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PERFORMANCE OF THREE FLAME-RETARDANT FINISHED, BOTTOM-WEIGHT FABRICS AS MEASURED BY IN-FIELD SERVICE AND LABORATORY TESTING.

THE UNIVERSITY OF NORTH CAROLINA AT GREENSBORO, PH.D., 1978

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PERFORMANCE OF THREE FLAME-RETARDANT FINISHED, BOTTOM-WEIGHT FABRICS AS MEASURED BY IN-FIELD SERVICE AND LABORATORY TESTING

by

K. Rinn McLellan

A Thesis Submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
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of the Requirements for the Degree
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Approved by

Dissertation Adviser

APPROVAL PAGE

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MCLELLAN, KAY RINN. Performance of Three Flame-Retardant Finished, Bottom-Weight Fabrics as Measured by In-Field Service and Laboratory Testing. (1978)
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The purpose of this study was to investigate the performance of selected bottom-weight, flame-retardant fabrics for use in career apparel. Performance was defined to include flame resistance, durability, and aesthetic properties of fabrics.

Fabrics selected for study were twill-weave constructions of 100% cotton, 50/50 polyester/cotton intimate blend, and 100% polyester. One flame-retardant treated and one untreated fabric of each fiber content were studied.

Laboratory measurements of performance characteristics were made after subjection of fabric to in-field service and repeated launderings. Subjective measurements of performance were obtained by wearer assessments of garments constructed from test fabrics. Mean values of data collected were compared to minimum requirements of selected performance standards. Data collected were evaluated statistically using analysis of variance and Scheffe's formula for pairwise comparisons. Results of flammability testing were evaluated on the basis of established pass/fail criteria.

All fabrics exhibited durability to more than 50 launderings. Flame-retardant finished fabrics gave performance

comparable to or better than untreated fabrics, and the use of the flame-retardant finishes on fabrics did not alter the aesthetic properties of 50/50 polyester/cotton or 100% polyester. Fabric hand was altered somewhat on the treated 100% cotton which remained uncomfortably stiff. Assessments by wear subjects indicated that the 100% cotton was unsatisfactory for use in career apparel. Subjects wearing the 50/50 polyester/cotton blend and the 100% polyester fabrics indicated high levels of satisfaction for using these fabrics in career apparel.

Fabric that was worn as well as washed 50 times differed statistically in some aspects of performance from fabrics subjected to laundering only. These differences were not important to the usefulness of the fabric except in the case of greater loss of flame-retardant finish from the worn 50/50 blend fabric than from the same fabric subjected to 50 launderings and no wear.

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CHAPTER I

INTRODUCTION

The continuing trend toward governmental protection of consumer rights, particularly the right to safety, has resulted in much interest in the flammability hazards of textiles. Until the spring of 1977, legislation controlling the flammability of all types of consumer-related textile products appeared inevitable. However, the Consumer Product Safety Commission ban of tris (2,3-dibromopropyl) phosphate, a suspected carcinogenic chemical used in flame-retardant children's sleepwear, caused reconsideration of all-encompassing standards governing apparel fabrics. Consumer and industry skepticism resulted in marketing insecurity of flame-retardant fabrics and finishes. Extensive toxicological testing and time have helped to establish a more optimistic outlook for flame-retardants, with the probable result that future legislation will be restricted to specific types of textiles.

One type of apparel end-use which has continued to employ flame-retardant fabrics is occupational clothing including protective garments, uniforms, and career apparel. Protective garments such as aprons, coats, smocks, or coveralls are worn by laboratory technicians, machine shop workers, and factory employees over street clothes to prevent soiling of apparel or damage from heat or chemicals. Flame-retardant fabrics are widely used in protective garments for workers in the petroleum and molten steel industries.

Uniforms are garments of strict conformity required of employees and usually provided by the employer. Flame-retardant fabrics are of primary importance in uniforms for firemen and are also used in uniforms of military personnel and policemen.

In many other occupations "career apparel," which is provided for employees but is not as restrictive in appearance as uniforms, has become a new approach to public relations. Although protection is usually not a prime consideration in these occupations, there is some support for the use of flame-retardant fabrics that are fashionable and comfortable in garments. The increasing emphasis on safety in occupational settings may result in voluntary, if not legislated, use of flame-retardant garments in career apparel. Untreated bottom-weight fabrics of cotton, polyester, or cotton/polyester blends have dominated the recent market for career apparel. Little research has been reported concerning finishes that are available for bottom-weight fabrics of these fiber contents or concerning the performance of flame-retardant fabrics in career apparel end-uses.

Statement of Problem

The purpose of this research was to investigate the performance of selected bottom-weight, flame-retardant fabrics which are currently available to manufacturers of career apparel. "Currently available" was defined to include only fabrics which were treated with technologically feasible finishes that had not been banned from the market and that had given negative results on tests designed to determine possible health hazards. Performance was defined to include flame-resistance, durability, and aesthetic properties of fabrics.

Laboratory measurements of performance characteristics were made after subjection of fabric to in-field service and repeated launderings. Subjective measurements of performance were obtained by wearer assessment of garments constructed from test fabrics.

Objectives

The objectives of this study were:

1. To determine differences in flame resistance, durability, and aesthetic properties of selected bottom-weight, flame-retardant fabrics.

2. To determine differences in durability and aesthetic properties of treated and untreated fabrics.

3. To determine differences in performance characteristics of fabrics subjected to various laundering conditions.

4. To determine wearer satisfaction with selected bottom-weight, flame-retardant fabrics.

Hypotheses

The following hypotheses were tested:

1. There is no significant difference in flame resistance, durability, and aesthetic properties of selected bottom-weight, flame-retardant fabrics.

2. There is no significant difference in durability and aesthetics of flame-retardant treated fabrics as compared to untreated fabrics.

3. There is no significant difference in performance characteristics of fabrics after subjection to in-field service or repeated launderings.

4. There is no significant difference in wearer satisfaction with selected bottom-weight, flame-retardant fabrics.

Assumptions

The following assumptions were made:

1. Fabrics selected were representative of fabrics currently used in career apparel.

2. Subjects selected to wear test garments were representative of the population of employees who wear career apparel.

3. Treated and untreated fabrics of identical fiber content must vary somewhat in certain physical fabric characteristics to give comparable performance.

Definitions of Terms

The following definitions are provided to clarify terms which are used throughout this dissertation.

Bottom-Weight Fabric. This phrase is used to describe apparel fabric weighing more than 4.0 ounces per square yard that is generally used for skirts and slacks.

Career Apparel. This term refers to occupational clothing which is more decorative than protective in function. Career apparel is distinguished from uniforms which normally follow much stricter rules of duplication among wearers.

Flame-Retardant Textile. This phrase describes a fiber or fabric which will not support combustion after the source of ignition is removed. Charring of the area in contact with the flame is expected.

Flame-Resistant Textile. This term is used interchangeably with flame-retardant textile.

Inherently Flame-Retardant Fiber. This term is used by the textile industry to refer to any fiber which exhibits flame-retardant characteristics but has not been topically treated for flame retardance. For the purposes of this paper, this term will refer only to those fibers which have been modified by the addition of a flame retardant to the melt or solution before spinning.

Durable Flame-Retardant Finish. This term refers to a chemical system which retains its ability to impart flame retardancy to textiles through repeated home laundering or institutional laundering.

CHAPTER II

REVIEW OF LITERATURE

The flammability of fabrics and the treatment of fabrics with flame-retardant finishes have been topics of research since the seventeenth century. In the last two decades research concerning textile flammability has been boosted by the passage of laws regulating many types of consumer-related textile products. Recently, the public disclosure of test results indicating possible health hazards associated with specific flame-retardant chemicals has caused reconsideration of potential laws regulating all apparel products. However, various consumer, governmental, and professional groups continue to support legislation governing the flammability of certain types of clothing including children's wearing apparel and career apparel. Passage of legislation governing these textile categories would necessitate the availability of bottom-weight, flame-retardant fabrics exhibiting satisfactory performance under conditions of moderate to heavy wear. The following survey of literature reviews the history and development of flame-retardant treatments for textiles; past, present, and future legislation of textile flammability; recent developments in flame-retardant apparel fabrics; and research concerning the performance of flame-retardant fabrics.

History and Development of Flame-Retardant Treatments For Textiles

The treatment of textiles for flame retardance has been documented as early as 1638 A.D. when a mixture of clay and plaster of Paris was used to impart flame resistance to canvas (Kasem & Rouette, 1972). The treatment was in part the result of a pamphlet published that year by Nicolas Sabatini which pointed out the need for flame-retardant furnishings in theaters including theater decorations and scenery. In 1735, Obadiah Wyld was granted a patent for a nondurable flame-retardant mixture used for theater curtains (Drake, 1976).

Near the beginning of the nineteenth century, Louis XVIII of France commissioned Gay-Lussac to investigate methods of imparting flame resistance to linen and jute. Gay-Lussac's research led to the development of a very successful nondurable finish composed of ammonium phosphate, ammonium chloride, and borax (Lewin & Sello, 1975).

In 1859, Versmann and Oppenheim invented a flame-retardant process which involved precipitating stannic oxide in the fiber. In the early 1900's, work by William Henry Perkins on a flame-retardant system for cotton flannelette resulted in an improvement of the stannic oxide method. His process, called NonFlam, was the first durable-to-laundering finish to be marketed (Drake, 1976).

Further development of flame-retardant finishes was promoted by the need for flame-resistant military uniforms and tenting canvas during World War II. Research was centered on the development of multifunctional finishes which would impart properties such as water repellency as well as flame retardance. Dupont's Erifon process was an early attempt which proved to be unsuccessful due to degradation of the cellulose during treatment. A more successful finish which was developed was known as the FWWMR finish because it imparted resistance to fire, water, weather, mildew, and rot. This system is still used for military purposes, and for end-uses such as awnings and truck covers. Due to high add-on levels which severely alter the hand of fabrics, the finish is not suitable for clothing (Drake, 1976).

Stimulated by the Korean conflict, research continued to be conducted toward the development of durable flame-retardant (FR) finishes for cellulose. Much effort was directed toward the use of finishes based on phosphorus which would combine chemically with the cellulose molecule. In 1953, a major breakthrough came with the introduction of tetrakis (hydroxymethyl) phosphonium chloride, generally referred to as THPC (Smith, 1971). In the following years, many modifications of the THPC system were found to be useful as flame-retardants. By 1976, there were 13 durable FR finishes for cotton, nine of which were based on THP salts or their derivatives (Drake, 1976).

Research was also conducted to develop flame-resistant treatments for synthetic fibers and, in particular, polyester which was becoming a favored fiber for use in apparel fabrics. Bromine compounds were found to be very effective in controlling melt drip as well as flaming of polyester. One of the most successful finishes of this type in the early 1970's was tris (2,3-dibromopropyl) phosphate (Drake, 1976).

Legislation of Textile Flammability

Public concern over textile flammability was aroused in 1942 when 492 people died in a fire at the Coconut Grove night club in Boston. Fabric-covered walls and ceiling contributed to rapid spreading of the blaze. In 1945, highly flammable brushed rayon "cowboy chaps" were blamed for several burn injuries and at least three deaths of young boys. The issue regained national attention in 1951 when rayon "torch sweaters" were responsible for a wave of deaths and severe burns (LeBlanc & Weaver, 1976). Congressional concern also developed, and in 1953 the Flammable Fabrics Act was passed. The purpose of the legislation was to remove from the market "any dangerously flammable clothing textiles" (American Association of Textile Chemists and Colorists, 1975, p. 3).

A committee formed by the American Association of Textile Chemists and Colorists in the early 1940's was renamed the Committee on Flammability of Clothing Textiles in 1952. This committee was responsible for studying various modifications of the required test procedure to simplify it or to make it more accurate. In 1967 the 1953 act was amended to broaden its scope considerably. The amended act provided means of changing the existing standard and establishing other regulations where such action was deemed necessary. The revision also called for extensive research to be conducted concerning relationships of textile products to burn injuries (McDonald, Dardis, & Smith, 1971).

In the following years, much effort was directed toward gathering information concerning burn victims. Groups collecting the data attempted to find significant correlations of burn data with age, sex, geographical location, and many other factors. Often results of these surveys were conflicting. However, the Department of Commerce determined that children under six years of age were injured by clothing fires more frequently than most other age groups and that special hazards were associated with children's sleepwear. Based on these findings, the Department of Commerce instigated proceedings in 1970 to establish standards of flammability for children's sleepwear ("News: Flammability Standard," 1970; "Children's Wearing Apparel," 1970). DOC FF 3-71, Standard for the Flammability of Children's Sleepwear became law in 1972 and became effective the following year.

In 1973, responsibility for implementation and enforcement of the Flammable Fabrics Act and other textile flammability standards was transferred from the Department of Commerce to the newly formed Consumer Product Safety Commission (CPSC) which is directly responsible to the executive branch of the government. A new regulation covering children's sleepwear from sizes 7 to 14 became effective in 1975. The same year J.C. Penney instituted a voluntary program to provide consumers with a choice between FR garments and identical untreated garments at the same prices. The stylish and reasonably priced garments covered a wide range of merchandise including men's and women's sleepwear and robes; women's and girls' skirts and blouses; women's uniforms; girls' dresses; men's, women's, boys', and girls' pants and slacks; and men's and boys' sport shirts (Gross, 1976).

The future of FR fabrics for all types of apparel end-uses appeared to be very bright. In 1976 the National Bureau of Standards submitted a proposal to the CPSC for regulation of the flammability of all wearing apparel (Telthorst, 1976). Before the CPSC was ready to take action on the proposal, research results were released which caused serious reconsideration of all flammability standards.

The "Tris" Issue

In March 1976, the Environmental Defense Fund filed a petition with the Consumer Product Safety Commission requesting "immediate action to reduce the exposure of children and other persons to sleepwear treated with the flame-retardant tris (2,3-dibromopropyl) phosphate" (Tris) (Suchecki, 1976, p. 42). The petition was based on findings by Dr. Bruce Ames of the University of California that the chemical is a mutagen.

The test for mutagenicity is considered to be about 80% accurate as an indicator of carcinogenicity (Blum & Ames, 1977). Following the conclusion of further testing, the CPSC decided in early 1977 to ban the sale of all garments and fabrics containing Tris.

Widespread publicity of the ban brought FR garments to the attention of consumers. Public fear was aroused by news articles concerning the possibility of cancer due to skin absorption of Tris from sleepwear or due to ingestion of the finish by children who chewed or sucked on the treated fabric (Reynolds, 1976). To aggravate the situation, information was released indicating that the chemical might cause sterility of young males who wore the pajamas (Byrne, 1977d). Consumers' negative reactions to the information about Tris were quickly generalized to all topical FR treatments (Sanders, 1978).

Manufacturers, who bore the financial burden, also became skeptical about FR finishes. The Tris ban resulted in estimated losses of $70 million to producers of children's sleepwear fibers, fabrics, and garments (Sanders, 1978, p. 22). Many companies became unwilling to assume the financial risk of using topical treatments that were not 100% safe from future bans. This attitude, coupled with the high cost of running extensive tests to determine the potential safety or danger of finished fabrics, resulted in a sudden and sharp decrease in demand for topically treated FR fabrics. Within one month of the ban, two major fabric manufacturers withdrew all of their FR fabric from the market (Luther, 1977). By the end of four months, most manufacturers and retailers of children's sleepwear were demanding fabrics made with inherently flame-retardant (IFR) fibers (Byrne, 1977a).

In February 1978, the CPSC revised the children's sleepwear regulation for sizes 0 to 6X to eliminate the residual-flame-time requirement. This decision allows the use of certain polyester and nylon fabrics which can meet the less rigid flammability requirements without being topically treated or chemically modified. Although demand for FR treated fabric has dropped off considerably, it is expected that the CPSC will continue to initiate flammability regulations which will require the use of topically treated fabrics. Finishes which are able to pass strict toxicological testing will probably regain favor in end-uses where a wide variety of fabric types is desired (Sanders, 1978).

