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RESTORATION SHRINKAGE LABORATORY

TEST METHOD

by

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CHAPTER I

INTRODUCTION

It is generally accepted that the lack of dimensional stability in knit structures is a problem to manufacturers, retailers, and consumers. Extensive use of knit structures in a greater variety of garments has increased the need for knowledge and understanding of the dimensional behavior of such fabric.

The dimensional stability of any textile material depends on its microscopic and macroscopic properties.[1] Microscopic properties are those inherent physical properties of textile fiber polymers which depend on their chemical nature and morphological structure. Macroscopic properties include fabric geometry, fiber surface characteristics, and friction between fibers and yarns.

Deformation of knit structures occurs easily; microscopic and macroscopic properties allow knits to

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[1]Manfred Wentz, Ivan H. Andrasik, and William E. Fisher, "Knit Shrinkage in Drycleaning--Statistics and Causes," (AATCC Symposium, Knit Shrinkage: Cause, Effect and Control, October, 1973), p. 3. (Photographed)

exhibit varying dimensions depending on the conditions of stress and relaxation during production and use. A fabric is considered to have reached its smallest dimension when the fibers, yarns, or knit loops have reached the state of minimum internal elastic energy. Knit structures are easily deformed from the smallest dimension by low force loads. When stressed, knit fabric achieves a new geometry in equilibrium with the stress.[2] Upon release of stress full return to the smallest dimension does not occur due to incomplete elastic recovery. Consolidation shrinkage or return to a dimension less than either the dimension under stress or after incomplete elastic recovery occurs when friction between yarns and fibers or forces within fibers are released by refurbishing.

Knit structures experience deformation in production processes and also may show further growth in use. When a knit garment is refurbished for the first time, the knit structure will return to a state of minimum internal elastic energy. To the consumer, this change is shrinkage.

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[2] J. M. Whitney and J. L. Epting, Jr., "Three Dimensional Analysis of a Plain Knitted Fabric Subjected to Biaxial Stresses," Textile Research Journal, 36 (Feb. 1966), 143.

Garment manufacturers compensate for this shrinkage with fabric specifications combined with cutting allowances to allow for acceptable shrinkage. Shrinkage tolerances for knits have been based on woven fabric standards. Acceptable shrinkage in women's garments has been considered to be 3 percent in each direction after five home launderings and tumble dryings. For men's wear, the acceptable shrinkage was 2 percent in each direction under the same conditions.[3] In 1973, Dan River established minimum fabric standards for knit fabrics which were proposed as an industry standard. A total shrinkage of 4 percent after pressing, curing, and three refurbishing cycles was allowed in wale and course direction.[4]

Knit garments do not maintain the refurbished dimension in use, but readily reach a new state of equilibrium with the deformation incurred by low force loads of the actions involved in donning and wearing the garment. Tests for dimensional change in fabrics are based on measurements taken before and after refurbishing while the fabric or

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[3] H. T. Pratt, "What to Do About Knit Shrinkage," American Dyestuff Reporter, 61 (April, 1972), 23.

[4] "Apparel Fabric Standards--Finally," Textile Industries, 138 (Nov., 1974), 110.

garment is spread flat on a solid surface. Scott,[5] discussing shrinkage tests, emphasized the need for considering restorative forces in measuring dimensional change. He reported incidents where garments failed the flat test but were acceptable to consumers in actual use. Scott maintained that shrinkage measured after successive refurbishings without restoration was greater than shrinkage of fabrics restored between refurbishings. Pratt[6] also recognized the effect of restoration in wear when he suggested that acceptable shrinkage levels for fabric intended for garments could be 3 percent in the width and 1 percent in length.

Although restoration is recognized as an important property of a knit fabric, there is currently no single accepted method for measurement of restoration simulating the general conditions of consumer use. Methods of determining dimensional characteristics now used include wear

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[5]Thomas P. Scott, Jr., "A Survey of Shrinkage Test Methods," (AATCC Symposium, Knit Shrinkage: Cause, Effect and Control, October, 1973), pp. 17, 19. (Photographed)

[6]Pratt, loc. cit.

tests, hand restoration, and the Knit Shrinkage Gauge.[7] Time and expense eliminate wear tests as practical for extensive industrial use. Hand restoration procedures cannot be standardized as controlled replicable actions cannot be assured in the actions of a single individual or in actions between individuals. The Knit Shrinkage Gauge is used to measure restoration of knit fabric resting on a flat surface and stretched between twenty tensioned pins placed in a circle so that restorative forces occur simultaneously in all directions and in the plane of the fabric only. Test results from this instrument more nearly indicate dimensional behavior of garments which fit close to the body and are restricted from slipping along the body.

Industry continues to base rejections due to unacceptable shrinkage on laboratory test methods which do not incorporate restorative forces. Financial losses may be incurred by rejecting products which could meet both consumer expectations and size specifications if knit fabrics were tested for acceptable restoration shrinkage.

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[7]AATCC Test Method 96-1972, "Dimensional Changes in Laundering of Woven and Knitted Textiles Except Wool," Technical Manual of the American Association of Textile Chemists and Colorists, 49 (1973), 187.

Restoration shrinkage is the dimensional loss that remains after refurbishing and restoration from donning and wearing a garment.

W. N. Lilly[8] developed the Shrinkage Restoration Frame to measure restoration shrinkage and proposed a test method which would indicate dimensional changes under conditions similar to wear. The two innovations incorporated in the Shrinkage Restoration Frame are simulated fabric slippage on the body and restoration by an unsupported spherical force. Members of Committee R-84, Knit Fabric Technology, American Association of Textile Chemists and Colorists, expressed interest in further development of this test method. Since no empirical research has been conducted to establish any test procedures for the use of this instrument, this study will evaluate empirically the use of the Shrinkage Restoration Frame.

PURPOSES AND OBJECTIVES OF THIS STUDY

The purpose of this study was to establish laboratory procedures which utilize the Shrinkage Restoration

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[8] Manager, Piece Goods Quality, Blue Bell, Inc. Greensboro, North Carolina.

Frame for the measurement of restoration shrinkage of weft-knit structures. Specifically, the objective was to determine whether a significant difference occurs in measurements of restoration shrinkage in weft-knit fabrics which vary in structure and yarn type using the Shrinkage Restoration Frame after the following: (1) application of 8, 12, and 16 pound weights, (2) restoration after each of five refurbishing cycles.

The results of experimentation with the restoration frame were compared to the shrinkage and restoration of garments made of similar fabrics worn and refurbished five times.

HYPOTHESES

The following null hypotheses were rejected if $P \leq .05$ level of significance:

Hypothesis 1: There is no difference in the dimensions of weft-knit fabrics measured flat after consecutive refurbishing cycles and no restoration and those measured flat following refurbishing after restoration between each of five refurbishing cycles.

Alternate hypothesis: There is greater dimensional change exhibited by weft-knit fabrics measured flat after five consecutive refurbishings and no restoration than those measured flat after restoration between each of five refurbishings.

Hypothesis 2: There is no significant difference in the dimensional behavior among fabrics with similar knit construction but with different yarn structure refurbished and then restored under three conditions of weight.

Alternate hypotheses: There is a significant difference in dimensional behavior between fabrics of similar knit construction but with different yarn structures refurbished and then restored under three conditions of weight. There is a significant difference in dimensional behavior among fabrics of similar knit construction and yarn structure refurbished and restored under three conditions of weight.

Hypothesis 3: There is no difference in impaled sample measurements before and after friction is removed.

Alternate hypothesis: There will be a change at the P=.05 level of significance in impaled sample measurements after friction is removed.

Hypothesis 4: There is no significant difference in the dimension of any of the four test fabrics following restoration after the five refurbishing cycles and the dimensions of the test fabrics after one and three refurbishing cycles.

Alternate hypothesis: There is significantly greater dimensional loss by each of the four test fabrics refurbished and restored five times than after one and three refurbishings and restorations.

Hypothesis 5: There is no difference in the circumference of the hip, thigh, and knee or the length of the crotch, inseam, and outseam on slacks worn before any and after each of five refurbishings, and slacks refurbished five times and not worn.

Alternate hypothesis: There will be significantly less dimensional change in slacks worn before any and after each of five refurbishing cycles than in those refurbished and not worn.

LIMITATIONS AND ASSUMPTIONS

This study was limited to weft-knit fabrics of plain single knit and plain double knit structures available from the stock of North Carolina producers in December and January, 1974-75. From these, plain single knit and Ponte di Roma double knit fabrics were selected as having fewer variations in the knit stitch and fabric structure. Fiber content was limited to 100 percent polyethylene terephthalate polyester. Fibers for three fabrics were produced by

E. I. duPont de Nemours and Company and one fiber for one fabric by Monsanto Company. Yarn structure was limited to 100 percent spun staple, 100 percent textured filament, spun staple blended with textured filament, and spun staple blended with regular non-textured filament. There was no testing for relaxation, fusion, residual or swelling shrinkage.

Garments and test fabrics were refurbished in approved test models of an automatic washing machine and a tumble dryer. The hot water wash cycle was used in laundering to obtain 120F conditions specified by AATCC Test Method 135-1973.[9] Detergent WOB was used since optical brighteners have no significant effects on the test results under consideration. The number of samples in each test group was limited by surface space available for flat measurements at the time of testing. Because all fabrics could not be obtained before testing was begun, possible randomization of test fabrics within test groups was limited. Mechanical failure in the control system for the environmental control room prevented maintaining 70$\pm$2F and 65$\pm$2%

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[9]AATCC Test Method 135-1973, "Dimensional Changes in Automatic Home Laundering of Durable Press Woven or Knit Fabrics," <u>Technical Manual of the American Association of Textile Chemists and Colorists</u>, 49 (1973), 185.

humidity. Tests were run in conditions which ranged from 90F and 58%RH to 70F and 72%RH since humidity would not affect the variables being tested.

Test garments were cut in one style from Ponte di Roma double knit of 100 percent textured filament polyester which duplicated the specifications of the double knit fabric used in the laboratory test. Wear test participants were female students associated with the University of North Carolina at Greensboro during the first summer session of 1975.

It was assumed that fabric of the same specifications of similar weight, cut, fiber content, yarn type, and knit structure from the same manufacturer would be expected to exhibit similar behaviorial characteristics in laboratory and wear tests.

DEFINITIONS

For the purposes of this study, the following definitions are presented.

Bagging - the appearance of excessive deformation or growth of a knit garment at points of strain.

Elasticity - immediate recovery of the initial size and shape of a knit structure after the deformation force is removed.

Growth - a plus change in fabric dimensions.

Recovery - the ability of a knit structure to return to its original size after stretch.

Refurbishing - one home laundry cycle of machine washing and tumble drying.

Restoration - mechanical or physical pressure applied to knit structures to stretch them after consolidation shrinkage has taken place.

Shrinkage - the decrease in length and/or width of a knit structure.

Consolidation shrinkage - the shrinkage which occurs when a knit structure is subjected to moisture, agitation and heat as in machine washing and tumble drying.

Fusion shrinkage - the molecular shrinkage which occurs within a thermoplastic fiber treated above the temperature at which it was heat set thus releasing internal stresses.

Relaxation shrinkage - the shrinkage which occurs when knit fabric is released from physical strains and allowed to remain flat and static for 24 hours.

Residual shrinkage - the shrinkage of a knit fabric after pre-shrinking excluding fusion and swelling shrinkage.

Restoration shrinkage - the shrinkage that remains in the fabric or garment after restoration.

Swelling shrinkage - the shrinkage due to yarns perpendicular to the line of shrinkage swelling from humidity or wetting.

CHAPTER II

REVIEW OF LITERATURE

The review of literature pertinent to this study was restricted to information regarding (1) the chemistry, morphology and dimensional properties of polyethylene terephthalate (PET) polyester fibers, (2) structural properties of yarns, and (3) physical and geometric properties of plain weft-knit and plain double-knit structures. In addition, literature relating to testing procedures involving fabric structure and dimensional behavior in refurbishing and wear testing is presented.

CHEMISTRY, MORPHOLOGY AND DIMENSIONAL PROPERTIES

The chemical composition and the morphological structure of the molecules in the fiber chain affect the chemical behavior and physical properties of textile fibers. Chemical and physical reactions of fibers can affect the dimensional properties of fabrics.

Properties of PET Polyester

The Federal Trade Commission definition of a polyester fiber is "a manufactured fiber in which the fiber forming substance is any long chain polymer composed of at least 85 percent by weight of an ester of a dihydric alcohol and terephthalic acid." The three polyesters which meet these conditions are PET poly (ethylene terephthalate); PCDT poly (1,4 cyclohexylene-dimethylene terephthalate); and poly (ethylene oxybenzoate).

Chemistry. PET is a linear homopolymer formed by a condensation reaction between ethylene glycol and terephthalic acid producing an ester linkage. In PCDT, the only other linear homopolymer, 1,4 cyclohexane-dimethanol is substituted for ethylene glycol. PET is the most commonly used polyester for apparel. PCDT is a staple manufactured in limited amounts under the brand name Kodel II for use in wool-like fabrics. In poly (ethylene oxybenzoate) p-hydroxyethoxybenzoic acid is also used. This fiber, developed in Japan, is produced in limited quantities and sold under the brand name A-Tell. This fiber meets the FTC definition when 85 percent of the fiber weight is of esters of dihydric alcohol and terephthalic acid.

Polyester is melt spun, a factor which permits modification of physical properties for specific end uses. Polyester can be produced as multifilament yarn, monofilament yarn, staple, and tow in a wide range of deniers.[10] The cross section may be modified from the usual round shape for esthetic and behavioral effects. Molecular orientation for stability and tenacity is achieved by hot drawing. To achieve the stability and tenacity appropriate for use in apparel, the fiber is usually drawn five times the original length. Yarns destined for use as staple fibers are drawn less to lower the tenacity, decrease flex life, and decrease pilling.

Morphology. In the process of hot drawing, the fiber molecules are aligned parallel to each other and to the fiber axis. The molecular arrangement is nearly planar with both oriented and amorphous areas. The most accepted theory of oriented fiber areas suggests microfibrils which form crystallites parallel to each other and the fiber axis. Amorphous areas occur where the polymer chain either folds

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[10] J. Gordon Cook, _Handbook of Textile Fibres 2: Man-Made Fibres_ (Herts, England: Merrow Publishing Co. Ltd., 1968), p. 357.

or becomes entangled or where ends of polymer chains are located.[11] At room temperatures, the amorphous regions of PET are effectively rigid.[12] The orientation and composition of the non-crystalline areas affect (1) the mechanical properties of strength, elongation without breaking, recovery from deformation, abrasion resistance, and flexibility; (2) the ability to absorb moisture; and (3) the availability of sites for chemical reaction to occur. The degree of crystallinity affects tenacity and shrinkage.[13]

Dimensional properties. Fiber shrinkage can occur from intermolecular shifting in amorphous areas. McGregor and Tucker reported that:

> fibers contain regions of stress but spontaneous relaxation or shrinkage is inhibited by internal frictions between the structural elements and by crystallites which tend to lock the structure together.[14]

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[11] Ralph McGregor and Paul A. Tucker, "The Fine Structure of Poly (Ethylene Terephthalate) Fibers in Relation to Yarn Barre," AATCC Symposium Knit Barre--Causes and Cures, (May, 1972), p. 15. (Multilithed)

[12] I. M. Ward, "The Molecular Structure and Mechanical Properties of Polyester Terephthalate Fibers," Textile Research Journal, 31 (July, 1961), 663.

[13] E. G. Farrow, E. S. Hill and P. L. Weinle, "Polyester Fibers," Encyclopedia of Polymer Science and Technology, 11 (New York: Interscience Publishers, 1969), 22.

[14] McGregor and Tucker, op. cit., p. 19.

Intermolecular shifting resulting in fiber shrinkage occurs in the presence of heat, moisture and swelling agents.[15]

Heating a polymer to at least the glass-transition temperature (about 83C [181F] for PET) causes molecules in the amorphous areas to become highly mobile.[16] A fiber hot drawn at or above the glass-transition temperature and under tension produces a more homogeneous structure with more order in both the crystalline and amorphous areas. More ordered amorphous areas restrict intermolecular changes. Generally, polyester is classified as a fiber which does not shrink because the fiber can be heat set under tension to desired dimensions. For polyester, heat setting to prevent shrinkage should be above 375F (191C).[17] After the fiber is hot drawn and set in the yarn stage, it is then exposed to high temperatures in yarn processing, fabric processing, garment manufacture, and care.

Heat setting can be a critical factor in the dimensional stability of knits. Pratt[18] suggested that heat

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[15] J. J. Press, ed., Man-Made Textile Encyclopedia, (New York: Textile Book Publishers, 1959), p. 118.

[16] McGregor and Tucker, op. cit., p. 17.

[17] Press, op. cit., p. 119.

[18] Pratt, op. cit., pp. 24, 26.

setting should occur after dyeing at a temperature high enough to relieve stresses built in by stretching during processing. Stretched fabric has the potential for relaxation shrinkage. Further size loss could result from fusion shrinkage during garment manufacturing processes using high temperatures such as steam pressing. Fabric extended beyond the minimum internal elastic energy and heat set has potential for shrinkage. Pratt further suggested that shrinkage can be prevented by knitting fabric more tightly with a lower denier yarn rather than stretching for yield. Benes and Westarp[19] believed that framing to the fabric dimensions after scouring rather than stretching for yield was one means of maintaining a level of 3 percent shrinkage.

Polyester has such a low level of moisture absorption under ordinary conditions that the mechanical properties are "virtually unaffected."[20] At 70F and 65%RH, PET has a moisture regain of 0.4 percent, which does not change the tensile strength or elongation of the fiber. At 100%RH, the moisture absorption increases to only 0.5

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[19]Jaime Benes and Tom Westarp, "Dyeing and Finishing of Textured Double Knits," Unpublished paper in the collection of Dr. Victor S. Salvin, Professor of Home Economics, University of North Carolina at Greensboro, 1975.

[20]Cook, op. cit., p. 390.

percent. When measured in relative humidity ranging from 0 - 100 percent, polyester increases in length only 0.1 percent.

Since 10 percent absorption lowers the glass-transition temperature 10C (50F), the glass-transition temperature of polyester is considered to be 63C (105F) in water.[21] Ribnick and Weigmann[22] have extrapolated the zero shrinkage temperature of polyester in water to be -45C (-113F). Completely overcoming natural molecular shrinkage which occurs in wetting the fabric does not seem feasible for laundering. Creasing, however, can be overcome by holding the temperature of wash water used on PET to 40-50C (104-122F).[23] Polyester is chemically resistant to bleaches and alkalis normally used in laundering. In a research project involving polyester/cotton fabric,

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[21] P. H. Middleburg, "The Effect of Detergent on Dynamic Glass-Rubber Transition Temperature of a Polyester/Cotton Fabric," Textile Research Journal, 43 (Jan., 1973), 59.

[22] A. S. Ribnick and H. D. Weigmann, "Interactions of Nonaqueous Solvents with Textile Fibers, Part III: The Dynamic Shrinkage of Polyester Yarns in Organic Solvents," Textile Research Journal, 43 (June, 1973), 323.

[23] Cook, op. cit., p. 396.

Middleburg[24] found that detergent had no effect on the glass-transition temperature of the fabric.

The fiber morphology which allows only low moisture absorption impedes easy dyeing of polyester fiber. To open the fiber for dye penetration, solvents may be used to swell the fiber. Some solvents used for this purpose have an active hydrogen atom which reacts with polyester at room temperature changing the dimensional properties of the fibers.[25] Recovery of mechanical properties after drying and reconditioning is only partial for polyester which has reacted with most solvents. For example, shrinkage is irreversible. When drawn polyester yarns react with organic solvents, longitudinal shrinkage results.[26] Further, the rate of shrinkage produced in any particular solvent depends on the temperature of the solvent in which the fiber is being immersed. It is assumed that solvent-induced shrinkage is a result of relaxation of internal stresses imparted

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[24] Middleburg, loc. cit.

[25] Arthur S. Ribnick, H. D. Weigmann, and L. Rebenfeld, "Interactions of Nonaqueous Solvents with Textile Fibers, Part I: Effects of Solvents on the Mechanical Properties of a Polyester Yarn," Textile Research Journal, 43 (Dec., 1972), 723-24.

[26] Ribnick and Weigmann, op. cit., pp. 316, 325.

during processing. When the fiber is heated rapidly, crystallites do not interfere with shrinkage. At low rates of heating, crystallites affect the speed of fiber shrinkage.

STRUCTURAL PROPERTIES OF YARNS

Fiber properties can be augmented, counteracted, or overcome by the yarn structure into which the fiber is made. Textured filament and spun staple are two yarn structures commonly found in knits.

Yarn Structure

PET produced for apparel end use is most often textured if used in filament length and crimped if used in staple length. Production is varied according to fiber use.

