To the Graduate Council:

I am submitting herewith a thesis written by Kathryn V. Andrews entitled "Effects of Commercial Dryer Cycle Fabric Softeners on Selected Parameters of Shirting Weight Fabrics." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Textiles and Clothing.

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EFFECTS OF COMMERCIAL DRYER CYCLE FABRIC SOFTENERS ON SELECTED PARAMETERS OF SHIRTING WEIGHT FABRICS

A Thesis

Presented for the

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Degree

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ABSTRACT

The objectives of this research were: (1) to determine the effects of dryer cycle fabric softeners on the moisture absorbency, softness, and static cling of 100% cotton, 65/35 polyester/cotton, and 100% polyester fabrics, (2) to determine whether repeated use of a dryer cycle fabric softener would cause a fabric to change fabric classifications according to the Mushroom Apparel Flammability Test (MAFT) fabric classiciation system, and (3) to determine whether differences exist between two dryer cycle fabric softeners, both of the solid flexible substrate type.

The three shirting weight fabrics were subjected to three different laundering procedures over a total of twenty launderings. Laundering procedure A served as a control since no fabric softener was introduced. Laundering procedures B and C both utilized dryer cycle fabric softeners.

After 1, 3, 5, 10, and 20 launderings the fabrics were evaluated for moisture absorbency, softness and static cling. Wicking heights in both the warp and filling directions were used to evaluate moisture absorbency. Drape coefficient was used as a measure of softness. Static cling was measured in terms of electrical resistivity. After the initial and final launderings each fabric was evaluated for flammability. Ignition time and maximum heat transfer were used to classify the fabrics according to the MAFT fabric classification system.

Results indicated that dryer cycle fabric softeners had no effect on the softness or flammability of the fabrics tested.

However, the dryer cycle fabric softeners did affect the moisture absorbency and static cling of the fabrics. When laundering with a dryer cycle fabric softener, the wicking heights decreased. Launder-ing with a dryer cycle fabric softener decreased the electrical resistivity for each of the fabrics.

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CHAPTER I

INTRODUCTION

"Second only to the appearance and color of fabric used in various garments is the touch or feel" (9). The touch or feel of the garment is dependent on various properties such as its component fibers, yarn size, yarn twist, and fabric construction; now chemical additives are available on the market which reportedly tend to soften the garment.

Most fabrics receive certain finishes and softening agents in the production process, but many of them wash out after one or more launderings. Home-applied fabric softeners offer a remedy to this problem. The regular use of fabric softeners might also tend to reduce fabric stiffness, static cling and other unwanted laundering effects.

The use of fabric softeners has increased rapidly since their introduction to the public some twenty years ago. "On a weight basis, the use of household softeners has increased over 15% in the past year and over 50% in the past 5 years" (44). The first products introduced were liquid products which were added during the rinse cycle of the laundering process. Since their initial introduction, fabric softeners have been supplied in various forms including liquids, sheets, packets, and sprays, with their method of application ranging from the wash or rinse cycle to the dryer cycle.

Fabric softeners applied in the dryer cycle constitute a breakthrough in softener technology. This approach to fabric softeners is a method which provides convenience, for the consumer can place the softener directly into the dryer. At the present time there are three types available. These are: (1) semi-permanent, in place softener, (2) spray-in type, and (3) softener on a solid flexible substrate. The third type was reported to approach 30% of total softener sales in one city after its introduction in a market trial (44).

The primary effect of fabric softeners is that of lubrication, providing reduced yarn-to-yarn or fiber-to-fiber friction, but they affect more than this characteristic. They tend to increase surface hydrophilicity as can be seen by the decrease in static cling, to increase apparent bulk of the fabric, and to decrease fabric moisture absorbency due to the hydrophobic portion of the softener molecule. Another interesting factor may be the effect of softeners on flammability due to the softener's addition of hydrocarbon fuel.

Advertisements for dryer cycle fabric softeners emphasize work simplification--"no liquids to pour or rinse cycle to catch." Manufacturers claim that fabric softeners reduce static cling, impart a clean fresh smell, and leave clothes really soft. While data are available regarding various properties of conventional rinse cycle softeners, relatively little appears to be published concerning dryer cycle softeners. The increased consumer use of dryer cycle fabric softeners indicates a need for research in this area. This study of dryer cycle fabric softeners will determine the softener's effects on selected properties of textile fabrics.