Future Flammability Legislation

Two standards are currently under consideration by the CPSC for apparel fabrics. First, the Standard For The Flammability of General Wearing Apparel mentioned previously is still being studied by a subcommittee of the CPSC. This standard would require fabrics to be classed according to the Mushroom Apparel Flammability Test and would impose restrictions on garment types and designs made from the various fabric classes. Women's outerwear and children's garments would be most dramatically affected by this standard ("LeBlanc Research," 1976).

The second standard being considered has been designated as PFF 7-74, Proposed Standard For Flammability of Fabric For Specific Apparel Items (McMackin, 1977). The specific apparel items include women's nightgowns and robes, men's and women's pajamas, women's and children's dresses, and men's and boys' shirts and trousers.

Predominant in both standards are the increased safety requirements for children's apparel. California, generally the forerunner in consumer legislation, developed a standard for the flammability of children's clothing in 1975. Basically, the standard required all fabrics used in children's outerwear to pass the vertical test currently required only of sleepwear. Full compliance with the standard was to be required as of 1979 (Walsky, 1976; AATCC, 1975, pp. 193-197). However, in July 1977, the CPSC voted to reject the request for the state standard based on potential effects on interstate commerce (Byrne, 1977b).

Research conducted prior to the Tris ban (Noel, 1978) indicated that consumers felt positively toward the expansion of flammability standards to all clothing for children and for the elderly. Data do indicate that the number of burn injuries to children has been reduced significantly since the sleepwear standards have been in effect (Sanders, 1978).

Data from burn injury studies continue to be analyzed to provide information concerning the types of future legislation needed.

A committee of the American Textile Manufacturer's Institute has launched a study of 60 high-volume apparel fabrics using 15 different laboratories and 14 test methods. Tests of flammability of these fabrics will be correlated with burn data in an attempt to ascertain the types of apparel that may require regulation (LeBlanc, 1977).

Another apparel end-use which may utilize a large share of the future flammable fabrics market is occupational clothing. Flame-retardant fabrics are required for use in military uniforms (AATCC, 1975, pp. 83-88) and are currently being produced for use in work garments for fire fighters, air flight crews, steel workers, and other molten metal industries (Smith, 1978). California law currently regulates hospital apparel (Sanders, 1978), and the National Bureau of Standards is working with the Federal Aviation Administration on a standard for flight attendants' uniforms (Huggett, 1978).

Career apparel is the newest form of occupational clothing and is becoming popular in businesses which have not traditionally been associated with uniforms. Garments of a particular color combination but which allow for matching of pieces are provided for the employees and wear is required. The Career Apparel Institute released figures indicating that 850,000 employees were wearing career apparel in 1977, as opposed to only 250,000 in 1970 (Yaeger, 1977). It is estimated that this figure will triple by 1982. Some of the major users of career apparel are fast food chains. Employees who work in or near hot kitchen appliances may desire to have career apparel produced from flame-resistant fabric. Other types of jobs where career apparel is worn and burn injuries are possible may develop a demand for FR fabrics in the future.

If such a demand develops, fabrics must be produced which can meet the basic requirements of career apparel: functionalism and practicality, simplicity and attractiveness, appropriateness of color, and economy. Based on current productions there are three options concerning FR fabrics for use in career apparel: intrinsically flame-resistant or self-extinguishing fibers, inherently flame-retardant fibers, and topically-treated flame-retardant fabrics. For the purposes of this review, "intrinsically flame-resistant or self-extinguishing" refers to those fibers whose unmodified chemical composition or physical structure is normally resistant to flame. "Inherently flame-retardant" (IFR) will refer to those fibers whose chemical composition has been altered by the addition of a flame-retardant chemical to the melt or solution before extrusion of the fiber.

Intrinsically Flame-Resistant and Self-Extinguishing Fibers

Of the four common natural fibers, wool and silk burn slowly and are intrinsically self-extinguishing. These fibers are not considered to be fire hazards for most end-uses, but comfort and cost limit their usefulness. Of the 18 generic classifications of synthetic fibers, four are intrinsically flame-resistant: modacrylic, vinyon, aramid, and novoloid.

Modacrylics are difficult to ignite because they shrink from flame and melt. Once ignited, the fibers do not support combustion and when the source of ignition is removed, the fibers self-extinguish (Lyle, 1976). Dynel, a modacrylic produced by Union Carbide, was a popular fiber for use in wigs and was used by some sleepwear manufacturers when the flammability regulation was first passed ("Flammability," 1972). Production of Dynel was discontinued in 1974 due to declining demand and rising costs. Eastman Chemical Products makes Verel modacrylic fiber which is a copolymer of acrylonitrile and vinylidene chloride. Verel has been used primarily for carpets, draperies, and high pile fabrics (Sanders, 1978).

Vinyon is the generic name for a group of fibers made primarily from polyvinyl chloride. The most common use of vinyon in flame-retardant garments in the United States is in a stretch terry fabric which was produced by Maiden Mills for children's sleepwear using 65% Leavil polyvinylchloride and 35% polyester ("Flammability," 1972). The fabric is no longer available since production of Leavil fiber was discontinued in 1977 (Sanders, 1978).

A related fiber made in Japan since 1967 is Cordelan, formerly called Kohjin. Cordelan is a matrix fiber manufactured by emulsion spinning after blending polyvinyl alcohol with a copolymer of polyvinyl alcohol and polyvinyl chloride ("Development of Flame-Proof Fibers," 1977). Cordelan was introduced in the United States in 1971 for use in children's sleepwear and draperies. The fiber has a wool-like hand and is available in a wide range of deniers (Sanders, 1978; "Flammability," 1972).

In 1972, Monsanto introduced its modacrylic SEF (self-extinguishing fiber). The fiber is a copolymer of acrylonitrile and vinyl chloride. SEF has been used primarily in children's sleepwear but is also available in heavier constructions for end-uses such as blankets, robes, and draperies. For some apparel end-uses, SEF is blended with polyester (Sanders, 1978).

Dupont's Nomex was the first aramid fiber to be produced and was introduced commercially in 1967. Because of its high resistance to heat and flame, it has been used extensively in protective clothing for firemen, race car drivers, munitions workers, petroleum workers, Army tank drivers, and Air Force pilots. Other aramid fibers have been produced, but due to limited markets for these fibers and high production costs, none has gained a significant level of production (Sanders, 1978).

Novoloid fibers are highly cross-linked phenol-formaldehyde polymers which do not melt or burn but char at temperatures above 260°C. The only novoloid fiber on the present market is Kynol which was developed by the Carborundum Co. in New York but is currently produced in Japan. Fabric from the Kynol fiber is used chiefly for safety apparel but has also been used on a small scale in nonapparel industrial end-uses (Sanders, 1978).

Intrinsically flame-resistant fibers have been used in blends with other synthetic fibers, primarily polyester or nylon, to produce fabrics of fashionable style which are resistant to flame. However, due to the high cost of most of these fibers, it has been financially more feasible to use other methods of imparting flame resistance.

Since the CPSC ruled that the residual-flame-time requirement could be dropped from the flammability standard for children's sleepwear, some polyester and nylon fibers can be used to produce fabrics which pass the standard without being chemically finished for flame retardance. The physical structure of the fiber plus the construction of the fabric affect the ability of the fabric to resist flaming.

Allied Chemical Corporation's Caprolan 24 nylon shrinks from flame and self-extinguishes. This fiber was engineered for use in a brushed tricot with unbroken loops. Celanese Corporation's Fortrel polyester also shrinks from flame and self-extinguishes and Celanese's Nylon 66 is flame-resistant when constructed in 100% nylon knits ("Flammability," 1972). Currently manufacturers seem to be more interested in fibers that have been modified to have even greater flame retardancy.

Inherently Flame-Retardant Fibers

Although interest in inherently flame-retardant fibers has mushroomed since the Tris issue, the fibers have actually been gaining in importance since the late 1960's. The term "inherently-flame-retardant" (IFR) is somewhat misleading since the fiber does have to be modified in order to exhibit flame-retardant characteristics. The modifying substance which is added to the melt or solution generally attaches itself chemically to the fiber molecules; and after spinning, the fiber exhibits flame-retardant characteristics which are essentially permanent ("Development of Flame-Proof Fibers," 1977).

In 1973, Dupont introduced the first modified polyester and called it Dacron 900F. The fiber was used in children's sleepwear, but production was discontinued in late 1976 due to lack of demand for the fiber which cost 40 to 50 cents a pound more than regular polyester (Sanders, 1978).

The Toyobo Company of Japan introduced a modified polyester called Heim in the United States in 1974. This polyester was modified by the addition of a phosphorus-containing flame-retardant to the viscose solution. The production of Heim ceased in mid-1977 when an improved modified polyester called Toyobo GH was introduced. The new fiber is also modified with a phosphorus compound but is easier to spin and dye and has other advantages over the Heim fabric. Both fabrics are currently being marketed in children's sleepwear garments (Sanders, 1978; Byrne, 1977a; Furukawa, 1977).

In October of 1977 Hoescht Fibers Industries announced the production of a modified polyester called Trevira 271. The fiber is made from polyethylene terephthalate but the nature of the modifier has not been disclosed. The company hopes to gain 20 to 25% of the children's sleepwear market with the new fiber. Future plans are to produce the fiber in a wider range of deniers and to employ the fiber in home furnishings, industrial fabrics, and other apparel end-uses ("Hoescht Develops Flame-Resistant Fiber," 1977).

Other than polyester, Japan has developed a modified polynosic rayon fiber which is inherently flame-retardant. Commercial production of the fiber, called DFG for Daiwabo Flame Guard, was begun in 1972. A high molecular-weight flame-retardant is added to the fiber solution before spinning and results in a fiber which is self-extinguishing. The fiber is suggested for use in interior furnishings, apparel for children and the elderly, and career apparel.

Its advantage over other inherently flame-retardant fibers is that it does not melt and stick to the skin. However, the fiber is weaker than many apparel fibers and is thus best used in a blend with polyester or nylon for most apparel (Daiwa, 1977).

Topical Flame-Retardant Treatments

Cotton. In 1976, cotton accounted for just under 40% of the total fiber consumption for bottom-weight fabrics employed in apparel end-uses ("Textile Fiber End-Use Survey," 1977). Cotton fibers are neither intrinsically flame-resistant nor self-extinguishing; and since cotton is a natural fiber, chemical modification is only possible by topical treatment.

The most successful finishes for flame-retarding cotton are those based on phosphorus compounds. Three of the most widely used processes in the mid-1970's were: THPOH-NH_3, Fyrol 76, and Pyrovatex CP.

THPOH-NH_3 is the common abbreviation for the process involving the use of tetrakis (hydroxymethyl) phosphonium hydroxide and ammonia. The THPOH-NH_3 system is an improvement of the THPC finish discovered by Reeves and Guthrie in the early 1950's. This latter process was subjected to an intermediate modification in which the chloride salt was converted to the hydroxide (THPOH) by the addition of sodium hydroxide to the THPC solution. This conversion raised the pH of the solution to 7.2 and reduced the degree to which the cotton was degraded during treatment. Fabric treated with an aqueous solution of THPOH, trimethylolmelamine, and urea were dried and then cured at 150°C to produce a polymer that cross-linked the cotton fibers. This process was known as the THPOH-amide process and gave better fabric characteristics than the THPC finish but produced fabric that was still objectionably stiff. In 1967 the THPOH-NH_3 process was developed. It was superior to the amide finish because it did not require the use of a methylol melamine. The finish is highly effective on cellulose fibers and can be used in cellulosic/synthetic blends with up to 35% synthetic fiber. Testing indicates that a highly insoluble polymer forms inside the fiber without cross-linking the cotton, thus producing little change in hand or strength of the fiber. However, the disadvantage of the non-cross-linking finish is the lack of permanent press characteristics in the finished fabric. Due to higher levels of phosphorus content necessary to attain self-extinguishing properties, the THPOH-NH_3 process is also more expensive (Drake, 1976; Lewin & Sello, 1972).

Another tetrakis (hydroxymethyl) phosphonium (THP) salt has had moderate marketing success since 1976 when producers of THPC decided to stop making the chloride salt and switch production to the sulfate (THPS). This action was prompted by concern that in the processing of THPC finishes the release of formaldehyde and chloride might result in the production of bis (chloromethyl) ether, a known carcinogen. The sulfate finish is sold by Hooker Chemical Company as THPS and until mid-1977 was sold by the American Cyanamid Company as Pyroset TKO. Currently, the latter company has ceased production of all FR chemical finishes due to lack of profitability in that market (Sanders, 1978).

Fyrol 76 is the trade name of Stauffer Chemical Company for its flame-retardant finish which is a vinyl phosphonate oligomer containing approximately 23% phosphorus. Used in conjunction with N-methylolacrylamide in the presence of a catalyst such as potassium persulfate, the compound polymerizes within the cotton fiber during heat curing and produces a durably flame-retardant fabric with a relatively soft hand and good wrinkle resistance. The disadvantages are that the fabric loses about 15% in tensile strength and 35% in tear strength (Sanders, 1978).

In 1968 Pyrovatex CP was introduced in the United States by the Ciba Company. The finish is based on N-methylol dialkyl phosphonopropionamide. This compound is mixed with a melamine resin using an acid catalyst and is applied by a pad-dry-cure technique with subsequent alkaline neutralization. The treated fabric has a good hand and retains flame retardance through repeated launderings, but it also reduces tensile strength and tear strength of cotton fabrics and adds 25 to 35% to the weight of the fabric (Sanders, 1978; Drake, 1976; "Flammability," 1972).

Cotton/Polyester Blends. Blends of cotton and polyester have been popular with consumers for many years and recently accounted for approximately one-third of the fabrics used for apparel (Tesoro, 1973). It is believed that a small market in industrial work clothes will develop for these blends even if no further regulation is passed ("LeBlanc Research," 1976). Flame-retardant finishing of polyester/cotton blends involves problems not encountered in treating either fiber individually. Phosphorus-based finishes such as those previously described have little effect on the polyester in the blend. THPOH-NH_3 and Fyrol 76 can be used on blends as long as the polyester content is 35% or less. Bromine finishes used to flame-retard polyester are not substantive to cotton. Combinations of finishes may be applied to blended fabrics, but durability to laundering is not easily obtained without loss of aesthetic properties (Metropolitan Section, AATCC, 1975).

Several experimental finishes for polyester/cotton blends were announced in 1976. LeBlanc Research Corporation announced a finish called LRC-15 which is prepared by the condensation of THP sulfate and aqueous ammonia. The precondensate is applied to blends in conjunction with trimethylol melamine and urea in a pad-dry-cure-oxidizing process. An undesirably high level of add-on is necessary for the treated fabric to pass the vertical test required by the children's sleepwear standard. A lower level of add-on is possible if Class 1 of the Mushroom Apparel Flammability

Test (Segal & Drake, 1977) is the criterion. At these lower levels of add-on the hand of the fabric may be acceptable ("LeBlanc Research," 1976).

Toyobo, Sandoz, and Michigan Chemical also announced experimental finishes for polyester/cotton blends. The two Toyobo fibers, Taien TPD-V and TPD-100, are based on precondensates of THP salt, urea, and melamine and are applied similarly to the LeBlanc product. The Sandoz product, FR 1030-190, is prepared from phosphonitrilic chloride and dibromoneopentyl glycol and is applied in conjunction with an acrylic latex. The primary disadvantage is the stiff hand of the treated fabric. The Michigan Chemical product is no longer under consideration since it was based on a two-component system with one component being the since-banned tris (2,3-dibromopropyl) phosphate (LeBlanc, 1977).

White Chemical Company has two commercial finishes for use on polyester/cotton blends. Caliban F/R P-44 is based on decabromodiphenyl oxide and antimony oxide, while Caliban F/R P-53 is based on decabromodiphenyl oxide used in conjunction with THP salts. Both finishes are durable to laundering but have adverse effects on fabric hand and exhibit problems of frosting of dark colors (McMackin, 1977; LeBlanc, 1977).