Textured filament. False-twist is the most used texturing process for filament yarns. False-twist inserts a helical configuration in a continuous process which involves the total length of the fiber giving bulk and cover while maintaining wrinkle resistance and stretch recovery.[27,28] Temperature and tension in twisting the yarn and

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[27] Cook, op. cit., p. 394.

[28] Berkeley L. Hathorne, Woven Stretch and Textured Fabrics (New York: Interscience Publishers, 1964), pp. 21, 54.

dwell time in the heat zone are important in achieving stability in false-twist yarns throughout production and use.

Spun staple. Staple fibers are produced with a lower tenacity than textured filament with greater elongation and lower resistance to elongation.[29] Before being cut into staple, tow is usually gear crimped. Gear crimped fiber retains the heat set energy only at the points of bending and heat setting. Loading removes some crimp which is not recoverable. Under sufficient loading fiber slippage would also be expected to occur in spun yarns. Fabrics should be designed to incorporate shrinkage, stretch, and recovery properties built into the yarn during production.[30] Crimped polyester yarns must have more tension in the heated zone than nylon and must be overfed to take up for successful torque-crimp. Even then, polyester crimp is still not durable. However, dye carriers cause a regain of crimp which is retained when crimped yarn is heat set after dyeing.[31]

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[29]Cook, op. cit., p. 379.

[30]Hathorne, op. cit., p. 21.

[31]Hathorne, op. cit., p. 135.

PHYSICAL AND GEOMETRIC PROPERTIES OF WEFT-KNIT

The behavioral properties of knit fabric result from the loop configuration. The loop gives knit greater extensibility than is found in traditional woven fabrics. Loop configuration also contributes to wrinkle resistance, drape, and air permeability.

Physical Properties of Weft-Knit Structures

Weft-knit structures are highly extensible fabrics with incomplete elastic recovery which contributes to comfort in wear. Single weft-knit structures are formed by yarns feeding horizontally at more or less right angles to the rows of loops. The face loops form vertical wales on the front of the fabric and the courses are formed by horizontal rows on the reverse of the fabric.[32] Single weft-knit structures are used in garments where elasticity and stretch are a comfort factor[33] and where close fit with ease and comfort in movement is desired. Munden described the

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[32] Peter Brown, Knitting Principles (Burlington, N. C.: Burlington Printing Services, 1972), pp. 3, 15.

[33] Philo D. Atwood, "New Dimensions in Stretch Fabrics," Modern Textiles Magazine, February 6, 1964, p. 6.

appropriateness of the use of loop structures in garments:

> The knitted fabric is ideal for next-to-the-skin wear, since it possesses high extensibility under low loading conditions which allows it to fit snugly and without discomfort on any form on which it is pulled.[34]

Most knit garments were of single weft or warp knit construction until double knit outerwear was introduced on the clothing market in the 1950's. By 1961, double knits were ranked among the staple fabrics.[35] Double knit structure is a weft-knit made on two sets of needles (dial and cylinder) which cast off stitches in opposite directions. It is usually 16 cut or finer, and is constructed of either tuck or float loops in addition to knit loops. Double knit structures are classified as plain fabrics, ripple fabrics, and flat rib Jacquards.[36]

A plain double knit differs from the other two classes of double knits by its structure. It is derived from a 1 x 1 rib interlock and has either tuck or float loops. A single 1 x 1 rib fabric is a variation of a

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[34] D. L. Munden, "The Geometry and Dimensional Properties of Plain-Knit Fabrics," Journal of the Textile Institute, 50 (July, 1959), T449.

[35] "The Expanding World of Circular Knits," Modern Textiles Magazine, (Sept., 1961), p. 63.

[36] Brown, op. cit., pp. 59, 63.

weft-knit in which every other stitch is a face loop with the stitch between forming a back loop. Interlock is an intermeshing of two 1 x 1 single ribs which produce a fabric with the same surface appearance on both sides.[37] Ponte di Roma is an example of a plain double knit fabric whereby a cylinder yarn feed and a dial yarn feed produce a two-course interlock, the third yarn feed is dial only, and the fourth yarn feed is cylinder only.[38]

The type of loop stitch affects physical properties of stretch and recovery. Tuck loops (loops not knit) remain on the needle, are knit on a consequent round, and make the fabric wider, thicker and less extensible than plain knit. Float loops (loops dropped and not knit) make the fabric narrower, thicker and even less extensible than tuck.[39]

Fabric geometry. In the 1944 Edgar Marburg Lectures, Smith[40] introduced the philosophy that textile fibers

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[37] Brown, op. cit., pp. 44, 50.

[38] Charles Reichmann, ed., Knitting Dictionary (New York: National Knitted Outerwear Association, 1966), p. 76.

[39] Brown, op. cit., p. 35.

[40] H. D. Smith, "Textile Fibers: An Engineering

should be considered engineering materials and designed to meet specific end uses. Peirce[41] later proposed geometric formulas for the structure of woven and knit fabrics. Doyle,[42] who experimented with the structural geometry of dry-relaxed plain-knitted fabrics, introduced the concept of a state of equilibrium or minimum elastic energy. Studies of the equilibrium state of dry-relaxed plain knit fabrics showed that the number of stitches per square inch was dependent on the length of yarn in a stitch and independent of yarn material, yarn structure, and system of knitting. Munden[43] extended knit geometry research to wet-relaxed fabric and substantiated Doyle's findings. In addition, it was found that the effect of both internal and external stress affected fabric equilibrium. Further geometric formulas were developed through studies conducted

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Approach to their Properties and Utilization," p. 42. (reprint from copyrighted Proceedings of American Society for Testing and Materials, 44, 1944).

[41] F. T. Peirce, "Geometrical Principles Applicable to the Design of Functional Fabrics," Textile Research Journal, 17 (March, 1947), 144.

[42] P. J. Doyle, "Fundamental Aspects of the Design of Knitted Fabrics," Journal of the Textile Institute, 44 (1953), 563, 564.

[43] Munden, op. cit., p. 450.

by other researchers.[44,45,46] Formulas were arrived at for predicting the minimum equilibrium states of knit structures which are knit of bulk yarn and 1 x 1 rib, interlock, and double pique knit structures. The importance of input tension and cam setting on fabric quality and plain knit loop formation was investigated by Knapton and Munden.[47] The ability today to duplicate cloth of the same quality by controlling the length of yarn supplied at each feed and the ability to reproduce yarn feed conditions is a result of this research.[48]

Fabric extension results from fiber or yarn slippage, yarn extension, or molecular slippage. Uniaxial

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[44] T. S. Nutting and G. A. V. Leaf, "A Generalized Geometry of Weft-Knitted Fabrics," Journal of the Textile Institute, 55 (Jan., 1964), T45.

[45] B. C. Eggleston and M. Cox, "The Geometry of Bulked Nylon Yarns in Weft-Knitted Fabrics," Journal of the Textile Institute, 55 (Jan., 1964), T31.

[46] J. A. Smirfitt, "Worsted 1 x 1 Rib Fabrics, Part I: Dimensional Properties," Journal of the Textile Institute, 56 (May, 1965), T248.

[47] J. J. F. Knapton and Dennis L. Munden, "A Study of the Mechanism of Loop Formation on Weft-Knitting Machinery, Part I: The Effect of Input Tension and Cam Setting on Loop Formation," Textile Research Journal, 36 (Dec., 1966), 1072.

[48] Reichmann, loc. cit.

stress only was considered in early geometric studies. Popper[49] formulated an explanation of biaxial knit fabric extension. Photographs then substantiated the process of fabric extension following a pattern where the yarns in the knit loops straighten in the direction of the stress applied and slip by one another until the yarns jam where the loops interlock. It is at this point that fabric extension ceases and yarn extension begins. MacRory and McNamara,[50] using fabrics of wool and cotton, extended Popper's work and concluded that friction was a significant factor in determining knit fabric deformation. Shanahan and Postle, experimenting with all-wool fabric, compared initial textile modulus and lent further support to the postulate that interyarn friction is a factor in knit extension.[51]

Friction between yarns is one of the factors preventing the complete elastic recovery of knit fabrics.

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[49] Peter Popper, "The Theoretical Behavior of a Knitted Fabric Subjected to Biaxial Stresses," Textile Research Journal, 36 (Feb., 1966), 149.

[50] Brian M. MacRory and Aiden B. McNamara, "Knitted Fabrics Subjected to Biaxial Stress--An Experimental Study," Textile Research Journal, 37 (Oct., 1967), 910.

[51] W. J. Shanahan and R. Postle, "A Theoretical Analysis of the Tensile Properties of Plain Knitted Fabrics, Part II: The Initial Load-Extension Behavior for Fabric Extension Parallel to the Wales," Journal of the Textile Institute, 65 (May, 1974), 254.

Procedures to remove friction between yarns have been suggested for knit fabric relaxation. Murray[52] explained that a process as simple as "flip-shake" (holding the fabric at both corners at one end giving it a quick shake) removes friction and therefore reduces fabric size before cutting garments. Such a procedure could be a means to eliminate garment shrinkage from release of friction tension. In a proposed "Bagging Test for Double Knit Fabrics"[53] developed by Monsanto Textiles Company, it was suggested that friction be removed by flicking the fabric from underneath before applying the weight to induce bagging. In the study by Grunewald and Zoll,[54] the removal of inherent friction was achieved by flexing the test instrument before conducting the static flex test for bagging.

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[52] John M. Murray, "Cutting, Sewing and Pressing Practices to Reduce Shrinkage," (AATCC Symposium, Knit Shrinkage: Cause, Effect and Control, October, 1973), p. 96. (Photographed)

[53] Letter from Frank B. Lutz, Supervisor of Textile Research for Monsanto Textile Company, Decatur, Alabama, June 12, 1974.

[54] K. H. Grunewald and I. W. Zoll, "Practical Methods for Determining the Bagging Tendency in Textiles," International Textile Bulletin (Weaving World Edition), 13 (March, 1973), English, 273-275.

TESTING PROCEDURES

Tests have been conducted to determine the effect of laundering procedures and products on dimensional behavior of knit fabrics. Further research has investigated the validity of laboratory procedure in testing what occurs in actual wear.

Refurbishing Related to Macroscopic Properties

Fletcher and Roberts[55] investigated the effect of laundering on the rearrangement of the structure of plain, rib, and interlock fabrics knit of cotton, acetate, viscose, and nylon. Six plain and six 1 x 1 rib fabrics were knit of each fiber. The AATCC (1950) standard method for laundering woven goods was used. Temperature of 212-140F were used with cotton and 100F for the acetate, viscose, and nylon. One set of three 15 x 15 inch specimens of each greige and each finished fabric was measured. After five launderings, a second set of specimens was soaked for two hours to the approximate dimension of the laundered fabric

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[55] Hazel M. Fletcher and S. Helen Roberts, "Distortion in Knit Fabrics and Its Relation to Shrinkage in Laundering," Textile Research Journal, 23 (Jan., 1953), 37-42.

and dried relaxed on a screen. This was followed by five launderings. Wale and course count, stitch length, and yarn diameter were taken before and after laundering. The results showed the changes in dimensions of these knit goods in laundering were due largely to the rearrangement of fabric structure.

Munden, Leigh and Chell,[56] in a later study on wool blended with rayons, nylon, azlon, casein, and polyester found that static wet-relaxation was not sufficient to bring plain knit fabrics to complete relaxation; it took 30 to 40 minutes of washing to do so. As the amount of polyester in the blend was increased, the relaxation shrinkage decreased.

The chemical reaction of laundry products with fabrics during refurbishing can effect dimensional behavior. In a recent study evaluating the effects of phosphate and nonphosphate detergent on selected fabric properties, it was found that there was no difference in knit shrinkage related to type of detergent.[57]

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[56] D. L. Munden, B. G. Leigh and F. N. Chell, "Dimensional Changes During Washing of Fabrics Knitted from Wool/Man-made Fibre Blends," Journal of the Textile Institute, 54 (1961), 136, 141.

[57] Anne L. Lyng, "Care of Knits - Consumer Style" (paper presented at the AATCC Symposium Knit Shrinkage: Cause, Effect and Control, New York, October, 1973).

Laboratory Test Correlated to Wear Tests

Patton,[58] addressing the 1969 AATCC Wear Test Symposium, pointed out the need for developing or modifying laboratory test methods to correlate with actual wear of fabrics. Only one published study was found where laboratory tests for knit fabrics were correlated to a wear test. Grunewald and Zoll[59] developed an instrument for measuring bagging which involved the use of a suspended arm. A "sleeve" was positioned on the arm by four tension springs. After static, dynamic, and combined static and dynamic test periods static extension was selected to obtain the highest degree of bagging. The "arm" was flexed three times to remove inherent tension before being positioned in an 80° angle for five hours. When the sleeve was removed, it was pulled over a horizontal arm and the height of bagging measured by a sliding rule.

Wear tests were conducted on trousers made from the same source of fabric as tested on the bagging instrument. Garments were worn five times, evaluated, then cleaned and

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[58] J. P. Patton, Jr., "Post Mortem on Wear Testing," Textile Chemist and Colorist, 1 (Nov., 1969), 38.

[59] Grunewald and Zoll, op. cit., pp. 273-275.

pressed. Wear trials were conducted for 50 days per garment. It was found that the instrument was a valid test for bagging since fabrics showing the degree of bagging of at least 5 mm in height in the laboratory test were judged unwearable in wear tests.

SUMMARY

Dimensional properties of textile fibers, such as polyethylene terephthalate (PET) polyester, are a result of their chemical composition and morphological structure. PET polyester, used widely in knit fabrics, is considered to be dimensionally and chemically stable. Dimensional behavior of PET polyester can be altered during fiber production, yarn spinning, fabric production, and fabric finishing for controlled performance for specific end use.

Knit structures are an unstable form of fabrication easily deformed dimensionally during production, garment manufacturing, wear, and refurbishing. Fabric instability is more significant than fiber instability in polyester knit fabric dimensions. Some control of knit fabric has been achieved through regulated stitch length and production procedures.

Authorities have asserted that textile tests should apply to actual use. Such tests include refurbishing with comparisons made among fibers and between wetting conditions, effect of detergent types, and bagging correlated to wear testing.

CHAPTER III

PROCEDURES

This investigation was conducted in two parts: (1) laboratory testing of restoration of weft-knit fabrics using the Shrinkage Restoration Frame and (2) wear testing of women's slacks to indicate dimensional characteristics in consumer use. The fabrics used in laboratory testing were weft-knit structures of 100 percent polyethylene terephthalate polyester produced for use in apparel. The fabric used in garments for the wear test was a plain double knit structure which duplicated one of the fabrics used in the laboratory testing.

LABORATORY TESTING

Description of Testing Equipment

The Shrinkage Restoration Frame (Figure 1) was made by assembling four pieces of Plexiglas measuring 20 x 6 x 1/8 inches into a twenty inch square frame held at the corners by metal angles. A one-half inch U channel was attached to the top outside edge of the Plexiglas with the U facing

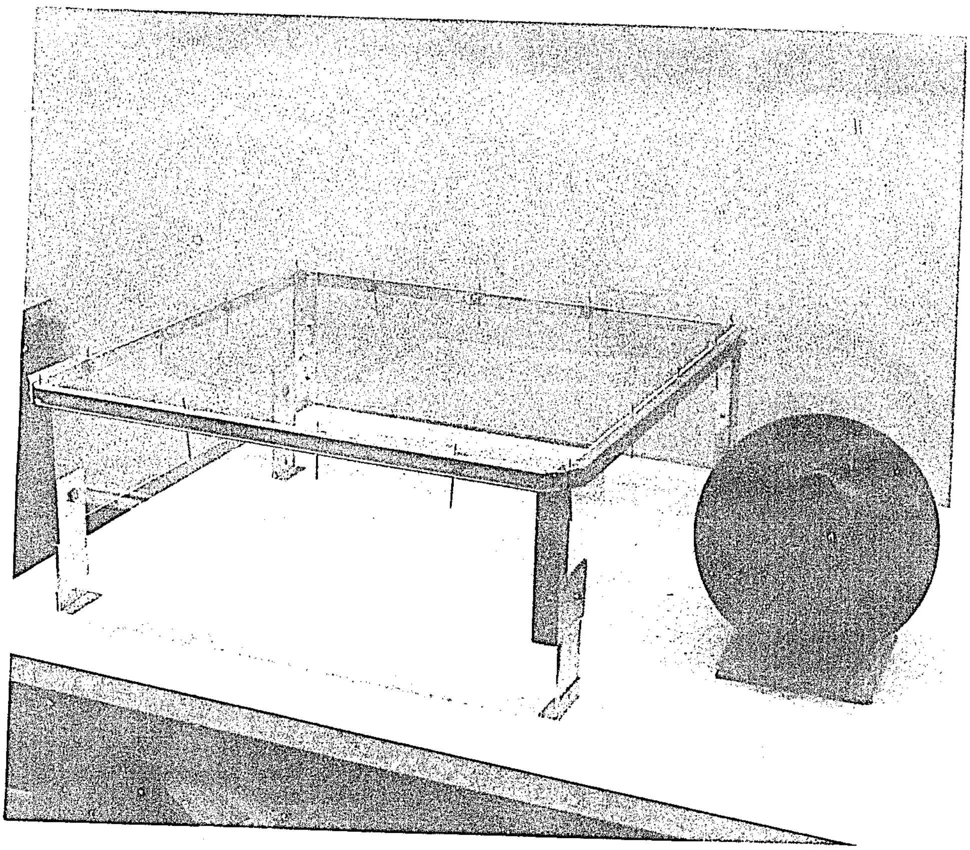


Figure 1

Shrinkage Restoration Frame

outward. Sixteen holes were drilled in the sides of the channeling so needles could be inserted to protrude above the frame. One needle was placed at each of the four corners. The remaining twelve needles were placed three to a side and staggered so that each needle was midway between needles on the opposite side of the frame. The needles were inserted with the points protruded three-eighths inch above the frame edge. Each needle was held by a washer secured by a nut and bolt. To raise the frame nine inches above the tabletop for testing, footed legs were made by attaching 6 x 5 x 2 inch metal strips to metal angles. The legs were bolted abutting the corner, two each to two opposing sides of the frame.

Tenpin bowling balls were used to test fabric impaled on the Shrinkage Restoration Frame. Three balls of 8, 12, and 16 pound (± 1/2 pound) weights were used. Impaled fabric dimensions were measured with reinforced fiber glass dressmaker measuring tapes, Scoville #838, which had a metal tab end with a small hole. Two of these tapes were attached by the metal tab to brass cup hooks screwed into wooden blocks stabilized on the table holding the Shrinkage Restoration Frame. One tape was centered across the impaled fabric sample parallel to the wales and the other centered parallel to the courses.

The Cluett, Peabody and Company, Inc., mechanical marker was used to mark six bench marks placed in a manner to measure three wale and three course dimensions on the fabric. In order to facilitate accuracy in marking samples and the impaling of fabrics on the Shrinkage Restoration Frame, the mechanical marker and the Shrinkage Restoration Frame were modified. The mechanical marker was modified by placing a mark on the center of each side of the marker. The Shrinkage Restoration Frame was modified by marking the center of each of the four sides.

It was found that the action of removing samples occasionally caused movement of the Shrinkage Restoration Frame. Masking tape was then applied to the table top to outline the placement of each Shrinkage Restoration Frame leg and to define the perimeter of the wooden blocks holding the cup hooks.

Pretesting to Achieve Experimental Accuracy

Pretesting included experimentation with fabrics and equipment to determine (1) the optimum time interval for the elongation of fabrics, (2) dimensions and marking of test fabrics, and (3) determination of laundering and drying temperatures.