I. STATEMENT OF PROBLEM

The problem selected for study was to evaluate the effects of dryer cycle fabric softeners of the solid flexible substrate type on selected properties of various fabrics. More specifically, the effects of dryer cycle fabric softeners on the moisture absorbency, softness, and static cling of 100% cotton, 65/35 polyester/cotton, and 100% polyester fabrics were investigated. The second portion of this study was to determine whether the application of a dryer cycle fabric softener will cause a fabric to change fabric classification according to the MAFT fabric classification system. The final portion of the study was to determine whether differences exist between two dryer cycle fabric softeners, both of the solid flexible substrate type.

II. NULL HYPOTHESIS

The use of dryer cycle fabric softeners will not affect the moisture absorbency, static cling, softness, and flammability of fabrics.

III. SPECIFIC NULL HYPOTHESES

1. A dryer cycle fabric softener of the solid flexible substrate type will not decrease the absorbency of fabrics, as measured by wicking.

2. A dryer cycle fabric softener will not increase the softness of fabrics, as measured by drape.

3. A dryer cycle fabric softener will not decrease the static cling of fabrics, as measured by AATCC 76-1975 Electrical Resistivity of Fabrics.

4. A dryer cycle fabric softener will increase the flammability of fabrics, as measured by the MAFT maximum heat transfer rate and ignition time.

5. Two different dryer cycle fabric softeners will not differ in their effects on the fabric characteristics.

IV. OBJECTIVES

1. To determine the effects of dryer cycle fabric softeners on selected characteristics of fabrics. These characteristics are: moisture absorbency, static cling, and softness.

2. To determine whether the application of a dryer cycle fabric softener will cause a fabric to change fabric classification according to the MAFT fabric classification system.

3. To determine whether differences exist between two dryer cycle fabric softeners, both of the solid flexible substrate type.

V. ASSUMPTIONS

1. The commercial detergent chosen for use in this study is representative of those commonly used by the consumer.

2. The commercial dryer cycle fabric softeners chosen for use in this study are representative of those commonly used by the consumer.

3. The active softener content is evenly distributed throughout each of the products.

4. Use of a mixed load in laundering is typical of consumer practice.

VI. LIMITATIONS

1. The dryer cycle fabric softeners evaluated in this study were limited to two.

2. The fabrics were limited to three, which would be representative of a mixed load.

3. Only one detergent was used in all the laundering procedures.

4. Softener effects were evaluated at the following laundering intervals: after 1, 3, 5, 10, and 20 launderings.

VII. DEFINITIONS

Absorbency--The ease, speed, and amount of liquids a material will absorb (32).

Wicking--The ability of a material to disperse or spread liquid or moisture throughout a given area in either or both directions (32).

Drape--The manner in which a fabric falls when hung on a form, frame, or manikin (32).

Static Electricity--The force which causes the attraction of small bits or particles to an object after the object has been rubbed or exposed to abrasion (32).

Electrical Resistivity--Refers to the fabric's capacity for resisting electricity or to resist an electrical charge (32).

MAFT Fabric Class--The fabric classification of 1, 2, 3, or 4 as determined by the test criteria (8).

Class 1--Fabrics which have a maximum heat transfer rate of 0.4 Joules per square centimeter per second [J/(cm^2.s)] or less, regardless of ignition time (8).

Class 2--Fabrics which a maximum heat transfer rate of greater than 0.40 J/(cm^2.s) and an ignition time greater than 1 second (8).

Class 3--Fabrics which have a maximum heat transfer rate of greater than 0.40 J/(cm^2·s) and an ignition time of 1 second or less, but greater than 1/2 second (8).

Class 4--Fabrics which have a maximum heat transfer rate of greater than 0.40 J/(cm^2.s) and an ignition time of 1/2 second or less (8).

Ignition Time--The minimum time required for a specimen to ignite as specified in the test criteria (8).

Heat Transfer Rate--The rate at which heat is transferred from a burning specimen to the test apparatus measured as specified in the test criteria (8).

Maximum Heat Transfer Rate--The greatest heat transfer rate transferred from a burning specimen to the test apparatus measured as specified in the test criteria (8).

Mixed Load--A typical wash load which is composed of different types of fabrics (4).

CHAPTER II

REVIEW OF LITERATURE

Recent literature pertaining to the broad subject of fabric softeners was reviewed under the following headings: Development of Fabric Softeners, Classification and Composition of Fabric Softeners, Type of Fabric Softeners, Fabric Softeners and Absorbency, Fabric Softeners and Static Cling, Fabric Softeners and Softness, and Fabric Softeners and Flammability.

I. DEVELOPMENT OF FABRIC SOFTENERS

Softening of textile materials probably dates back to prehistoric times with the application of oils and fats to condition hides (15,36). Although the methods used today are quite different from those used in the past, we still continue to soften our textile materials.