A two-year consortium study on the development of flame-retardants for polyester/cotton blends was completed in 1976. Testing of a wide range of experimental and commercial finishes led to the conclusion that blends of 50% or more polyester cannot be made sufficiently flame-retardant to pass DOC FF 3-71 requirements and maintain the aesthetic quality necessary for apparel (Barker & Drews, 1976).

Polyester. Yaeger (1977) reports that 80% of the new career apparel wardrobes are made from 100% polyester in both woven and knit constructions. Despite the growing interest in modified polyesters, the availability of bottom-weight fabrics from such fibers is poor. Untreated fabrics which exhibit some level of flame resistance do not provide enough assurance of safety.

Tris (2,3-dibromopropyl) phosphate was the most commonly-used FR finish for 100% polyester until the product was banned by the CPSC. After the ban, fabric manufacturers turned to three less effective finishes: Antiblaze 19, a product of Mobil Chemical Company; Pyron 650P, a product of Chemonic Industries; and Fyrol FR-2 produced by Stauffer Chemical Company (LeBlanc, 1977). Due to conflicting results from mutagenicity tests on the Fyrol product, Stauffer has withdrawn the chemical from the apparel market but continues to sell it for use in urethane foams (Byrne, 1977c; Sanders, 1978).

Toxicological testing on Antiblaze 19 and Pyron 650P has given negative results. Antiblaze 19 is a mixture of cyclic phosphonates containing 21% phosphorus. Due to high phosphorus content of the finish, low add-on levels are required to pass the vertical flame test for children's sleepwear ("Textile Flammability," 1977).

Pyron 650P contains bromine, nitrogen, and phosphorus and is designed primarily for use on light-weight polyester fabrics. A more recent development by Chemonic Industries is Pyron 5115 which contains aromatic bromine, nitrogen, and phosphorus for use on heavier-weight polyester in napped, woven, or knit fabrics ("Textile Flammability," 1977).

Some specialized finishes based on THP salts have been developed for use on industrial safety clothing. The finishes have the advantage of being durable to commercial laundering but have a stiff hand and suffer strength losses (LeBlanc, 1977).

Performance Testing of FR Fabrics

A study by Cotton Incorporated in 1972 (Mueller) revealed that men, women, and teenagers rank comfort as the most important fabric characteristic in apparel that they purchase for themselves. The second most important characteristic for all three groups was value received for money spent. Based on these findings, Cotton Incorporated's philosophy for product development is "comfort plus performance" (p. 76).

Information published in 1977 (Seidel, p. 134) indicated that consumer satisfaction with overall quality of apparel purchases was decreasing. Durability topped the list of performance characteristics for which consumers would be willing to pay more per garment.

When the textile industry was faced with compliance to flammability standards for children's sleepwear, the level of technology was not sufficient for providing consumers with durable FR fabrics. As discussed previously, many fabrics were stiff and boardy after treatment and most suffered significant losses in tensile strength and abrasion resistance (Rozelle, 1977). Strength losses are a particular problem for all-cotton garments. One company found that after three or four washings a child can put his foot through FR sleepwear made from 100% cotton (Suchecki, 1976b). Stiffness becomes more of a problem with increased add-on levels (Suchecki, 1976b). Tesoro (1975) discusses the possibility of reducing stiffness of treated blends by applying the finish in a discrete pattern on the fabric in a manner similar to printing.

Besides strength and stiffness, resilience is also an important factor in assessing fabric performance. Resilience of FR fabrics has been measured using tests for wrinkle recovery and appearance ratings. Sleepwear fabrics of polyester or modacrylic give high durable press ratings after five washings, but appearance is marred by the presence of pilling ("Textile Flammability Update," 1975). Simpson and Campbell (1975) tested treated, light-weight fabrics of 100% cotton and found an initial decrease in wrinkle recovery followed by a gradual increase through 50 launderings. In the same study, 100% polyester fabric showed an initial increase in wrinkle recovery after ten washings and maintained a recovery angle throughout the remainder of the 50 launderings that was higher than that of the original fabric.

Rowland and Mason (1977) found a general decrease in strength and abrasion resistance of cotton sheeting finished with seven different flame-retardants to be associated with an increase in the resilience of the fabrics. Resilience was determined by durable press ratings and wrinkle recovery angles. Ratings for the cotton fabrics were low as compared to studies of sleepwear fabrics. Tesoro (1973) suggests that combination finishes incorporating durable press with flame-retardant could be a useful means of improving the appearance of FR fabrics, especially blends.

Abrasion resistance of fabrics can be measured by many methods (Weiner & Pope, 1963). In recent years favor has been given to tests based on the Accelerotor and Stoll Flex machines. In the Rowland and Mason study (1977) these tests gave conflicting evidence of fabric performance. Simpson and Campbell (1975) obtained random data from flat abrasion of sleepwear fabrics. Cotton treated with Pyrovatex-CP and a flame-retardant polyester both showed less resistance to flat abrasion after 50 launderings while cotton treated with $THPOH\text{-}NH_3$ increased in abrasion resistance. The authors suggested that these results could be partly due to higher shrinkage of the $THPOH\text{-}NH_3$ finished fabric.

Extensive research has been conducted to determine the effects of varied laundering procedures on the durability of flame-retardant finishes. Results of several studies indicate that unless the laundry water is very soft, phosphate detergents must be used to maintain flame retardance of finished fabrics (Joseph & Bogle, 1974; LeBlanc & LeBlanc, 1973; Pacheco & Carfagno, 1972; Smith, 1976). There are some indications that high water temperature and high temperatures in tumble drying cause loss of flame retardance in the care process ("Textile Flammability: The Vital Questions," 1976; Segal, 1976; Smith, 1976).

Needed Research on Flame-Retardant Apparel Fabrics

In 1976 Weaver (p. 176) pointed out that 92.5% of all apparel fabrics being manufactured would fail the vertical flame test required of children's sleepwear. Tesoro (1973) and McMackin (1977) expressed concern for the lack of progress in developing flame-retardant finishes in the event of the passage of flammability standards for general wearing apparel. Although the cost of toxicity testing has discouraged research on new flame retardants, chemists for many companies have continued their attempts to develop compounds that are more effective, less expensive, more durable, more versatile, and less detrimental to fabrics (Sanders, 1978).

Currently, burn injury data are being gathered and reviewed to determine types of apparel fabric which present the greatest hazard (Weaver, 1976; McDonald, Dardis, & Smith, 1971; Laughlin, Trautwein, & Parkhurst, 1978; Meacher & Word, 1977). Meacher and Word suggest that flame-retardant garments be made available to the public for use in high risk situations. However, there should be a choice for the consumer between FR garments and untreated garments.

Results of the J.C. Penney program which provided customers with such a choice showed that the presence of the FR finish was not detrimental nor particularly advantageous to the sale of garments (Suchecki, 1977). Instead, garments sold by style and color, factors which were limited in the fabrics available to Penney's merchandisers. In most cases, sales of both FR garments and their identical untreated counterparts were below sales goals.

Comprehensive testing programs on the flammability of various categories of apparel and fabrics have been recently completed, are currently being evaluated, and are expected to give guidance to consumer and governmental groups concerned with legislating flammability standards (LeBlanc, 1977; "LeBlanc Symposium," 1978; Sanders, 1978; Weaver, 1976). Testing to determine the ability of currently available, flame-retardant fabrics to satisfy consumer expectations in performance is necessary in order to supplement findings that such fabrics are needed.

CHAPTER III

PROCEDURE

This research is part of the Southern Regional Research Project S-109 sponsored by the Cooperative State Research Service of the United States Department of Agriculture. The project participators include Home Economics research personnel associated with the Agriculture Experiment Stations in Alabama, California, Colorado, Louisiana, Nebraska, North Carolina, Tennessee, and Wisconsin. This dissertation applies to Objective III A of the regional project which is concerned with characterizing flammability in relation to fabric construction and determining factors affecting the performance of flame-retardant fabrics (Technical Committee, Note 1).

Fabrics

Fabrics selected for research were bottom-weight textiles which fall into three categories based on fiber content: 100% cotton, 50/50 polyester/cotton blend, and 100% polyester. In each category, a flame-retardant treated fabric and an untreated fabric were studied. To reduce performance variabilities caused by fabric construction, all selected fabrics were right-hand twill weaves. Variations in physical characteristics of the treated and untreated fabrics in a specific category and variations across categories were necessary for fabrics to be considered comparable in performance expectations.

Fabric 1. The first fabric was 100% cotton denim. The untreated fabric was a $\frac{3}{1}$ 45° right-hand twill with a thread count of 65 X 43 and an average fabric weight of 8.8 oz/yd^2. Warp yarns were dyed prior to weaving with an indigo dye typical of those used in the production of denim. Filling yarns were not dyed.

The flame-retardant denim fabric was the same weave as the untreated fabric but varied slightly in thread count (66 X 44). The fabric was treated for flame-retardance using THPOH-NH$_3$ [tetrakis (hydroxymethyl) phosphonium hydroxide--ammonia] finish and was subsequently Sanforized. The flame-retardant used on the fabric was a precondensate of a phosphonium salt and urea. The flame-retardant was applied by pad/dry/ammoniation and then was oxidized, scoured, and Sanforized. The finished fabric with approximately 20% add-on was analyzed to have 2.20% phosphorus content. The finished fabric had an average weight of 14.4 oz/yd^2. Research done under contract from the Southern Regional Research Center (Mazzeno & Gruener, 1977) indicates that the THPOH-NH$_3$ flame-retardant finish does not give positive results when subjected to the Ames test.

Fabric 2. The second type of fabric included in the study was a 50/50 intimate blend of cotton and polyester staple. The untreated fabric was a $\frac{2}{1}$ 45° right-hand twill with a thread count of 71 X 38 and an average weight of 7.6 oz/yd^2. Warp yarns were dyed prior to weaving using typical dyes. No other chemical finish was applied to the fabric.

The flame-retardant blend was a $\frac{2}{2}$ 45° right-hand twill with a thread count of 67 X 43 and an average weight of 10.5 oz/yd^2. Both warp and filling yarns were dyed prior to weaving. The fabric was finished for flame-retardance by the Pyroset TKO system marketed by the American Cyanamid Company. The flame-retardant finish is 13.0% phosphorus in the form of tetrakis (hydroxymethyl) phosphonium sulfate (THPS) which co-reacts with urea to form cross-links. The finish was applied by a pad/dry/cure/oxidize/scour process with proprietary modifications introduced by researchers at Burlington Industries Corporate Research and Development Laboratories. The application modifications produce a treated 50/50 polyester/cotton blend with satisfactory flame retardance and improved fabric hand. Initial phosphorus content of the treated fabric, with approximately 33% add-on, was 3.77%. The fabric was also Sanforized but due to the cross-linking properties of the flame-retardant finish, the effect of the shrinkage process was negligible. Toxicity testing on THPS conducted by Hooker Chemical Corporation has shown both the chemical and the finished fabric to be nonmutagenic ("LeBlanc Symposium," 1978).

Fabric 3. The final type of fabric was 100% textured polyester gabardine. The untreated fabric was a $\frac{2}{2}$ 45° right-hand twill of Dupont 242 polyester with a thread count of 71 X 59 and an average weight of 6.1 oz/yd^2. The fabric was subjected to a heatsetting process for dimensional stability and was disperse dyed but underwent no other finishing process.

The flame-retardant treated fabric was identical to the untreated fabric except for the addition of the FR finish Pyrovatex 3887 marketed by the Chas. S. Tanner Company. The finish (37% Br) is composed of 50% solids of hexabromocyclododecane and was applied by a pad/dry/thermosol/afterwash process to the previously dyed and heatset fabric. Initial bromine content of the flame-retardant finished fabric, with approximately 6% add-on, was 4.92%. Addition of the surface finish increased the average fabric weight to 6.5 oz/yd^2 and altered the thread count to 71 X 55. The finish is reported ("CST Product Information," Note 2) to be durable to laundering and dry cleaning, to have no effect on aesthetic properties of the fabric, and to be capable of application by conventional finishing equipment. Toxicological testing of the finish by the manufacturer revealed no evidence of microbiological mutagenicity nor any evidence of sensitization of human subjects to repeated Insult Patch Tests ("CST Product Information," Note 3).

Testing Conditions

Fabrics were tested for performance in their original state and after subjection to seven laundering conditions. Specimens taken from the fabrics in their original states as received from the manufacturers served as control specimens. The control condition is designated as Condition 1.

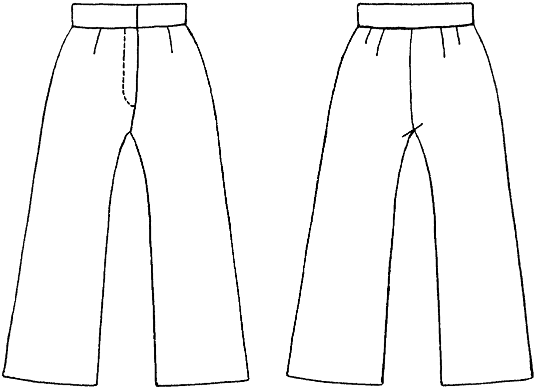
For Conditions 2, 3, 4, 5, 6, and 7 fabrics were laundered according to procedures outlined in "AATCC Test Method 124-1975, Appearance of Durable Press Fabrics after Repeated Home Launderings," (AATCC, 1976, pp. 181-182) using a wash temperature of 120° ± 5F, a cold water rinse, and an automatic tumble dryer with exhaust temperatures of approximately 140°F. In order to more closely simulate actual home laundering conditions for bottom-weight garments, the test method was altered to employ an eight-pound load except for fabric performance tests which specifically designated laundering in a four-pound load. "All," a commercially-available detergent of Lever Brothers Company containing 7.5% phosphorus in the form of phosphates, was used in place of the AATCC standard detergent (high phosphate) to more closely simulate actual practices of consumers.

Condition 2 specimens were subjected to a single home laundering and drying cycle as described above. Condition 3 specimens were subjected to five laundering and drying cycles. Conditions 4, 5, and 6 involved subjection of specimens to 20, 35, and 50 laundering/drying cycles, respectively.

In Condition 7, fabrics (preshrunk by a single laundering) were constructed into slacks for female workers in the University of North Carolina at Greensboro Infant Care Center. One pair of slacks was constructed from each of the six test fabrics. The illustrations in Figure 1 show the basic pattern design used to construct the slacks.

Figure 1

Pattern for Garments Constructed From Test Fabrics



Front

Back

Subjects wore the slacks for periods of six to eight hours a day. The garments were washed at the end of each workday following the laundering and drying methods described previously. All garments were subjected to 50 wear/wash cycles.

In Condition 8, fabrics were subjected to 50 laundering/drying cycles as previously described and 50 additional home launderings without accompanying drying cycles. The additional launderings were conducted in a standard washing machine designed to automatically repeat the laundering process. Water temperatures and load size were the same as described previously, but "Tide" detergent, a product of Proctor and Gamble (6.1% phosphorus), was used for the additional 50 launderings.

Measurements of Fabric Performance

Three categories of fabric performance characteristics were measured in laboratory tests: flame resistance, durability, and aesthetics. Specific test methods used to measure these characteristics are described below.

Flame Resistance. All Condition 1 (control) fabric specimens were tested for flame resistance by use of the vertical flame test required by federal regulation "DOC FF 3-71 Standard for the Flammability of Children's Sleepwear, 0-6X." Three specimens in the warp direction and two specimens in the filling direction were tested. Char length and residual flame time were recorded for each specimen. Further testing for flame resistance was conducted only for the FR-treated fabrics. These fabrics were subjected to the vertical flame test after 20, 35, 50, and 100 launderings and after 50 wear/wash cycles.