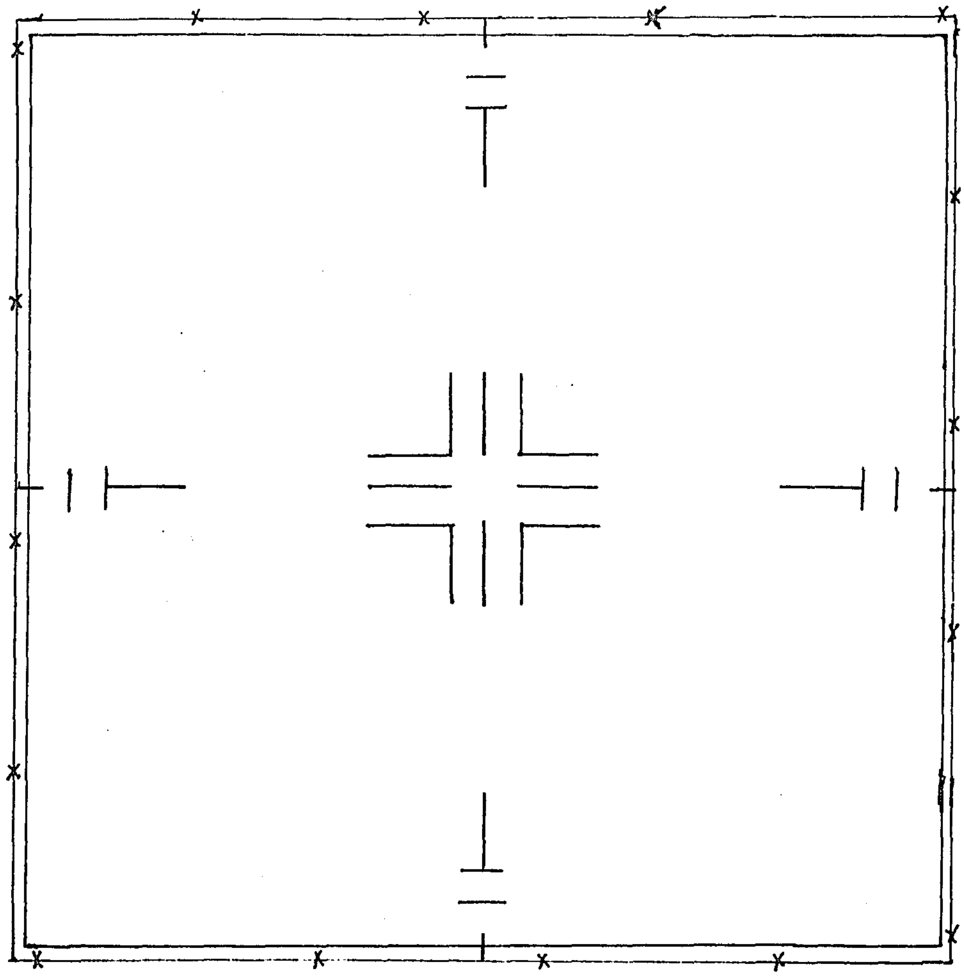
Time interval for elongation. To determine the length of time a fabric should be restored or left under tension, four fabrics which varied in fiber content or yarn and knit structure were tested under static weight of the 16-pound tenpin bowling ball and dimensional change was recorded at eight time intervals. The four pretest fabrics were a 100 percent textured polyester double knit, a 100 percent cotton double knit, a 50/50 polyester and cotton double knit, and a 50/50 polyester and cotton single knit. Measurements of dimensional change were taken with two measuring tapes stretched across the sample. Measurements were recorded at eight times: 10 seconds, 30 seconds, one minute, five minutes, 30 minutes, one hour, four hours, and after an overnight relaxation period of approximately sixteen hours. No significant dimensional change was found to occur in any of the time intervals after ten seconds. Consequently, later test readings were made immediately after restoration.

Dimensions and marking of test fabrics. Sample sizes used by Lilly had been 24 x 27 inches which is one-half a square yard, a convenient size for analyzing fabric data. A 24 x 27-inch sample simplifies changing sample weight to weight per square yard. Sample size was tested to ascertain whether the amount of fabric extending beyond the needles and overhanging the Shrinkage Restoration Frame would affect elongation readings. Three sample sizes were tested: (1) 27 x 27 inches, (2) 24 inches in the wale direction by 27 inches in the course direction, and (3) 27 inches in the wale direction by 24 inches in the course direction. There were two reasons for choosing these sizes: (1) to determine the effect of equal overhang on elongation readings, and (2) to determine if the greater amount of overhang in wale or in course direction affected elongation readings. There were differences in the data in the wale direction as overhang varied, but not in the course direction. As a result, test samples were cut 27 inches in the wale direction by 24 inches in the course direction.

To determine the area necessary to give the most accurate measurements for dimensional change, a 16-inch square was drawn inside an 18-inch square on the same sample and both were measured while the fabric was impaled and restored on the Shrinkage Restoration Frame. There was no difference in the amount that either of the marked areas extended. The 18-inch square was selected for measurement of dimensional change since there was a mechanical marker available to apply 18-inch markings.

A 20-3/8 inches square template (Figure 2) of heavy Kraft paper was slit to mark the position of each pin, the center of each side, and five placement positions for centering the mechanical marker. The template was prepared for three purposes: (1) to center the mechanical marker used to apply bench marks for measuring wale and course dimensions, (2) to center samples on the Shrinkage Restoration Frame, and (3) to mark needle spacings to guide the impaling of the samples on the Shrinkage Restoration Frame. Each specimen was marked with a Texpen using the template. The Texpen was also used to overmark bench marks where the ink used in the mechanical marker did not show up on the dark test fabric. An arbitrary decision was made to record fabric dimensions in one-sixteenth of an inch if a measurement fell between the one-eighth inch marks on the measuring tapes.

Determination of laundering and drying temperatures. AATCC Test Method 135-1973 was used for refurbishing. In order to reach 120±5F, the cold water had to be turned off while the wash cycle filled. The dryer had to be set for normal drying for 20 minutes and spaced midway between the Lo and Hi settings on the heat range to maintain a



Scale: 1/8" = 1"

Figure 2

Diagram of the Template Used to Mark the Specimens temperature between 140F and 160F. Dryer temperature was checked by a laboratory thermometer at exhaust and by Thermopaper wrapped in polyvinyl film and secured in a mesh bag and tumbled with the dryer load. More consistent temperature readings were obtained when 100 percent polyester dummy pieces were substituted for the cotton specified in the test method.

Experimental Fabric and Sample Preparation

Experimental fabrics. The four weft-knit fabrics all of 100 percent polyethylene terephthalate polyester were:

1. Plain double knit fabric of 100 percent textured filament
2. Plain double knit fabric of 88 percent spun staple and 12 percent regular filament
3. Plain single knit of 100 percent spun staple
4. Plain single knit containing 60 percent spun staple and 40 percent textured filament

Fabric construction characteristics are shown in Table 1 which includes fabric information supplied by the manufacturers.

Table 1

Data Pertaining to Fabric Specifications
Furnished by Manufacturers

	Fabric Construction			
	Double Knit		Single Knit	
Characteristics	1 Ponte di Roma	2 Mock Ponte di Roma	1 Plain Knit	2 Plain Knit
Yarn	150/34 textured filament	22/1 spun staple 150/34 regular filament	22/1 spun staple	22/1 spun staple 1/150/34 textured filament
Cut	22	18	20	20
Greige width	72 in.	68 in.	69 in.	64 in.
Finished width	66-68 in.	59 in.	54 in.	64 in.
Heat setting temperature	370F	360F	335F	335F
Yards per minute	20	20	25	25
Weight oz./yd.	13.5	13.7	5.4	4.5

Double knit fabrics. Double Knit Fabric 1 was a Ponte di Roma plain double knit of 100 percent PET polyester textured continuous filament yarns. All stitches were a plain loop. The Ponte di Roma was a two-course repeat produced by four feeds where two feeds are yarns fed to the dial needles and the other two feeds are yarns fed to the cylinder needles. One course was an interlock involving dial and cylinder needles. In the next course, one feed went to the dial needles which knit every stitch and the other feed went to the cylinder needles which knit every stitch. The polyester for this fabric was produced by Monsanto Chemical Company.

Double Knit Fabric 2 was a mock Ponte di Roma double knit of 100 percent PET polyester produced by E. I. duPont de Nemours and Company. The yarn was 88 percent spun polyester and 12 percent regular continuous filament. One course of the two-course repeat was an interlock knit by dial and cylinder needles from two feeds. The next course was knit of two feeds which went either to the dial or the cylinder needles which knit every other stitch giving a construction of a knit stitch alternating with a loop stitch.

Single knit fabrics. Both single knit fabrics were supplied by the same fabric producer and were knit of PET polyester produced by E. I. duPont de Nemours and Company. Both fabrics in this group exhibited skew. Single Knit Fabric 1 was skewed eight inches and Single Knit Fabric 2 was skewed ten and one-fourth inches. Samples were cut parallel to the wales.

Single Knit Fabric 1 was a plain weft knit of 100 percent spun staple fibers. Single Knit Fabric 2 was a plain weft knit of 60 percent spun staple fibers and 40 percent textured filament.

Sample preparation. Twelve 27 x 24 inch samples (with the 27-inch dimension in the wale direction) were cut from each fabric so that no sample was cut nearer than one-tenth the width of the fabric from the edge or one yard from the end of the fabric. Before cutting, a cutting plot was prepared which would assure that samples tested by the same weight came from different needles and/or courses. (Table 2)

Each sample was coded by fabric type, sample replication, and test weight to be used. Double Knit Fabric 1 was assigned the digits 1, 2 and 3. Double Knit Fabric 2 was assigned digits 4, 5 and 6. Single Knit Fabric 1 was assigned digits 7, 8 and 9. Single Knit Fabric 2 was assigned digits 10, 11 and 12. The control samples (no weight) were numbered 1 through 12. The 8-pound weight, 101-112; 12-pound weight, 201-212; and 16-pound weight, 301-312. A piece of white polyester twill tape was stitched to the sample on the extreme edge of the lower right hand corner in the wale direction and contained the number assigned to that sample.

Table 2

Sample Replication Cutting Chart

Fabric							
Double Knit				Single Knit			
1		2		1		2	
103	1	106	4	109	7	112	10
2	303	5	306	8	309	11	312
301	202	304	205	307	208	310	211
3	101	6	104	9	107	12	110
102	203	105	206	108	209	111	212
201	302	204	305	207	308	210	311

Laboratory Testing for Dimensional Changes

Since the fabrics were all 100 percent polyester, it was decided that controlled humidity and temperature were not critical factors affecting the properties being studies in this research. Therefore, an air-conditioned laboratory with other than standard conditions was used. After resting in a flat state in an atmosphere of not more than 78%RH at a temperature of 70F or less than 58%RH at a temperature of 90F, the following data were recorded before either restoration or refurbishing tests were made: (1) sample weight, (2) wale and course dimensions, (3) wale and course count, and (4) sample weight per square yard (Appendix A).

Dimensional measurements. Samples which had rested flat for at least four hours were weighed on an Ohaus gram balance. The fabric samples were rested flat for another four hours before wale and course dimensions were measured at the three bench marks using a reinforced fiber glass dressmaker measuring tape. Measurements were made (1) walewise starting with the bench mark nearest the sample number marker, and (2) course-wise starting with the mark farthest from the edge to which the sample number marker was attached.

Wale and course counts were made using an Alfred Suter micrometer. Five randomly spaced counts were made on each sample originally and after each of five refurbishing cycles.

Samples were centered and impaled on the Shrinkage Restoration Frame so that no strain was evident. Samples were placed so the number mark was in the lower right hand corner of the Shrinkage Restoration Frame. Dimensional measurements to ascertain the importance of the removal of friction on final measurements were taken after impaling the test samples (Appendix B). Friction was removed by flicking the fabric five times from underneath while impaled on the Shrinkage Restoration Frame. Measurements at the center bench marks in both wale and course direction were recorded (1) after impaling and (2) after removing friction. Wale and course dimensions were measured after the sample was taken from the frame, placed on a flat surface, and had rested for at least four hours. The required samples were then refurbished.

Sample refurbishing. Samples were refurbished by specifications in AATCC Test Method 135-1973. One wash cycle in a Kenmore Automatic Washer (model 24401) followed by one drying cycle in a Kenmore Automatic Electric Dryer (model 64401) was considered one refurbishing cycle. The washer and dryer were each tested and procedures established to meet the standards of 120 ± 5F. The dryer was set midway between the Lo and Hi settings on normal cycle for twenty minutes to obtain the 140F to 160F internal temperature level. Four-pound loads of samples and dummy pieces of 100 percent polyester were refurbished using ninety grams of Detergent WOB in each wash load. Each load was removed from the dryer as soon as the cycle was completed. Care was taken to handle the fabric samples as little as possible to prevent excessive distortion. After refurbishing, they were placed on a flat surface and wale and course dimensions measured immediately. After resting at least four hours, the wale and course dimensions were again measured and five random wale and course counts were made. (Appendix C)

Nine samples of each fabric were restored after each of five refurbishing cycles. Three samples were refurbished five times and not restored.

Results of measurements taken at the bench marks in both wale and course directions were calculated as follows:

$$\% \text{ Shrinkage} = \frac{\text{Original length} - \text{length after refurbishing}}{\text{Original length}} \times 100$$

% Restoration Shrinkage =

$$\frac{\text{Original length} - \text{length after refurbishing and restoration}}{\text{Original length}} \times 100$$

WEAR TESTING

Experimental garments were women's slacks made of Ponte di Roma double knit fabric similar to that used in the laboratory testing. The slacks were obtained from Saul Brothers of Atlanta, Georgia, in a fabric produced by the donor of the Ponte di Roma double knit used in the laboratory testing. Twenty female students of the University of North Carolina at Greensboro who wore Misses size 10 or Misses size 12 slacks volunteered to participate in the study.

Preparation of Garments for Experimentation

Description of test garments. The women's slacks were each made from the same four-piece basic pant design with the front crease stitched in. There were no darts as the waist was elasticized. The pant legs tapered slightly to the knee and flared out again slightly to the hem edge. The seams were 1/8-inch overcast construction. Waistband casing and hems were machine stitched.

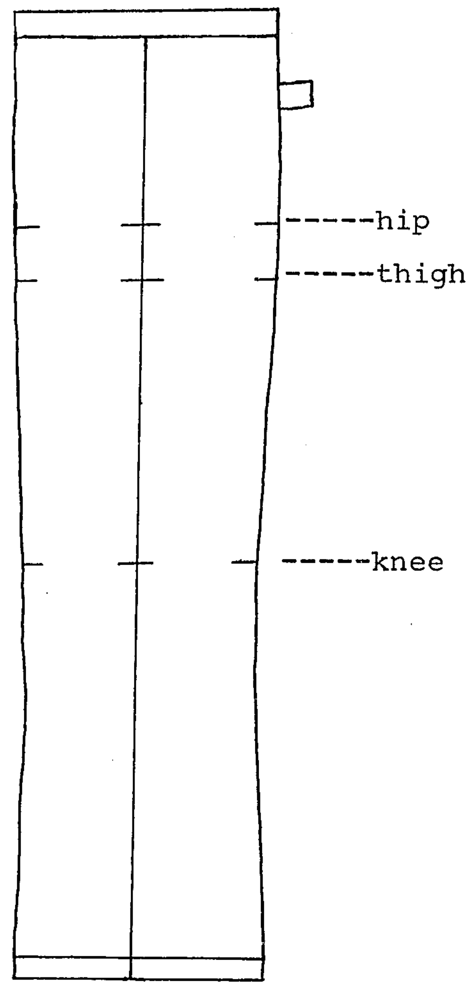
The slack fabric was a Ponte di Roma double knit similar to laboratory test fabric Double Knit Fabric 1. Twenty slacks of two dye lots, navy and maroon, were distributed to wear test participants. Four slacks, one navy and one maroon in each of the two sizes tested, were retained for controls.

The dimensions given by the manufacturer as specifications for construction for body height of 5'5" were as follows:

Outseam Measurement		41-5/8 inches
	Misses Size 10	Misses Size 12
Waist	24-1/2 inches	26 inches
Hip	35-1/2 inches	37 inches

The manufacturer's sewing error tolerance for the slacks was +3/4 inch to -1/2 inch.

Marking of test garments. Using an L-square, the hip, thigh, and knee were marked inside each garment with a yellow Texpen at the side seam and edge creases (Figure 3). The hip was marked eight inches below the waist seam, the thigh immediately below the crotch seam, and the knee twenty-two and one-half inches below the waist seam.



Scale: 1/8" = 1"

Figure 3

Inside View of Marked Test Garments

Measuring test garments. The system developed for measuring the slacks incorporated a minimum amount of handling. Data were recorded on a form developed for the purpose (Appendix D). First, the waist measurement was made inside the band from center back to center back along the waistline seam. Second, the slacks were turned wrong side out and working with the waistband to the left, the front seam was measured along the stitching from the waistline seam to the crotch seam. The slacks were then turned over and the back seam measured. The remaining measurements were taken with all side seams aligned and the waistband to the left: the inseam was measured from the crotch seam to the bottom of the hem along the inseam of the right pant leg; the slacks were turned over so the marked right pant leg was uppermost and the outseam measured from the top of the waistband to the bottom of the hem; the knee and thigh measurements taken from folded edge to folded edge and doubled; and the hip measurement taken from folded edge to folded edge plus folded edge to the back seam and folded edge to front seam and doubled. After the slacks rested flat for four hours this measuring process was reversed. Measurements were taken before wearing, after being worn, and after refurbishing and resting flat for four hours.

Assignment of test garments. The procedure for assigning test garments was: (1) garments were numbered, (2) participants were measured, (3) garments were distributed, and (4) test schedules distributed.

Numbered two-inch strips of white 100 percent polyester twill tape were zig-zagged to the back crotch seam near the garment tags. Size 10 garments were assigned numbers one through ten and size 12 garments numbers eleven through twenty. Numbers twenty-one and twenty-two were assigned to size 10 control garments and numbers twenty-three and twenty-four to size 12 control garments.

Data concerning age, height, and weight were collected on each participant (Appendix E). Body measurements were taken over undergarments and recorded by a professional home economist. A waist tape was used to define the waistline. Measurements were taken in the following order: (1) horizontal measurements (waist; hip, eight inches below the waist; right thigh, immediately below the crotch; right knee, across the center of the knee cap and where the knee bends in back) and (2) vertical measurements (outseam, waist to floor; and crotch depth, from the waist to flat surface while seated). Body measurements which were within the sewing error tolerances, particularly waist, hip and thigh, were considered in assigning slacks to participants. Color was assigned by the choice indicated on the demographic data sheet. The number of the pair of slacks assigned to a participant was then recorded on the demographic data sheet.

Each volunteer was instructed to wear the slacks six hours during each of six wear test periods. A schedule was established for wearing and turning in garments. No restrictions were placed on the type of activity. Upon donning the slacks and before removing them, the participants were to record their reaction to the fit of the slacks upon a form developed for that purpose (Appendix F). The slacks were then brought back to the laboratory for measurement and refurbishing. At the completion of the study, the participants were allowed to keep the slacks.

Refurbishing of Test Garments

Six pairs of slacks or slacks and dummy pieces of 100 percent polyester to make a four-pound load were refurbished in the same laundry equipment following the same test procedures as those used in refurbishing the laboratory test fabrics.

After refurbishing, the same care and handling were given to the slacks as to the laboratory test fabrics. The slacks were measured following the procedure used in obtaining the original data. After four hours of flat relaxation, the slacks were again measured and returned to the participants for the next wear test.

STATISTICAL ANALYSES

Statistical analyses used in this study were: (1) a four-factor analysis of variance with repeated measures on three replications, (2) the Duncan Multiple Range Test, (3) a t-test, and (4) a two-factor analysis of variance on change scores with repeated measures. Both analyses of variance were computed by the Statistical Analysis System (SAS).[60] A probability of .05 was the level of rejection chosen for all statistical analyses.

A four-factor analysis of variance with repeated measures on three replicates was used to determine the effect of weight, yarn type, restoration, and number of refurbishing cycles on dimensional behavior of laboratory

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[60]Jolayne Service, A User's Guide to the Statistical Analysis System (Raleigh, N. C.: North Carolina State University, 1972).

test fabrics. The statistical significance was determined by the F value for each measurement taken. Significant interactions of main effects were tested further with the Duncan Multiple Range Test[61] to distinguish where the means of one, three and five refurbishings differed. A t-test[62] of difference between means of two samples of equal size was used to determine whether the removal of friction as a test procedure was statistically significant.

The wear test data were subjected to a two-factor analysis of variance on change scores with repeated measures. The statistical significance was determined by the F value for each measurement taken. Change scores were arrived at by subtracting measurements after refurbishing from original measurements.

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[61]Charles R. Hicks, Fundamental Concepts in the Design of Experiments (New York: Holt, Rinehart and Winston, 1964), pp. 31-33.

[62]John E. Freund, Statistics: A First Course (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1970), p. 223.

CHAPTER IV

ANALYSIS OF THE DATA AND DISCUSSION OF FINDINGS

The purpose of this study was to establish laboratory procedures which utilize Lilly's Shrinkage Restoration Frame for the measurement of restoration shrinkage of weft-knit structures. Conditions investigated which affected dimensional change in fabrics varying in structure and yarn type were:

1. Effect of restoration between refurbishing cycles
2. Effect of weights
3. Effect of number of refurbishings
4. Effect of removal of friction between yarns

Wear tests of women's slacks constructed from Ponte di Roma double knit fabric were conducted to determine the effects of wear and refurbishing on the dimensional stability of similar experimental fabrics.

Results of the laboratory and the wear tests are presented in the following sequence:

1. Description of experimental fabrics
2. Analysis and discussion of laboratory test data

3. Description of the wear test

4. Analysis and discussion of the wear test data

5. Discussion of comparison of laboratory and wear test data

DESCRIPTION OF EXPERIMENTAL FABRICS

The four experimental fabrics used in this study were of 100 percent polyester. They varied as to yarn and fabric structure in the following manner:

1. Plain double knit fabric of 100 percent textured filament (Double Knit Fabric 1)

2. Plain double knit fabric of 88 percent spun staple and 12 percent regular filament (Double Knit Fabric 2)

3. Plain single knit of 100 percent spun staple (Single Knit Fabric 1)

4. Plain single knit of 60 percent spun staple and 40 percent textured filament (Single Knit Fabric 2)

Fabric Construction Characteristics

The double knit fabrics differed somewhat since the two fabrics were knit with differing cuts and structures. In Double Knit Fabric 1, every stitch on all four yarn feeds was knit on both the dial and the cylinder needles. Double Knit Fabric 2 was a mock Ponte di Roma with stitches in the third and fourth feed knit alternately on both the dial and the cylinder needles. There were more courses per inch than wales per inch in each fabric; Fabric 1 had the most wales and courses per inch. Fabric 2 was the heavier, weighing 1.09 ounces per square yard more than Fabric 1 (Table 3).