In the late 1930's, fabric softeners began to be used in the textile industry. Originally used to improve the wash fastness of direct dyes on cellulose, they also had germicidal properties (12,15, 51). These early softeners were not suitable for home use, and thus were limited to industrial application.

By the middle 1950's fabric softeners were introduced to the consumer for home use. The need for softeners in the household was prompted when consumers switched from soap to detergents for home laundering. Soap had provided a natural fiber lubricant and fabric softener by leaving a fatty residue on the fabric. Detergents removed the fats and other residues from the fabric, resulting in a stiffer and harsher fabric (3,14,44).

Initially, the growth of fabric softeners on the retail market was slow (15). Since the first softeners had to be added to the rinse cycle, they required an extra step on the part of the consumer; consequently, many were hesitant to try the product. Marketing and advertising campaigns were developed to overcome the consumer's reluctance to try the product (41).

The majority of softeners available today are still added to the rinse cycle, but recent advances are changing this tradition. The newer products include fabric softeners which can be added to the wash cycle or the automatic dryer (44). This added convenience may account for the increased use of fabric softeners.

In 1961, the fabric softener business in the United States showed a 25%/year growth rate (41). By 1974 over half of the homemakers in the United States used a fabric softener regularly (18) The popularity of fabric softeners today has grown to such a point that they are considered necessities by most homemakers. An estimated 68 to 72 million pounds of softener are consumed each year (14). All this has occurred within 20 years of the introduction of the product.

II. CLASSIFICATION AND COMPOSITION OF FABRIC SOFTENERS

Fabric softeners can be classified into three main groups: anionic, nonionic, and cationic. They are grouped according to the electrical charge possessed by the hydrophobic portion of the softener molecule (9,19,21,30,44). Most of these are variations of a few straight chain alkyl or fatty radicals containing between 12 and 18 carbon atoms (21).

Shenai and Mulla (43) classify the softening agents according to their ability to penetrate the surface of the textile material. They are referred to as substantive or non-substantive. The cationic softeners fall into the substantive category because they adhere strongly to the fabric's surface. Anionic and nonionic softeners are classified as non-substantive.

Anionic softeners are those that contain a negative chemical charge on the portion of the molecule which acts as the softener. Since the surface of most textile materials and synthetic detergents possess a negative charge, these softeners repel the negatively charged molecules (21). These anionic softeners must be laid or padded on the fabric's surface (30). Application is very difficult and therefore anionic softeners are not conducive to use in home laundering.

Nonionic softeners are neutral, containing no electrical charge. They are popular in industry because most are highly compatible with other finishing agents (9,21). In home laundering they prove to be undesirable. Like the anionic softeners, they must be physically laid on the fabric.

The cationic softeners are those that contain a positive charge on the portion of the molecule which serves as the softener. A review of the literature and of the retail market indicates that the softeners most used by the consumers today are cationic (9,12,13,14,15,20,21,23, 24,25,26,30,35,40,43). They have been described as substances which dissolve or disperse in water, and concentrate and orient at interfaces (40).

The cationics are long chain nitrogenous compounds, containing at least one long chain hydrophobic (water-hating) tail with a positive charge and small hydrophilic (water-loving) head which has a negative charge (43). This group of softeners tends to be the most effective because the surfaces of most fabrics are negatively charged.

It has been reported that the typical chemical composition of fabric softeners is approximately 75% cationic surface active agent (frequently a quaternary ammonium chloride or sulfate), 18% isopropanol and 7% water (41). The isopropanol is used to dissolve the cationic agent, and water is used to insure dispersion of the softener (51). This paste is further diluted with water solutions of wetting agents. The finished softener has an active ingredient concentration which varies from 3% to 8% (41).

Cationic softeners are classified according to the chemical composition of the active ingredient. At the present time three types of active ingredients are utilized in fabric softeners. The first group used was simpler quaternary ammonium salts obtained by alkylation of fatty amines with methyl chloride, dimethyl sulfate, or benzyl chloride (19).

The second group is composed of amino amides and imidazolines, which are obtained by reacting two moles of fatty acid or fat with diethylenetriamine (44). The third and final group is composed of complex difatty quaternaries whose exact composition has not been disclosed. Chemical compositions of fabric softeners, as seen in Figure 1, are representative of the active ingredients found in fabric softeners.

The dialkyl dimethyl ammonium chloride type is reported to have increased solubility, greater pH stability, and better all-around softening characteristics compared to other types (12). This type of cationic quaternary at 90% active is a solid which can be produced in a powdered or flaked form. For this reason, its use has increased in the dryer style softeners (44).