To quantify the degree of flame retardance lost in laundering and use, specimens of the treated fabrics were analyzed for finish content by researchers at Burlington Industries Corporate Research and Development Laboratories after 0, 20, 35, 50, and 100 launderings and after 50 wear/wash cycles. Phosphorus content of the treated denim and treated blend was determined colormetrically as molybdic-vanadophosphoric acid according to a proprietary method of Burlington Industries Corporate Research and Development Laboratories. The treated polyester was analyzed for bromine content using a nondispersive X-ray spectrochemical analyzer (Nelson, Brown, & Staruch, 1973).

Durability. Durability characteristics of fabrics were measured using tests for abrasion resistance, breaking strength, tear resistance, dimensional stability, and weight loss.

The two tests used to measure abrasion resistance of the test fabrics were "AATCC Test Method 93-1974, Abrasion Resistance of Fabrics: Accelerotor Method" (AATCC, 1976, pp. 168-170) and "ANSI/ASTM D1175-71, Standard Methods of Test for Abrasion Resistance of Textile Fabrics" (flexing and abrasion method) (ASTM, 1976, pp. 169-199). In the accelerotor method, preparation and evaluation of test specimens were carried out following Method B (grab breaking-strength loss method). Liners of No. 180 grit were used and were attached to an unlined collar. Specimens were subjected to two minutes of abrasion at 2,000 rpm. Three warp specimens and three filling specimens were measured from fabrics subjected to 0, 20, 35, and 50 laundering cycles. Due to limited width of fabric pieces, only warp specimens were taken from the washed and worn garments.

The second measure of abrasion resistance was obtained using a flexing and abrasion tester (Stoll Flex Abrader). Tests were conducted following standard procedures using a one-pound head load (pressure) and four pounds of tension. The number of cycles necessary to cause rupture of the specimen was recorded. Three warp specimens and three filling specimens were measured from fabrics subjected to 0, 20, and 50 laundering cycles.

Breaking strength of fabric specimens was determined by "ANSI/ASTM D1682-64 (Reapproved 1975), Standard Method of Test for Breaking Load and Elongation of Textile Fabrics" (ASTM, 1976, pp. 295-302). The procedure selected involved the use of one-inch ravelled strip specimens and a constant-rate-of-traverse tensile testing machine (Scott tester). Tests were conducted on fabrics subjected to 0, 20, 35, 50, and 100 launderings and to 50 wear/wash cycles. In each case, five warp and five filling specimens were tested.

Fabric durability was also measured using "ANSI/ASTM D1424-63 (Reapproved 1975), Standard Test Method for Tear Resistance of Woven Fabrics By Falling-Pendulum (Elmendorf)

Apparatus" (ASTM, 1976, pp. 265-271). Five warp and five filling specimens from fabrics subjected to 0, 20, 35, 50, and 100 launderings and 50 wear/wash cycles were tested. A testing apparatus with a capacity of 0 to 6400 grams was used.

Dimensional stability of fabrics was determined by "AATCC Test Method 135-1973, Dimensional Changes in Automatic Home Laundering of Durable Press Woven or Knit Fabrics" (AATCC, 1976, pp. 195-196). Measurements were made after 1, 5, 20, 35, 50, and 100 launderings using the previously described laundering procedures. Due to limited supply of test fabric, a single square was used instead of the three squares suggested by the test procedure. Garments worn by wear subjects provided validation of results of the laboratory test.

The 15 X 15-inch squares used to measure dimensional stability were also used to determine weight loss after 20, 35, 50, and 100 launderings. The edges of each square were overcast to prevent loss of yarns from ravelling. Specimens were conditioned as specified by the test for a minimum of eight hours before being weighed. Weight of each square was measured three times to the nearest .001 gram. The measurement was converted to ounces per square yard and percent weight loss was determined by the formula:

$$\%\text{ Weight Loss} = \frac{\text{Original Weight} - \text{New Weight}}{\text{Original Weight}} \times 100$$

Aesthetics. Tests used to determine changes in aesthetic characteristics of fabrics measured fabric appearance, color loss, stiffness, and wrinkle resistance.

"AATCC Test Method 124-1975, Appearance of Durable Press Fabrics after Repeated Home Launderings" (AATCC, 1976, pp. 181-182) was followed for evaluating the appearance of the 15 X 15-inch dimensional stability squares after 1, 5, 20, 35, 50, and 100 launderings. Appearance was judged by a three-member panel. Ratings assigned to fabrics were based on comparisons with Monsanto Three-Dimensional Wash and Wear Standards. Fabrics were assigned the number of the replica most nearly resembled.

Loss of color of fabric specimens after 1, 5, 20, 35, 50, and 100 launderings and after 50 wear/wash cycles was determined by a panel of three judges using "AATCC Evaluation Procedure 1, Gray Scale for Color Change." Fabrics were rated only for loss of color. A rating of 5 (no change) was given for fabrics which appeared darker than the original fabric.

Fabric stiffness before laundering, after 20, 35, and 50 launderings, and after 50 wear/wash cycles was measured using the Single Cantilever Test (Shirley Stiffness Apparatus) described in "ANSI/ASTM D1388-64 (Reapproved 1975), Standard Test Method for Stiffness of Fabrics" (ASTM, 1976, pp. 245-255). Three warp and three filling specimens were tested for each fabric.

Wrinkle recovery of fabrics was determined by "AATCC Test Method 66-1975, Wrinkle Recovery of Fabrics: Recovery Angle Method" (AATCC, 1976, pp. 265-266) using the Monsanto Wrinkle Recovery Tester. Testing was conducted on fabrics subjected to 0, 20, 35, and 50 launderings and 50 wear/wash cycles.

Table 1 gives a summary of the laboratory tests run on fabric specimens from the eight conditions. Conditions 2 (1 wash) and 3 (5 washings) were necessary for only three tests which specified testing at these laundering levels. Omissions of tests at other conditions were primarily due to impracticality of implementation.

Wearer Assessments of Fabric Performance

A wearer assessment questionnaire was administered to the six subjects who wore the test fabrics. The purpose of the questionnaire was to determine wearer satisfaction with factors affecting the comfort and aesthetic properties of the garment during and after the 50 wear/wash cycles. Factors rated by the wear subjects included fabric hand, colorfastness, generation of static electricity, dimensional stability, wrinkle resistance, visual evidence of fabric wear, and suitability to varying climatic conditions. Information concerning satisfaction with garment characteristics such as fit, style, and puckering at seams was obtained in order to determine if strong dissatisfaction with such properties had

Table 1

Chart of Tests Conducted for Each Laundering Condition

Test	Number of Launderings							
	0	1	5	20	35	50	Wear/ Wash	100
Vertical Flammability	X			X[a]	X[a]	X[a]	X[a]	X[a]
Finish Content	X[a]			X[a]	X[a]	X[a]	X[a]	X[a]
Accelerotor	X			X	X	X	X	
Flex Abrasion	X			X		X		
Breaking Strength	X			X	X	X	X	X
Tear Resistance	X			X	X	X	X	X
Dimensional Stability	X[b]	X	X	X	X	X		X
Weight	X			X	X	X		X
Appearance		X	X	X	X	X		X
Color Loss		X	X	X	X	X	X	X
Stiffness	X			X	X	X	X	
Wrinkle Recovery	X			X	X	X	X	

Note. An X indicates that the test was conducted.

[a] Conducted only on FR-treated fabrics.

[b] Measurements on the original fabric were necessary to determine changes that occurred in laundering.

affected ratings of satisfaction with fabric characteristics. Each fabric was evaluated by the one person who wore the pair of slacks that was constructed from that fabric. A sample questionnaire is found in Appendix A.

Treatment of Data

Pass/Fail Criteria. Results of the vertical flame test were subjected to the pass/fail criteria established by the federal regulation for children's sleepwear. Results of the finish-content analyses were compared with vertical flame data to more clearly explain the degree of flame retardance retained by the fabric.

Performance Standards. Results of tests for breaking strength, tear resistance, dimensional stability, colorfastness, and weight loss were compared with the minimum requirements set forth in "L.22.10.35-68, USA Standard Performance Requirements for Women's and Girls' Woven Uniform Fabrics" and "L.22.10.36-68, USA Standard Performance Requirements for Women's and Girls' Woven Work Pants Fabrics" (NRMA, 1968, pp. 55-58). Comparisons were also made with the minimum requirements established by Burlington Industries for the three types of fabric studied ("Burlington," Note 4).

The results of the wearer assessment questionnaire were not statistically analyzed, since each fabric was evaluated by a single and different subject. However, some additional information regarding the ability of fabrics to meet standards set by consumers for comfort and aesthetics was obtained with this instrument.

Statistical Analysis. Analysis of variance tests were conducted on appearance, weight, dimensional stability, accelerotor, Stoll Flex, color change, stiffness, tensile, tear, and wrinkle recovery data. Factors tested for significance were treatment (untreated vs. FR finished), fabric (cotton vs. blend vs. polyester), and wash condition (0, 1, 5, 20, 35, 50, and 100 launderings and 50 wear/wash cycles).

CHAPTER IV

RESULTS

Mean values of data collected are presented and discussed with regard to pass/fail criteria for flame resistance, minimum requirements of performance standards, and results of statistical analyses. To simplify the presentation, Fabric 1 (100% cotton) will be referred to as "cotton," Fabric 2 (50/50 polyester/cotton blend) will be referred to as "blend," and Fabric 3 (100% polyester) will be referred to as "polyester." Test conditions 1, 2, 3, 4, 5, 6, 7, and 8 will be referred to as 0 wash, 1 wash, 5 wash, 20 wash, 35 wash, 50 wash, 50 wear/wash, and 100 wash, respectively. In referring to the test conditions as a group, the term "wash level" will be used to include test specimens from the worn and washed garments as well as specimens from fabrics that were laundered only.

Flame Resistance

Although both residual flame time and char length were measured for test fabrics, all failures were due to char length rather than residual flame time and only those measurements will be discussed. Failure was determined using the criterion of "DOC FF 3-71 Standard for the Flammability of Children's Sleepwear" (AATCC, 1975) which states that if the average char length of the five specimens is in excess of seven inches or if any specimen burns the entire length, the fabric fails the test.

As expected, all three untreated fabrics failed the char length criterion. All specimens of the untreated cotton and untreated blend and two specimens of the untreated polyester burned the entire length. Untreated fabrics were tested only in the 0 wash condition.

All treated fabrics passed the char length criterion of the vertical flame test at 0, 20, 35, 50, and 100 launderings. In the 50 wear/wash condition, the treated cotton passed the test, but one specimen each of the FR blend and the FR polyester burned the entire length and resulted in failure of these fabrics. In both cases the specimen was taken from the front thigh area of the worn garments.

Results of the finish-content analyses run by researchers at Burlington Industries verified these findings. Table 2 gives mean results of the finish-content analyses for the three treated fabrics. The minimum levels of phosphorus or bromine determined by Burlington Industries to be necessary to retain flame retardance (Johnson, Note 5) are given at the bottom of the table. These values are based on the fiber content and physical characteristics of the fabrics.

Table 2

Mean Percentage of Phosphorus or Bromine Content of Treated Fabrics by Wash Condition

Wash Condition	Fabric		
	Cotton (% Phosphorus)	Blend (% Phosphorus)	Polyester (% Bromine)
0 wash	2.20	3.77	5.78
20 wash	2.09	3.83	1.70
35 wash	2.01	3.49	4.71
50 wash	2.03	3.49	4.90
50 wear/wash	2.02	2.49	2.56
100 wash	1.99	2.91	2.82
Minimum necessary to retain flame retardance[a]	1.80	2.70	2.50

[a] Minimum values determined by researchers at Burlington Industries Corporate Research and Development Laboratories.

In all laundering conditions, the cotton fabric retained more than the necessary minimum of 1.80% phosphorus. The treated blend retained more than the minimum 2.70% phosphorus in all conditions except the 50 wear/wash. The presence or absence of finish indicated for the two fabrics is in direct agreement with results of the vertical flame test.

Finish content analyses of the treated polyester show wide fluctuations in bromine content at the various wash levels. Initial bromine content (0 wash) and content after 35 and 50 launderings are much higher than the 2.5% minimum.

Specimens from the 20-wash fabric, however, indicate a level of bromine content that is well below the required minimum. These results do not correlate perfectly with results of the vertical flame test in which fabrics passed the test in all but the 50-wear/wash condition.

Performance Standards

Mean values of research fabrics were compared to minimum requirements set forth in the voluntary L-22 standards and the proprietary standards of Burlington Industries to determine acceptability of the fabric for career apparel end-uses. Results of these comparisons are discussed by the types of performance tests conducted.

Abrasion Resistance.

The L-22 standards do not give minimum requirements for abrasion resistance. The Burlington Industries (BI) requirements are based on the number of cycles to rupture a specimen on the Stoll Flex Abrader. Minimums of 1200 cycles for 100% cotton denim and 2000 cycles for 50/50 polyester/cotton twill have been established but no requirement has been set for the 100% polyester gabardine. Table 3 gives the mean number of cycles required to rupture warp and filling specimens of the cotton and blend fabrics before laundering and after 50 launderings.

Untreated and treated cotton specimens surpassed the minimum 1200 cycles in both warp and filling before laundering. After 50 launderings the untreated cotton dropped substantially below the minimum, but the treated cotton retained resistance to rupture well above the 1200-cycle minimum.

Table 3

Comparison of Mean Results of Stoll Flex Test With Minimum Requirements Established by Burlington Industries

Stoll Flex Cycles		Fabric			
		100% cotton		50/50 Blend	
		U[a]	T[b]	U[a]	T[b]
	BI min.[c]	1200	1200	2000	2000
0 wash	warp	2276	3085	5672	8698
	filling	2736	7480	5570	5411
50 wash	warp	249	3168	842	4533
	filling	534	4065	976	3663

[a] U stands for untreated.

[b] T stands for treated.

[c] BI min. is the minimum requirement established by Burlington Industries.

A similar trend is noted for the blend with both treated and untreated specimens resisting rupture to at least 3000 cycles beyond the 2000-cycle minimum in both warp and filling directions before laundering. After laundering, the treated blend exhibited resistance well beyond the minimum; but the untreated blend dropped considerably below the minimum.

Tensile Strength. Since there exist some differences in the L-22 standard for women's and girls' uniforms and the L-22 standard for women's and girls' work pants, requirements of both standards will be discussed and will be referred to as the L-22 uniform standard and the L-22 work pants standard, respectively. The L-22 uniform standard sets a minimum of 50 lbs. for dry breaking strength of fabrics while the L-22 work pants standard sets the minimum at 40 lbs. The Burlington Industries requirements for the cotton are 150 lbs. in the warp and 70 lbs. in the filling. BI requirements are 45 lbs. in both directions for the blend and 210 lbs. in both directions for the polyester. Table 4 gives the minimum requirements of the three standards and the mean tensile strength values of each fabric at the 0 wash and 50 wash level.

All fabrics exhibited tensile strengths in excess of the two L-22 standards in both warp and filling before and after 50 launderings. Grab strength measurements of warp and filling of each fabric also surpassed the Burlington Industries requirements before laundering. These more rigid requirements set by Burlington Industries were met by all fabrics except the untreated denim after 50 launderings. As indicated by the table, some fabrics actually showed an increase in tensile strength after laundering.

Table 4

Comparison of Mean Tensile Strength and Tear Resistance of Test Fabrics With Minimum Requirements of L-22 Standards and Burlington Industries Standards

Wash Level		Tensile Grab Strength (lbs.)					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
	L-22 U min.[c]	50	50	50	50	50	50
	L-22 WP min.[d]	40	40	40	40	40	40
	BI min.[e] warp	150	150	45	45	210	210
	filling	70	70	45	45	210	210
0 wash	warp	163	206	170	194	246	258
	filling	83	139	112	138	224	217
50 wash	warp	139	195	172	212	243	243
	filling	98	129	92	156	219	227
Wash Level		Tear Resistance (grams)					
	L-22 U min.[c]	1125	1125	1125	1125	1125	1125
	L-22 WP min.[d]	1125	1125	1125	1125	1125	1125
	BI min.[e] warp	4075	4075	1350	1350	6300	6300
	filling	2275	2275	1350	1350	6300	6300
0 wash	warp	6400+	5580	6420	6420	6400+	6400+
	filling	3720	5040	5140	5140	6400+	6260
50 wash	warp	2560	4040	3020	5140	6400+	6400+
	filling	2160	3740	2220	4980	6400+	6120

[a] U stands for untreated.

