Color Loss Mean Scores			
		Print Fabric		Solid Color Fabric	
Laundering Temperatures	Number of Launderings	Gray Scale	Color Chart	Gray Scale	Color Chart
85°F	5	3.8	3.7	4.1	4.0
	10	3.8	3.7	4.1	3.7
	15	3.8	3.7	3.5	3.7
	20	3.5	3.5	3.5	3.5
120°F	5	3.7	3.0	4.0	3.6
	10	3.5	3.0	3.6	3.6
	15	3.5	3.0	3.5	3.3
	20	3.3	3.0	3.2	3.3
160°F	5	3.0	2.5	3.5	3.0
	10	3.0	2.3	3.5	3.0
	15	2.7	2.0	3.3	3.0
	20	2.7	2.0	2.8	2.7
180°F	5	2.2	1.7	2.7	2.3
	10	2.2	1.7	2.5	2.3
	15	2.1	1.7	2.3	2.0
	20	1.8	1.3	2.0	2.0

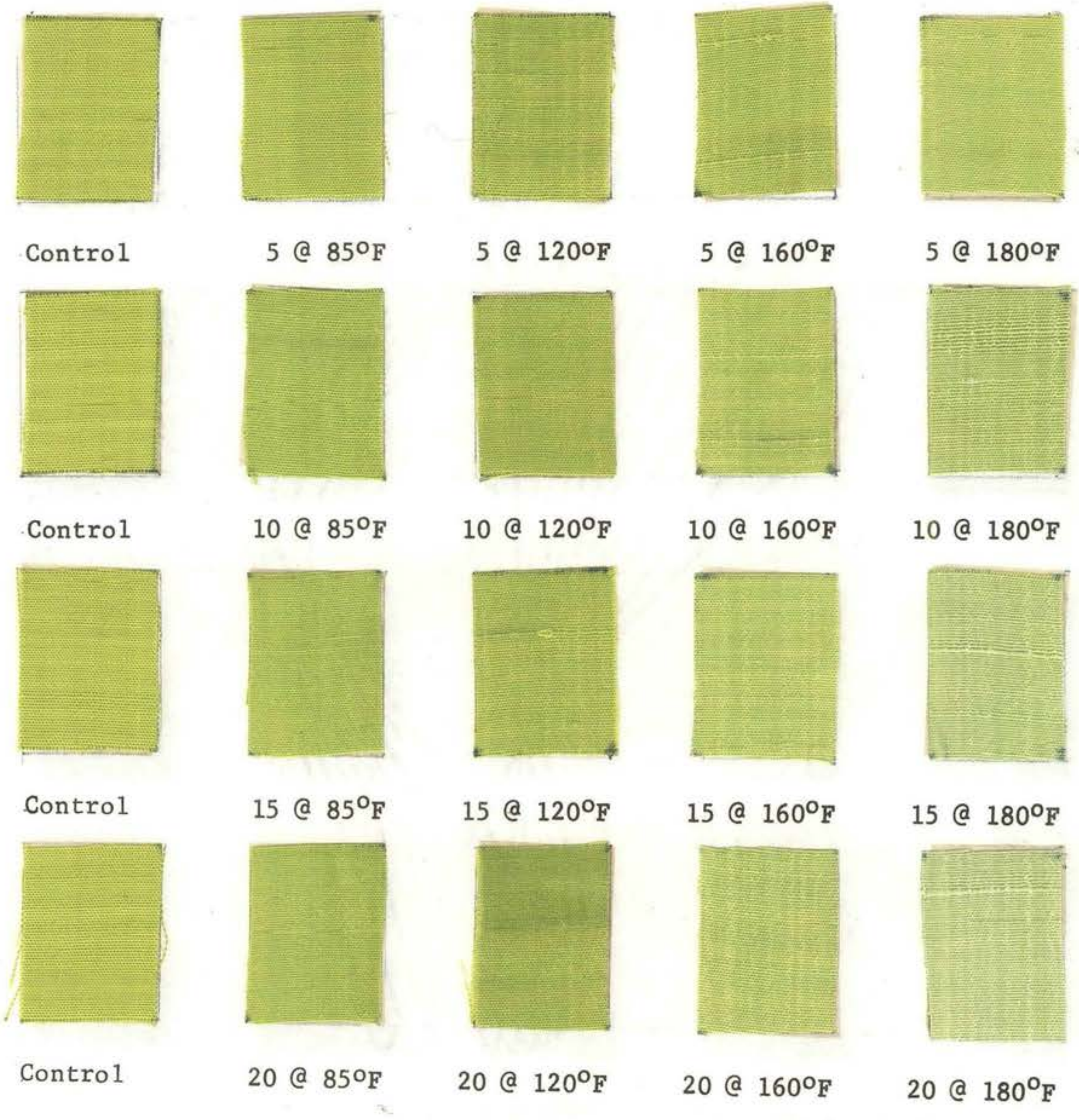

Figure 9. Color Specimens by Number of Launderings and Washing Temperature

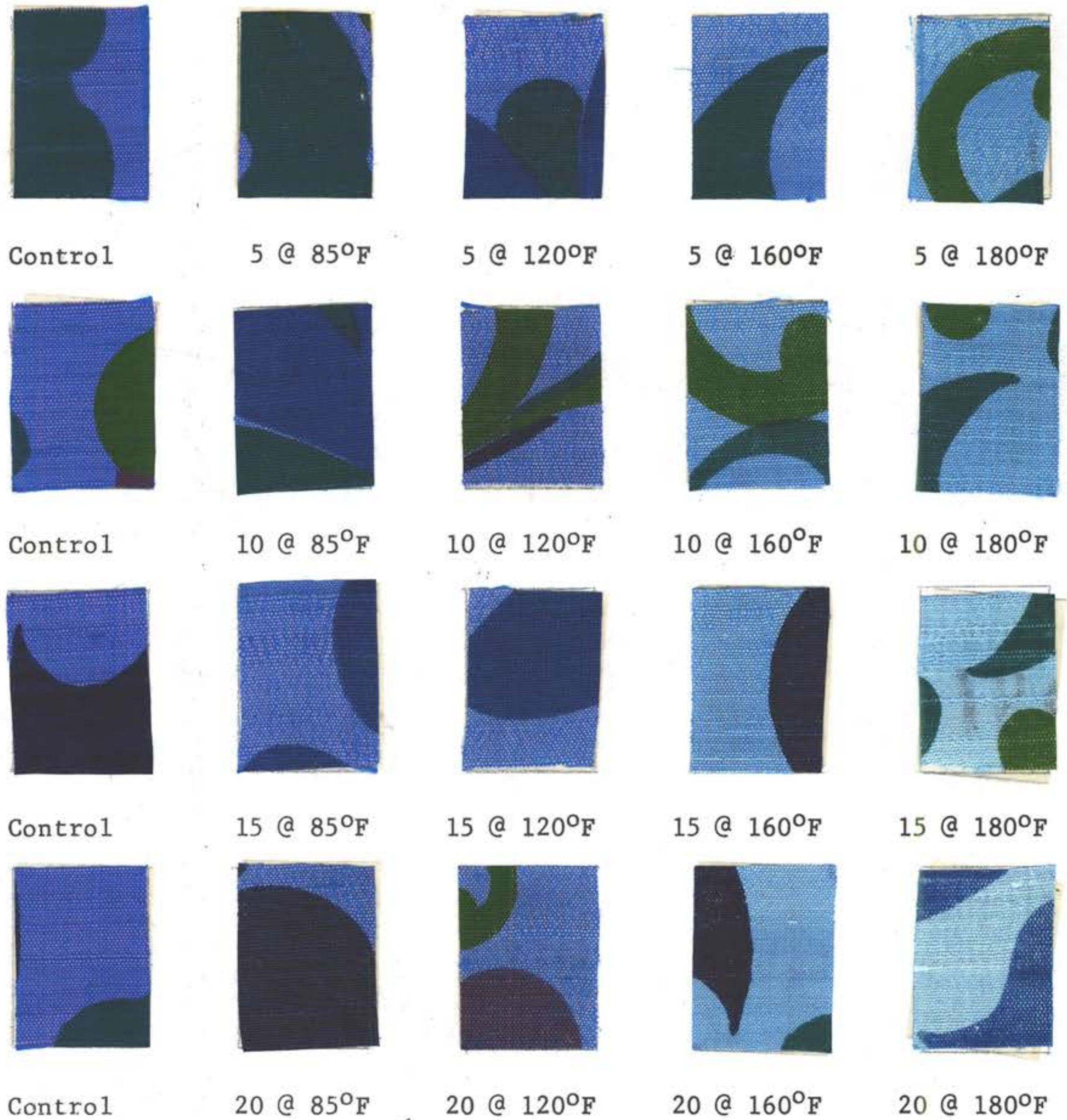

Figure 10. Print Specimens by Number of Launderings and Washing Temperature

was not a valid error since each set of five specimens made only one experimental unit. Since there was no valid experimental error, care must be exercised in declaring differences that might be found in this experiment. Since the sampling error may underestimate the experimental error, it is likely that this term is an overestimate of the true experimental error in this study.

Dimensional Change

The analysis of variance to determine the significant difference in dimensional change of the two experimental fabrics due to washing temperature and number of launderings in the warp and filling directions revealed that the significant differences in shrinkage due to washing temperatures and number of launderings occurred. This was observed at .005 level of confidence in the warp direction, while there was a significant difference at .05 level of confidence in the shrinkage in the filling direction.