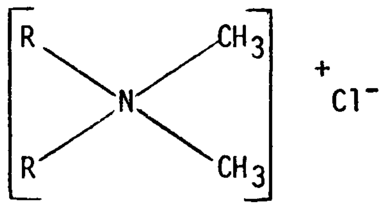
III. TYPES OF FABRIC SOFTENERS

Fabric softeners are available according to their use in the laundering process. These consist of three types which can be added to the wash cycle, rinse cycle, or the automatic dryer. They are produced in a variety of physical forms including emulsions, sprays, solids, coated papers and fabrics, sponges and liquids (27).

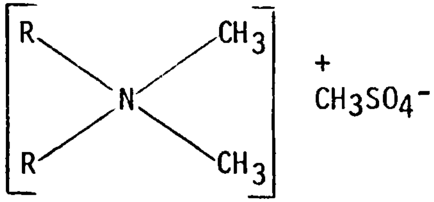
Fabric softeners used in the rinse cycle still constitute the majority of softeners available today. They are creamy emulsions tinted in a variety of colors and slightly perfumed. They may or may not contain bluing, brighteners, or other bacteriostats.

Fabric softeners work by being deposited on the fabric's surface, therefore anything that interferes with this process also interferes with the effectiveness of the softener. This is one of the major reasons rinse cycle softeners are so efficient. The rinse cycle is free of residual detergent and soil that could interact with the softener (3,30).

Simple Quaternary Ammonium Types

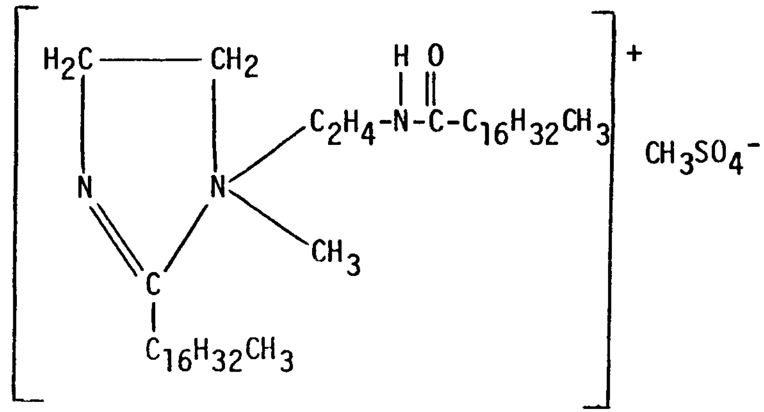
A. 

Distearyl Dimethyl Ammonium Chloride

B. 

Distearyl Dimethyl Ammonium Methyl Sulfate

Imidazoline Types



1-Methyl-1-(Stearylamide) Ethyl-2 Heptadacyl-4,5, Dihydroimidozalinium Methyl Sulfate

Complex Difatty Quaternary Types

Ditallow	Plus	Diethylenetriamine	Plus	Ethylene Oxide	And	Quaternized
2R	+	$H_2N\text{-}C_2H_4\text{-}N(H)\text{-}C_2H_4\text{-}NH_2$	+	C_2H_4O		$C_2H_6SO_4$ $(CH_3)_2$

R = Stearyl

Figure 1. Types of fabric softener active ingredients. Source: 44.

These first fabric softeners proved to be inconvenient to the consumer because they required an extra step in the laundering procedure. The consumer had to make a trip to the washing machine at a precise time, otherwise the washer would pass the rinse cycle. This inconvenience prompted washing machine manufacturers to provide dispensers which added the softener at a designated time in the laundry cycle. Researchers then developed fabric softeners which could be used in the wash cycle or the automatic dryer.

Wash cycle softener formulations are similar to rinse cycle softeners, but they are not as effective. When added with detergents or soaps, both the cleaning and softening effects are reduced due to the interaction with the detergent (14,44). Wash cycle softeners were designed to overcome the inconvenience of adding a softener to the rinse cycle. Most are effective as rinse cycle softeners, which gives the consumer the added choice of selecting the cycle.

Presently there are three variations of dryer softeners available: (1) semi-permanent in-place softener, (2) spray-in softener, and (3) softener on a solid flexible substrate (44). In the dryer, the current of the heated dry air and water vapor which evolves from the fabric causes the softener to deposit on the fabric as it is tumbled through the softener-saturated air (27).

The semi-permanent in-place softener is used by placing a small fabric pouch which contains a solid softener in the dryer drum. The amount of softener released is determined by the cycle time of the dryer and the softener formulation. The spray-in type was first introduced as an aerosol product. They are now available as liquid dispersions which are sprayed in the dryer before starting (44). The third dryer softener is represented by two products, both of which contain softener which is dispersed on a solid flexible substrate. One product uses as its substrate a polyurethane sponge-like material (Cling Free). Another product uses a non-woven rayon fabric sheet as its solid substrate (Bounce) (44).