[b] T stands for treated.

[c] L-22 U min. is the minimum requirement set by the L-22 standard for women's and girls' uniforms.

[d] L-22 WP min. is the minimum requirement set by the L-22 standard for women's and girls' work pants.

[e] BI min. is the minimum requirement set by Burlington Industries for the particular type of fabric.

Tear Resistance. Table 4 also gives minimum requirements and mean results of tear resistance tests for each fabric. Both L-22 standards set the minimum tear resistance requirement at 1125 grams. BI requirements are much higher for the cotton fabrics (4075 grams, warp; 2275 grams, filling), slightly higher for the blend fabrics (1350 grams, warp and filling), and much higher (6300 grams, warp and filling) for the polyester.

All specimens, treated and untreated, exhibited tear resistance above the requirements of the L-22 standards before laundering and after 50 launderings. All unwashed specimens of treated and untreated fabrics surpassed BI requirements for both warp and filling except the filling of the treated polyester.

Untreated cotton specimens laundered 50 times fell below the BI minimum tear resistance requirement for both warp and filling. Treated cotton specimens at the 50-wash level exhibited warp tear resistance slightly below the BI requirement but maintained a mean filling tear resistance that was well above the BI standard.

All specimens of the untreated and treated blend fabrics surpassed the minimum tear resistance requirements set by Burlington Industries for warp and filling even after 50 launderings. The untreated polyester specimens also exhibited greater tear resistance than required by the BI standard.

Treated polyester specimens met the requirement for the warp specimens but fell below the minimum for the filling.

Dimensional Stability. All three standards give a maximum value for the percent shrinkage of fabrics in both warp and filling. Except for the BI standard for polyester, the L-22 uniform standard is the strictest, allowing 3.5% shrinkage in warp and/or filling after five launderings. Requirements of the BI standards vary between these values for the cotton and the blend and are based on subjection of the fabric to three launderings.

Table 5 gives the standards' requirements and the mean values for warp and filling of each fabric after one wash and after five washes. The untreated cotton specimens exhibited shrinkage much in excess of the allowable maximum in the most lenient standard. The high level of shrinkage was present in both the warp and the filling after a single laundering and became even higher after five launderings.

The treated cotton met shrinkage requirements of all three standards after one wash in both warp and filling. After five washes, the filling exhibited a low enough level of shrinkage to pass even the strictest requirement given (2.5%); but warp shrinkage was slightly in excess of the more lenient 3.5% set by the L-22 work pants standard.

The treated blend, the untreated polyester, and the treated polyester were highly dimensionally stable. Each of the three fabrics exhibited little or no shrinkage in both warp and filling even after five launderings and thus met even the strictest maximum shrinkage requirements of the three standards.

Table 5

Minimum Requirements for Dimensional Stability According to Three Standards and Mean Values for Percent Shrinkage of Test Fabrics After 1 and 5 Washes

Wash Level		Percent (%) Shrinkage					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
	L-22 U min.[c]	2.5	2.5	2.5	2.5	2.5	2.5
	L-22 WP max.[d]	3.5	3.5	3.5	3.5	3.5	3.5
	BI max.[e] warp	3.0	3.0	2.5	2.5	1.8	1.8
	filling	3.0	3.0	2.5	2.5	1.0	1.0
1 wash	warp	13.3	1.8	3.4	0.1	0.0	0.0
	filling	6.5	0.2	0.0	0.5	0.1	0.0
5 wash	warp	15.2	3.7	4.5	0.8	0.2	0.1
	filling	8.0	0.3	0.1	1.1	0.4	0.0

[a] U stands for untreated.

[b] T stands for treated.

[c] L-22 U max. is the maximum allowable percent shrinkage allowed by the L-22 standard for women's and girls' uniforms.

[d] L-22 WP max. is the maximum allowable percent shrinkage allowed by the L-22 standard for women's and girls' work pants.

[e] BI max. is the maximum allowable percent shrinkage set by Burlington Industries for the particular type of fabric.

Weight Loss. Burlington Industries establishes no maximum requirement for weight loss of fabrics. The L-22 uniform standard sets a limit of 3.0% weight loss after three launderings while the L-22 work pants standard allows up to 7.0% weight loss for the same number of launderings. Table 6 gives the mean weight loss percentages for each fabric after 20, 35, 50, and 100 launderings.

Table 6

Maximum Weight Loss Allowable in Two Standards and Mean Percentage Weight Loss of Fabrics After Laundering

Wash Level	Percent (%) Weight Loss					
	Cotton		Blend		Polyester	
	U[a]	T[b]	U	T	U	T
L-22 U max.[c]	3.0	3.0	3.0	3.0	3.0	3.0
L-22 WP max.[d]	7.0	7.0	7.0	7.0	7.0	7.0
20 wash	7.7	3.9	1.7	9.9	0.2	1.0
35 wash	8.6	5.0	2.4	13.2	0.3	1.1
50 wash	9.4	5.9	2.8	15.7	0.3	1.2
100 wash	11.2	8.2	4.3	20.7	0.5	1.6

[a] U stands for untreated.

[b] T stands for treated.

[c] L-22 U max. is the maximum allowable percent weight loss after three launderings allowed by the L-22 standard for women's and girls' uniforms.

[d] L-22 WP max. is the maximum allowable percent weight loss after three launderings allowed by the L-22 standard for women's and girls' work pants.

The untreated cotton was marginally beyond the maximum set by the L-22 work pants standard at 20 washes, indicating that at a lower wash level the fabric would probably be within the limitation. The treated cotton was somewhat above the 3% maximum after 20 washes but remained below the 7% maximum of the work pants standard through 50 launderings.

The untreated blend lost only 1.7% of its weight in 20 launderings which is well within the limits of both L-22 standards. This fabric did not lose more than the maximum 3% allowed by the L-22 uniform standard even after 50 launderings. Weight loss of the fabric at 100 launderings was in excess of the 3% requirement but was still well within the limitations of the L-22 work pants standard.

The treated blend lost considerably more than the 7% allowed by the L-22 work pants standard after 20 launderings. However, both the untreated and treated polyester retained a sufficient amount of weight to be within the 3% limitation of the L-22 uniform standard even after 100 launderings.

Color Loss. Both L-22 standards require a Class 4 rating of fabrics for colorfastness to five launderings. Burlington Industries also sets this requirement for the cotton fabric but sets no standard for the blend or the polyester fabrics. The untreated cotton was the only fabric which failed to meet this requirement, having a mean color loss rating of 3.3 after five launderings. The treated cotton was only slightly better than the minimum requirement with a mean rating of 4.2 after five launderings. The treated blend had a high mean rating of 4.8 while the untreated blend and both polyester fabrics had mean ratings of 5.0 (which indicates essentially no color loss).

Wearer Assessments of Performance

Each wear subject indicated her level of satisfaction with nine fabric and seven garment characteristics on a Likert scale with the following ratings: (1) highly unsatisfied, (2) somewhat unsatisfied, (3) no opinion, (4) satisfied, and (5) extremely satisfied. Subjects indicated presence or absence of 11 fabric characteristics by checking "no," "somewhat," or "considerably" after phrases describing the characteristics. Each subject was responsible for rating only the garment she wore. Results of the wearer assessments are discussed according to broad categories of fabric characteristics.

Fabric Hand. One item on the Likert scale ("fabric feel") and six descriptive phrases were used to measure fabric hand. Subjects wearing the untreated cotton, the treated blend, and the treated polyester indicated that they were "extremely satisfied" with fabric feel while the subjects wearing the untreated blend and the untreated polyester indicated that they were "satisfied". Fabric feel was not rated by the subject wearing the treated cotton.

Table 7 gives the six descriptive phrases and wearer responses for each fabric. In general, fabrics were rated positively in smoothness and ability to "give" with body movement. Other phrases were dominated by negative responses with a few noticeable exceptions. Untreated blend and untreated polyester were rated as somewhat scratchy while the corresponding treated fabrics were not attributed this characteristic. Both polyester fabrics were considered to be somewhat limp. The treated cotton was rated high in stiffness while the other five fabrics were given "no" responses for stiffness.

Colorfastness. Two items on the Likert scale measured color loss although this was not originally intended. Initially, "fading" was the only item designed to measure color loss. However, comments of respondents during administration of the questionnaire indicated that ratings for "edgewear" were based on loss of color at edges rather than damage to fibers.

The subject wearing the untreated cotton responded "no opinion" for fading but was "somewhat unsatisfied" with color loss at garment edges. The treated cotton wear subject was "highly unsatisfied" with fabric fading and was "somewhat unsatisfied" with color loss on garment edges.

Subjects wearing the untreated blend, the untreated polyester, and the treated polyester were "satisfied" with fabric fading while the subject wearing the treated blend was "extremely satisfied" with fabric fading. The same ratings were given for loss of color of edges except for the subject wearing the untreated polyester who did not respond to this item.

Table 7

Responses of Wear Subjects to Phrases Describing Fabric Hand of Test Fabrics

Descriptive Phrases	Responses					
	Cotton		Blend		Polyester	
	U[a]	T[b]	U	T	U	T
Fabric is scratchy.	No	No	Some[c]	No	Some	No
Fabric is limp.	No	No	No	No	Some	Some
Fabric is smooth.	Some	Some	Some	Very[d]	Very	Very
Fabric is stiff.	No	Very	No	No	No	No
Fabric irritates skin.	No	No	No	No	No	No
Fabric gives with body movement.	Some	Some	No	Very	Very	No

[a] U stands for untreated.

[b] T stands for treated.

[c] Some stands for a response of "somewhat."

[d] Very stands for a response of "considerably."

Generation of Static Electricity. Subjects rated "static cling" and "lint pickup" on the Likert scale. All respondents were "extremely satisfied" with static cling characteristics except the subject wearing the treated polyester who indicated that she was "satisfied." Subjects wearing the untreated cotton, the treated cotton, and the untreated blend responded "extremely satisfied" to lint pickup characteristics while those wearing the other three fabrics were "satisfied."

Dimensional Stability. On the Likert scale, subjects were asked to rate "shrinkage" and "shape retention" of fabrics. Shape retention was further questioned by a descriptive phrase concerning garments (slacks) bagging at the knees. Responses on the Likert scale were quite varied. The subjects wearing the untreated cotton and the treated blend were "highly unsatisfied" with shrinkage of the fabrics and the subject wearing the treated cotton was "somewhat unsatisfied" with this characteristic. Subjects wearing the untreated blend and the treated polyester were satisfied with shrinkage while the subject wearing untreated polyester was "extremely satisfied."

Ratings for shape retention of the untreated cotton and the treated polyester indicated subjects were "somewhat unsatisfied." Subjects wearing the treated cotton and the treated blend were "satisfied" while the subject wearing the untreated blend was "extremely satisfied." The subject wearing the untreated polyester did not give a response for shape retention.

All subjects responded "no" to the statement, "Slacks bagged in knees," except for the subject whose garment was made from the treated polyester. This respondent indicated that bagging in the knees occurred "somewhat."

Wrinkle Resistance. Fabrics were rated for wrinkle resistance on the Likert scale and through responses to the phrase, "Fabric wrinkles easily." The subject wearing the untreated cotton was "somewhat unsatisfied" with wrinkle resistance of the fabric and responded "somewhat" to the phrase given above.

All other subjects responded "no" to the phrase concerning ease of wrinkling. Subjects wearing the treated cotton and the untreated and treated polyester were "satisfied" with wrinkle resistance while both subjects wearing blends were "extremely satisfied."

Visual Evidence of Fabric Wear. Two of the descriptive phrases concerned visual evidence of wear. The first phrase questioned the existence of thin spots in the fabric while the second considered the possibility of pilling. All subjects responded "no" to thin spots in the fabric except the subject wearing the untreated cotton who responded "somewhat." Respondents answered "no" to the presence of pills, knots, or snags on the fabric surface except in the case of the untreated polyester which was rated as having these problems "somewhat."

Suitability of Fabrics to Climatic Conditions. Three items on the Likert scale measured the suitability of fabrics to cold, hot, and moderate weather. The subject wearing the untreated cotton indicated she was "satisfied" with the fabric in all three conditions. The subject wearing the treated cotton indicated that she was "satisfied" with it for cold or moderate weather but "highly unsatisfied" with it for hot weather.

The subject wearing the untreated blend was "satisfied" with the fabric for use in cold or moderate weather but "somewhat unsatisfied" with it for use in hot weather. The subject wearing the treated blend was "highly satisfied" with the fabric for use in all three types of weather.

Ratings for the untreated polyester were "no opinion" for cold weather, "extremely satisfied" for hot weather, and "satisfied" for moderate weather. The subject wearing the treated polyester was "somewhat unsatisfied" with the fabric for cold weather but was "satisfied" with the fabric for use in hot or moderate weather.

Overall Comfort and Performance. Two items on the Likert scale, "overall comfort" and "suitability for use in uniforms," measured the overall level of wearer satisfaction with fabrics. The subject wearing the untreated cotton indicated she was "extremely satisfied" with the overall comfort of the fabric but was "somewhat unsatisfied" with it for use in a uniform. Response for the treated cotton was similar with overall comfort rated "satisfied" and suitability for uniforms rated "somewhat unsatisfied." Both items were marked "satisfied" for the untreated blend and the treated polyester while both were marked "extremely satisfied" for the treated blend and the untreated polyester.

Statistical Analyses

Analyses of variance were conducted to determine significant differences (at the .01 level) in untreated and treated fabrics; in 100% cotton, 50/50 polyester/cotton blends, and 100% polyester; and in fabrics after subjection to various levels of laundering or to in-field service. In general, test results of fabrics washed 1, 5, 20, 35, 50, and 100 times were compared to the test results of unwashed fabric but were not compared with each other unless an obvious or unusual trend existed. Measurements of fabrics subjected to 50 wear/wash cycles were compared to measurements on 50-wash fabric as well as those of unwashed fabric.

Results of these analyses are discussed by performance test. Summary tables giving F values and the corresponding sums of squares and degrees of freedom are provided in Appendix B.

Accelerotor Abrasion. At the .01 level of significance, treatment and fabric were significant variables for both warp and filling before and after abrasion in the accelerotor. Before abrasion, treated fabrics had significantly higher mean grab strength (215 lbs., warp; 168 lbs., filling) than untreated fabrics (187 lbs., warp; 150 lbs., filling). Subjection to abrasion reversed the direction of the significant difference with treated fabrics having mean grab strengths of 43 lbs. in the warp and 57 lbs. in the filling. This was significantly lower than the untreated means of 56 lbs. in the warp and 71 lbs. in the filling.

Mean warp grab strength increased significantly from the cotton (172 lbs.) to the blend (186 lbs.) to the polyester (246 lbs.) before abrasion. Subjection of the fabrics to accelerotor abrasion changed the order of significance with the cotton fabric remaining significantly lower (35 lbs.) than the other two fabrics, but the blend exhibiting a higher mean strength (63 lbs.) than the polyester (50 lbs.).

In the filling, polyester again had the highest mean strength (221 lbs.) before abrasion; but mean strengths of the blend (123 lbs.) and the cotton (117 lbs.) did not differ significantly. After abrasion, the cotton exhibited a filling strength of 79 lbs. which was significantly greater than the blend strength of 69 lbs. which, in turn, was significantly greater than the polyester strength of 45 lbs.

Table 8 gives mean grab strengths of fabrics by wash level. Statistical analyses indicated a significant drop in warp grab strength before abrasion for fabrics subjected to 50 wear/wash cycles and a significant drop in abraded warp specimens after 50 launderings. Wash level was not found to be significant for unabraded filling specimens; but for abraded filling specimens, 50-wash fabric was significantly lower in grab strength than the unwashed fabric. Calculations of percent strength loss based on wash level indicates a loss of 7.3% for 50 wear/wash unabraded warp specimens, 23.2% loss for 50 wash abraded warp specimens, and 11.9% loss for 50 wash abraded filling specimens.