Table 3

Data Pertaining to Fabric Characteristics
Before Treatments

	Fabric Construction			
	Double Knit		Single Knit	
Characteristics	1	2	1	2
Weight oz./sq. yd.	7.3	8.4	1.4	1.3
Mean Wale Per Inch	31.1	29.3	24.2	24.6
Mean Courses Per Inch	55.9	39.8	24.2	25.0

The two single knit fabrics were plain weft-knit constructed on the same cut machine and heat set under the same conditions. The number of wales and courses per inch were the same in Single Knit Fabric 1. The number of wales and courses in Single Knit Fabric 2 were practically the same with only a mean difference of .4 course count. Fabric 2 had more wales and courses per inch, but Fabric 1 weighed .17 ounces more.

ANALYSIS AND DISCUSSION OF LABORATORY TEST DATA

Wale and course counts were taken before any and after each of five refurbishings, but were not statistically analyzed for the effect of test variables on the changes which occurred. Two dimensional measurements taken in both the wale and the course direction were analyzed statistically to determine the effect of the test variables on dimensional change. The two dimensions were:

1. Wale and course dimensions after the fabric had lain on a flat surface for four hours after refurbishing or after refurbishing and restoration

2. Wale and course dimension after removing friction by flipping the fabric five times from underneath while it was impaled on the Shrinkage Restoration Frame

Wale and Course Count

Both the wale and course count increased slightly in all four test fabrics (Table 4). Greater changes in count occurred in the single knits than in the double knits.

The fabric direction where the least change occurred varied with the fabric structure. The least change in the double knits occurred in the wale direction. There was little or no difference between the amount of increase in wale and course direction in the single knits. Greater change in both fabric structures occurred with combination of yarns. No pattern of increase within fabric or between weights are observable in the mean data (Appendixes G and H).

Table 4

Mean Wale and Course Count Per Inch of Double and Single Knit Fabrics Before Refurbishing and After Five Refurbishings (N=12)

	Double Knit Fabrics				Single Knit Fabrics			
	1 Count		2 Count		1 Count		2 Count	
	Wale	Course	Wale	Course	Wale	Course	Wale	Course
Before Refurbishing	31.1	55.9	29.3	39.8	24.2	24.2	24.6	25.0
After five refurbishings	31.3	56.4	29.6	40.4	25.1	25.1	25.7	26.0
Average total change	+.2	+.5	+.3	+.6	+.9	+.9	+1.1	+1.0

Wale count. The mean wale count for all fabrics over five refurbishings (Table 5) showed a slight increase after each refurbishing. The total change in count was slightly less than one wale per inch. Increase in wale count varied from .01 to .58 wale between refurbishing cycles. The greatest change occurred after the first refurbishing.

Table 5

Mean Wale Count Per Inch of All Fabrics
Over Five Refurbishings (N=48)

Refurbishing	Wale Count	Change in Count
0	27.33	
1	27.81	+.48
2	27.99	+.18
3	28.12	+.13
4	28.13	+.01
5	28.26	+.14
Total Change		+.93

Single knit fabrics increased 1.44 wales per inch and double knits .43 wale per inch (Table 6). The mean wale count increased more after the first refurbishing in both fabric structures. The least increase (.16) occurred in the double knits while the single knits increased by .82

wale. The wale count increased slightly after each refurbishing but not in the same manner. The double knits showed a pattern of increasing, then decreasing. The single knits increased in wale count by decreasing amounts until the fifth refurbishing when an increase occurred. Both double knit and single knit fabrics of a combination of spun staple and filament yarn increased in wale count more than similar structures knit of yarn that was all staple or all filament (Table 7). Double knit fabric of yarn 1 increased .42 of a wale after five refurbishings; yarn 2 increased .44 of a wale. Single knits increased by a mean of 1.23 wales when knit of yarn 1 and 1.64 wales when knit of yarn 2.

Table 6

Mean Wale Count Per Inch of Fabric
Over Five Refurbishings (N=24)

	Double Knit		Single Knit	
Refurbishing	Wale Count	Change in count	Wale Count	Change in count
0	30.21		24.44	
1	30.37	+.16	25.26	+.82
2	30.45	+.08	25.54	+.28
3	30.56	+.11	25.68	+.14
4	30.55	-.01	25.71	+.03
5	30.64	+.09	25.88	+.17
Total Change		+.43		+1.44

Table 7

Mean Wale Count Per Inch Change of Fabric by Yarn Over Five Refurbishings (N=12)

	Double Knit			Single Knit		
Yarn	Before	After	Change	Before	After	Change
1	31.11	31.53	+.42	24.26	25.79	+1.23
2	29.31	29.75	+.44	24.63	26.27	+1.64

<u>Course count</u>. There was a fractional increase in mean course count after each refurbishing to a total increase of 1.13 courses per inch, over five refurbishings for all forty-eight samples (Table 8). The increase in course count varied from .07 to .53 between refurbishings. The greatest increase (.53) occurred after the first refurbishing.

Single knits increased more courses per inch (1.42) than double knits (.77) (Table 9). The mean course count increased more after the first refurbishing than after any other subsequent refurbishings. The double knits increased in course count by declining amounts until the fourth refurbishing when an increase occurred and then no change occurred in sequence. The single knits increased in course count by decreasing amounts after each of five refurbishings.

Table 8

Mean Course Count Per Inch of All Fabrics
Over Five Refurbishings (N=48)

Refurbishing	Course Count	Change in Count
0	36.22	
1	36.75	+ .53
2	37.02	+ .27
3	37.12	+ .10
4	37.28	+ .16
5	37.35	+ .07
Total Change		+1.13

Table 9

Mean Course Count Per Inch of Fabric
Over Five Refurbishings (N=24)

	Double Knit		Single Knit	
Refurbishing	Course count	Change in count	Course count	Change in count
0	47.86		24.59	
1	48.19	+ .33	25.32	+ .73
2	48.43	+ .24	25.62	+ .30
3	48.50	+ .07	25.84	+ .22
4	48.63	+ .13	25.93	+ .09
5	48.63	.00	26.01	+ .08
Total Change		+ .77		+1.42

Comparison by yarn structure showed that the double knit fabric of combined staple and filament fibers changed course count more (.98) than that of 100 percent textured filament (.27). The single knit fabric behaved in the opposite manner (Table 10). Greater increase in course count (1.45) occurred with 100 percent staple yarn than with a combination of yarns of spun staple and textured filament (1.40). Yarn 1 continued increasing in count while yarn 2 leveled off.

Table 10

Mean Course Count Change of Fabric by Yarn Over Five Refurbishings (N=12)

	Double Knit			Single Knit		
Yarn	Before	After	Change	Before	After	Change
1	55.95	56.62	+ .27	24.16	25.61	+1.45
2	39.77	40.75	+ .98	25.02	26.42	+1.40

Discussion

The knit fabrics tested increased in wale and course count over refurbishings. The greatest change occurred after the first refurbishing.

When analyzed by fabric structure, differences in mean count change varied by fabric structure with more change occurring in the single knits. In double knit fabrics, more change occurred in the course direction. The amount of change in dimension was similar in both wale and course direction in the single knits.

When analyzed by yarn structure, the change in count varied by fabric direction. In the wale direction, a combination of yarns showed a greater change in yarn count in both double and single knit fabrics. In the course direction, double knit fabrics showed more change in count in the combination yarns while single knits showed more change in 100 percent spun staple yarns than in combination of yarns.

Dimensional Changes Following Refurbishing

Three samples from each of the four test fabrics were subjected to repeated refurbishings without being restored. Three samples from each test fabric were restored by weight of 8 or 12 or 16 pounds before any and after each of five refurbishings.

Three measurements were taken both in the wale and in the course direction on all fabrics after they had rested on a flat surface in the testing laboratory for at least four hours before either being refurbished or restored by the addition of weights. Measurements were again taken after resting four hours in the flat state after being refurbished or after being refurbished and restored.

Wale dimension. Mean wale dimensions for all samples are shown in Appendix I. Greater dimensional loss occurred in single knit fabrics than in double knit fabrics in both the restored and not-restored fabric. In all fabrics except Double Knit Fabric 2, greater dimensional loss occurred in those refurbished and restored than in those refurbished only (Table 11).

Table 11

Mean Wale Dimensional Loss in Inches of
Restored and Not-Restored Fabric
Over Five Refurbishings (N=3)

	Double Knit		Single Knit	
Restoration Weight	Fabric 1 Yarn 1	Fabric 2 Yarn 2	Fabric 1 Yarn 1	Fabric 2 Yarn 2
Pounds	Inches	Inches	Inches	Inches
0	- .30	- .34	- .89	- .95
8	- .36	- .28	-1.08	-1.34
12	- .36	- .28	- .91	-1.14
16	- .35	- .29	- .95	-1.03

The restoration shrinkage within each double knit fabric remained practically equal over all weights. The restoration shrinkage in the wale dimension of samples of both of the double knit fabrics varied the same amount from the shrinkage of the not-restored fabric samples, but in opposite directions.

The single knit of combination yarn (Fabric 2) had decreasing amounts of dimensional loss as the weight increased. The single knit of 100 percent spun staple (Fabric 1) was inconsistent in behavior over all weights. The most restoration shrinkage in single knit occurred in single knit fabric restored with the 8-pound weight.

Analysis and Discussion

A four-factor analysis of variance with repeated measures on three replicates was used to determine the effect of the variables weight, yarn type, restoration, and number of refurbishing cycles on dimensional behavior in the wale direction of laboratory fabrics over five refurbishings. Five statistically significant variables (Table 12) were identified: two main effects (fabric, F=944.2972, df=1, P=0.0001; refurbishing, F=143.7882, df=5, P=0.0001); two two-way interactions (fabric by refurbishing F=145.1222, df=5, P=0.0001; weight by refurbishing F=2.1798, df=15,

Table 12

Analysis of Variance of Wale Dimension

Source	df	SS	F	P
Fabric	1	18.9420	944.2972	0.0001
Yarn	1	0.0133	0.6649	NS
Weight	3	0.1215	2.0186	NS
Refurbishing	5	14.4215	143.7882	0.0001
F x Y	1	0.0061	0.3016	NS
F x W	3	0.1498	2.4900	NS
Y x W	3	0.0443	0.7364	NS
F x R	5	4.0158	145.1222	0.0001
Y x R	5	0.0346	1.2518	NS
W x R	15	0.1809	2.1798	0.0091
F x Y x W	3	0.0152	0.8588	NS
F x Y x R	5	0.0947	3.4138	0.0061
F x W x R	15	0.1205	1.4509	NS
R x W x R	15	0.0031	0.3985	NS
F x Y x W x R	15	0.0531	0.6391	NS

P=0.0091); and one three-way interaction (fabric by yarn by refurbishing F=3.4138, df=5, P=0.0061).

The main effect, fabric, was statistically significant which indicates that dimensional changes occurring over five refurbishings differed because of fabric structure. Greater dimensional loss occurred in the single knit fabrics. After five refurbishings, the mean dimension of 144 samples was 17.20 for single knits and 17.72 for double knits.

The main effect, refurbishing, was statistically significant because different amounts of dimensional loss occurred among the five refurbishings. Over a total of five refurbishings (Table 13), the greatest dimensional loss (.34 of an inch) occurred after the first refurbishing.

Table 13

Mean Wale Dimensional Loss in Inches
by Refurbishing (N=48)

Refurbishing	Wale Dimension	Inches Change
0	17.90	
1	17.50	-.34
2	17.44	-.22
3	17.35	-.09
4	17.29	-.07
5	17.22	-.07
Total Change		-.68

After experimentation, the Duncan Multiple Range Test was used to test the significant mean wale dimensions after refurbishing treatments (Table 14). A statistically significant dimensional loss is shown by the difference in the means of the double knit fabrics recorded after the first and second refurbishing. A statistically significant dimensional loss occurred after each of the five refurbishings in the single knit fabrics.

Table 14

Mean Wale Dimension in Inches of Test Fabric

Refurbishings	Double Knit	Single Knit
0	17.93	17.87
1	17.76	17.35
2	17.71	17.17
3	17.67	17.02
4	17.63	16.96
5	17.61	16.84

The statistically significant two-way interaction, fabric by refurbishing, indicates that the pattern of dimensional change over five refurbishings differed in each of the two fabrics (Figure 4). The pattern of change over refurbishing showed the double knits leveling off after the second refurbishing and single knits continuing to shrink. Greater loss (1.03 inches) occurred in single knits and the lesser (0.32 inch) in double knits (Table 15).

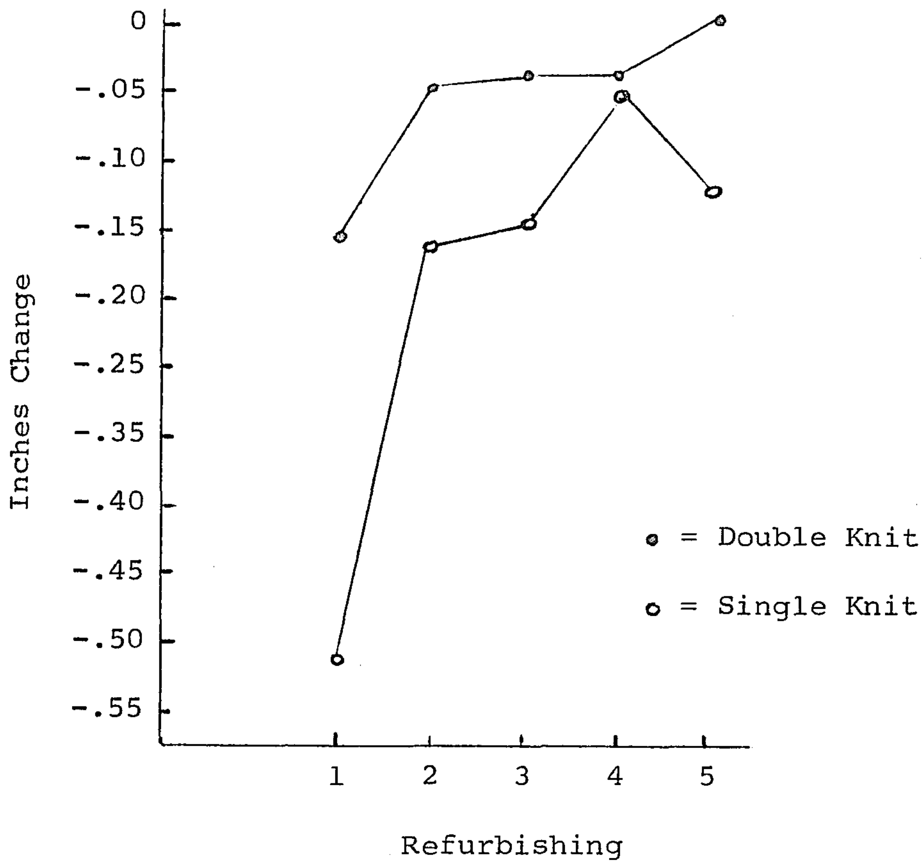

Figure 4

Mean Wale Dimensional Loss of Fabrics By Refurbishings Over Five Refurbishings (N=24)

Table 15

Mean Wale Dimensional Loss in Inches of Fabrics by Refurbishing Over Five Refurbishings (N=24)

Refurbishing	Double Knit Measurement (Inches)		Single Knit Measurement (Inches)	
	Dimension	Change	Dimension	Change
0	17.93		17.87	
1	17.76	-.17	17.35	-.52
2	17.71	-.05	17.17	-.18
3	17.67	-.04	17.02	-.15
4	17.63	-.04	16.96	-.06
5	17.61	-.02	16.84	-.12
Average Total Change		-.32		-1.03

That the two-way interaction, weight by refurbishing, was significant indicates a different pattern of dimensional loss by weight over refurbishings. The greatest dimensional loss in the wale direction occurred after the first refurbishing, regardless of restoration. Greater original dimensional loss occurred in fabrics restored than in the fabrics not restored (Table 16). Fabric samples exhibited the least dimensional loss (0.62 inch) in the wale direction when refurbished without restoration. The greatest dimensional loss (0.76 inch) in the wale direction occurred when samples were restored with 8-pound weights and the least

(0.66 inch) occurred when samples were restored by the 16-pound weight.

Table 16

Mean Dimensional Loss in Inches in Wale Direction in All Fabrics by Weight Over Refurbishing (N=12)

Refur-	No Weight		8 Pound		12 Pound		16 Pound	
bishings	Inches	Chg.*	Inches	Chg.*	Inches	Chg.*	Inches	Chg.*
0	17.87		17.92		17.88		17.93	
1	17.62	-.25	17.51	-.41	17.56	-.32	17.54	-.39
2	17.47	-.15	17.41	-.10	17.43	-.13	17.44	-.10
3	17.41	-.06	17.32	-.09	17.32	-.11	17.35	-.09
4	17.32	-.09	17.30	-.02	17.29	-.03	17.27	-.08
5	17.25	-.07	17.16	-.14	17.20	-.09	17.27	.00
Total Mean Change		-.62		-.76		-.68		-.66

*Change

Fabrics not restored changed by decreasing amounts until the fourth refurbishing. At this point there was a slight increase followed again by a decrease in amount change after the fifth refurbishing. Fabrics restored by all weights decreased in dimensions through the fourth refurbishing. An increase in the amount loss occurred after the fifth refurbishing in fabric restored by 8- and 12-pound weight. In fabrics restored by the 16-pound weight, no dimensional change was noted after the fifth refurbishing. The non-restored fabric and fabric restored by the 16-pound weight showed distinctly different patterns of loss which differed between them and from the fabric restored by 8 and 12 pounds (Figure 5).

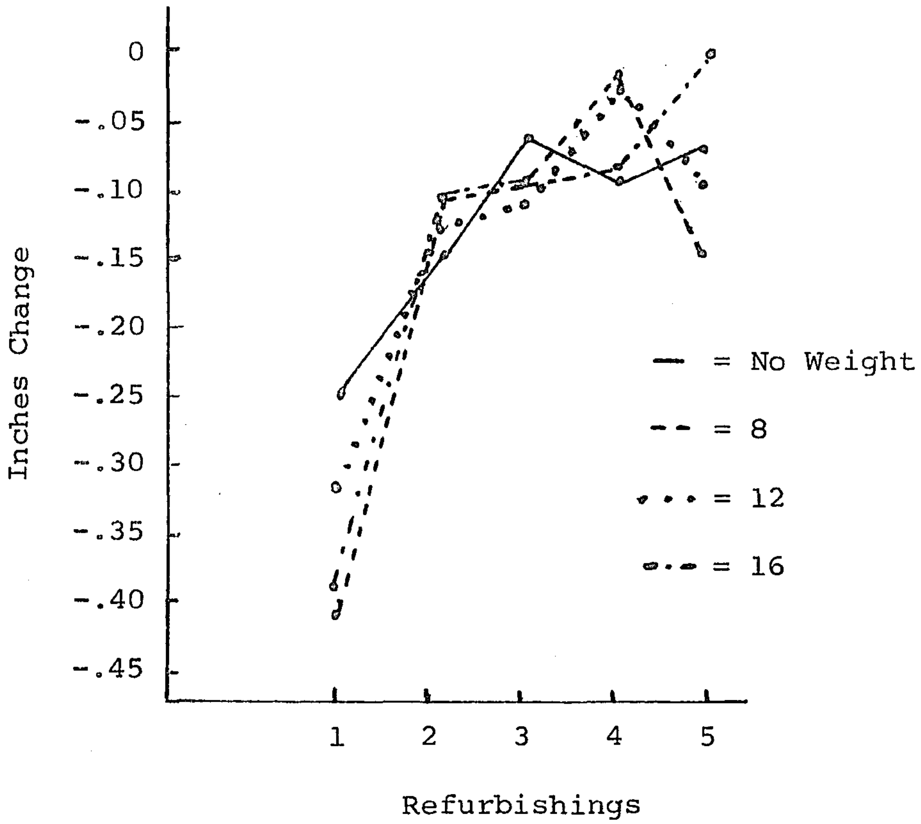

Figure 5

Mean Loss in Inches in the Wale Dimension in Fabric by Weight Over Five Refurbishings (N=12)

Course dimension. The mean dimensional change in the course direction over five refurbishings is given for each sample (Appendix J). In Table 17, it can be seen that a greater dimensional loss occurred in single knits under all conditions than in double knit fabric. Double knit fabric of a combination of yarns (Yarn 2) had equal shrinkage and restoration shrinkage except when it was restored by a 16-pound weight. Single knit fabric of 100% spun yarn (Yarn 1) had less restoration shrinkage than shrinkage when refurbished only. Restored Double Knit Fabric 1 and single knit fabrics showed greater restoration shrinkage than shrinkage from refurbishing only.