Appearance of Smoothness

The analysis of variance for smoothness of the two experimental fabrics indicated that at .005 level of confidence there was a significant difference between the rated scores according to the Standard Plastic Replicas for Wash-n-Wear Fabric, of the specimens due to washing temperatures, and number of launderings.

Colorfastness

Differences observed in the rated scores for color changes by Gray Scale between the two experimental fabrics due to washing temperatures and number of launderings were significant at .005 level of confidence. The differences in the rated scores for color staining by Color Transference Chart between the two experimental fabrics due to washing temperatures were significant at .005 level of confidence.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Two types of medium weight, yarn-dyed Thai silk fabrics were used in this study, designed to determine dimensional stability, appearance of smoothness, retention of original appearance and colorfastness. One fabric was a solid color and the other had a printed design. Both fabrics were hand-woven from pure silk in a plain weave construction. The fabrics were commercially finished, dyed and printed with unidentified dyestuffs.

Specimens cut from each of the two experimental fabrics were categorized into three groups for the test purposes. One group of the specimens were prepared according to the AATCC Method 196-1967 and the AATCC Method 124-1967 in order to study dimensional stability and the appearance of smoothness. The second group of specimens were prepared in accordance with the AATCC Method 4-1957 for the study of colorfastness as determined by the evaluation of color changes and by the evaluation of color stain on the multifiber test cloth attached to the specimens. The AATCC Gray Scale for Color Change and the AATCC Color Transference Chart were the standards used to evaluate color changes and color stain. The third group of the specimens was not subjected to testing and was used as the control for comparing with the tested specimens. All specimens were coded and laundered at four different temperatures in an Atlas Launder-Ometer according to AATCC standards with some variations. After a specified number of launderings at each washing temperature, the specimens were evaluated independently by three trained observers. The AATCC Standard Plastic Replicas for Wash-n-Wear Fabric was used to evaluate the appearance of smoothness of the specimens. The AATCC Standard Gray Scale and the AATCC Standard Color Transference Chart were used to evaluate the colorfastness of the two experimental fabrics.

The assumption was that each specimen was treated equally and uniformly under each washing condition. Data were statistically analyzed as a complete randomized design having a factorial arrangement of three factors: experimental fabrics, washing temperatures, and number of launderings. The mean square for specimens within the Experimental Fabric x Washing Temperature x Number of Launderings was used as the mean square for testing the effects due to the three factors.

Both experimental fabrics shrank when washed. Washing temperatures affected shrinkage more than the number of launderings for both fabrics. Greater shrinkage occurred in the warp direction than in the filling direction. Shrinkage in both warp and filling directions increased as the washing temperature and number of launderings increased. Both experimental fabrics shrank most when they were laundered at 180°F for 20 times.

The print fabric specimens presented a better appearance of smoothness than the solid color fabric after laundering. The smoothness of the fabrics decreased as the washing temperature increased. The poorest appearance of smoothness of each experimental fabric occurred when the fabric was laundered at 180°F. Statistical analysis indicated a significant difference at .005 level of confidence between the rated scores for the appearance of smoothness of the two experimental fabrics due to washing temperatures and the number of launderings.

The print fabric changed more in color than did the solid color fabric. Both experimental fabrics exhibited an increasing change in color as the washing temperature and the number of launderings increased. The color stain evaluation showed that the print fabric lost more color than the solid color fabric. Staining on the multifiber test cloth increased as the washing temperature increased. It was also noted that the background of the print fabric lost the iridescent effect after 15 launderings at 160°F. The difference in the rated scores for color change between the two fabrics as indicated by Gray Scale were significant at .005 level of confidence. The differences in the rated scores for color staining by the AATCC Color Transference Chart between the two experimental fabrics were significant at .005 level of confidence.

Washing temperatures of 85°F and 120°F yielded "good" to "fair" results for fabric shrinkage, appearance of smoothness, and colorfastness for the print fabric, while the washing temperature of 85°F was the optimum temperature for washing the experimental solid color fabric used in this study.

The following suggestions are recommended for future research on Thai silk fabrics:

1. Use a mild detergent especially suggested for silk fabric, in order to duplicate home laundering situations.
2. Investigate breaking strength and other properties in order to observe overall behavior of the experimental fabrics as

subjected to different laundering conditions.