Table 8

Mean Grab Strengths of Fabrics Before and After Abrasion by Wash Level

Wash Level	Grab Strength (lbs.)			
	Warp		Filling	
	Original	Abraded	Original	Abraded
0 wash	206	56	152	67
20 wash	203	53	154	64
35 wash	204	49	156	67
50 wash	201	43	153	60
50 wear/wash	191	47	not measured	not measured

Table 9 gives the percent loss in strength due to accelerotor abrasion for each fabric by wash level. A loss of more than 50% in strength is considered to be indicative of fabrics which have passed the point of useful performance. All fabrics lost more than 50% in warp grab strength due to accelerotor abrasion except the untreated blend at the 0 wash level. Losses in filling grab strength were much lower than warp losses for the two cotton fabrics and the untreated blend. Of these three fabrics, only the 50-wash treated cotton lost more than 50% in filling strength. Strength loss of filling specimens of the treated blend was slightly below warp loss, but for the two polyester fabrics losses in warp and filling were essentially the same. Generally, for all fabrics an increase in wash level is accompanied by an increase in strength loss for both warp and filling.

Table 9

Percent Strength Loss in Fabrics After Accelerotor Abrasion at Varying Wash Levels

Wash Level		Percent (%) Strength Loss					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
0 wash	warp	81	83	42	68	76	82
	filling	14	40	14	56	75	84
20 wash	warp	42	87	58	84	79	80
	filling	18	42	24	66	75	83
35 wash	warp	81	81	56	77	80	78
	filling	20	33	8	65	78	82
50 wash	warp	75	92	61	81	94	76
	filling	21	55	15	65	80	80
50 wear/wash	warp	80	84	58	66	80	80

Note. Percent loss was calculated as:

$$\frac{\text{Unabraded Strength - Abraded Strength}}{\text{Unabraded Strength}} \text{ X } 100$$

[a] U stands for untreated.

[b] T stands for treated.

Flex Abrasion. Treatment, fabric, and wash level were found to be significant variables in flex abrasion of warp specimens. Fabric and wash level were also significant in flex abrasion of filling specimens, but treatment was not.

In the warp direction, treated fabrics required significantly more cycles to rupture (4461) than the untreated fabrics (3685). Fabric 3 specimens required a mean of 5775 cycles to rupture in the warp direction. This was significantly more than the 4242 cycles required by blend specimens which was significantly more than the 2202 cycles required by the cotton specimens. In the filling direction polyester fabrics again required significantly more cycles (6488) than the blend (3366) or the cotton specimens (3588), but the latter two did not differ significantly.

In both directions, 0 wash fabric resisted rupture to significantly more cycles (5058, warp; 5583, filling) than 20 wash fabric which required 3912 cycles in the warp and 4377 cycles in the filling. Specimens of 50 wash fabric were significantly lower in cycles to rupture in the filling (3482) than 20 wash fabric but did not differ significantly from 20 wash fabric in the warp (3249).

The graphs in Figures 2 and 3 indicate the fabric/wash interaction for warp and filling, respectively. Use of Scheffe's test for pairwise comparisons gives no significant differences by wash level for polyester or cotton in either warp or filling. The only significant effect of wash level on flex abrasion occurs for the blend after 20 washes.

Figure 2

Flex Cycles Required to Rupture Warp Specimens by Wash Level

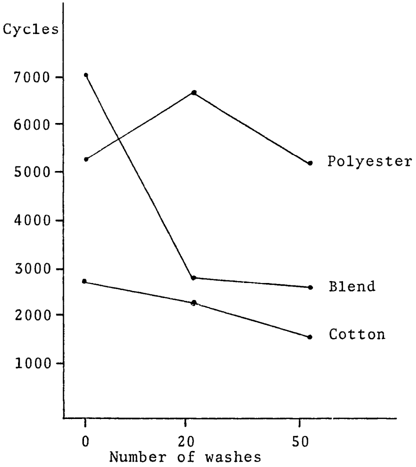
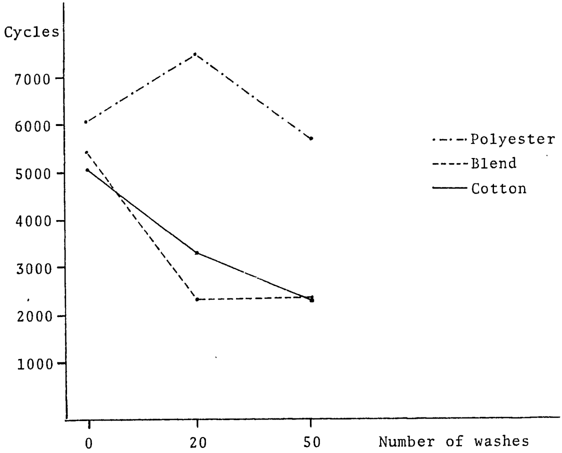


Figure 3

Flex Cycles Required to Rupture Filling Specimens by Wash Level



The graphs also indicate that the order of significance of fabrics in the warp (polyester > blend > cotton) is affected by wash level. The polyester is not significantly different from the blend at the 0 wash level, but it is significantly higher after 20 and 50 washes. The blend is only significantly higher than the cotton at the 0 wash level. The two fabrics do not differ significantly after laundering.

Differences in treated and untreated fabrics vary in direction of significance based on fabric. In both warp and filling the untreated polyester has significantly higher means (7445 and 9006, respectively) than the treated polyester (4106 and 3970, respectively). In the cotton and blend fabrics the earlier trend of treated > untreated prevailed.

Tensile Strength. Overall results of analyses indicated that treated fabrics were significantly stronger in the warp (144 lbs.) and in the filling (103 lbs.) than untreated fabrics (125 lbs. and 93 lbs., respectively). Significant differences in warp strength by fabric followed the pattern, polyester > blend > cotton, with polyester having a warp strength of 163 lbs., the blend having a strength of 124 lbs., and the cotton having a strength of 118 lbs. In the filling direction, polyester was again significantly highest in strength (128 lbs.), followed by cotton with a filling strength of 89 lbs. which was significantly higher than the blend strength of 76 lbs.

Wash level had a significant effect on fabric strength in both warp and filling. Table 10 gives individual fabric means and overall warp and filling means at each wash level. Use of Scheffe's equation on the overall means for wash level indicated a significant drop in fabric strength after 20 launderings but no significant difference in 20, 35, or 50 wash or 50 wear/wash fabrics. However, fabrics washed 100 times were found to be significantly higher in strength than all other laundered fabrics. Fabrics washed 100 times did not differ significantly from the unwashed fabric in either warp or filling strength.

Table 10

Mean Tensile Strengths of Fabrics in Warp and Filling by Wash Level

Wash Level	Tensile Strength (lbs.)							
	Cotton		Blend		Polyester		Overall Mean	
	Warp	Fill	Warp	Fill	Warp	Fill	Warp	Fill
0 wash	144	92	127	75	171	136	147	101
20 wash	114	90	124	72	160	127	133	96
35 wash	113	91	124	80	160	124	132	98
50 wash	109	82	124	78	160	130	131	97
50 wear/wash	106	81	116	70	156	129	126	93
100 wash	122	96	128	82	171	125	140	101

Table 11 gives percent strength lost by subjection of fabrics to various test conditions. Cotton fabrics show the greatest strength loss at all wash levels. The untreated blend and the two polyester fabrics showed low percentages of strength loss while the treated blend had almost no strength loss except in the 50-wear/wash condition. For all fabrics the highest level of strength loss was for warp specimens of the 50-wear/wash fabric. Loss of strength in filling specimens was considerably less than loss of strength in warp specimens. In most cases, the lowest level of strength loss of specimens was in the 100 wash specimens.

Table 11

Percent Strength Loss in Warp and Filling
After Laundering and After Wear

Wash Level		Fabric Strength Percent (%) Loss					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
20 wash	warp	28	15	6	0	7	6
	filling	0	5	2	6	5	8
35 wash	warp	23	20	7	0	7	6
	filling	0	5	2	0	5	12
50 wash	warp	29	20	4	0	7	7
	filling	8	13	2	0	4	4
50 wear/wash	warp	32	21	11	6	8	10
	filling	5	17	3	9	5	5
100 wash	warp	14	16	2	0	1	0
	filling	0	2	0	0	0	16

[a] U stands for untreated.

[b] T stands for treated.

Tear Resistance. Results of the tear test were significantly affected by treatment, fabric, and wash level in warp and filling. Treated fabrics were significantly higher in mean warp (5222 grams) and filling tear resistance (4996 grams) than untreated fabrics (4622 grams and 3974 grams, respectively). The significant pattern for fabrics in both warp and filling was polyester > blend > cotton. Mean warp tear resistances for the three fabrics were 6400+ grams, 4697 grams, and 4020 grams, respectively, while the mean filling measurements were 6348 grams, 3848 grams, and 3258 grams, respectively.

Unwashed specimens in both the warp and filling direction were significantly more resistant to tearing than specimens from all other wash conditions. Table 12 gives tear strength values for each fabric and overall resistance values for each laundering condition. The loss in tear resistance due to laundering was not evident in the two polyester fabrics but did hold true for the cotton and blend fabrics.

Percent loss of tear resistance in warp and filling is given in Table 13. The untreated cotton and the untreated blend showed the greatest losses in tear resistance in both warp and filling. The treated cotton and the treated blend had lower levels of tear resistance loss, and the two polyester fabrics exhibited essentially no loss.

Dimensional Stability. Mean dimensional stability of treated fabrics (9.76 warp and 9.93 filling) was significantly greater than that of untreated fabrics (9.34 warp and 9.71 filling). Fabric and wash level were also significant variables. In both warp and filling, polyester fabric exhibited significantly better dimensional stability than blend fabrics which in turn exhibited better dimensional stability than cotton. Warp measurements were 9.95, 9.65, and 9.04, respectively, while filling measurements were 9.97, 9.91, and 9.57, respectively.

Table 12

Mean Tear Resistance of Fabrics by Wash Level

Wash Level		Tear Resistance (grams)						Over-all Mean
		Cotton		Blend		Polyester		
		U[a]	T[b]	U	T	U	T	
0 wash	warp	6400+	5580	6400	6400	6400+	6400+	6320
	filling	3720	5040	5140	5140	6400+	6260	5300
20 wash	warp	3900	4860	3480	5480	6400+	6400+	5120
	filling	2680	4120	2700	3940	6400+	6180	4353
35 wash	warp	3000	4420	3440	5500	6400+	6400+	4893
	filling	2500	4180	2520	5060	6400+	6180	4490
50 wash	warp	2560	4040	3020	5140	6400+	6400+	4626
	filling	2160	3740	2220	4980	6400+	6120	4286
50 wear/ wash	warp	3120	4080	2940	5800	6400+	6400+	4823
	filling	2140	3620	2220	4380	6400+	6400+	4226
100 wash	warp	2440	3740	3380	5340	6400+	6400+	4650
	filling	1940	3260	2600	5280	6400+	5940	4253

[a] U stands for untreated.

[b] T stands for treated.

Table 13

Percent Tear Resistance Loss of Fabrics by Wash Level

Wash Level		Tear Resistance Loss Percent (%)					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
20 wash	warp	40	13	46	15	0	0
	filling	28	18	47	23	0	1
35 wash	warp	54	21	46	14	0	0
	filling	33	17	51	2	0	1
50 wash	warp	61	28	53	20	0	0
	filling	42	26	57	3	0	2
50 wear/wash	warp	52	27	54	10	0	0
	filling	42	28	57	15	0	0
100 wash	warp	62	33	47	17	0	0
	filling	48	35	49	0	0	5

[a] U stands for untreated.

[b] T stands for treated.

Fabrics retained significantly less in the warp dimension after subjection to 1, 5, 20, 35, 50, and 100 launderings. Mean values for dimensional stability of the warp are given in Table 14 along with the mean warp values for each untreated and treated fabric. Filling values are also given. Overall mean dimensional stability in the filling direction was significantly less after 1, 5, and 20 launderings. Losses between 20 and 35 washes, 35 and 50 washes, and 50 and 100 washes were not significant; but the cumulative losses between 20 and 50 launderings and between 35 and 100 launderings were significant.

Table 14

Mean Dimensional Stability of Fabric Warps and Fillings by Wash Level

Wash Level		Mean Dimensions (inches)						Over-all Mean
		Cotton		Blend		Polyester		
		U[a]	T[b]	U	T	U	T	
0 wash	warp	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	filling	10.00	10.00	10.00	10.00	10.00	10.00	10.00
1 wash	warp	8.67	9.82	9.66	9.99	10.00	10.00	9.69
	filling	9.35	9.98	10.00	9.95	9.99	10.00	9.88
5 wash	warp	8.48	9.63	9.55	9.92	9.98	9.99	9.59
	filling	9.20	9.97	9.99	9.89	9.96	10.00	9.84
20 wash	warp	8.30	9.36	9.39	9.76	9.90	9.97	9.45
	filling	9.09	9.89	9.96	9.83	9.92	10.00	9.78
35 wash	warp	8.22	9.30	9.34	9.72	9.89	9.97	9.41
	filling	9.03	9.89	9.96	9.82	9.92	10.00	9.77
50 wash	warp	8.22	9.22	9.31	9.67	9.89	9.96	9.38
	filling	8.95	9.86	9.95	9.80	9.90	10.01	9.74
100 wash	warp	8.17	9.14	9.23	9.56	9.86	9.92	9.31
	filling	8.95	9.79	9.96	9.76	9.87	9.97	9.72

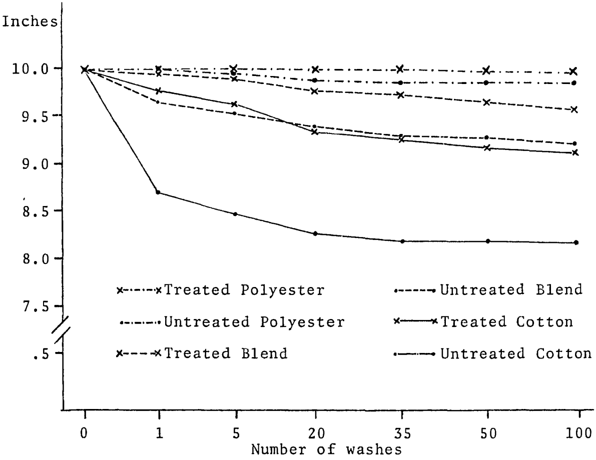
[a] U stands for untreated.

[b] T stands for treated.

Figure 4 shows the three-way interaction of fabric, treatment, and wash level for warp dimensional stability. The significantly greater stability of treated over untreated fabrics is true for cotton and blend fabrics, but the treated and untreated fabrics did not differ significantly. The effect of wash level is also significant for the cotton and blend fabrics, but there is no significant difference in warp stability for polyester fabrics at any wash level except 100 washes.

Figure 4

Retention of Warp Dimension of Treated and Untreated Fabrics Through 100 Launderings



Weight Loss. Fabrics weighed significantly less at each wash level tested (20, 35, 50, 100). Figure 5 shows the interaction of fabrics, treatment, and wash level. The greatest weight losses occurred for the two cotton fabrics and the treated blend for which a significant loss of weight occurred between each wash level. Significant losses in weight of the untreated blend occurred between each wash level except from 35 to 50 launderings. The only significant loss in weight for either of the polyester fabrics was the loss of the treated polyester after 20 washes.

Appearance. Treatment and fabric were significant variables for appearance, but wash level was not. The mean appearance rating for treated fabrics of 4.54 was significantly higher than the mean of 4.35 for the untreated fabrics. The cotton fabrics, with a mean of 3.81, were significantly lower in rating than the blend (4.69) or the polyester fabrics (4.83); but the latter two did not differ significantly. Mean values of each fabric at various wash levels are given in Table 15. A rating of 3.5 is commonly used by the textile industry as the minimum acceptable rating for fabrics finished for permanent press. The untreated cotton had mean appearance ratings below this minimum after 1, 20, 35, and 50 launderings but had ratings above 3.5 at the 5 wash and 100 wash levels.