Table 17

Mean Course Dimensional Loss in Inches of
Restored and Not-Restored Fabric
Over Five Refurbishings (N=3)

Restoration Weight	Double Knit Fabric 1	Double Knit Fabric 2	Single Knit Fabric 1	Single Knit Fabric 2
Pounds	Inches	Inches	Inches	Inches
0	-.22	-.21	-1.02	-1.00
8	-.28	-.21	- .69	-1.28
12	-.25	-.22	- .90	-1.17
16	-.24	-.26	- .93	-1.09

A greater difference in loss between yarn structure occurred in restored fabric than in non-restored in both double and single knit fabrics. The most consistent behavior in dimensional change occurred in Double Knit Fabric 2 knit of combination yarns. Single Knit Fabric 2 of combination yarn lost in decreasing amounts as the weight increased.

Analysis and Discussion

A four-factor analysis of variance with repeated measures on three replicates was used to determine the effect of the variables weight, yarn type, restoration, and number of refurbishing cycles on the dimensional behavior with course direction of laboratory fabrics over five refurbishings. Five statistically significant variables (Table 18) were identified: three main effects (fabric, $F=797.53$, $df=1$, $P=0.0001$; yarn, $F=7.13$, $df=1$, $P=0.0114$; refurbishing, $F=86.04$, $df=5$, $P=0.0001$); two two-way interactions (fabric by refurbishing, $F=174.09$, $df=5$, $P=0.0001$; yarn by refurbishing, $F=3.52$, $df=5$, $P=0.0051$); and two three-way interactions (fabric by yarn by weight, $F=3.09$, $df=3$, $P=0.04$; fabric by yarn by refurbishing, $F=5.80$, $df=5$, $P=0.0002$).

That the main effect, fabric, was statistically significant indicates that dimensional changes occurring over five refurbishings differed because of fabric structure.

Table 18

Analysis of Variance of Course
Dimensions by Refurbishing

Source	df	SS	F	P
Fabric	1	23.9778	797.5343	.0001
Yarn	1	0.2145	7.1349	.0114
Weight	3	0.0245	0.2721	NS
Refurbishing	5	12.9336	86.0378	.0001
F x Y	1	0.1128	3.7523	NS
F x W	3	0.0316	0.3499	NS
Y x W	3	0.665	0.7372	NS
F x R	5	5.0454	174.0938	0.0001
Y x R	5	0.1021	3.5237	0.0051
W x R	15	0.0453	0.5205	NS
F x Y x W	3	0.2785	3.0878	.0402
F x Y x R	5	0.1681	5.8014	.0002
F x W x R	15	0.0361	0.4154	NS
Y x W x R	15	0.0958	1.1014	NS
F x Y x W x R	15	0.1354	0.0911	NS

The difference in double knit and single knit structures had a significant effect on the dimensional changes in the course direction over five refurbishings. Mean dimensional measurement of all double knit samples following five refurbishings was 17.78 inches. The mean dimensional measurement for all single knit fabrics after five refurbishings was 17.21. A greater dimensional loss occurred in single knit structure.

The main effect, yarn, was statistically significant which indicates that yarn structure affects dimensional behavior. Fabrics knit of Yarn 2, combination of yarns, when analyzed over an N=144, lost dimension to 17.47 inches which was a greater loss than 17.52 inches in fabrics knit of yarn which was 100 percent textured polyester or 100 percent spun staple polyester.

The statistical significance of main effect, refurbishing, indicates that different dimensional behavior occurred among five refurbishings. The greatest change in the mean course dimension occurred after the first refurbishing (Table 19). Continued dimensional losses occurred by steadily decreasing amounts following each refurbishing. Over half the total dimensional loss accruing over the five refurbishings occurred as a result of the first refurbishing.

Table 19

Mean Course Dimensional Loss in Inches
by Refurbishings (N=48)

Refurbishings	Dimension	Change
	Inches	
0	17.92	
1	17.57	-.35
2	17.46	-.11
3	17.38	-.08
4	17.33	-.05
5	17.30	-.03
Total Change		-.62

After experimentation, the Duncan Multiple Range Test was used to test the significance of the mean course dimensions after refurbishing treatments (Table 20). A statistically significant change in dimension occurred in the double knits after the first and second refurbishings only. Statistically significant changes occurred after each of the five refurbishings in the single knits.

The two-way interaction, fabric by refurbishing, was a result of a different pattern of dimensional change in the two fabrics (Figure 6). Greater course dimensional loss occurred in single knit fabric over five refurbishings than in double knit (Table 21). Single knits showed a greater initial loss and steadily declining subsequent losses. Double knits showed the greatest loss after the first refurbishing but performed inconsistently following subsequent refurbishing treatments. Both fabric structures lost the greatest amount after the initial refurbishing. Single knits lost .58 inch and double knits lost .12 inch each of which were at least one-half the amount lost after five refurbishings.

Table 20

Mean Course Dimension in Inches of Test Fabric Over Five Refurbishings (N=24)

	Double Knit		Single Knit	
Refurbishing	Dimension	Change	Dimension	Change
0	17.93		17.91	
1	17.82	- .12	17.33	- .58
2	17.77	- .05	17.14	- .19
3	17.75	- .02	17.02	- .12
4	17.71	- .04	16.94	- .08
5	17.70	- .01	16.90	- .04
Total Change		- .25		-1.01

The statistically significant two-way interaction, yarn by refurbishing, indicates a different pattern of loss by yarn structure over refurbishing (Figure 7). Greater

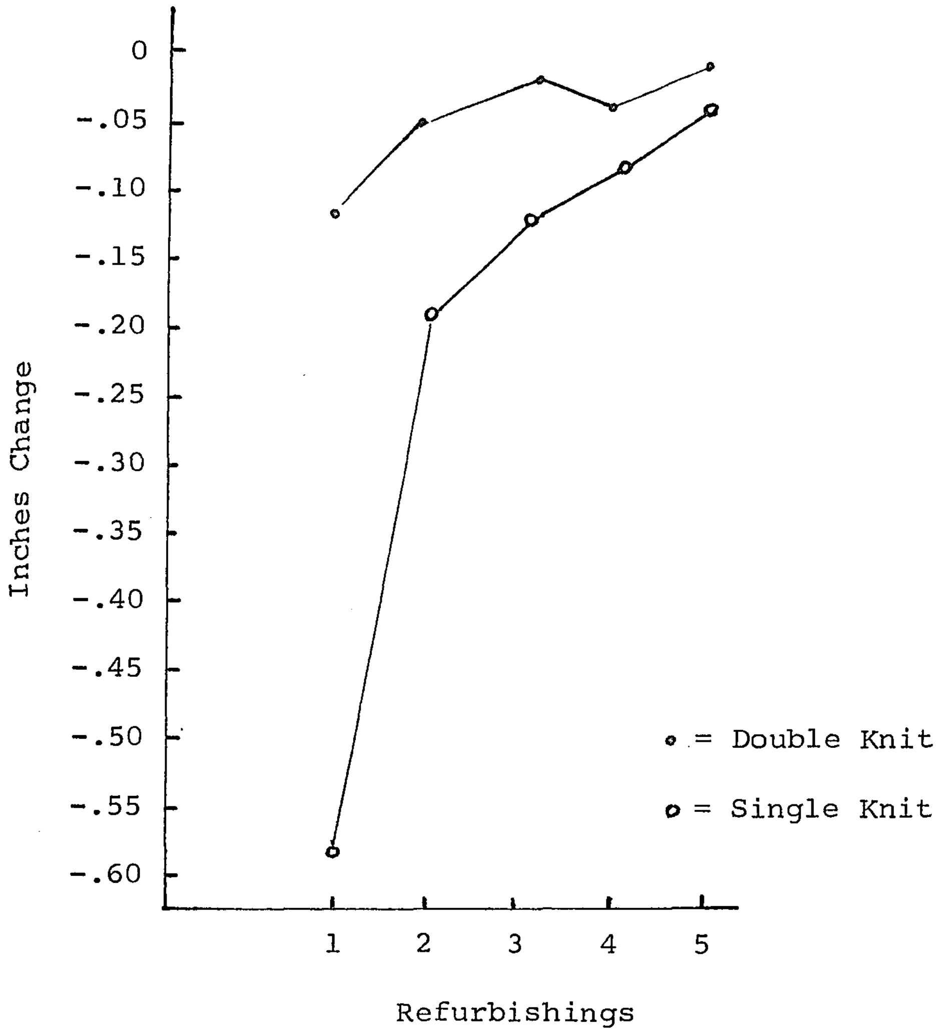

Figure 6

Mean Course Change of Fabric by Refurbishing
Over Five Refurbishings (N=24)

shrinkage occurred in fabric knit of combination yarn (Yarn 2) than of yarn knit of 100 percent filament or staple yarn (Table 22). Fabric knit of Yarn 1 decreased by slightly decreasing amounts until the fifth refurbishing when it reversed direction of dimensional change. Yarn 2 followed the same pattern as Yarn 1 through the fourth refurbishing, but continued to shrink after the fifth refurbishing.

Table 21

Mean Course Dimensional Loss in Inches of Fabric by Refurbishing Over Five Refurbishings (N=24)

	Double Knit		Single Knit	
Refurbishing	Inches	Change	Inches	Change
0	17.94		17.91	
1	17.82	- .12	17.33	- .58
2	17.77	- .05	17.14	- .19
3	17.75	- .02	17.02	- .12
4	17.71	- .04	16.94	- .08
5	17.70	- .01	16.90	- .04
Total Change		- .24		-1.01

Discussion of Dimensional Changes Following Refurbishing

Fabric structure was a highly significant variable affecting dimensional behavior. When all fabrics were

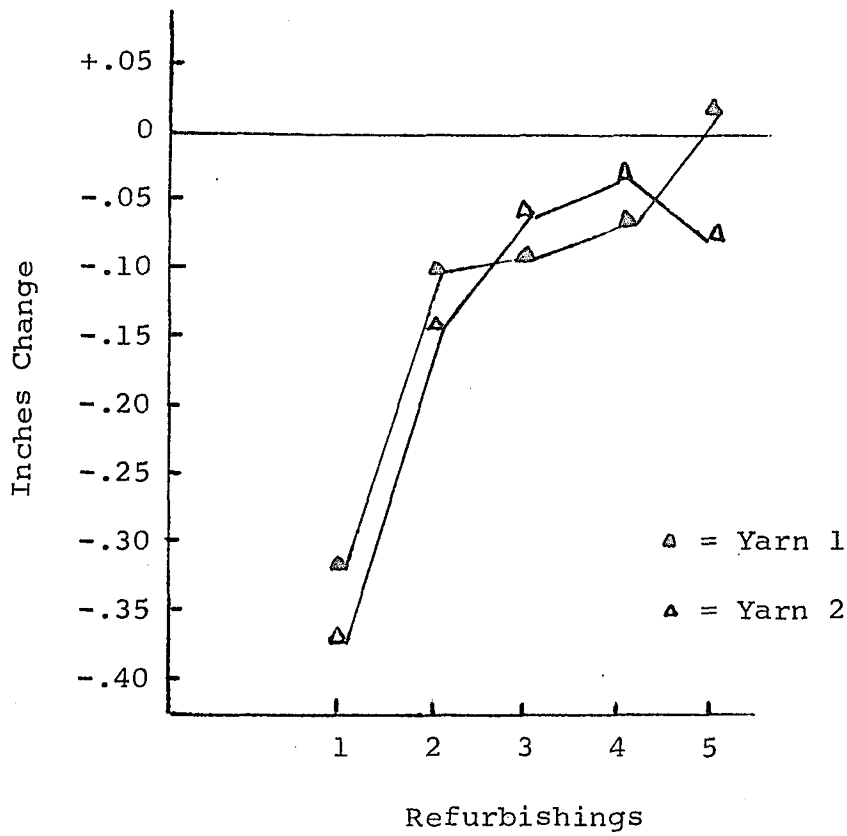

Figure 7

Change in Mean Course Dimension by Interaction of Yarn by Refurbishing of Impaled Fabric Over Five Refurbishings (N=24) analyzed together, neither the wale nor the course dimension met the standards of shrinkage currently adopted by industry.[63] The amount of shrinkage in both directions was acceptable under the proposed Dan River standards.[64] When all fabrics were considered together and when analyzed by fabric structure, the greater loss in dimension occurred in the wale direction. A greater difference in the amount of dimensional loss in the wale and course direction occurred in the double knits than in the single knits.

Table 22

Mean Course Dimensional Loss in Inches by Interaction of Yarn by Refurbishing Over Five Refurbishings (N=24)

	Yarn 1		Yarn 2	
Refurbishing	Measurement		Measurement	
	Dimension	Change	Dimension	Change
0	17.92		17.87	
1	17.60	- .32	17.55	- .37
2	17.50	- .10	17.41	- .14
3	17.41	- .09	17.35	- .06
4	17.34	- .07	17.32	- .03
5	17.36	+ .02	17.24	- .08
Average Total Change		- .32		-1.03

[63] Pratt, loc. cit.

[64] "Apparel Fabric Standards," loc. cit.

When analyzed by fabric structure (double knit and single knit), the double knit structure would meet both the current and proposed standards for fabric shrinkage. Single knit fabric would meet neither standard in either direction.

Refurbishing was a significant variable in both the wale and course direction. The number of refurbishings after which statistically significant shrinkage occurred was two in double knits in both fabric directions and five in single knits in both fabric directions. The greatest loss followed the initial refurbishing which is consistent with the general assumption that knit fabrics will return to a state of minimum internal elastic energy when refurbished the first time.

Yarn structure was a significant variable in the course direction only with the fabric knit of a combination of yarns losing the greatest amount. Weight was not a significant variable affecting dimensional behavior in either the wale or the course direction.

The two-way interaction, fabric by refurbishing, was significant in both the wale and the course direction. A different pattern of behavior occurred by fabric structure between refurbishings. The pattern of behavior was not identical by fabric direction.

Dimensional Changes Following Removal of Friction

When impaled fabrics were treated to release friction between yarns, double knit fabrics increased in dimension .04 inch and the single knits increased .05 inch in the wale direction. In the course direction double knits increased .03 per inch and the single knits increased .08 per inch (Table 23).

Table 23

Mean Dimensional Change in Inches of Impaled Fabric Before and After Removal of Friction (N=108)

Fabric	Wale Direction Inches			Course Direction Inches		
	Before	After	Change	Before	After	Change
Double Knit	17.98	18.02	+.04	18.03	18.06	+.03
Single Knit	17.76	17.81	+.05	17.90	17.98	+.08

Analysis and Discussion

A four-factor analysis of variance with repeated measures on three replicates was used to determine the effect of the variables weight, yarn type, restoration, and number of refurbishing cycles on the dimensional behavior in the wale direction of fabric samples impaled on Lilly's Shrinkage Restoration Frame with friction removed over five refurbishing cycles. Five statistically significant variables were identified: two main effects (fabric, F=81.50, df=1, P=0.0001; refurbishing, F=41.02, df=5, P=0.0001); two two-way interactions (yarn by weight, F=3.79, df=2, P=0.0362; fabric by refurbishing, F=17.74, df=5, P=0.0001); and one three-way interaction (fabric by yarn by weight, F=3.6, df=2, P=0.0419) (Table 24).

Wale dimension. The main effect, fabric, was significant at the P=.0001 level in the wale direction which indicates that one fabric structure increased in dimension more than the other when friction was removed. The mean wale dimension of double knits was 18.02 inches (N=108) and was 17.81 inches for single knits.

That the main effect, refurbishing, was significant indicates the amount of dimensional change which occurred after friction was removed varied among refurbishings (Table 25). The greatest loss occurred after the first refurbishing. An irregular pattern of amount of loss occurred over the five refurbishings.

The statistically significant two-way interaction, yarn by weight, indicates that fabric knit of differing yarns change dimensionally by different patterns.

Table 24

Analysis of Variance of Wale Dimension After Friction is Removed

Source	df	SS	F	P
Fabric	1	2.38	81.50	0.0001
Yarn	1	.03	.93	NS
Weight	2	.08	1.31	NS
Refurbishing	5	6.00	41.02	0.0001
F x Y	1	.002	.08	NS
F x W	2	.05	.82	NS
Y x W	2	.22	3.79	0.0362
F x R	5	1.77	17.74	0.0001
Y x R	5	.05	.52	NS
W x R	10	.10	.53	NS
F x Y x W	2	.21	3.6	0.0419
F x Y x R	5	.14	1.41	NS
F x W x R	10	.23	1.17	NS
Y x W x R	10	.13	.64	NS
F x Y x W x R	10	.15	.78	NS

Fabric knit of 100 percent textured filament or spun staple (Yarn 1) and restored with an 8-pound weight reached the largest dimension and the 12-pound weight the smallest. Fabrics knit of combination yarns (Yarn 2) restored by 12-pound weight reached a larger dimension than fabric restored either by a 16-pound weight or by a 8-pound weight (Table 26). Dimensions reached after removal of friction were more nearly the same for fabrics of both yarn types weighted with 16 pounds. The pattern of loss was exactly opposite in the two yarns (Figure 8).

Table 25

Mean Wale Dimension in Inches by Refurbishing of Impaled Fabric with Friction Removed (N=36)

Refurbishing	Measurement	
	Dimension	Change
0	18.23	
1	17.99	-.24
2	17.93	-.06
3	17.85	-.08
4	17.77	-.08
5	17.72	-.08
Total Change		-.54

A significant two-way interaction, fabric by refurbishing, indicates the two fabric types lost dimension by a different pattern over the five refurbishings (Table 27). Single knits exhibited greater change in dimension after friction (.77 inch) was removed than did double knits (.25 inch) after five refurbishings (Table 27). The amount of dimensional change which occurred after friction was removed varied between refurbishings in the two fabrics. The pattern of change (Figure 9) differed with double knit growing in size after the third refurbishing while single knit lost dimensions between each refurbishing.

Table 26

Mean Wale Dimensional Change in Inches of Yarn by Weight After Friction Removed (N=36)

Weight	Yarn 1	Yarn 2
8	17.92	17.86
12	17.89	17.98
16	17.90	17.93

Course dimension. Data were analyzed by a four-factor analysis of variance with repeated measures over three replicates to determine the effect of the variables of weight, yarn type, restoration, and number of refurbishing cycles on the dimensional behavior in the course direction of fabric impaled on Lilly's Shrinkage Restoration

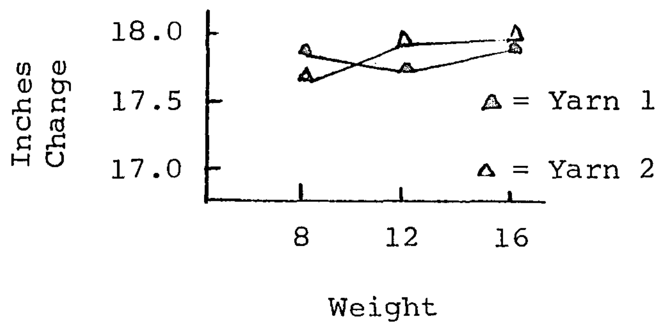

Figure 8

Mean Dimensional Change in Inches of Yarn by Weight After Friction is Removed (N=36)

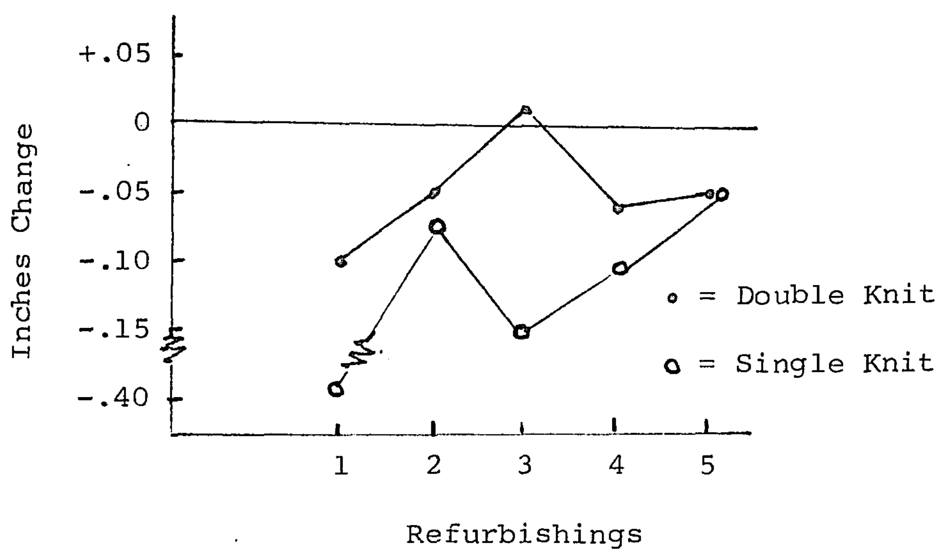

Figure 9

Change in the Mean Wale Dimension of Impaled Fabric by Refurbishing Over Five Refurbishings With Friction Removed (N=18)

Frame with friction removed. Four statistically significant variables were identified: (fabric, F=9.0244, df=1, P=0.0062; refurbishing, F=34.8653, df=5, P=0.0001); one two-way interaction (fabric by refurbishing, F=28.5315, df=5, P=0.0001); and one three-way interaction (fabric by yarn by refurbishing, F=5.4299, df=5, P=0.0003) (Table 28).