Dryer softeners constitute 40% of softeners marketed today (44). While the rinse cycle softeners soften more effectively, research indicates that dryer softeners impart excellent anti-static properties (14). This is due in part to the fact they are applied directly to the source of static problems--the dryer.

IV. FABRIC SOFTENERS AND ABSORBENCY

The effect of fabric softeners on the absorbency of fabrics has been investigated. Most consumers believe ". . . that absorbency of textile products is affected by the use of fabric softeners" (37). The consensus of studies dealing with rinse cycle fabric softeners suggest that regular use of a fabric softener will result in decreased absorbency.

Two test procedures are commonly used to determine absorbency. The first, known as sinking time, is the time required for a specimen to sink beneath the water's surface. The second, known as wicking, measures the height of a liquid that travels up a fabric's surface in a designated time.

It is believed that continued use of fabric softeners tends to build up a waxy coat on the fabric's surface. This build-up interferes with the fabric's ability to absorb liquids (15,16). Both sinking time and wicking tests showed considerable reduction in absorbency for rinse-cycle softened fabrics in research conducted by Kennedy (29).

Consumer Reports (17) conducted wicking tests on cotton terry cloth. They found that rinse-cycle fabric softeners decreased absorbency sharply. The towels took from four to six times as long to absorb a given quantity of liquid as they had before treatment. Further studies done by Consumer Reports (18) found similar results. The tests recorded the time required for a drop of water to be absorbed by a fabric that had been washed six times with a rinse cycle fabric softener. The softened fabrics took ten times as long to absorb the water as did untreated fabric.

Ginn (20) studied the effect of rinse cycle fabric softener on cotton terry cloth through four launderings. Results indicated that at high concentration of softeners, the rate of wetting was adversely affected; at normal concentrations, it is not greatly reduced. Linfield (31) claimed the amount of softener add-on has an effect upon the rate of water absorption of treated fabric. At low percentages of add-on, such as those used in laundering, the effect is not objectionable.

The Northern Piedmont Section of AATCC (37) carried out a study of repeated rinse cycle fabric softener application to terry cloth towel. Water absorbency was tested by three test methods; the results indicated there was no significant loss of absorbency due to the use of softeners. Wachter's (50) research revealed that at very high levels of add-on, synthetic fabrics became more absorbent with rinse cycle fabric softener, while cotton became less absorbent.

V. FABRIC SOFTENERS AND SOFTNESS

The methods used to evaluate fabric softeners are both subjective and objective. Subjective methods generally consist of a panel evaluation of the fabric hand, and visual comparisons (6,20, 23,37). Objective or laboratory evaluations of softness include fabric drapeability and yarn lubricity.

Fabric drapeability, as measured by the FRL drapemeter, provides some indication of softener effects. Since softeners provided lubrication and increased fabric pliability, it seems that a softener would increase fabric drapeability. In a study of softeners applied to fabrics by various methods, the drape test was used as a measure of softness. It was found that fabric drapeability was improved significantly with the application of rinse cycle fabric softeners (37).

Yarn lubricity is a measure of the force necessary to remove a single yarn from the fabric structure. This method was developed by Gagliardi and has been reported as a method for evaluation of softness. Essentially, this method measures the friction of a single yarn moving through the cross yarns (47). Since a fabric softener is believed to provide lubrication by reducing friction, the relative ease of yarn removal should provide an indication of softener effect. Kennedy's (29) study revealed that rinse cycle fabric softener increased the yarn lubricity.

VI. FABRIC SOFTENERS AND STATIC CLING

Static electricity, or the undesirable build-up of charges on a fabric's surface has become a problem with the increased use of synthetic fibers. For the consumer, synthetic fabrics present many annoying problems. Examples consist of the clinging of apparel, such as pants to socks, skirts to legs and dresses to the body, or when garments are taken off and there is a crackling sound with flashes of light as the static is discharged (15,42).

Natural fibers, because of their affinity for water, have the ability to conduct a charge away from the fabric. Synthetic fibers, which are hydrophobic (water-hating), have no surface water to conduct the charge away so it remains localized on the fabric surface. This build-up of excess charges on the surface causes undesirable cling or slight electrical shocks. When a fabric softener is applied to a synthetic fiber, it coats the surface and the hydrophilic portion of the softener provides water necessary to dissipate any charge (50).

Fabric softeners have been reported to serve as effective anti-static agents (15,17,31,40,49). Consumer Reports (17) conducted research on polyester/cotton blends and nylon to measure the softeners' effect on static cling. Most samples showed reduction in static cling after just two launderings with a rinse cycle fabric softener; after five launderings all fabrics showed a reduction. Rinse cycle fabric softeners proved to be effective as anti-static agents in research conducted by Linfield (31).