All other fabrics had mean ratings above 3.5 except the treated polyester at the 100 wash level. This drop in rating was significant for the polyester which had very high appearance ratings at all other wash levels.

Figure 5

Progressive Weight Loss of Fabrics Through 100 Launderings

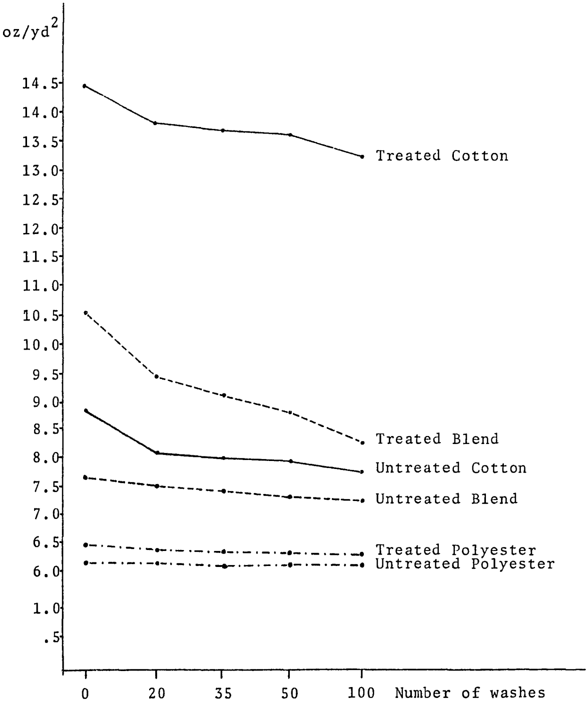


Table 15

Mean Appearance Ratings of Fabrics by Wash Level

Wash Level	Mean Appearance Ratings					
	Cotton		Blend		Polyester	
	U[a]	T[b]	U	T	U	T
1 wash	3.3	4.0	4.3	5.0	5.0	4.7
5 wash	4.3	4.0	3.7	4.3	5.0	5.0
20 wash	3.0	3.7	4.7	5.0	5.0	5.0
35 wash	3.3	4.7	4.3	5.0	5.0	5.0
50 wash	3.3	4.0	5.0	5.0	5.0	5.0
100 wash	4.0	4.0	5.0	5.0	5.0	3.3

[a] U stands for untreated.

[b] T stands for treated.

Color Loss. Fabric and wash level were significant variables in color loss but treatment was not. Cotton fabrics showed significantly more loss of color than the blend or polyester fabrics which did not differ significantly. Cotton fabrics had a mean rating of 2.8 while the blend mean was 4.9 and the polyester mean was 4.8. No two consecutive wash levels exhibited a significant loss of color except the 5 wash to 20 wash interval. However, cumulative color loss was significant at 35, 50, and 100 washes and after 50 wear/wash cycles.

Table 16 gives mean values for the interaction of treatment, fabric, and wash level. Losses of color due to wash level essentially exist only for cotton fabrics. The treated blend improved its color loss rating from 1 to 35 washes. Color loss ratings on the treated polyester do not follow an upward or downward trend through consecutive launderings.

Table 16

Mean Color Loss Ratings for Fabrics by Wash Level

Wash Level	Color Loss Rating					
	Cotton		Blend		Polyester	
	U[a]	T[b]	U	T	U	T
1 wash	3.2	4.8	5.0	4.7	5.0	5.0
5 wash	3.3	4.2	5.0	4.8	5.0	5.0
20 wash	3.0	3.2	5.0	4.5	5.0	4.0
35 wash	2.5	3.2	5.0	5.0	5.0	4.8
50 wash	2.7	2.8	5.0	5.0	5.0	4.2
50 wear/wash	2.0	1.7	5.0	5.0	5.0	5.0
100 wash	1.7	1.5	4.7	5.0	4.8	4.5

[a] U stands for untreated.

[b] T stands for treated.

Stiffness. Bending length was used as a measure of stiffness of fabrics. Table 17 gives mean bending lengths of fabrics measured on both face and back sides of warp and filling specimens. Analyses indicated that treated fabrics are significantly stiffer than untreated fabrics for both sides and both directions of specimens. Fabric was also found to be a significant variable with cotton fabrics being significantly stiffer than blend fabrics which were in turn stiffer than polyester fabrics. In the warp direction, unwashed fabric was significantly stiffer on both face (59) and back (66) than washed fabrics (52-48, face; 56-52, back). Washed fabrics did not significantly differ from each other based on wash level. In the filling direction, bending length of the face side of unwashed fabric (49) does not differ significantly from 35 (48) or 50 (48) wash fabric but is significantly higher than 20 wash (46) and 50 wear/wash (44) fabrics. On the back side there is no significant difference between unwashed fabrics (45) and 20 (43), 35 (45), or 50 (44) wash fabric; but the 50 wear/wash fabric is significantly lower (38).

Table 17

Mean Bending Lengths of Fabrics

Fabric	Stiffness[a]			
	Warp		Filling	
	Face	Back	Face	Back
Untreated Cotton	48	64	55	46
Treated Cotton	69	78	72	57
Untreated Blend	50	54	41	37
Treated Blend	55	54	42	45
Untreated Polyester	43	41	37	39
Treated Polyester	48	48	36	35

[a] Bending length of fabric in millimeters.

Wrinkle Recovery. Specimens were measured for wrinkle recovery on face and back sides of both warp and filling. Statistical analyses indicated that fabric was the only significant variable in wrinkle recovery of warp face specimens with polyester fabrics (149) recovering significantly better than blend fabrics (98) which recovered significantly better than cotton fabrics (73).

Measurements of warp back specimens indicated that both fabric and treatment were significant. Untreated fabrics (122) recovered significantly better than treated fabrics (115). Polyester specimens again recovered better (147) than blend (103) or cotton fabrics (106) which were not significantly different. Wash level was found to have no significant effect on recovery of warp specimens.

Treatment was not a significant variable for filling specimens regardless of side of the specimen measured. Fabric, wash level, and fabric/wash interaction were found to be the significant variables. Table 18 gives recovery measurements for fabrics, wash levels, and fabric/wash combinations. Measurements made on the face side of filling specimens indicate a significantly higher recovery for polyester than for blend or cotton fabrics which do not differ significantly. Recovery is significantly better for unwashed fabrics than for 50-wash fabrics but does not differ significantly for any other wash level.

Table 18

Mean Recovery Angles of Filling Specimens by Fabric and by Wash Level

Wash Level		Recovery Angles (degrees)			
		Cotton	Blend	Polyester	Overall Means
0 wash	face	145	120	153	139
	back	103	128	160	130
20 wash	face	125	125	143	132
	back	113	101-	143	119
35 wash	face	113	112	147	124
	back	87	106	151	115
50 wash	face	108	111	148	122
	back	85	103	142	110
50 wear/wash	face	114	124	161	133
	back	85	115	158	119
Overall Mean	face	121	119	151	☒
	back	95	111	151	

Filling specimens measured for recovery on the back again indicated that polyester had significantly better recovery than blend fabrics, but also showed recovery of the blends to be significantly better than that of cotton fabrics. Recovery of unwashed fabric was significantly better than that of 35- or 50-wash fabric but did not differ significantly from 50-wear/wash or 20-wash fabric. Use of Scheffe's test on fabric/wash values indicated that the loss of recovery in washing existed only for the cotton. Differences in wrinkle recovery of blend fabric and polyester fabric after laundering were not significant.

Mean wrinkle recovery measurements at 20 and 50 washes were compared to mean appearance ratings of fabrics at these wash levels. The Pearson Correlation Coefficient was calculated for each of the four wrinkle recovery measurements and were as follows: warp face, .75; warp back, .27; filling face, .42; and filling back, .40. An overall mean wrinkle recovery value was determined for each fabric by averaging the four mean wrinkle recovery measurements at each wash level. The overall values were correlated with appearance ratings, and a coefficient of .42 was calculated. Table 19 gives wrinkle recovery angles and appearance ratings used in calculating the correlation coefficients. The values in the table indicate that low correlation values are primarily due to inconsistent results for blend fabrics. Calculations based only on the 100% cotton and 100% polyester fabrics indicated a high correlation (r=.86) between wrinkle recovery measurements and appearance ratings.

Table 19

Mean Wrinkle Recovery Angles and Appearance Ratings of Fabrics After 20 and 50 Launderings

Measurement		Wrinkle Recovery Angles (degrees)					
		Cotton		Blend		Polyester	
		U[a]	T[b]	U	T	U	T
Warp Face	20 wash	68	85	99	91	148	149
	50 wash	66	63	101	103	141	156
Warp Back	20 wash	120	106	104	94	149	145
	50 wash	110	100	121	82	146	151
Filling Face	20 wash	119	132	134	118	144	143
	50 wash	110	106	111	111	144	152
Filling Back	20 wash	110	116	104	98	145	140
	50 wash	99	72	94	111	142	142
Overall Mean	20 wash	104	110	110	100	147	144
	50 wash	96	85	82	102	143	150
Wash Level		Appearance Ratings[c]					
	20 wash	3.0	3.7	4.7	5.0	5.0	5.0
	50 wash	3.3	4.0	5.0	5.0	5.0	5.0

[a] U stands for untreated.

[b] T stands for treated.

[c] A rating of 5.0 is extremely good wrinkle resistance while a rating of 1.0 is extremely poor.

CHAPTER V

SUMMARY AND CONCLUSIONS

Specific information obtained from testing can be summarized into broader statements describing general trends in fabric performance. Identification of these trends and explanations for their existence lead to various conclusions about the test fabrics and suggest possible avenues for future research.

Summary

Generalizations concerning each fabric are discussed according to the three categories of fabric performance characteristics that were measured: flame resistance, durability, and aesthetics.

Flame Resistance. All fabrics behaved as expected before laundering. Untreated fabrics failed and treated fabrics passed the vertical flame test. The flame-retardant finished fabrics showed unexpectedly good durability to 100 washes. The failure of the blend specimen and the polyester specimen taken from the worn garments was an unexpected and very significant result. Several explanations may be offered.

First, results of the finish content analyses show a consistently downward trend for phosphorus content of the blend (indicating a decrease in flame retardance) but show an inconsistent trend for bromine content (flame retardance) of polyester specimens. The bromine content of the polyester dropped considerably below the necessary minimum after only 20 washes, but at 35 washes the bromine content was far above the minimum level. Such a drastic increase in finish level cannot be attributed to normal fluctuations in fabric characteristics or measurement techniques. Rather, it provides reasonable evidence that the finish was not evenly distributed on the fabric originally.

Finish content results for the blend fabric followed a logical pattern and gave no evidence of uneven finishing. The sharp difference in phosphorus content of specimens taken from the worn garments may have significant implications for FR finishing of blends. One possible explanation is that the cotton fibers are being abraded away from the blend. Since the finish is primarily attached to the cotton rather than the polyester, the percent of finish on the fabric will be strongly affected by the percent of cotton remaining. This theory is further supported by the fact that the specimen that failed the vertical flame test was taken from the front thigh area of the garment which would be expected to receive considerable wear.

It is also possible that loss of the finish is due to loosening of the finish-fiber bonds by skin excretions. If such an effect occurs, it may be important to determine whether the finish is transferred to the surface of the skin during wear or is merely loosened enough to be removed more readily by the laundering process.

It is possible that wear abrasion or skin excretions had an effect on the polyester fabric since reductions in finish content of the 100-wash and 50-wear/wash level are consistent with trends noted for the blend. It is, however, unknown to what extent the uneven distribution of finish on the polyester affected the above measurements.

Durability. All fabrics showed excellent durability to wear and laundering. In most cases fabrics surpassed minimum performance requirements of L-22 and Burlington Industries standards even after 50 launderings. All fabrics were high in abrasion resistance, tensile strength, and tear resistance before laundering. Untreated cotton fabrics suffered the most severe strength losses in launderings. Shrinkage was also a problem for the untreated cotton as well as for the untreated blend. Weight loss in laundering was most severe for the untreated cotton and the treated blend.

Loss of flex abrasion resistance due to laundering was more severe for warp specimens than for filling specimens. Also subjection of specimens to accelerotor abrasion caused greater percent loss in strength for warp specimens than for filling specimens. In both tests, abrasion is inflicted on the face side of fabrics. Since all fabrics were warp-face twills, the surface warp yarns are assumed to have acted as protection for the filling yarns to some degree.

Accelerotor abrasion of polyester fabrics does not affect warp strength more than filling strength. This may be due to the finer diameter of warp yarns which cannot provide as much protection to filling yarns as the thicker warp yarns of the cotton and blend. It is also possible that the yarns aid in abrading one another since polyester fabrics were found to lose significantly more warp strength in abrasion than blend fabrics and significantly more filling strength than either blend or cotton fabrics.

The effects of abrasion on filling strength may also be related to shrinkage. A significant amount of shrinkage produces even better warp coverage and would increase the amount of protection for the filling yarns. The low level of shrinkage in polyester fabrics prevented this added protection. The high level of shrinkage of the cotton fabrics appears to correspond to the low level of filling strength loss. However, results showed that abrasion resistance was significantly lowered by 50 launderings in both warp and filling. Thus, the effect of shrinkage was not great enough to overcome the detrimental effects of laundering.

Flex abrasion resistance of treated fabrics was greater than that of untreated fabrics. Again, it is possible that yarns are protected by the finish covering their surface. This possibility is consistent with the loss of flex abrasion resistance of the treated cotton and treated blend in laundering since tests for finish content and weight loss indicate that some degree of finish is removed from these fabrics during washing.

Treated fabrics were also significantly better in tensile strength and tear resistance than untreated fabrics. These results were somewhat unexpected but may be explained by the fact that treated fabrics were selected to be sturdier in construction based on assumptions that the presence of the flame-retardant finish would affect fabrics adversely, thus making them comparable to untreated fabrics. Test results indicated that improved flame-retardant formulations and application processes used on the selected test fabrics did not affect strength properties as much as expected.

In a reverse of the expected trend, fabrics laundered 100 times were higher in tensile strength than fabrics laundered 20, 35, or 50 times. Shrinkage could account for some increase in tensile strength, but tensile strength did not increase after 50 launderings where fabric shrinkage was essentially the same as for 100 launderings. The results cannot be explained based on the data collected in this study.

It is believed that shrinkage did contribute to the pattern of strength loss of warp and filling. Warp yarns lost considerably more strength in laundering than did filling yarns. The high degree of warp shrinkage means that filling yarns were pulled closer together by the shrinking warp yarns and the fabric thus had more filling yarns per inch than it had before laundering. Since filling shrinkage was much less than warp shrinkage, the increase in warp yarns per inch would not be as great. The increase in filling yarns per inch would offset strength loss to some degree.

Wearer assessments of dimensional stability of fabrics do not appear to correlate closely with laboratory results. In addition to subjective factors, satisfaction with the amount of shrinkage observed may have been related to height of subjects. The same percentage of warp shrinkage in a pair of slacks may be more critical for a tall person than a short person. Cut of the garments and shrinkage of sewing thread may have affected observed shrinkage of garments. Some variation in wearer expectations was also responsible for differences in ratings. Other ratings of fabric durability by wear subjects verified laboratory results indicating good durability of all fabrics.

Aesthetics. As expected, appearance ratings of fabrics were better for treated than untreated fabrics and were better for polyester and blend fabrics than for cotton fabrics. Except for the untreated cotton, however, most ratings were 4.0 or better which indicate very good wrinkle resistance of all fabrics. Wrinkle recovery measurements (which actually measure crease recovery rather than wrinkle recovery) were not highly correlated with appearance ratings for the blend fabrics but were highly correlated with ratings for the cotton and the polyester fabrics. Fabric was a significant factor for both wrinkle recovery and appearance ratings with cotton being the least resistant to wrinkling or creasing and polyester being the most resistant.