Table 27

Mean Wale Dimensional Change in Inches of Fabric by Refurbishing Over Five Refurbishings of Impaled Fabric with Friction Removed (N=18)

Refurbishing	Double Knit		Single Knit	
	Dimension	Change	Dimension	Change
0	18.16		18.30	
1	18.06	-.10	17.91	-.39
2	18.01	-.05	17.84	-.07
3	18.02	+.01	17.69	-.15
4	17.96	-.06	17.58	-.11
5	17.91	-.05	17.53	-.05
Average Total Change		-.25		-.77

The main effect, fabric, was statistically significant in the course direction which indicates a difference in behavior after friction was removed. The double knit fabric grew to 18.06 inches while single knit grew to only 17.98 inches.

Table 28

Analysis of Variance of Course Dimension
After Friction is Removed

Source	df	SS	F	P
Fabric	1	0.3545	9.0244	.0062
Yarn	1	0.1296	3.2985	NS
Weight	2	0.1107	1.4087	NS
Refurbishing	5	6.8471	34.8653	.0001
F x Y	1	0.0392	0.9981	NS
F x W	2	0.0199	0.2533	NS
Y x W	2	0.0270	0.3442	NS
F x R	5	2.6576	28.5315	.0001
Y x R	5	0.2018	2.1668	NS
W x R	10	0.0782	0.4199	NS
F x Y x W	2	0.2019	2.5704	NS
F x Y x R	5	0.5058	5.4299	.0003
F x W x R	10	0.1556	0.8354	NS
Y x W x R	10	0.1729	0.9281	NS
F x Y x W x R	10	0.1073	0.5759	NS

The main effect, refurbishing, resulted in statistically significantly different dimensional behavior among the five refurbishings. Slightly over one-half the total loss occurred after the first refurbishing (Table 29). Loss continued by increasing amounts through the fourth refurbishing. The fabric shrank the same amount after the fourth and fifth refurbishings.

Table 29

Mean Course Dimension in Inches of Impaled Fabric by Refurbishing After Friction Removed (N=36)

Refurbishing	Dimension	Change
0	18.36	
1	18.07	-.29
2	18.02	-.05
3	17.96	-.06
4	17.88	-.08
5	17.80	-.08
Total Change		-.56

The two-way interaction, fabric by refurbishing, showed statistically significantly different patterns of change in the course direction by each of the two fabric structures over five refurbishings (Table 30). Single knit fabrics changed dimension after friction was removed by increasing amounts from the second refurbishing through the fifth. The dimension of impaled double knit fabric with friction removed followed an erratic pattern of increase and decrease in amount of change between each of the five refurbishings (Figure 10).

Table 30

Mean Course Dimension in Inches of Impaled Fabric by Refurbishing After Friction Removed (N=18)

Refurbishing	Double Knit		Single Knit	
	Dimension	Change	Dimension	Change
0	18.20		18.53	
1	18.10	-.10	18.05	-.48
2	18.04	-.06	17.99	-.06
3	18.02	-.02	17.91	-.08
4	17.97	-.05	17.79	-.12
5	18.01	+.04	17.59	-.20
Total Change		-.19		-.94

<u>Friction removal</u>. After test samples were impaled for restoration, wale and course dimensions were read from two measuring tapes stretched across the sample. The samples were then flipped from underneath five times to release friction between yarns. The fabrics increased in dimension after friction between yarns was removed. Using overall means based on 216 measurements in both wale and course

direction, the wale dimension increased from 17.87 to 17.92 and the course dimension increased from 17.97 to 18.02.

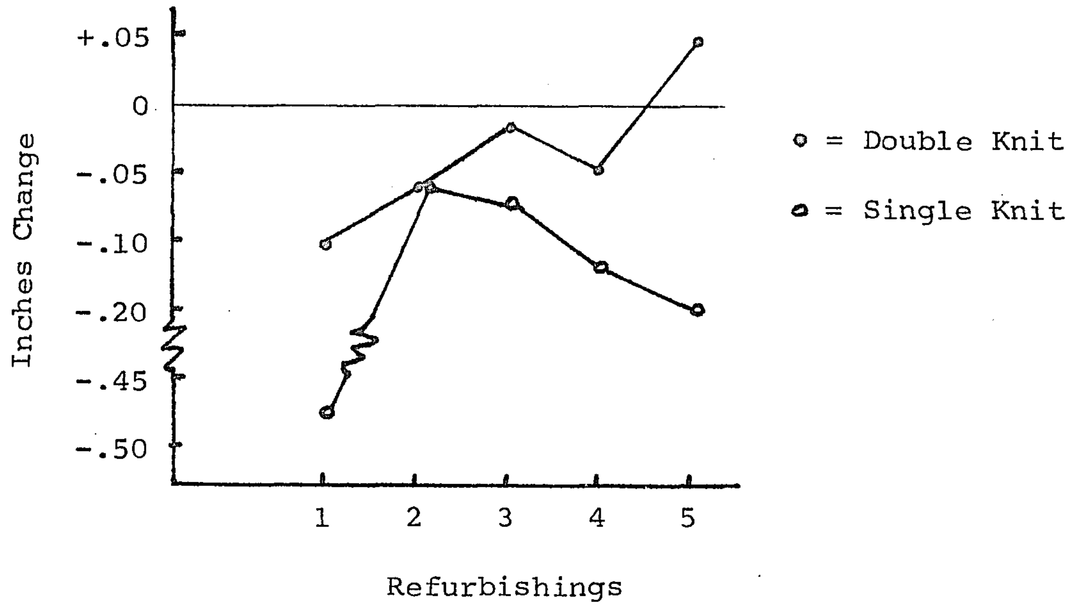

Figure 10

Change in Dimension of Impaled Fabric by Refurbishing After Friction Removed (N=18)

A t-test of difference between two means of samples of equal size was performed to determine whether the mean dimensions of samples with friction removed was significantly different from the impaled fabric without friction removed.[65]

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[65]Freund, loc. cit.

The obtained t values in the course direction and in the wale direction, (2.5 and 2.7, 430 df, P=.01) indicate that friction removal by physical manipulation of impaled test samples significantly changes the wale and course dimensions.

Discussion of Dimensional Changes Following Removal of Friction

The results which show that friction removal by physical manipulation makes a significant change in dimensions supports the generally accepted theory. The work of Scott and Murray[66,67] reported fabric relaxation. Both fabric structures (double knit and single knit) increased in the wale and course dimensions when friction was removed by manually manipulating fabric impaled on Lilly's Shrinkage Restoration Frame.

Fabric structure was a statistically significant variable in the dimensional behavior of both the wale and course directions. Single knits showed slightly more size increase in both wale and course direction than did double knits. There was a greater growth in the course direction in single knits.

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[66]Scott, loc. cit

[67]Murray, loc. cit.

Refurbishing was a significant factor in dimensional behavior in both the wale and course direction. Greater loss (1.03 inches) occurred in the wale than in the course (.56 inch).

When the effects of the two-way interaction of fabric by refurbishing was analyzed, the double knits increased more in the wale direction and the single knits increased more in the course direction. The single knits increased more than the double knits in both directions.

SPECIFICATIONS AND DESCRIPTION OF THE WEAR TEST

Participants

The wear test was conducted during the first 1975 Summer Session at the University of North Carolina at Greensboro. Participation by twenty female students from the School of Home Economics was voluntary. The experimental slacks were Misses size 10 and Misses size 12. Garment measurements were recorded before any tests were conducted (Appendix K). An equal number of subjects were chosen who, when questioned, said they wore one of the two sizes.

All slacks were styled for figure height of 5'5". The participants who wore size 10 ranged in height from

5'2" to 5'7-3/4" and those who wore size 12, 5'2-3/4" to 5'7". The crotch depth for those who wore size 10 ranged from 10 to 11-1/2 inches and from 10-1/2 inches to 13-3/4 inches for those who wore size 12 (Table 31).

The manufacturer's sizing for Misses size 10 slacks was 24-1/2 inch waist and 35-1/2 inch hip with tolerances of +3/4 inch and -1/2 inch. Participants who said they wore size 10 ranged in waist measurement from 23 to 27 inches and hip 35-1/2 to 37 inches. Manufacturer's size 12 was 26-inch waist and 37-inch hip, +3/4 and -1/2 inch. Participants who wore size 12 ranged in waist measurements from 25 to 28 inches and in the hip from 36-1/2 to 38 inches.

The manufacturer did not specify thigh size for garments. The thigh measurement for participants ranged from 19-3/4 inches to 22 inches for those participants wearing size 10, and from 20-1/2 inches to 25-3/4 inches for those wearing size 12. The weight of the size 10 participants ranged from 105 to 128 pounds and for size 12, from 116 to 130 pounds.

Garments

Twenty-four garments of Ponte di Roma double knit fabric from two dye lots were used in the wear tests:

Table 31

Demographic Data of Individual Wear Test Participants

Participants	Height	Weight	Age	Waist to Knee	Outseam	Crotch Depth	Waist	Hip	Thigh	Knee	Size Garment
1	5'2"	118	21-25	22	37-1/2	10	26	37	22	13-1/4	10
2	5'2-3/4"	116	16-20	23-1/2	38-3/4	10-3/4	25	37-1/2	23-1/4	14	12
3	5'3-1/2"	105	16-20	24	38-3/4	10-3/4	25	36	19-3/4	13-1/4	10
4	5'3-1/2"	116	21-25	23-1/2	39-3/4	11-1/4	25-1/4	36	21-1/2	13-1/4	10
5	5'3-1/2"	126	40+	24	39-1/2	11	25-3/4	37-3/4	20-1/4	14	12
6	5'4"	105	21-25	24-3/4	40	10-1/4	23	35-1/4	20	12-3/4	10
7	5'4"	130	21-25	24-1/2	41	11-1/4	26-1/4	37-1/4	21	13-3/4	12
8	5'4"	130	40+	23	40-1/4	11	28	37-3/4	25-3/4	14	12
9	5'4-1/2"	123	16-20	24	39-3/4	10-3/4	26-1/4	37-1/4	22	16	12
10	5'5"	126	21-25	24	40-3/4	10-1/2	25-1/4	37-1/4	22-1/4	14	12
11	5'5-1/2"	118	21-25	23-1/4	38-1/4	11-1/4	25-3/4	37	21-1/2	13-1/4	10
12	5'6"	120	26-30	25-1/4	42-1/2	11-1/2	26	36-1/4	21	13-3/4	12
13	5'6"	126	26-30	24	41-3/4	12	25-1/2	37	20-1/4	14	10
14	5'7"	117	16-20	25	41-1/4	13-3/4	25-1/4	37	22	13-1/2	10
15	5'7"	120	21-25	24-1/2	41-1/4	11-1/4	25-1/2	36-3/4	21-1/2	14-1/2	10
16	5'7"	120	31-35	25	41-3/4	12	25	37-3/4	20-3/4	14	12
17	5'7"	124	21-25	24-1/2	42	11-3/4	26	38	20-3/4	14	12
18	5'7"	124	31-35	24	40-3/8	10-1/4	27-1/2	37	22-1/2	14-1/2	12
19	5'7"	128	26-30	24	41	12-1/4	27	36-3/4	22	13-5/8	10
20	5'7-3/4"	120	21-25	24-1/2	41-1/4	11-1/4	25-1/2	36-3/4	21-1/2	14-1/2	10

ten Misses size 10 (5 blue, 5 maroon) and ten Misses size 12 slacks (8 blue, 2 maroon). Two slacks, one of each size and each dye lot, were held as control garments which were refurbished and not worn.

The mean wale and course count for the slacks indicated that some control and some test garments lost in wale or course count over refurbishings. No pattern of loss or gain in count could be detected (Appendixes M and N). The change in course count was greater than the wale count. More losses (4) occurred in size 12 than size 10 (2). More blue slacks lost dimension (6, or 40 percent) than maroon (1 or 11.1 percent).

ANALYSIS AND DISCUSSION OF THE WEAR TESTS

Participant Responses

For each of the six test periods, the minimum time of wear for each garment was six hours. Five physical activity categories were reported by the participants: leisure activities, study, active sports, class, and other. The categories most frequently reported were leisure activity followed by study and wear to class. The "other" activities with the highest frequencies were desk work, sewing, shopping, and driving (Appendix O).

Results of the Wear Test

In checking returned garments after the first Wear Test Period, it was found that one participant had removed all garment labels and manufacturer's tags. Two participants had shortened the slacks. Before refurbishing, the amount of fabric removed was determined and subsequent measurement adjusted to the original dimensional length.

Relatively little, if any, dissatisfaction was recorded by wear test participants. Only two participants wearing the slacks which shrank reported that the slacks fit more tightly than preferred. One reported tightness when donned and looseness when removed. One reported the slacks a looser fit than preferred. There was no pattern of consistency concerning preferred fit when garments decreased or increased in size over refurbishings (Table 32).

Statistical analysis of the wear test garments was based on data recorded from laboratory measurements of the 4 control and 20 experimental garments. Analysis of each group over five repeated refurbishings indicated there was more dimensional change (growth) occurring in the slacks which were worn than occurred in the control group (Table 33). Growth occurred in two of the three circumference measurements (hip and thigh) but in only one of the four lengthwise measurements (back seam).

Table 32

Change in Garment Fit Observed by Participants (N=688)

	Looser Than Preferred		Tighter Than Preferred	
	Donning	Removing	Donning	Removing
Hip	13	17	32	30
Thigh	29	22	31	14
Knee	24	0	25	0
Crotch	28	33	34	26
Inseam	33	2	35	1
Outseam	31	3	32	2

Table 33

Mean Dimensional Change in Inches of Test Groups Over Five Refurbishing Cycles

	Measurements (Mean Dimensional Change in Inches)						
	Circumference			Length			
Group	Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Outseam
Control	-.40	+.18	-.29	-.05	-.21	-.10	-.18
Experimental	+.41	+.31	-.06	-.23	+.03	-.19	-.19

Comparison of the combined groups (Table 34) over five refurbishing cycles indicated that the hip and thigh measurements increased in dimension. The greatest increase occurred after the second and third refurbishing. The amount of increase declined after the fourth refurbishing and then gained after the fifth, but not to the amounts reached after the second and third refurbishings. The circumference at the knee and the length of the front seam, inseam and outseam decreased in dimension between refurbishings. The back seam length increased slightly following the first two refurbishing treatments, and then decreased with subsequent treatments. All four lengthwise measures (front seam, back seam, inseam, outseam) showed decreased dimensions as a result of refurbishing treatment.

The mean dimensional change in inches for each group was analyzed statistically over five refurbishings. The control group (Table 35) showed a total decrease in dimensional change for all variables measured except the thigh, which increased after each of the five refurbishing treatments. An increase occurred in the hip measurements only after the third refurbishing and the front crotch measurement after the first two refurbishings.

Table 34

Mean Dimensional Change in Inches in Control and Experimental Wear Test Garments Measured After Refurbishing

Refurbishing	Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Outseam
	Measurements (Mean Dimensional Change in Inches)						
1	+.17	+.22	-.07	-.15	+.05	-.02	-.24
2	+.43	+.35	-.04	-.11	+.03	-.17	-.29
3	+.43	+.36	-.09	-.18	-.07	-.25	-.13
4	+.10	+.24	-.15	-.25	-.03	-.23	-.10
5	+.21	+.26	-.14	-.29	-.04	-.22	-.20

Table 35

Mean Dimensional Change in Inches of Control Test Garments Over Five Refurbishing Cycles

Refurbishings	Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Outseam
	Measurements (Mean Dimensional Change in Inches)						
1	-.44	+.13	-.25	+.04	-.06	-.06	-.19
2	-.44	+.13	-.25	+.16	-.06	-.00	-.38
3	+.31	+.38	-.31	-.03	-.31	-.16	-.22
4	-.69	+.19	-.31	-.16	-.34	-.22	-.07
5	-.75	+.06	-.31	-.25	-.28	-.06	-.07

Analysis of the data from the experimental garments measured over five refurbishings (Table 36) showed that the hip, thigh, and back seam measurements increased in dimension over five refurbishings. The hip and thigh increased after each refurbishing. The front seam measurement decreased only after the third. All other measurements decreased in dimension from the first through the fifth refurbishings.

Table 36

Mean Dimensional Change in Inches of Experimental Garments Over Five Refurbishing Cycles

	Measurements (Mean Dimensional Change in Inches)						
Refur-bishings	Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Outseam
1	+.29	+.25	-.04	-.19	+.07	-.01	-.26
2	+.61	+.40	.00	-.17	+.04	-.29	-.27
3	+.46	+.36	-.05	-.21	-.02	-.27	-.11
4	+.26	+.25	-.11	-.27	+.03	-.23	-.11
5	+.41	+.29	-.10	-.30	.00	-.25	-.22

Two-way analysis of variance of mean change scores of each of the seven area measurements taken on the garments show the hip measurement to be the only measurement which was statistically significant at the P=.01 level (Table 37).

For the test garments the mean hip measurement increase was .40 inch after five refurbishings; and there was a mean hip decrease of .75 inch in the control garments, for a total mean difference of .15 inch. Thigh dimensional changes were not statistically significant (Table 38). Both control and experimental garments increased in dimension--.06 inch and .29 inch respectively or a difference of .23 inch--in the area.

Table 37

Analysis of Variance of Mean Dimensional Changes at Hip Measurement

Source	df	SS	F
Group	1	10.80	9.79*
Subjects Within Groups	22	24.27	
Refurbishing	4	2.29	1.37
Group x Refurbishing	4	2.16	1.29
Refurbishing x Subjects Within Groups	88	36.81	

*Significant at P=.01

The dimensional change at the knee was not statistically significant when the two groups were compared

(Table 39). The control group decreased .31 inch in the knee and the test garment group decreased .10 inch for a difference of .21 inch.

Table 38

Analysis of Variance of Mean Dimensional Changes at the Thigh Measurement

Source	df	SS	F
Group	1	.31	.31
Subjects Within Groups	22	22.00	
Refurbishing	4	.41	1.74
Group x Refurbishing	4	.19	.79
Refurbishing x Subjects Within Groups	88	5.18	

The front seam length dimensional change difference (.05 inch) was not statistically significant (Table 40). Both garments decreased in dimension. However, there was a statistically significant change found in dimensions among refurbishings and in the interaction of test groups and refurbishings at P=.01. Figure 11 shows different behavior patterns as each change occurred in each test group from one refurbishing to another.

Table 39

Analysis of Variance of Mean Dimensional Changes at the Knee

Source	df	SS	F
Group	1	.86	2.68
Subjects Within Groups	22	7.07	
Refurbishing	4	.18	2.08
Group x Refurbishing	4	.009	.11
Refurbishing x Subjects Within Groups	88	1.91	

Table 40

Analysis of Variance of Mean Dimensional Changes of the Front Seam Length

Source	df	SS	F
Group	1	.53	.96
Subjects Within Groups	22	12.01	
Refurbishing	4	.48	10.86*
Group x Refurbishing	4	.15	3.46*
Refurbishing x Subjects Within Groups	88	.97	

*Significant at P=.01 level

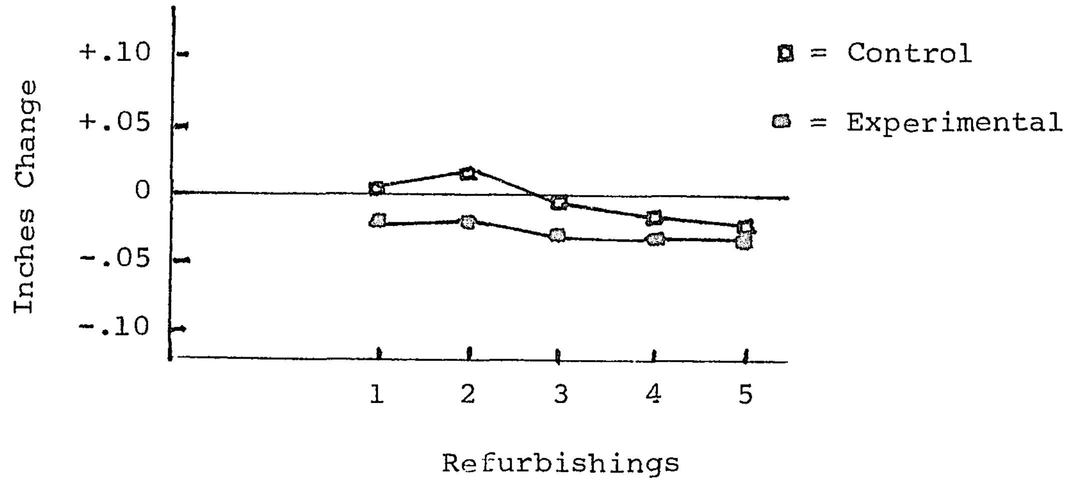

Figure 11

Dimensional Changes in Test Garments of Group by Refurbishing for Front Seam Length

Analysis of the back seam length shows no statistically significant difference in the dimensional changes occurring in the control and experimental garments (Table 41). The control garments decreased .38 inch and the experimental garments increased less than .01 inch for a total difference of .39 inch.