3. Tumble dry the specimens for study of the appearance of smoothness.

4. Consider types of dyestuffs used since different dyestuffs display different degrees of colorfastness to washing.

5. Repeat the experiment for each washing condition in order to get a more accurate statistical analysis.

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APPENDIX A

TABLE VI

WIDTH MEASUREMENTS OF THREE YARD LENGTHS
OF TWO EXPERIMENTAL FABRICS

	Print Fabric (inches)	Solid Color Fabric (inches)
	39.725	40.0
	39.85	40.0625
	40.0	40.125
	39.875	39.1875
	40.0	40.125
	39.875	40.0
	40.0	40.1875
	39.875	40.125
	40.0	40.25
AVERAGE	39.91	40.118

TABLE VII

THREAD COUNTS OF THREE YARD LENGTHS OF TWO EXPERIMENTAL FABRICS

	Print Fabric		Solid Color Fabric	
	Warp/in.	Filling/in.	Warp/in.	Filling/in.
	90	60	107	64
	93	52	108	73
	95	48	110	63
	112	65	107	70
	93	50	112	62
	94	50	108	62
	92	57	107	60
	90	54	108	72
	94	53	107	62
	94	52	107	62
AVERAGE	94	55.6	108	65

TABLE VIII

CHANGES IN DIMENSIONS AFTER 5, 10, 15, AND 20 LAUNDERINGS OF SPECIMEN GROUP A AT 85°F

Number of Launderings	Specimens	Average Measurements Before Laundering W (in.)	Average Measurements Before Laundering F (in.)	Average Measurements After Laundering W (in.)	Average Measurements After Laundering F (in.)	Percentage Changes in Dimensions W	Percentage Changes in Dimensions F
	P1	11.0	11.0	10.52	10.90	4.36	0.90
	P2	11.0	11.0	10.54	10.91	4.17	0.83
	P3	11.0	11.0	10.54	10.91	4.20	0.81
5	S1	11.0	11.0	10.57	10.85	3.89	1.34
	S2	11.0	11.0	10.51	10.87	4.45	1.15
	S3	11.0	11.0	10.60	10.86	3.64	1.11
	P1	11.0	11.0	10.49	10.98	4.67	0.22
	P2	11.0	11.0	10.51	10.92	4.49	0.76
	P3	11.0	11.0	10.50	10.91	4.55	0.83
10	S1	11.0	11.0	10.54	10.89	4.17	1.02
	S2	11.0	11.0	10.53	10.88	4.24	1.02
	S3	11.0	11.0	10.58	10.90	3.86	0.89
	P1	11.0	11.0	10.46	10.94	4.95	0.57
	P2	11.0	11.0	10.46	10.92	4.87	0.70
	P3	11.0	11.0	10.44	10.88	5.12	1.06
15	S1	11.0	11.0	10.54	10.87	4.17	1.21
	S2	11.0	11.0	10.61	10.87	3.55	1.20
	S3	11.0	11.0	10.56	10.86	4.05	1.26
	P1	11.0	11.0	10.36	10.88	5.80	1.23
	P2	11.0	11.0	10.42	10.90	5.24	0.87
	P3	11.0	11.0	10.40	10.88	5.50	1.12
20	S1	11.0	11.0	10.50	10.80	4.54	0.20
	S2	11.0	11.0	10.50	10.80	4.54	1.84
	S3	11.0	11.0	10.50	10.82	4.54	1.65

TABLE IX

CHANGES IN DIMENSIONS AFTER 5, 10, 15, AND 20 LAUNDERINGS OF SPECIMEN GROUP A AT 120°F

Number of Launderings	Specimens	Average Measurements Before Laundering W (in.)	Average Measurements Before Laundering F (in.)	Average Measurements After Laundering W (in.)	Average Measurements After Laundering F (in.)	Percentage Changes in Dimensions W	Percentage Changes in Dimensions F
5	P1	11.0	11.0	10.55	10.91	4.29	0.83
	P2	11.0	11.0	10.53	10.92	3.89	0.76
	P3	11.0	11.0	10.74	10.92	2.38	0.75
	S1	11.0	11.0	10.60	10.93	3.66	0.63
	S2	11.0	11.0	10.60	10.88	3.73	1.10
	S3	11.0	11.0	10.55	10.98	4.12	0.22
10	P1	11.0	11.0	10.50	10.91	4.55	0.83
	P2	11.0	11.0	10.48	10.89	4.74	1.02
	P3	11.0	11.0	10.45	10.89	4.99	1.01
	S1	11.0	11.0	10.54	10.92	4.17	0.70
	S2	11.0	11.0	10.50	10.91	4.61	0.83
	S3	11.0	11.0	10.48	10.89	4.75	1.02
15	P1	11.0	11.0	10.44	10.88	5.12	1.12
	P2	11.0	11.0	10.44	10.88	5.13	1.12
	P3	11.0	11.0	10.49	10.89	4.61	0.95
	S1	11.0	11.0	10.59	10.87	3.70	1.15
	S2	11.0	11.0	10.54	10.89	4.17	0.95
	S3	11.0	11.0	10.50	10.85	4.45	1.33
20	P1	11.0	11.0	10.32	10.83	6.19	1.51
	P2	11.0	11.0	10.31	10.87	6.25	1.19
	P3	11.0	11.0	10.36	10.85	5.84	1.38
	S1	11.0	11.0	10.48	10.84	4.74	1.45
	S2	11.0	11.0	10.49	10.85	4.61	1.33
	S3	11.0	11.0	10.51	10.83	4.42	1.52