Color loss was essentially negligible except for cotton fabrics. Improvements in color loss ratings were due to shrinkage of fabrics which brought warp yarns closer together and blocked the white filling yarns from view. The absence of the white yarns gave the fabric a darker appearance. The erratic pattern of color loss rating for the treated polyester (taken from different areas of the fabric at each wash interval) may have been due to uneven distribution of the flame-retardant finish.

Flame-retardant finishes added significantly to the stiffness of cotton fabric. Laboratory results of stiffness measurements were verified by wearer assessments of fabric hand in some cases, but stiffness measurements were not a good indication of scratchiness of fabrics. Untreated blend and untreated polyester fabrics were considered somewhat scratchy while the corresponding treated fabrics were not. It is possible therefore that the FR treatment improved the hand of these fabrics. However, some variations in subject responses are due to varying personalities and expectations of wear subjects. Subjects were generally satisfied with wrinkle resistance and colorfastness of garments. The response of "no opinion" to the fading of the untreated cotton was explained by the wearer as indicating that although color loss was noticeable, it was not unexpected nor undesirable for the type of fabric.

Conclusions

The major conclusion of this research is that there do exist flame-retardant finishes for bottom-weight fabrics available on demand to manufacturers of career apparel which are durable to more than 50 launderings. Flame-retardant finished fabrics gave performance comparable to or better than untreated fabrics, and the use of the FR finishes on fabrics did not alter the aesthetic properties of 50/50 polyester/cotton blend or 100% polyester. Fabric hand was altered somewhat on the 100% cotton which was uncomfortably stiffer when treated.

Assessments by wear subjects of the suitability of fabrics for use in uniforms indicated that the 100% cotton denim, treated or untreated, was not suitable for this end-use. Subjects wearing the 50/50 polyester/cotton blend and the 100% polyester fabrics indicated high levels of satisfaction for using these fabrics in career apparel. Satisfaction with garments of these fiber contents was not affected by presence of the FR treatment.

Comparison of test results of 50-wash fabric to test results from fabric that was worn as well as washed 50 times indicate some statistical differences in performance. In reality, these differences are not important to the usefulness of the fabric except in the case of the loss of flame-retardant finish due to wear. This finding could have significant implications for the treating of blends for flame retardance.

Recommendations for Future Research

To determine the true nature of the effect of wear on FR finishes in blends, more specific research should be conducted on a wide range of fabrics used in career apparel. The scope of the research should be sufficient to include a significant number of subjects wearing each FR-finished fabric. Testing should be conducted to determine the universality of the greater loss of finish from worn fabric than from fabric that is laundered under controlled conditions. If such loss is verified, further testing should be conducted to determine how the loss occurs.

Also, further testing is needed to determine if other suitable FR fabrics of different fabric constructions and fiber contents are available for use in career apparel. Research design should include a wide range of occupations requiring career apparel, uniforms, and safety clothing to determine differences in the amount of wear and the kind of wear fabrics receive.

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APPENDIX A

WEARER ASSESSMENT QUESTIONNAIRE

You either have completed or are nearing completion of the wear-testing period. Please indicate below your evaluation of the slacks that you wore for this test.

I. Circle the number which best indicates your level of satisfaction with the following characteristics of the slacks fabric.

	highly unsatisfied	somewhat unsatisfied	no opinion	satisfied	extremely satisfied
Shrinkage	1	2	3	4	5
Fabric feel	1	2	3	4	5
Fading	1	2	3	4	5
Static cling	1	2	3	4	5
Edge wear	1	2	3	4	5
Wrinkle resistance	1	2	3	4	5
Shape retention	1	2	3	4	5
Lint pickup	1	2	3	4	5
Overall comfort	1	2	3	4	5

II. Place a check next to the descriptive phrases below indicating the extent to which these phrases are descriptive of your slacks.

	no	somewhat	considerably
Fabric is scratchy.	____	____	____
Fabric is limp.	____	____	____
Slacks bagged in knees.	____	____	____

	no	somewhat	considerably
Thin spots in fabric.	____	____	____
Fabric is smooth.	____	____	____
Pills, knots, or snags on fabric surface.	____	____	____
Fabric is stiff.	____	____	____
Fabric wrinkles easily.	____	____	____
Fabric irritates skin.	____	____	____
Fabric gives with body movement.	____	____	____
Puckering of seams.	____	____	____

III. Circle the number which best indicates your level of satisfaction with the following garment characteristics.

	highly unsatisfied	somewhat unsatisfied	no opinion	satisfied	extremely satisfied
Fit at beginning of wear testing.	1	2	3	4	5
Fit at end of wear testing.	1	2	3	4	5
Garment design or style.	1	2	3	4	5
Suitability for wear in cold weather.	1	2	3	4	5
Suitability for wear in hot weather.	1	2	3	4	5
Suitability for wear in moderate weather.	1	2	3	4	5
Suitability for use in uniforms.	1	2	3	4	5

APPENDIX B

ANALYSIS OF VARIANCE TABLES

Variable: Accelerotor, Original Warp

Source	df	Sums of Squares	F value
Treatment	1	18119.211	324.78*
Fabric	2	92372.156	827.87*
Wash Level	4	2402.044	10.76*
Treatment X Fabric	2	7403.089	66.35*
Treatment X Wash	4	146.844	.66
Fabric X Wash	8	1609.622	3.61*
Treatment X Fabric X Wash	8	483.356	1.08
Error	60	3347.333	

*Significant at .01 level.

Variable: Accelerotor, Abraded Warp

Source	df	Sums of Squares	F value
Treatment	1	3802.500	36.40*
Fabric	2	11140.622	53.32*
Wash Level	4	1827.289	4.37*
Treatment X Fabric	2	2897.067	13.87*
Treatment X Wash	4	3499.333	8.37*
Fabric X Wash	8	4761.378	5.70*
Treatment X Fabric X Wash	8	3924.267	4.70*
Error	60	6268.000	

*Significant at .01 level.

Variable: Accelerotor, Original Filling

Source	df	Sums of Squares	F value
Treatment	1	13972.347	148.82*
Fabric	2	165330.083	880.46*
Wash Level	4	109.264	0.39
Treatment X Fabric	2	9350.194	49.79*
Treatment X Wash	4	464.375	1.65
Fabric X Wash	8	481.361	0.85
Treatment X Fabric X Wash	8	2374.583	4.22*
Error	60	4506.667	

*Significant at .01 level.

Variable: Accelerotor, Abraded Warp

Source	df	Sums of Squares	F value
Treatment	1	3655.125	114.27*
Fabric	2	14442.333	225.76*
Wash Level	4	640.153	6.67*
Treatment X Fabric	2	3081.000	48.16*
Treatment X Wash	4	252.931	2.64
Fabric X Wash	8	1569.222	8.18*
Treatment X Fabric X Wash	8	1450.778	7.56
Error	60	1525.333	

*Significant at .01 level.

Variable: Stoll Flex, Warp

Source	df	Sums of Squares	F value
Treatment	1	8111537.796	12.06*
Fabric	2	115685466.778	85.99*
Wash Level	2	30139051.444	22.40*
Treatment X Fabric	2	117215693.593	87.12*
Treatment X Wash	2	1053714.926	0.78
Fabric X Wash	4	57875150.778	21.51*
Treatment X Fabric X Wash	4	6205840.185	2.31
Error	36	24216921.333	

*Significant at .01 level.

Variable: Stoll Flex, Filling

Source	df	Sums of Squares	F value
Treatment	1	603991.130	0.90
Fabric	2	109228091.259	80.97*
Wash Level	2	40023211.704	29.67*
Treatment X Fabric	2	199914194.370	148.20*
Treatment X Wash	2	1524525.481	1.13
Fabric X Wash	4	33997965.074	12.60*
Treatment X Fabric X Wash	4	6915276.185	2.56
Error	36	24280497.333	

*Significant at .01 level.

Variable: Tensile Strength, Warp

Source	df	Sums of Squares	F value
Treatment	1	16245.000	267.69*
Fabric	2	70775.811	583.13*
Wash Level	5	8657.244	28.53*
Treatment X Fabric	2	2467.433	20.33*
Treatment X Wash	5	279.067	0.92
Fabric X Wash	10	3787.056	6.24*
Treatment X Fabric X Wash	10	688.500	1.13
Error	144	8738.800	

*Significant at .01 level.

Variable: Tensile Strength, Filling

Source	df	Sums of Squares	F value
Treatment	1	4971.756	156.67*
Fabric	2	88963.378	1401.73*
Wash Level	5	1314.911	8.29*
Treatment X Fabric	2	15531.244	244.71*
Treatment X Wash	5	402.644	2.54
Fabric X Wash	10	2380.756	7.50*
Treatment X Fabric X Wash	10	1469.956	4.63*
Error	144	4569.600	

*Significant at .01 level.

Variable: Tear Test, Warp

Source	df	Sums of Squares	F value
Treatment	1	36449999.999	894.48*
Fabric	2	197205777.778	2419.70*
Wash Level	5	60899111.111	298.89*
Treatment X Fabric	2	25233333.333	309.61*
Treatment X Wash	5	13465333.333	66.09*
Fabric X Wash	10	34444222.222	84.53*
Treatment X Fabric X Wash	10	8215333.333	20.16*
Error	144	5868000.000	

*Significant at .01 level.

Variable: Tear Test, Filling

Source	df	Sums of Squares	F value
Treatment	1	46920055.556	303.58*
Fabric	2	322923999.999	1044.69*
Wash Level	5	25239833.333	32.66*
Treatment X Fabric	2	40833777.778	132.10*
Treatment X Wash	5	5338944.444	6.91*
Fabric X Wash	10	17962666.667	11.62*
Treatment X Fabric X Wash	10	10014222.222	6.48*
Error	144	22856000.000	

*Significant at .01 level.

Variable: Dimensional Stability, Warp

Source	df	Sums of Squares	F value
Treatment	1	5.590	1454.11*
Fabric	2	18.219	2369.49*
Treatment X Fabric	2	4.180	543.60*
Replication (T X F)	12	0.046	
Wash	6	6.127	3233.95*
Treatment X Wash	6	0.945	488.89*
Fabric X Wash	12	3.590	947.49*
Treatment X Fabric X Wash	12	0.739	195.09*
Error	72	0.023	

*Significant at .01 level.

Variable: Dimensional Stability, Filling

Source	df	Sums of Squares	F value
Treatment	1	1.429	858.01*
Fabric	2	4.001	1200.90*
Treatment X Fabric	2	3.686	1106.33*
Replication (T X F)	12	0.020	
Wash	6	1.011	392.09*
Treatment X Wash	6	0.260	100.71*
Fabric X Wash	12	0.793	153.83*
Treatment X Fabric X Wash	12	0.695	134.72*
Error	72	0.031	

*Significant at .01 level.

Variable: Weight

Source	df	Sums of Squares	F value
Treatment	1	149.607	99999.99*
Fabric	2	332.025	99999.99*
Treatment X Fabric	2	112.872	99999.99*
Replication (T X F)	12	0.001	
Wash	4	6.406	43690.08*
Treatment X Wash	4	1.258	8579.85*
Fabric X Wash	8	2.772	9450.59*
Treatment X Fabric X Wash	8	1.736	5918.04*
Error	48	0.002	

*Significant at .01 level.

Variable: Appearance

Source	df	Sums of Squares	F value
Treatment	1	.926	11.11*
Fabric	2	22.389	134.33*
Treatment X Fabric	2	3.685	22.11*
Replication (T X F)	12	1.000	
Wash Level	5	.667	1.04
Treatment X Wash	5	3.741	5.86*
Fabric X Wash	10	9.611	7.52*
Treatment X Fabric X Wash	10	2.981	2.33
Error	60	7.667	

*Significant at .01 level.

Variable: Color Change

Source	df	Sums of Squares	F value
Treatment	1	0.000	0.00
Fabric	2	114.873	1809.25*
Wash Level	6	11.385	59.77*
Treatment X Fabric	2	3.190	50.25*
Treatment X Wash	6	2.417	12.69*
Fabric X Wash	12	19.710	51.74*
Treatment X Fabric X Wash	12	4.060	10.66*
Error	84	2.667	

*Significant at .01 level.

Variable: Stiffness, Warp Face

Source	df	Sums of Squares	F value
Treatment	1	2517.511	117.82*
Fabric	2	2583.489	60.46*
Wash Level	4	1266.044	14.81*
Treatment X Fabric	2	1350.289	31.60*
Treatment X Wash	4	344.711	4.03*
Fabric X Wash	8	1260.956	7.38*
Treatment X Fabric X Wash	8	584.156	3.42*
Error	60	1282.000	

*Significant at .01 level.

Variable: Stiffness, Warp Back

Source	df	Sums of Squares	F value
Treatment	1	1109.511	66.13*
Fabric	2	11088.289	330.45*
Wash Level	4	2209.844	32.93*
Treatment X Fabric	2	778.022	23.19*
Treatment X Wash	4	249.711	3.72*
Fabric X Wash	8	1750.489	13.04*
Treatment X Fabric X Wash	8	254.089	1.89
Error	60	1006.667	

*Significant at .01 level.

Variable: Stiffness, Filling Face

Source	df	Sums of Squares	F value
Treatment	1	640.000	79.78*
Fabric	2	12187.822	759.63*
Wash Level	4	313.156	9.76*
Treatment X Fabric	2	1453.067	90.57*
Treatment X Wash	4	45.556	1.42
Fabric X Wash	8	166.178	2.59
Treatment X Fabric X Wash	8	94.711	1.48
Error	60	481.333	

*Significant at .01 level.

Variable: Stiffness, Filling Back

Source	df	Sums of Squares	F value
Treatment	1	513.611	43.53*
Fabric	2	3213.067	136.15*
Wash Level	4	553.733	11.73*
Treatment X Fabric	2	963.289	40.82*
Treatment X Wash	4	298.000	6.31*
Fabric X Wash	8	358.933	3.80*
Treatment X Fabric X Wash	8	184.267	1.95
Error	60	708.000	

*Significant at .01 level.

Variable: Wrinkle Recovery, Warp Face

Source	df	Sums of Squares	F value
Treatment	1	67.600	0.65
Fabric	2	90103.889	430.71*
Wash Level	4	320.267	0.77
Treatment X Fabric	2	238.467	1.14
Treatment X Wash	4	380.178	0.91
Fabric X Wash	8	1820.667	2.18
Treatment X Fabric X Wash	8	1641.422	1.96
Error	60	6276.000	

*Significant at .01 level.

Variable: Wrinkle Recovery, Warp Back

Source	df	Sums of Squares	F value
Treatment	1	1210.000	10.62*
Fabric	2	35048.956	153.84*
Wash Level	4	885.889	1.94
Treatment X Fabric	2	2334.467	10.25*
Treatment X Wash	4	397.667	0.87
Fabric X Wash	8	1082.378	1.19
Treatment X Fabric X Wash	8	929.533	1.02
Error	60	6834.667	

*Significant at .01 level.

Variable: Wrinkle Recovery, Filling Face

Source	df	Sums of Squares	F value
Treatment	1	102.400	0.70
Fabric	2	19056.289	65.55*
Wash Level	4	3453.511	5.94*
Treatment X Fabric	2	1235.267	4.25
Treatment X Wash	4	256.933	0.44
Fabric X Wash	8	4137.489	3.56*
Treatment X Fabric X Wash	8	1387.400	1.19
Error	60	8721.333	

*Significant at .01 level.

Variable: Wrinkle Recovery, Filling Back

Source	df	Sums of Squares	F value
Treatment	1	26.678	0.18
Fabric	2	50080.267	171.61*
Wash Level	4	4084.956	7.00*
Treatment X Fabric	2	953.956	3.27
Treatment X Wash	4	634.378	1.09
Fabric X Wash	8	4411.178	3.78*
Treatment X Fabric X Wash	8	1754.822	1.50
Error	60	8754.667	

*Significant at .01 level.