Analysis of the back seam length showed the only statistically different dimensional change occurred between refurbishing treatments at a P=.0224. No statistically significant interactions occurred between groups and refurbishing.

Table 41

Analysis of Variance of Mean Dimensional Changes of the Back Seam Length

Source	df	SS	F
Group	1	.95	1.134
Subjects Within Groups	22	.833	
Refurbishing	4	.25	2.99*
Group x Refurbishing	4	.17	1.98
Refurbishing by Subjects Within Groups	88	1.85	

*Significant at P=.01 level

Analysis of the inseam measurements indicated no statistically significant dimensional change occurred between the two test groups (Table 42). The control group decreased .06 inch and the experimental group decreased .25 inch. The dimensional changes which occurred in the inseam between each refurbishing cycle were statistically significant at P=.01. No statistically significant interaction occurred between groups and refurbishing.

Statistical analysis of the outseam measurement data shows no statistical significance between the dimensional changes occurring in the control and experimental garments (Table 43). The control garments decreased .07

Table 42

Analysis of Variance of Mean Dimensional
Changes of the Inseam Length

Source	df	SS	F
Group	1	.14	.442
Subjects Within Groups	22	7.16	
Refurbishing	4	.82	9.47*
Group x Refurbishing	4	.16	1.82
Refurbishing x Subjects Within Groups	88	1.91	

*Significant at the P=.01 level

Table 43

Analysis of Variance of Mean Dimensional
Changes of the Outseam Length

Source	df	SS	F
Group	1	.0002	.0007
Subjects Within Groups	22	8.39	
Refurbishing	4	.59	4.20*
Group x Refurbishing	4	.18	1.30
Refurbishing x Subjects Within Groups	88	3.11	

*Significant at P=.01 level

inch and the experimental garments decreased .22 inch. Statistically significant dimensional changes occurred in the pattern of dimensional change between refurbishings in the outseam measurements. No statistically significant interaction occurred between group and refurbishing.

The wale and course counts for both control and experimental garments were taken before testing and after each of five refurbishing cycles (Appendixes M and N). Analysis of the two sets of data over five refurbishings showed the wale count in both groups decreased (Table 44). However, in the course direction, there was an increase in the course count per inch in the experimental garments while the count in the control group decreased.

Table 44

Mean Change in Count Per Inch of Test Groups Over Five Refurbishings

	Mean Number Change by Count	
Test Groups	Wale	Course
Control	-.0850	-.2400
Experimental	-.0030	+.4450

Analysis of the test garments grouped together over five refurbishing treatments (Table 45) showed erratic behavior in the wale count. There was a decrease in count after the first, third and fourth refurbishings and an increase after the second and fifth refurbishings. The course count continued to increase for the first four refurbishings. The course count remained the same after the fourth refurbishing treatment.

Table 45

Mean Change in Count Per Inch by Count of Control and Experimental Garments Measured After Refurbishing

	Mean Change in Count	
Refurbishings	Wale	Course
1	-.0042	+.2797
2	+.0250	+.1542
3	-.1417	+.2125
4	-.0792	+.5042
5	+.1167	+.5042

The statistically significant changes occurred in both the wale (Table 46) and course (Table 47) counts between refurbishing treatments. Refurbishing was not statistically significant by groups.

Table 46

Analysis of Variance of Mean Change in Wale Count

Source	df	SS	F
Group	1	0.1120	.049
Subjects Within Group	22	2.27	
Refurbishing	4	0.9408	4.2638*
Group x Refurbishing	4	0.4888	2.0338
Refurbishing by Subjects Within Groups	88	4.8544	

*Significant at P=.01 level

Table 47

Analysis of Variance of Mean Change in Course Count

Source	df	SS	F
Group	1	7.8204	3.46
Subjects Within Groups	22	2.259	
Refurbishing	4	2.5913	3.82*
Group x Refurbishing	4	0.4167	0.6147
Refurbishing x Subjects Within Groups	88	14.9120	

*Significant at P=.01 level

Discussion of Dimensional Changes in Wear Test

There was a statistically significant difference in the dimensional behavior of control and test garments in the hip area. Control garments lost in dimension over five refurbishings while the test garments grew in dimension. These findings support the results reported by Scott[68] where behavior of garments in wear was acceptable, but failed when measured lying flat after refurbishing.

The same pattern of behavior (growth) was found in the thigh area in both the control and wear test garments. Although there were no statistically significant differences, more growth occurred in the test garments.

The test garments grew in the back seam area while the control decreased. Although there was not a statistically significant amount of change in the test garments, it is logical that the back seam would be under more strain in wear and would show growth. Less mean change occurred in the test garments in the knee area, but more in the front seam, inseam and outseam.

Statistically significant differences occurred among refurbishing in the front seam and inseam. One

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[68] Scott, loc. cit.

two-way interaction, group by refurbishing, was significant for the front seam. This indicates a difference in behavior by group over refurbishings. The control group grew in dimension after two refurbishings before subsequently shrinking in dimension. The wear test garments decreased in dimension after each of five refurbishings.

CHAPTER V

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The increasing usage of knit fabrics has focused attention on the problem of their dimensional stability. The dimensional stability of any textile depends on its chemical nature, morphological structure, fabric geometry, fiber surface characteristics, and friction between yarns. Knit structures are easily distorted by low force loads such as those encountered in donning and wearing a garment and fail to return completely to the original dimensions. Distortion of knit fabrics contributes to shrinkage, two types of which are restoration and consolidation. Restoration shrinkage is the amount of dimensional loss remaining after distortion. Consolidation shrinkage is a return to a minimum dimension when friction between yarns and fibers or forces within fibers are released by refurbishing.

Shrinkage tolerances for knit fabrics are presently based on woven fabric standards taken after five home launderings. It is generally believed that different tests are needed for knit and woven structures. Since dimensional limits are based on behavior after laundering, it is thought that tests for dimensional behavior of knits should include restoration as well as refurbishing. Restoration tests currently include wear tests, hand restoration, and the Knit Shrinkage Gauge. W. N. Lilly developed the Shrinkage Restoration Frame to measure restoration shrinkage. He proposed a test method which would measure dimensional change under conditions more similar to wear than those in use. No empirical data had been collected using this instrument.

It was the purpose of this study to establish laboratory procedures which utilize the Shrinkage Restoration Frame for the measurement of restoration shrinkage of weft-knit structures. Specifically, the objective was to determine whether a significant difference occurs in measurements of restoration shrinkage in weft-knit fabrics which vary in structure and yarn type using the Shrinkage Restoration Frame after the following:

1. application of 8, 12, and 16-pound weights
2. restoration after each of five refurbishing cycles

The results of experimentation with the restoration frame were compared to the shrinkage and restoration of garments made of similar fabrics worn and refurbished five times.

SUMMARY OF THE INVESTIGATION PROCEDURE

The investigation procedure consisted of laboratory testing and a wear test. Weft-knit fabrics used in the laboratory test consisted of two plain double knits (Ponte di Roma and mock Ponte di Roma) and two plain single knits of 100 percent polyethylene terephthalate (PET) polyester produced by two fiber manufacturers and available from fabric stock of North Carolina fabric producers in December and January, 1974-75. One double knit and one single knit contained a combination of filament and spun yarns. One double knit was of 100 percent textured filament and one single knit was of 100 percent spun yarns. Consolidation shrinkage and restoration shrinkage only were tested. Slacks used in the wear test were constructed from two dye lots of Ponte di Roma double knit fabric knit of 100 percent textured polyethylene (PET) polyester similar to that used in the laboratory test. It was assumed that similar fabric would behave in a like manner in the laboratory and wear tests.

The test instrument for the laboratory was Shrinkage Restoration Frame, a 20-inch square Plexiglas instrument raised 9 inches from the table surface. Sixteen sewing machine needles on which fabric was to be impaled were placed around the top of the frame so none were directly opposite each other. Tenpin bowling balls were used for restoration weights. Fiber glass dressmaker measuring tapes were used to obtain dimensional measures.

Pretesting. To achieve experimental accuracy, experimentation with fabrics and equipment determined (1) the optimum time interval for the elongation of fabrics, (2) dimension and marking of test fabrics, and (3) laundering and drying temperatures.

Four fabrics which varied in fiber content or in yarn and knit structure were tested under static weight of the 16-pound tenpin bowling ball and dimensional change was recorded at eight time intervals. Measurements were read from two dressmaker measuring tapes of stable construction stretched across the sample. No significant dimensional change occurred in any of the time intervals after ten seconds.

Three sample sizes (27 x 27 inches, 24-inch wale by 27-inch course, 27-inch wale by 24-inch course) were tested to ascertain whether the amount of fabric extending beyond the needles and overhanging the Shrinkage Restoration Frame would affect elongation readings. A difference occurred in the wale direction as the overhang varied, but not in the course direction. Samples for the laboratory test were cut 27 inches in the wale by 24 inches in the course direction.

To determine the area necessary to give the most accurate measurements for dimensional change, a 16-inch and an 18-inch square were drawn on the same sample and measured while the fabric was impaled and restored on the Shrinkage Restoration Frame. Since there was no difference in the amount that either of the marked squares extended, the 18-inch square was chosen for ease of marking with a Cluett, Peabody and Company mechanical marker modified with a center mark on each side.

A 20-3/8-inch square template was developed: (1) to mark the position of each pin, the center of each side, and five placement positions for centering the mechanical marker; (2) to center samples on the Shrinkage Restoration Frame, and (3) to guide in the impaling of samples on the Shrinkage Restoration Frame. Tape was positioned on a flat surface to define the perimeters of the Shrinkage Restoration Frame and measuring tape holders for greater accuracy in measuring.

Laboratory test. Twelve samples of each fabric were cut, coded, and marked (1) with the template and (2) for measuring dimensions. Five random wale and course counts were taken after samples had rested in a flat state for at least four hours before any tests were performed, and after each of five refurbishing cycles. Three measurements in both the wale and course direction were taken. Three control samples of each fabric were refurbished repeatedly without restoration between refurbishings. Three samples of each fabric were restored by either an eight, a twelve, or a sixteen-pound tenpin bowling ball for ten seconds. Wale and course dimensional measurements were taken when the sample was impaled on the Shrinkage Restoration Frame and after friction was removed. The restored fabrics were then refurbished and measured flat after resting for four hours. Four-pound loads of test fabrics and dummy pieces were refurbished by AATCC Test Method 135-1973 in a Kenmore washer (model 42201) with detergent WOB and tumble dried in a Kenmore dryer (model 64401). The fabric samples were handled as little as possible and placed on a flat surface in a room in which the atmosphere varied from 90F and 58%RH to 70F and 72%RH and where dimensional measurements and wale and course count were taken.

Wear test. The 24 double knit slacks in the wear test were made by one manufacturer in one style. Wale and course count and 7 dimensional measurements were recorded prior to issuing experimental garments to the participants. The system developed for measuring the slacks incorporated a minimum amount of handling. Garment measurements were taken before wearing, after being worn, and after refurbishing and resting flat for four hours using bench marks established for measuring. The twenty volunteer participants in the wear test were female college students. Ten of the participants normally wore Misses size 10 slacks and ten normally wore size 12 slacks. Each participant was instructed to wear the slacks six hours during each of six wear test periods. No restrictions were placed on the type of activity, but participants were asked to record activities participated in during wear. After donning slacks and before removing them, the participants were asked to record their reaction to the fit of the slacks. The slacks were returned to the laboratory for measurement and refurbishing. The slacks were refurbished in a four-pound load of slacks or slacks and dummy pieces in the same laundry equipment and using the same procedures used in the laboratory test.

HYPOTHESES

Five null hypotheses were tested. A probability of .05 was the level of rejection chosen. Whether the dimensional changes are significant in practical applications will have to be judged by the intended use of the data.

Hypothesis 1. There is no difference in the dimensions of weft-knit fabrics measured flat after consecutive refurbishing cycles and no restoration and those measured flat following refurbishing after restoration between each of five refurbishing cycles. The four-factor ANOVA on repeated measures of three replicates showed that weight was not a significant main effect (wale, $F=2.02$, $df=3$, NS; course, $F=0.27$, $df=3$, NS). The hypothesis was not rejected. These findings are contrary to the results of earlier research[69] and observations by researchers[70,71] has indicated that restored fabric would show less dimensional loss than fabric refurbished without restoration. Variance from the expected results might have resulted from the fabric being restored by less force load than occurs in wear since

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[69]Scott, loc. cit.

[70]Pratt, loc. cit.

[71]Lilly, loc. cit.

the heavier load (16-pound weight) generally had less variation in change than lighter loads. This would indicate the need for further testing to establish the appropriate load force when restoration is needed. The absence of conditions such as heat and moisture which are present when garments are worn might also have caused variations in results.

It was found that greater dimensional loss occurred after five consecutive refurbishings without restoration in the wale direction of double knit fabric of a combination of yarns and in the course direction of single knit fabric of 100 percent spun staple yarns. This gave some support to the alternative hypothesis that greater loss would occur in fabric refurbished without restoration than those refurbished and restored.

Refurbishing was a statistically significant main effect (wale, $F=143.79$, $df=5$, $P=.0001$; course, $F=86.04$, $df=5$, $P=.0001$). The greatest loss occurred after the first refurbishing in both knit structures. This is consistent with expected behavior of knit fabrics.

Hypothesis 2. There is no significant difference in the dimensional behavior of fabrics with similar knit construction but with different yarn structure refurbished and then restored under three conditions of weight.

Statistical analysis by a four-factor ANOVA over repeated measures of three replicates showed the hypothesis could not be rejected since yarn was a significant factor in the course direction (wale, $F=0.66$, $df=1$, NS; course, $F=7.13$, $df=1$, $P=.01$).

Fabric was a statistically significant main effect in both fabric directions on dimensional behavior (wale, $F=944.93$, $df=1$, $P=.0001$; course, $F=797.53$, $df=1$, $P=.0001$). Single knit fabrics decreased in dimension more than double knits. This behavior also is consistent with known fabric behavior.

The two-way interaction of fabric by yarn was not statistically significant (wale, $F=0.30$, $df=1$, NS; course, $F=3.75$, $df=1$, NS) which indicates there is no difference in the pattern of dimensional loss of fabric structure over yarn structure.

Hypothesis 3. There is no difference in impaled sample measurements before and after friction is removed. The hypothesis was rejected and the alternate accepted as determined by a t-test of difference between two means of samples of equal size.

Fabric impaled with friction removed grew in dimension in both directions (P=0.05). Growth was probably attributable to both gravitational pull and friction release. The dimensional behavior of fabrics with gravitational pull similar to that which occurs in garments in wear should be investigated further.

The difference in dimension of fabric after friction removal supports Murray's[72] proposal to remove friction before garment cutting to reduce fabric size and therefore garment shrinkage. Removal of friction[73,74] was included in previous research to remove possible effects of friction when conducting tests for bagging. No direction of change was stated. This study supports the idea that friction between yarns is a variable in fabric dimensional behavior. Further study is needed to determine the behavior of fabric suspended horizontally without support and fabric suspended vertically when friction is removed.

<u>Hypothesis 4</u>. There is no significantly greater dimensional loss by each of the four test fabrics

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[72] Murray, loc. cit.

[73] Grunewald and Zoll, loc. cit.

[74] Correspondence, Frank B. Lutz, loc. cit.

refurbished and restored five times than after one and three refurbishings. This hypothesis was not rejected based on results of the Duncan Multiple Range Test. Results were the same for both fabrics in both fabric directions. The double knit fabric did not change significantly between refurbishings after the second refurbishing. Single knits continued to change significantly after each of the five refurbishings.

The knowledge that significant shrinkage between refurbishings ceases after two refurbishings would be of value to home sewers who could subject double knit fabrics to two refurbishing cycles before cutting out garments. Fabric producers and garment manufacturers might also be able to reduce the number of cycles for double knit fabric when conducting tests.

These results indicate that tests and test standards need to be established for fabric and yarn structure. Further tests could establish parameters to be projected to all fabrics or to set standards for specific yarn and fabric structures.

Hypothesis 5. There is no difference in the circumference of hip, thigh and knee or the length of the crotch, inseam and outseam on slacks worn between, before any, and after each of five refurbishings and slacks refurbished and not restored. The hypothesis was not rejected since only one circumference measurement (hip) was statistically significant as determined by a two-factor ANOVA on change scores with repeated measures. Hip measurements showed a plus dimensional change in test garments but not in the laboratory test. This supports the findings of earlier research by Scott.[75] The test method for the Shrinkage Restoration Frame needs further refinement to replicate wear test behavior.

Conclusions

The purpose of this study, that of establishing procedures for measurement of restoration shrinkage of weft-knit fabrics, was partially achieved. Replicable laboratory procedures were established for precise location of the Shrinkage Restoration Frame, marking the test samples, time interval of restoration, and the direction of sample dimensions. The removal of friction was a statistically significant test procedure. Empirical data using the

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[75] Scott, loc. cit.

Shrinkage Restoration Frame was obtained and could be the basis for further study.

Results obtained using the Shrinkage Restoration Frame for dimensional behavior following refurbishing were those to be expected of weft-knit fabrics. Results of tests involving restoration weight affecting dimensional behavior differed from the expected results. Further, the results of the laboratory tests and the wear tests differed.

Four main effects were analyzed statistically: fabric, yarn, weight, and refurbishing. Fabric and refurbishing were statistically significant factors affecting dimensional behavior. Single knit fabrics showed greater dimensional loss than double knit. Statistically significant shrinkage between refurbishings did not occur after two refurbishings in double knit. Statistically significant shrinkage occurred between each of five refurbishings in single knits.

No clear-cut evidence was found to support the hypothesis that yarn structure was a significant factor. It was found that the weights selected for analysis did not significantly affect dimensional behavior.

A procedure for measuring garments with a minimum amount of handling was developed. Using this procedure bench marks were established to assure accuracy of repeated measurements. The two-factor analysis of variance on change scores of repeated measures showed the hip measure grew a statistically significant amount in wear. This result did not agree with the laboratory test results of restored fabrics. This indicates test conditions need to be modified to replicate test conditions.

RECOMMENDATIONS

Although this study did not validate the suggested weights as replicating wear conditions, the results indicate a need for further research to develop a test which does validate the behavior of knit structures in wear.

Studies in the following areas are suggested:

1. Establish the behavior properties of knit structures by yarn structures.

2. Test identical fabrics on the Shrinkage Restoration Frame and the Shrinkage Gauge.

3. Test bagging on the Shrinkage Restoration Frame.

4. Test the effect of horizontal gravitational pull on fabric dimensions using the Shrinkage Restoration Frame and vertical gravitational pull.

5. Validate restoration on the Shrinkage Restoration Frame by using garments constructed of the laboratory test fabrics.

6. Test fabric on the Shrinkage Restoration Frame with heat and moisture similar to body conditions.

7. Compare data on dimensional changes with and without friction removal.

8. Correlate test fabrics restored a short time to those restored a long time.

9. Investigate the dimensional behavior of garments with varying amounts of difference between body measurements and garment measurements.