TABLE X

CHANGES IN DIMENSIONS AFTER 5, 10, 15, AND 20 LAUNDERINGS OF SPECIMEN GROUP A AT 160°F

		Average Measurements Before Laundering		Average Measurements After Laundering		Percentage Changes in Dimensions	
Number Launderings	Specimens	W (in.)	F (in.)	W (in.)	F (in.)	W	F
5	P1	11.0	11.0	10.5	10.89	4.55	1.02
	P2	11.0	11.0	10.5	10.91	4.55	0.82
	P3	11.0	11.0	10.5	10.78	4.55	2.03
	S1	11.0	11.0	10.47	10.92	4.79	0.70
	S2	11.0	11.0	10.47	10.92	4.81	0.70
	S3	11.0	11.0	10.46	10.86	4.93	1.14
10	P1	11.0	11.0	10.45	10.92	4.66	0.74
	P2	11.0	11.0	10.48	10.93	4.74	0.64
	P3	11.0	11.0	10.62	10.88	3.45	1.14
	S1	11.0	11.0	10.46	10.88	4.94	1.14
	S2	11.0	11.0	10.45	10.88	4.99	1.08
	S3	11.0	11.0	10.44	10.86	5.13	1.26
15	P1	11.0	11.0	10.44	10.88	5.09	1.14
	P2	11.0	11.0	10.44	10.88	5.12	1.14
	P3	11.0	11.0	10.44	10.89	5.05	0.95
	S1	11.0	11.0	10.42	10.85	5.25	1.40
	S2	11.0	11.0	10.51	10.89	4.52	1.02
	S3	11.0	11.0	10.42	10.89	5.25	0.96
20	P1	11.0	11.0	10.31	10.81	6.25	1.76
	P2	11.0	11.0	10.35	10.85	5.93	1.33
	P3	11.0	11.0	10.38	10.82	5.67	1.62
	S1	11.0	11.0	10.35	10.81	5.88	1.71
	S2	11.0	11.0	10.35	10.82	5.90	1.65
	S3	11.0	11.0	10.37	10.74	5.69	2.40

TABLE XI

CHANGES IN DIMENSIONS AFTER 5, 10, 15, AND 20 LAUNDERINGS OF SPECIMEN GROUP A AT 180°F

Number of Launderings	Specimens	Average Measurements Before Laundering W (in.)	Average Measurements Before Laundering F (in.)	Average Measurements After Laundering W (in.)	Average Measurements After Laundering F (in.)	Percentage Changes in Dimensions W	Percentage Changes in Dimensions F
5	P1	11.0	11.0	10.40	10.89	5.45	0.95
	P2	11.0	11.0	10.14	10.83	7.82	1.53
	P3	11.0	11.0	10.44	10.09	5.12	+0.82*
	S1	11.0	11.0	10.60	10.87	3.60	1.23
	S2	11.0	11.0	10.48	10.89	4.73	0.95
	S3	11.0	11.0	10.51	10.93	4.43	0.67
10	P1	11.0	11.0	10.37	10.91	5.70	0.83
	P2	11.0	11.0	10.28	10.80	6.51	1.84
	P3	11.0	11.0	10.32	11.09	6.18	+0.82*
	S1	11.0	11.0	10.50	10.82	4.55	1.65
	S2	11.0	11.0	10.50	10.83	4.55	1.52
	S3	11.0	11.0	10.32	10.81	6.17	1.77
15	P1	11.0	11.0	10.28	10.78	8.60	2.03
	P2	11.0	11.0	10.07	10.86	6.19	1.30
	P3	11.0	11.0	10.32	11.02	6.51	+0.28*
	S1	11.0	11.0	10.50	10.86	4.55	1.26
	S2	11.0	11.0	10.42	10.87	5.25	1.20
	S3	11.0	11.0	10.51	10.87	4.50	1.20
20	P1	11.0	11.0	10.0	10.70	9.09	2.69
	P2	11.0	11.0	10.17	10.72	7.08	2.54
	P3	11.0	11.0	10.22	11.04	7.58	+0.36
	S1	11.0	11.0	10.30	10.81	6.38	1.71
	S2	11.0	11.0	10.44	10.78	5.12	1.96
	S3	11.0	11.0	10.45	10.79	5.04	1.99