The Philadelphia Section of AATCC (40) carried out research concerning rinse cycle fabric softener's effectiveness as anti-static agents. Results indicated that the quaternary ammonium compounds, similar to what is used in home laundering fabric softeners, were effective agents for acrylic, triacetate, and nylon. Tickle (49) found rinse cycle fabric softeners to be effective in reducing the static cling in nylon.

Egan (14) conducted a study comparing the effectiveness of wash cycle, rinse cycle, and dryer cycle softeners in reducing static cling. The anti-static properties displayed by the dryer cycle fabric softeners were excellent; reductions of 90% or higher were not uncommon. Anti-static properties were also displayed by the rinse and wash cycle softeners.

VII. FABRIC SOFTENERS AND FLAMMABILITY

The question of fabric flammability has been of great concern to both legislators and consumers for some time. The first legislation went into effect in 1953, when injuries and deaths were attributed specifically for fires caused by clothing ignitions. In 1974, the Consumer Products Safety Commission estimated that 28,000 persons were injured as a result of clothing ignitions (48).

The Flammable Fabrics Act passed in 1953 made it illegal to sell garments which did not comply with the CS 191-53 flammability standard (11). In 1967 this act was amended, and government agencies were given authority to establish regulations in specific areas of textile flammability. In 1971 one regulation was announced to regulate the flammability of sleepwear in children's sizes 0-6x. This regulation, DOC FF 3-71, which took effect in 1973 was later expanded to DOC FF 5-74 to include children's sleepwear sizes 7-14. If the proposed standard for the flammability of general wearing apparel is passed, further regulations will be imposed on all garments. The use of fabric softeners may affect the flammability of garments.

Most fabrics will burn, char, or melt given the proper conditions. The flammability of fabrics is very complex and influenced by the characteristics of the fiber, yarn, fabric and finish (28). Since fabric softeners alter the fabric surface, it has been postulated that they may affect the flammability of the fabric. Some research has been done on the interaction of fabric softeners and flame retardant finishes, but to date, little has been published concerning the effect of fabrics which were not treated with flame retardants.

The review of literature reveals conflicting reports concerning the effects of fabric softeners on flame retardant fabrics (7,10,27,29, 38,39,45,46,49). One reports the flame retardant finish was diminished or eliminated by the fabric softener (45,46). Others report no adverse effects were obtained after laundering with a fabric softener (50).

Kennedy (29) conducted research on the effect of a rinse cycle fabric softener on the flammability of children's sleepwear fabric. Three flame retardant (FR) finished fabrics were selected and subjected to two different laundering procedures, one with a softener and one without a softener. The effect of the softener on the flammability of the FR finished fabrics was to increase the char length for cotton fabrics and in some cases to cause failure of the test. Polyester fabrics were unaffected by the softener.

In research done by Simpson (45,46), the effects of fabric softeners on FR cotton fabrics were investigated. The softeners included those applied in the wash cycle, rinse cycle and one dryer spray. It was concluded that softeners applied in the wash and rinse cycles had detrimental effects on the FR finish, while the dryer spray had no adverse effects on the FR finish.

Research conducted by Collins (7) revealed a difference between hard and soft water when washing fabrics with fabric softener. In soft water, rinse cycle softeners produced no failures according to DOC FF 3-71, while wash cycle softeners failed after the 10th laundering. In hard water, failures were obtained after the 20th laundering using rinse cycle softeners, and wash cycle softener failed after 10 launderings. Research carried out by Wachter (50) revealed that the fabric softener and the level applied had no effect on fabric flammability. However, Wachter applied softeners by a pad-dry procedure, and no laundering was involved.

CHAPTER III

PROCEDURES

Three shirt weight fabrics were subjected to three different laundering procedures over 20 launderings. This chapter outlines the procedures for fabric selection, sample preparation, laundering procedures, physical testing, and analysis of data.

I. FABRIC SELECTION

The three fabrics selected for this study were acquired from Test Fabrics, Inc. Each fabric was of a plain weave and of a weight comparable to those seen in shirting. Physical properties of the samples were determined by the appropriate ASTM test methods: fabric weight (ASTM 1910-64) and yarn count (ASTM 1910-70) (2). The properties are shown in Table I.

TABLE I

PHYSICAL PROPERTIES OF FABRICS USED

Fabric	Fiber Content	Finish	Yarn Count	Fabric Weight
1	100% cotton	Wash & Wear	142 W 59 F	3.6 oz/sq yd.
2	65/35 poly/cotton	Durable Press	100 W 84 F	2.9 oz/sq yd.
3	100% polyester	Heat Set	63 W 53 F	4.0 oz/sq yd.