10. Establish validation of test procedures by repeating the test in another laboratory by other investigators.

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APPENDIX A

Original Fabric Data

Fabric ____________________

Sample Replication _______

Measurements:

Wales Per Inch __________

____

____

____

____

Courses Per Inch __________

____

____

____

____

Sample Size from 18 Inch Bench Marks:

Walewise __________

____

____

Coursewise __________

____

____

Weight ________________________

Weight per square yard _______

APPENDIX B

Impaled Fabric Test Data

Fabric ___________

Sample ___________

Ball Weight _____

Group Test Number _____

Measurements from 18 Inch Bench Marks:

Sample Size, Flat, 4 Hours Recovery

Wale ___________

____

____

Course ___________

____

____

Sample Size, Impaled,

Wale ___________

____

Course ___________

____

Sample Size, Impaled, Friction Removed

Wale ___________

____

Course ___________

____

Sample Size, Impaled, Weighted

Wale ___________

____

Course ___________

____

Sample Size, Impaled Immediate Removal

Wale ___________

____

Course ___________

____

Sample Size, Flat

	Immediate	4 Hours Recovery
Wale	___________	___________
	___________	___________
	___________	___________
Course	___________	___________
	___________	___________
	___________	___________

APPENDIX C

Fabric Refurbishing Test Data

Fabric __________

Sample __________

Ball Weight _____

Refurbishing Cycle _____

Test Run Number _____

Sample Size, Flat, Immediate After Refurbishing

Wale __________ Course __________

__________ __________

__________ __________

Sample Size, Flat, 4 Hours Recovery After Refurbishing

Wale __________ Course __________

__________ __________

__________ __________

Wales Per Inch __________ Courses Per Inch __________

__________ __________

__________ __________

__________ __________

__________ __________

APPENDIX D

Garment Wear Test Data

Participant #__________

Wale: __, __, __, __, __ Course: __, __, __, __, __

Refurbishing	Waist	Hip	Thigh	Knee	Front Seam	Back Seam	In Seam	Out Seam	
1 W C									After 4 hrs.
									After wear
__ __									After 4 hrs.
__ __ __ __									After refurbishing
__ __ __ __									After 4 hrs. relaxing
2 W C									After wear
__ __									After 4 hrs.
__ __ __ __ __ __									After refurbishing
__ __									After 4 hrs.
3 W C									After wear
__ __									After 4 hrs.
__ __ __ __									After refurbishing
__ __ __ __									After 4 hrs.
4 W C									After wear
__ __									After 4 hrs.
__ __ __ __									After refurbishing
__ __ __ __									After 4 hrs.
5 W C									After wear
__ __									After 4 hrs.
__ __ __ __									After refurbishing
__ __ __ __									After 4 hrs.

APPENDIX E

Participant Data Sheet

Participant Code Number _____

Personal Data:

Name ______________________

Campus Address ______________

Campus Telephone ____________

Height ______________________

Weight ______________________

Age (Check one)

16 - 20 _____

21 - 25 _____

26 - 30 _____

31 - 35 _____

36 - 40 _____

Over 40 _____

Size slacks normally worn _____

Occupation ___________________

Personal Measurements:

Lengthwise:

Waist to where the knee bends _____

Outseam waist to floor (right side) _____

Crotch waist to chair seat while seated (right side) _____

Circumference:

Waist _____

Hip (8 inches below waist) _____

Thigh (just below crotch, parallel to floor) right leg _____

Knee (right leg) _____

APPENDIX F

Participant Questionnaire

Name:__________________ Date Worn:____________

Directions:

A. Record your reaction to the fit of the garment using the number 5,4,3,2,1. Five (5) represents the highest score while one (1) indicates the lowest score.

5 - excellent (preferred fit, most comfortable length and width)

4 - very good (slightly less comfortable than preferred fit but not objectionable)

3 - good (noticeably less comfortable than preferred fit)

2 - fair (uncomfortable in length and/or width but wearable)

1 - poor (not wearable)

B. Check the direction of fit in the appropriate column only if the garment is not the preferred fit. For example, if the waist is rated 4, indicate whether it is tighter or looser than preferred.

	When garment is put on			Just before removing garment		
	Rating	Looser	Tighter	Rating	Looser	Tighter
Waist	___	___	___	___	___	___
Hip	___	___	___	___	___	___
Thigh	___	___	___	___	___	___
Knee	___	___	___	___	___	___
	Rating	Longer	Shorter	Rating	Longer	Shorter
Crotch	___	___	___	___	___	___
Inseam	___	___	___	___	___	___
Outseam	___	___	___	___	___	___

C. After wearing, record the following information:

Wear time: (check one) __6 hours __over 6 hours
Occasion: __Active sports __Leisure activity
__Class __Studying __Other (explain)

____

APPENDIX G

Mean Wale Count of Laboratory Test Fabric
Under Four Weight Conditions Over
Five Refurbishings (N=48)

Fabric	Refur-bishing	0		8		10		12	
		C*	R**	C*	R**	C*	R**	C*	R**
Double Knit 1	0	31.1	0.7	31.4	1.0	31.1	0.8	31.0	1.0
	1	31.3	0.7	31.3	0.8	31.3	0.8	31.2	1.0
	2	31.3	0.5	31.4	1.2	31.3	1.0	31.4	0.5
	3	31.4	0.8	31.5	1.0	31.4	0.8	31.5	1.2
	4	31.5	0.7	31.3	0.8	31.2	1.2	31.5	0.5
	5	31.5	0.8	31.6	0.7	31.5	0.7	31.5	1.0
Double Knit 2	0	29.4	0.8	29.2	0.7	29.3	0.5	29.2	0.7
	1	29.2	0.8	29.6	0.7	29.5	0.7	29.5	0.5
	2	29.6	0.7	29.6	0.8	29.5	0.7	29.5	0.7
	3	29.7	1.0	29.8	0.8	29.7	0.7	29.5	0.5
	4	29.7	0.7	29.7	0.7	29.9	0.8	29.7	0.7
	5	29.7	0.8	29.9	1.0	29.7	0.8	29.7	0.7
Single Knit 1	0	24.1	0.7	24.4	0.7	24.4	0.7	24.1	0.8
	1	24.8	0.7	25.1	0.7	25.0	1.0	24.5	1.2
	2	25.0	1.3	25.3	1.0	25.1	1.0	25.1	1.2
	3	25.3	0.8	25.6	1.3	25.3	1.0	25.3	1.2
	4	25.4	1.3	25.6	1.2	25.6	1.0	25.4	1.3
	5	25.4	1.0	25.6	0.8	25.6	1.2	25.4	0.8
Single Knit 2	0	24.7	0.3	24.5	1.3	24.6	0.8	24.7	0.2
	1	25.3	0.8	25.6	0.8	26.0	0.8	25.8	0.8
	2	25.7	1.0	25.8	0.7	26.0	1.0	26.0	1.0
	3	25.8	0.7	25.9	0.8	26.2	0.7	26.2	0.7
	4	25.7	0.8	25.9	1.2	26.0	1.3	26.0	1.0
	5	26.0	0.7	26.2	1.5	26.4	1.0	25.5	1.3

Column heading: Pounds Weight Applied (0, 8, 10, 12)

* = Count

** = Range

APPENDIX H

Mean Course Count of Laboratory Test Fabric
Under Four Weight Conditions Over
Five Refurbishings (N=48)

Fabric	Refur- bishing	Pounds Weight Applied 0		8		12		16	
		C*	R**	C*	R**	C*	R**	C*	R**
Double Knit 1	0	55.7	1.3	55.7	1.3	56.3	0.7	56.1	0.7
	1	56.3	1.7	56.0	1.3	56.4	1.7	56.4	1.3
	2	56.1	0.7	56.4	1.0	56.3	0.7	56.7	1.3
	3	56.3	0.7	56.3	1.3	56.6	1.3	56.7	1.0
	4	56.5	1.0	56.5	1.0	56.8	1.0	57.0	1.0
	5	56.4	1.0	56.5	1.0	56.7	1.0	56.8	1.3
Double Knit 2	0	39.5	1.7	40.1	0.3	39.6	0.7	39.9	1.0
	1	39.9	1.3	40.3	1.7	40.0	1.3	40.4	0.7
	2	40.4	0.7	40.7	0.7	40.2	0.7	40.5	1.0
	3	40.6	1.0	40.9	1.7	40.5	0.7	40.3	1.3
	4	40.5	1.3	40.6	1.3	40.6	1.7	40.5	0.7
	5	40.7	1.7	40.9	1.0	40.6	1.0	40.7	1.0
Single Knit 1	0	24.3	0.0	24.3	0.7	24.0	0.8	24.1	0.8
	1	24.9	1.0	24.8	1.0	24.6	0.7	25.0	0.7
	2	25.3	1.0	25.0	0.8	25.2	0.7	25.2	0.7
	3	25.4	0.8	25.4	0.0	25.2	0.7	25.4	0.8
	4	25.5	0.8	25.5	0.8	25.2	1.0	25.6	0.8
	5	25.5	1.0	25.6	1.3	25.6	1.0	25.8	1.3
Single Knit 2	0	25.4	0.8	24.9	0.3	24.8	1.0	24.9	0.5
	1	25.6	1.0	25.9	0.8	25.7	1.2	25.9	0.7
	2	25.9	1.0	26.1	1.0	26.0	0.8	26.2	1.0
	3	26.0	0.8	26.6	0.7	26.3	0.8	26.5	0.3
	4	26.5	0.7	26.4	1.0	26.3	0.7	26.3	1.2
	5	26.4	1.3	26.7	1.3	26.3	1.0	26.2	0.8

* = Count Per Inch

** = Range

APPENDIX I

Mean Wale Dimension in Inches of Samples by Weight Over Refurbishings (N=3)

Pounds Weight	Refurb.	Double Knit Fabric 1	Double Knit Fabric 2	Single Knit Fabric 1	Single Knit Fabric 2
		Inches	Inches	Inches	Inches
	0	17.90	17.91	17.81	17.87
	1	17.74	17.78	17.52	17.42
	2	17.69	17.71	17.26	17.21
0	3	17.68	17.69	17.11	17.16
	4	17.63	17.63	16.99	17.03
	5	17.60	17.57	16.92	16.92
	0	17.96	17.90	17.91	17.92
	1	17.76	17.74	17.33	17.22
	2	17.72	17.68	17.18	17.08
8	3	17.68	17.64	16.96	16.98
	4	17.64	17.61	17.00	16.95
	5	17.60	17.62	16.83	16.58
	0	17.95	17.90	17.72	17.93
	1	17.77	17.77	17.35	17.33
	2	17.73	17.70	17.14	17.16
12	3	17.68	17.67	16.97	16.94
	4	17.66	17.64	16.90	16.95
	5	17.59	17.62	16.81	16.79
	0	17.99	17.89	17.87	17.96
	1	17.77	17.73	17.34	17.32
	2	17.73	17.69	17.18	17.15
16	3	17.70	17.61	17.05	17.03
	4	17.65	17.60	16.85	16.98
	5	17.64	17.60	16.92	16.93

APPENDIX J

Mean Course Dimension in Inches of Sample by Weight Over Refurbishing (N=3)

Pounds Weight	Refurb.	Double Knit Fabric 1	Double Knit Fabric 2	Single Knit Fabric 1	Single Knit Fabric 2
		Inches	Inches	Inches	Inches
	0	17.94	17.91	17.91	17.87
	1	17.82	17.81	17.36	17.38
	2	17.78	17.73	17.21	17.10
0	3	17.75	17.74	17.05	17.05
	4	17.74	17.70	16.92	17.06
	5	17.72	17.70	16.89	16.87
	0	17.95	17.95	17.92	17.93
	1	17.77	17.88	17.40	17.17
	2	17.76	17.80	17.25	16.98
8	3	17.73	17.76	17.11	16.87
	4	17.72	17.71	16.99	16.92
	5	17.67	17.74	17.23	16.65
	0	17.96	17.92	17.92	17.96
	1	17.80	17.83	17.39	17.25
	2	17.78	17.78	17.22	17.08
12	3	17.76	17.75	17.12	16.98
	4	17.72	17.72	16.98	16.90
	5	17.71	17.70	17.02	16.79
	0	17.98	17.92	17.81	17.93
	1	17.85	17.81	17.39	17.27
	2	17.81	17.72	17.18	17.06
16	3	17.77	17.72	17.02	16.95
	4	17.75	17.66	16.90	16.89
	5	17.74	17.66	16.88	16.84

APPENDIX K

Original Data for Slacks Used in the Wear Test

Garment Number		Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Out-Seam
		Measurements in Inches						
Test Garments								
Size 10								
M*	1	37.00	22.25	20.00	12.50	31.13	31.13	41.50
M	2	37.00	22.00	19.00	11.44	12.13	27.13	28.63
M	3	36.50	22.50	20.00	10.88	13.25	31.00	41.25
M	4	37.50	22.25	20.25	11.50	13.38	31.13	41.00
M	5	36.50	22.50	20.00	10.75	12.50	31.38	41.00
B**	6	37.00	22.75	19.50	11.50	12.75	31.50	41.00
B	7	36.75	23.00	20.00	11.25	12.13	30.75	41.00
B	8	36.00	22.75	20.25	11.50	13.00	30.50	41.00
B	9	36.75	22.75	20.00	11.50	12.50	31.00	41.25
B	10	36.50	22.25	20.00	10.50	12.50	30.63	40.75
Size 12								
M	11	36.75	23.00	20.25	11.25	12.25	31.13	41.25
M	12	36.50	23.50	20.75	11.25	12.75	31.50	41.88
B	13	37.00	24.00	20.75	11.25	13.00	31.00	41.00
B	14	36.50	23.00	21.00	12.00	13.50	30.50	41.00
B	15	36.00	22.25	20.00	11.25	12.25	30.75	41.00
B	16	37.00	22.25	20.50	11.75	12.75	30.38	40.75
B	17	37.00	24.25	21.00	11.38	12.75	30.63	41.00
B	18	38.00	23.50	20.50	11.50	12.88	31.50	41.25
B	19	37.00	23.25	20.75	12.00	13.00	31.00	41.00
B	20	36.25	21.50	19.75	11.00	12.38	31.25	41.25
Control Garments								
Size 10								
M	21	37.50	22.50	20.25	11.00	13.00	31.00	41.38
B	22	35.50	22.50	20.25	10.75	12.25	31.13	41.25
Size 12								
M	23	39.00	23.75	21.00	10.75	12.50	31.00	40.75
B	24	37.00	22.50	20.25	11.63	12.38	31.00	41.38

* = Maroon Slacks
** = Blue Slacks

APPENDIX L

Test Data for Slacks Used in the Wear Test After All Treatments

	Measurements in Inches						
Garment Number	Hip	Thigh	Knee	Front Seam	Back Seam	Inseam	Out-Seam
Test Garments							
Size 10							
1	37.25	22.25	20.00	10.38	12.75	31.00	41.50
2	37.50	22.75	19.25	10.50	12.38	27.38	37.75
3	35.75	22.75	20.00	10.50	12.63	30.63	41.00
4	37.50	23.00	19.75	10.38	12.25	31.00	41.00
5	36.00	22.25	20.00	10.63	12.38	31.13	41.25
6	37.50	23.00	19.50	11.13	12.75	30.88	41.00
7	37.50	23.00	20.00	11.00	12.63	30.50	41.00
8	36.25	22.75	20.25	11.38	12.88	30.50	40.50
9	37.75	23.00	20.00	11.38	12.75	30.75	41.00
10	36.00	22.75	20.00	10.75	12.38	30.63	40.50
Size 12							
11	37.00	23.25	20.50	11.13	12.88	31.00	41.00
12	37.00	24.00	20.50	11.13	13.13	31.25	41.50
13	37.25	23.00	20.25	11.50	13.50	30.63	40.63
14	38.50	23.50	20.50	11.25	13.38	30.13	40.88
15	37.75	23.00	19.75	10.75	12.25	30.63	41.00
16	37.50	23.50	20.50	11.50	13.00	30.50	41.00
17	38.00	24.00	20.75	11.50	13.25	30.75	41.00
18	37.75	23.50	20.50	11.38	13.38	30.75	41.00
19	37.25	24.00	20.50	11.50	13.25	30.63	41.00
20	36.50	23.00	20.00	11.00	12.88	31.00	41.25
Control Garments							
Size 10							
21	37.00	23.50	20.75	10.75	12.38	31.00	41.00
22	36.50	22.25	19.75	10.25	12.38	31.25	41.50
Size 12							
23	36.50	22.50	20.00	10.88	12.50	30.88	41.00
24	36.00	23.25	20.00	11.50	12.75	30.75	41.00

APPENDIX M

Mean Wale Count of Garments Used in A Wear Test Over Five Refurbishings

Garment Number	Refurbishings 0	1	2	3	4	5
Test Garments						
1	31.0	31.4	31.4	31.3	31.5	31.6
2	31.3	31.9	31.9	31.8	32.1	31.9
3	31.0	31.5	31.3	31.2	31.4	31.3
4	31.0	31.5	31.2	31.0	31.2	31.3
5	30.9	31.6	31.8	31.2	31.4	31.7
6	28.5	28.1	28.2	28.4	28.4	28.6
7	28.0	28.4	28.1	28.1	27.9	28.2
8	30.6	27.7	28.2	27.6	28.2	28.4
9	28.2	28.1	27.9	28.3	28.2	28.1
10	28.5	28.5	28.0	28.5	28.2	28.6
11	32.0	31.9	32.0	31.4	31.6	31.9
12	31.7	31.9	31.5	31.8	31.5	31.9
13	30.2	30.8	30.9	30.6	31.0	31.2
14	31.7	31.2	31.0	30.6	31.1	31.2
15	31.7	31.5	31.5	31.3	31.0	31.2
16	28.4	27.9	28.2	28.4	28.1	27.8
17	27.8	28.2	28.3	27.6	28.2	28.1
18	30.2	31.2	31.4	30.8	29.8	31.0
19	28.0	28.3	28.1	28.2	28.0	28.2
20	30.8	31.1	31.2	31.1	30.7	31.5
Control Garments						
21	32.4	31.8	32.2	31.9	32.2	32.5
22	31.7	31.3	31.8	31.7	32.0	32.1
23	28.1	28.0	28.4	28.2	28.4	28.5
24	31.3	31.2	31.1	30.6	31.0	30.9

APPENDIX N

Mean Course Count of Garments Used in A Wear Test Over Five Refurbishings

Garment Number	Refurbishings 0	1	2	3	4	5
Test Garments						
1	58.6	58.8	57.6	58.2	58.8	58.2
2	52.0	54.6	54.8	54.2	54.2	54.0
3	60.0	59.6	59.6	60.0	59.8	60.0
4	61.7	62.2	62.4	62.0	63.6	63.0
5	62.2	62.6	61.8	62.4	62.0	62.4
6	60.4	60.4	60.6	60.8	61.0	61.0
7	58.4	58.2	58.4	58.0	59.4	58.8
8	58.8	58.8	59.4	59.4	59.4	59.6
9	58.0	58.0	57.8	57.6	58.8	58.0
10	57.6	57.8	57.0	56.6	57.0	57.2
11	54.8	55.8	55.6	55.6	56.0	56.0
12	56.6	57.8	57.4	58.8	57.8	58.8
13	50.4	50.4	50.2	50.2	51.0	50.6
14	49.0	49.2	49.8	49.4	50.0	49.6
15	51.6	51.4	51.6	51.4	51.4	52.0
16	59.6	59.0	59.0	58.4	59.2	59.4
17	59.0	59.0	58.8	59.0	59.6	59.8
18	49.0	49.6	50.0	49.4	50.0	50.0
19	59.4	61.0	59.4	60.4	60.2	60.6
20	57.6	51.8	53.0	52.8	52.2	52.2
Control Garments						
21	56.2	56.2	55.8	56.0	55.8	55.4
22	56.2	56.2	56.0	56.0	56.0	55.8
23	57.2	57.4	57.6	57.6	56.8	58.0
24	51.2	50.2	49.6	50.4	51.6	50.6

APPENDIX O

Tabulation of Wear Test Questionnaire

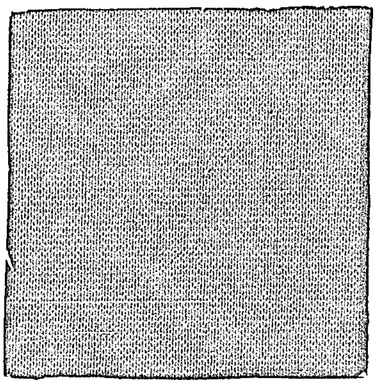
	Six Hours	Over Six Hours
Length of Time Garment Worn	79	35

Activity Categories of Wear

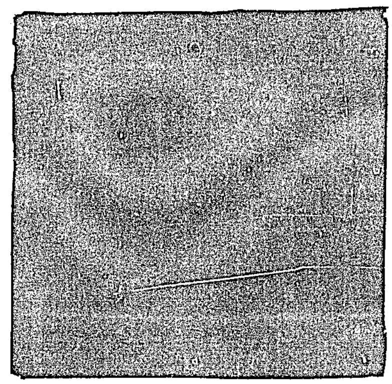
Activity	Number of Times Worn
Leisure	52
Studying	43
Other	37
Desk Work	6
Shopping	5
Sewing	5
Driving	4
Running Errands	3
House Cleaning	3
Meal Preparation	3
Walking	3
Miscellaneous	5
Class	33
Active Sports	1

APPENDIX P

Test Fabrics

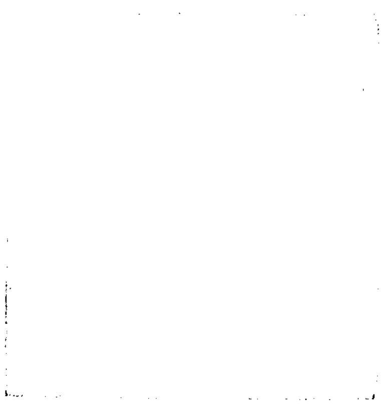


Fabric 1



Fabric 2

Double Knit



Fabric 1

Fabric 2

Single Knit