*Stretch

TABLE XII

SCORES FOR SMOOTHNESS OF SPECIMENS FROM PRINT AND SOLID COLOR EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 85°F

Number of Launderings	Print Fabric		Solid Color Fabric	
	Specimen	Smoothness	Specimen	Smoothness
5	P1	3.8	S1	1.7
	P2	3.8	S2	1.7
	P3	3.2	S3	1.7
10	P1	3.0	S1	1.8
	P2	3.0	S2	1.8
	P3	3.0	S3	1.8
15	P1	2.7	S1	1.3
	P2	2.7	S2	1.3
	P3	2.7	S3	1.3
20	P1	2.3	S1	1.0
	P2	2.3	S2	1.0
	P3	2.3	S3	1.0

TABLE XIII

SCORES FOR SMOOTHNESS OF SPECIMENS FROM PRINT AND SOLID COLOR EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 120°F

Number of Launderings	Print Fabric		Solid Color Fabric	
	Specimen	Smoothness	Specimen	Smoothness
	P1	2.2	S1	1.1
5	P2	2.2	S2	1.0
	P3	2.2	S3	1.1
	P1	2.2	S1	1.0
10	P2	2.2	S2	1.0
	P3	2.2	S3	1.0
	P1	2.2	S1	1.0
15	P2	2.2	S2	1.0
	P3	2.2	S3	1.0
	P1	1.8	S1	1.0
20	P2	1.8	S2	1.0
	P3	1.8	S3	1.0

TABLE XIV

SCORES FOR SMOOTHNESS OF SPECIMENS FROM PRINT AND SOLID COLOR EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 160°F

Number of Launderings	Print Fabric		Solid Color Fabric	
	Specimen	Smoothness	Specimen	Smoothness
	P1	1.5	S1	1.0
5	P2	1.5	S2	1.0
	P3	1.5	S3	1.0
	P1	1.5	S1	1.0
10	P2	1.5	S2	1.0
	P3	1.5	S3	1.0
	P1	1.3	S1	1.0
15	P2	1.3	S2	1.0
	P3	1.3	S3	1.0
	P1	1.3	S1	1.0
20	P2	1.3	S2	1.0
	P3	1.3	S3	1.0

TABLE XV

SCORES FOR SMOOTHNESS OF SPECIMENS FROM PRINT AND SOLID COLOR EXPERIMENTAL FABRICS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 180°F

Number of Launderings	Print Fabric		Solid Color Fabric	
	Specimen	Smoothness	Specimen	Smoothness
	P1	1.7	S1	1.0
5	P2	1.7	S2	1.1
	P3	1.7	S3	1.1
	P1	1.5	S1	1.0
10	P2	1.5	S2	1.0
	P3	1.5	S3	1.0
	P1	1.3	S1	1.0
15	P2	1.3	S2	1.0
	P3	1.3	S3	1.0
	P1	1.1	S1	1.0
20	P2	1.1	S2	1.0
	P3	1.1	S3	1.0

TABLE XVI

SCORES FOR APPEARANCE OF COLORFASTNESS OF PRINT SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 85°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	P1	3.8	3.7
	P2	3.8	3.7
5	P3	3.8	3.7
	P4	3.8	3.7
	P5	3.8	3.7
	P1	3.8	3.6
	P2	3.8	3.6
10	P3	3.8	3.6
	P4	3.8	3.6
	P5	3.8	3.6
	P1	3.6	3.6
	P2	3.6	3.6
15	P3	3.6	3.6
	P4	3.6	3.6
	P5	3.6	3.6
	P1	3.5	3.5
	P2	3.5	3.5
20	P3	3.5	3.5
	P4	3.5	3.5
	P5	3.5	3.5

TABLE XVII

SCORES FOR COLORFASTNESS OF SOLID COLOR SPECIMENS
RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 85°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	S1	4.1	4.0
	S2	4.1	4.0
5	S3	4.1	4.0
	S4	4.1	4.0
	S5	4.1	4.0
	S1	4.0	3.7
	S2	4.0	3.7
10	S3	4.0	3.7
	S4	4.0	3.7
	S5	4.0	3.7
	S1	3.5	3.7
	S2	3.5	3.7
15	S3	3.5	3.7
	S4	3.5	3.7
	S5	3.5	3.7
	S1	3.5	3.5
	S2	3.5	3.5
20	S3	3.5	3.5
	S4	3.5	3.5
	S5	3.5	3.5