II. SAMPLE PREPARATION

Each fabric was cut into 150 12 x 12 inch swatches and 144 23 x 12.5 inch swatches. The swatches were then randomly assigned groups for laundering without fabric softener, laundering with fabric softener B, and laundering with fabric softener C. The entire study was replicated two times.

The 23 x 12.5 inch swatches were used for flammability evaluation, and the 12 x 12 inch swatches were subdivided into specimens for evaluating drape, wicking, and electrical resistivity. All fabrics, after being cut in swatches were edge stitched and coded for laundering procedure and replication.

III. LAUNDERING PROCEDURE

All launderings were carried out in the same washer and dryer throughout the entire study. Each laundering procedure contained samples of all three fabrics. The order in which each group of fabrics was selected for a specific laundering procedure was randomized, as were the replications. Each group of fabrics was given one of the following laundering procedures.

Laundering Procedure A

Laundering procedure A served as the control. The fabric samples were washed using 90 grams of a commercial phosphate detergent (Tide, which contains 6.1% phosphorus). Samples were washed in a Sears Kenmore automatic washer with a 14-minute wash cycle and 5-minute rinse cycle. The machine was set on high load for a normal wash procedure with warm water (49°C) and a warm rinse (49°C). After the washing was complete, the swatches were placed in a Sears Kenmore dryer which was set for 25 minutes. After 1, 3, 5, 10, and 20 launderings, five 12 x 12 inch swatches of each fabric were removed for the evaluation of drape, wicking and electrical resistivity. After the initial and final launderings, 12 23 x 12.5 swatches of each fabric were removed for flammability evaluation, ignition time and maximum heat transfer rate. As the wash loads became smaller, the water level and the amount of detergent remained constant. Since this laundering procedure served as a control, no fabric softener was introduced.

Laundering Procedures B and C

These laundering procedures were identical to the first except that a sheet of fabric softener B or C (Bounce and Cling Free, respectively) was added to the dryer when the fabrics were dried. As the wash loads became smaller, the amount of fabric softener was decreased proportionately; a full sheet was used for the initial laundering, three-quarters of a sheet for launderings 2 through 5, and one-half sheet for launderings 6 through 20.

IV. PHYSICAL TESTING

Unless otherwise stated, testing procedures adhered to the methods of the American Association of Textile Chemist and Colorist (AATCC) and American Society for Testing Materials (ASTM). All specimens were subjected to standard conditions of 70° ± 2°F and a constant humidity of 65 ± 2% for at least 24 hours prior to testing, unless otherwise stated.

Absorbency Testing--Wicking

Three 1 x 8 inch strips were cut in the warp and fill directions from the 12 x 12 inch swatches. The specimens were suspended by tape from a horizontal rod and weighted with a paper clip at the bottom. The strips were then submerged into the distilled water. A soluble red coloring was added to the water to facilitate measurements. The height (in millimeters) of the water absorbed was recorded after 1, 5, and 10 minutes (37).

Static-Cling Testing--Electrical Resistivity

Six 1 x 3 inch strips were cut on the warp from the 12 x 12 inch swatches. The electrical resistivity of each fabric was determined according to the AATCC test method 76-1975, Electrical Resistivity of Fabrics. Testing was done under standard conditions rather than the recommended 40% relative humidity and 24°C. A Static-master Ionizing Unit was used to remove the static charges; an Electrical Resistance Tester Model CS-51, from Custom Scientific Instruments, Inc., was used to measure the electrical resistivity (1).

Softness Testing--Drape

One circular specimen measuring 10 inches in diameter was taken from each of the three 12 x 12 inch swatches for each test interval. The fabric drape, as measured by the FRL Drapemeter, was used to evaluate softness. Each specimen was measured on the front and back. The specimen was suspended from a 4 inch circular pedestal directly above a light source. The light source caused a shadow to be cast on the glass above the specimen. This shape was then traced onto tracing paper and cut out. The area of the tracing was determined by the drapemeter using the following equation:

$$\text{Area of tracing} = \frac{\text{Weight of the cut piece of tracing paper}}{\text{Weight per unit area}}$$

The drape coefficient (DC) was then obtained using equation:

$$DC = \frac{A_t - A_p}{A_c - A_p} \times 100$$

A_t = Area of the tracing.

A_p = Area of the 4 inch pedestal.

A_c = Area of the 10 inch circle (22).

Flammability Testing--Ignition Time

Four 12.5 x 23 inch specimens were cut in the warp and filling directions. The ignition time of each fabric was determined according to the proposed Mushroom Apparel Flammability Test (MAFT) (8).