TABLE XVIII

SCORES FOR COLORFASTNESS OF PRINT SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 120°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	P1	3.7	3.0
	P2	3.7	3.0
5	P3	3.7	3.0
	P4	3.7	3.0
	P5	3.7	3.0
	P1	3.5	3.0
	P2	3.5	3.0
10	P3	3.5	3.0
	P4	3.5	3.0
	P5	3.5	3.0
	P1	3.5	3.0
	P2	3.5	3.0
15	P3	3.5	3.0
	P4	3.5	3.0
	P5	3.5	3.0
	P1	3.3	3.0
	P2	3.3	3.0
20	P3	3.3	3.0
	P4	3.3	3.0
	P5	3.3	3.0

TABLE XIX

SCORES FOR COLORFASTNESS OF SOLID COLOR SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 120°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	S1	4.0	3.6
	S2	4.0	3.6
5	S3	4.0	3.6
	S4	4.0	3.6
	S5	4.0	3.6
	S1	3.6	3.6
	S2	3.6	3.6
10	S3	3.6	3.6
	S4	3.6	3.6
	S5	3.6	3.6
	S1	3.5	3.3
	S2	3.5	3.3
15	S3	3.5	3.3
	S4	3.5	3.3
	S5	3.5	3.3
	S1	3.2	3.3
	S2	3.2	3.3
20	S3	3.2	3.3
	S4	3.2	3.3
	S5	3.2	3.3

TABLE XX

SCORES FOR COLORFASTNESS OF PRINT SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 160°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	P1	3.0	2.5
	P2	3.0	2.5
5	P3	3.0	2.5
	P4	3.0	2.5
	P5	3.0	2.5
	P1	3.0	2.3
	P2	3.0	2.3
10	P3	3.0	2.3
	P4	3.0	2.3
	P5	3.0	2.3
	P1	2.7	2.3
	P2	2.7	2.3
15	P3	2.7	2.3
	P4	2.7	2.3
	P5	2.7	2.3
	P1	2.0	2.0
	P2	2.0	2.0
20	P3	2.0	2.0
	P4	2.0	2.0
	P5	2.0	2.0

TABLE XXI

SCORES FOR COLORFASTNESS OF SOLID COLOR SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 160°F

Designated Number of Launderings	Specimen	Colorfastness: Gray Scale	Colorfastness: Color Transference Chart
5	S1	3.5	3.0
	S2	3.5	3.0
	S3	3.5	3.0
	S4	3.5	3.0
	S5	3.5	3.0
10	S1	3.5	3.0
	S2	3.5	3.0
	S3	3.5	3.0
	S4	3.5	3.0
	S5	3.5	3.0
15	S1	3.0	3.0
	S2	3.0	3.0
	S3	3.0	3.0
	S4	3.0	3.0
	S5	3.0	3.0
20	S1	2.8	2.7
	S2	2.8	2.7
	S3	2.8	2.7
	S4	2.8	2.7
	S5	2.8	2.7

TABLE XXII

SCORES FOR COLORFASTNESS OF PRINT SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 180°F

Designated Number of Launderings	Specimen	Colorfastness Gray Scale	Colorfastness Color Transference Chart
	P1	2.2	1.7
	P2	2.2	1.7
5	P3	2.2	1.7
	P4	2.2	1.7
	P5	2.2	1.7
	P1	2.2	1.7
	P2	2.2	1.7
10	P3	2.2	1.7
	P4	2.2	1.7
	P5	2.2	1.7
	P1	2.0	1.5
	P2	2.0	1.5
15	P3	2.0	1.5
	P4	2.0	1.5
	P5	2.0	1.5
	P1	1.8	1.3
	P2	1.8	1.3
20	P3	1.8	1.3
	P4	1.8	1.3
	P5	1.8	1.3

TABLE XXIII

SCORES FOR COLORFASTNESS OF SOLID COLOR SPECIMENS RATED AFTER 5, 10, 15, 20 LAUNDERINGS AT 180°F

Designated Number of Launderings	Specimen	Colorfastness	
		Gray Scale	Color Transference Chart
	S1	2.7	2.3
	S2	2.7	2.3
5	S3	2.7	2.3
	S4	2.7	2.3
	S5	2.7	2.3
	S1	2.5	2.0
	S2	2.5	2.0
10	S3	2.5	2.0
	S4	2.5	2.0
	S5	2.5	2.0
	S1	2.0	2.0
	S2	2.0	2.0
15	S3	2.0	2.0
	S4	2.0	2.0
	S5	2.0	2.0
	S1	1.8	1.8
	S2	1.8	1.8
20	S3	1.8	1.8
	S4	1.8	1.8
	S5	1.8	1.8

APPENDIX B

TABLE XXIV

ANALYSIS OF VARIANCE FOR VARIABLE WARP

Source	DF	Sum of Squares	Mean Square
Fabric	1	13.1868	13.1868
Temperature	3	29.3465	9.7821
Temperature X Fabric	3	13.8524	4.6174
Wash	3	22.1001	7.3667
Fabric X Wash	3	4.4138	1.4712
Temperature X Wash	9	2.2815	0.2535
Temperature X Fabric X Wash	9	1.4994	0.1666
Specimen (Fabric)	4	2.2408	0.5602
Specimen (Temp)	8	0.8130	0.1016
Specimen (Temp Fabric)	16	3.6121	0.2257
Specimen (Wash)	8	3.8447	0.4805
Specimen (Fabric Wash)	16	6.2738	0.3921
Specimen (Temp Wash)	32	11.3686	0.3552
Specimen (Temp Fabric Wash)	64	19.7720	0.3089
Residual	-84	-28.1532	0.3351
Corrected Total	95	106.4527	1.1205

TABLE XXV

ANALYSIS OF VARIANCE FOR VARIABLE FILLING

Source	DF	Sum of Squares	Mean Square
Fabric	1	1.0944	1.0944
Temperature	3	0.9864	0.3288
Temperature X Fabric	3	0.9436	0.3145
Wash	3	5.6363	1.8787
Fabric X Wash	3	0.3943	0.1314
Temperature X Wash	9	1.5819	0.1757
Temperature X Fabric X Wash	9	0.9879	0.1097
Specimen (Fabric)	4	2.1534	0.5383
Specimen (Temp)	8	8.0565	1.0070
Specimen (Temp Fabric)	16	15.0308	0.9394
Specimen (Wash)	8	0.9866	0.1233
Specimen (Fabric Wash)	16	3.9295	0.2455
Specimen (Temp Wash)	32	10.0787	0.3149
Specimen (Temp Fabric Wash)	64	19.9528	0.3117
Residual	-84	-40.2355	0.4789
Corrected Total	95	31.5778	0.3323

TABLE XXVI

ANALYSIS OF VARIANCE FOR VARIABLE SMOOTHNESS

Source	DF	Sum of Squares	Mean Square
Fabric	1	27.7222	27.7222
Temperature	3	25.3212	8.4404
Temperature X Fabric	3	7.6312	2.5437
Wash	3	4.3042	1.4347
Fabric X Wash	3	0.6492	0.2164
Temperature X Wash	9	2.8762	0.3195
Temperature X Fabric X Wash	9	0.5112	0.0568
Specimen (Fabric)	8	0.0317	0.0039
Specimen (Temp)	16	0.1015	0.0063
Specimen (Temp Fabric)	32	0.2030	0.0063
Specimen (Wash)	16	0.0635	0.0039
Specimen (Fabric Wash)	32	0.1270	0.0039
Specimen (Temp Wash)	64	0.4060	0.0063
Specimen (Temp Fabric Wash)	128	0.8120	0.0063
Residual	-168	-0.9327	0.0055
Corrected Total	159	69.8277	0.4391

TABLE XXVII

ANALYSIS OF VARIANCE FOR VARIABLE GRAY

Source	DF	Sum of Squares	Mean Square
Fabric	1	1.2602	1.2602
Temperature	3	56.2152	18.7384
Temperature X Fabric	3	0.3522	0.1174
Wash	3	3.2902	1.0967
Fabric X Wash	3	0.8572	0.2857
Temperature X Wash	9	3.5422	0.3935
Temperature X Fabric X Wash	9	0.8302	0.0922
Specimen (Fabric)	8	0.0050	0.0006
Specimen (Temp)	16	0.0100	0.0000
Specimen (Temp Fabric)	32	0.0200	0.0006
Specimen (Wash)	16	0.0100	0.0000
Specimen (Fabric Wash)	32	0.0200	0.0006
Specimen (Temp Wash)	64	0.0400	0.0006
Specimen (Temp Fabric Wash)	128	0.0800	0.0006
Residual	-168	-0.1050	0.0006
Corrected Total	159	66.4277	0.4177

TABLE XXVIII

ANALYSIS OF VARIANCE FOR VARIABLE CHART

Source	DF	Sum of Squares	Mean Square
Fabric	1	9.0250	9.0250
Temperature	3	71.3062	23.7687
Temperature X Fabric	3	2.2625	0.7541
Wash	3	1.4312	0.4770
Fabric X Wash	3	0.0875	0.0291
Temperature X Wash	9	0.5062	0.0562
Temperature X Fabric X Wash	9	1.3750	0.1527
Specimen (Fabric)	8	0.0000	0.0000
Specimen (Temp)	16	0.0000	0.0000
Specimen (Temp Fabric)	32	0.0000	0.0000
Specimen (Wash)	16	0.0000	0.0000
Specimen (Fabric Wash)	32	0.0000	0.0000
Specimen (Temp Wash)	64	0.0000	0.0000
Specimen (Temp Fabric Wash)	128	0.0000	0.0000
Residual	168	0.0000	0.0000
Corrected Total	159	85.9937	0.5408

VITA

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