Flammability Testing--Maximum Heat Transfer Rate

Two 12.5 x 23 inch specimens were cut in the warp and filling directions. The maximum heat transfer rate of each fabric was determined according to the proposed MAFT (8).

The fabrics were classified according to the MAFT fabric classification system. Fabric classification of 1, 2, 3, or 4 were possible, one being the least flammable. (See the definition section of Chapter I, page 6, for further explanation of the classes.)

V. ANALYSIS OF DATA

Four four-way analyses of variance (ANOVA) were conducted using Statistical Analyses system (SAS) program on The University of Tennessee IBM 370 computer system. Four separate analyses determined the effects and interactions of laundering procedure, fabric, and interval on the absorbency in the warp and filling direction, drape, and electrical resistivity. If significant differences occurred, Duncan's Multiple Range post hoc tests were carried out to find the significant differences.

Evaluation of the interval models was carried out using the General Linear Model program of SAS '76. The best linear or quadratic regression analysis was obtained for the following data:

1. Absorbency--Average wicking height (after 10 minutes in warp and filling direction) vs. number of laundering for each laundering procedure and fabric.

2. Softness--Average drape coefficient (percent drape) vs. number of launderings for each laundering procedure and fabric.

3. Static Cling--Average electrical resistivity vs. number of launderings for each laundering procedure and fabric.

Flammability was evaluated by comparing the classification of the fabric after repeated launderings with and without fabric softeners. A change in fabric classification, according to MAFT fabric classification system, indicated that dryer cycle fabric softeners had affected the flammability of the fabric.

CHAPTER IV

RESULTS AND DISCUSSION

Four four-way analysis of variance (ANOVA) were conducted using Statistical Analysis System (SAS '76) program on The University of Tennessee IBM 360 computer system. The independent variables were fabric (FAB), laundering procedure (LPRO), laundry interval (INT), and replication (REP). Separate analyses were run on the dependent variables, wicking height after 10 minutes in the warp direction, wicking height after 10 minutes in the filling direction, drape coefficient, and electrical resistivity.

Significance levels of .05 and .01 were chosen as significant and highly significant, respectively. A more conservative error term was needed to test the hypotheses. The three-way interaction between fabric, laundering procedure, and replication was used as the error term to test for the effect of fabric, laundering procedure, and the interaction of these variables. The four-way interaction between fabric, laundering procedure, interval, and replication was used as the error term to test the effect of laundry interval and its interactions with fabric and laundering procedure.

Fabric, laundering procedure and the interaction of these variables were found to be highly significant for each dependent variable with the exception of drape. Interval was found to be highly significant for each dependent variable with the exception of electrical resistivity. After the analyses of variance were completed, Duncan's

Multiple Range post hoc tests were conducted.

The next step in the analysis was to evaluate the effect of laundering intervals on the dependent variables. This was done by using the General Linear Model program of SAS '76. Data were fit to both linear and quadratic models using laundering interval as the independent variable. In some cases, the data best fit the second order model; in others, the fit to a linear model was not improved by using the quadratic term. In some cases, there was no fit to either a linear or quadratic model; the scatter of the data appeared to be random.

The results will be discussed in separate sections evaluating the absorbency, softness, static cling and flammability. Ranking of the fabrics and laundering procedures as determined by Duncan's Multiple Range post hoc tests will also be discussed.

I. ABSORBENCY

Wicking tests were run for the evaluation of the absorbency of the fabrics tested. For each fabric, testing was done in both the warp and filling directions. Wicking heights after 10 minutes, measured in millimeters, were determined. An increase in wicking height indicates greater moisture absorbency.

The four-way ANOVA's for wicking height in the warp and filling directions, Tables II and III, show all effects and their interactions, with the replication, to be significant or highly significant. From Tables IV and V, one can see that as laundering proceeded without a softener, the 100% cotton and the 65/35 polyester/cotton tended to

TABLE II

FOUR-WAY ANOVA FOR WICKING HEIGHT AFTER 10 MINUTES IN WARP DIRECTION

Source	DF	Sum of Squares	F-Value
Test of Hypotheses Using Residual as Error Term			
FAB	2	74192	974.78**
LPRO	2	22835	300.02**
FAB*LPRO	4	17798	116.92**
INT	4	2612	17.16**
FAB*INT	8	1867	6.13**
LPRO*INT	8	3961	13.01**
FAB*LPRO*INT	16	2910	4.78**
REP	1	6	0.16
FAB*LPRO*REP	8	761	2.50**
FAB*LPRO*INT*REP	36	2584	1.89**
RESIDUAL	180	6850	
TOTAL	269	136376	
Test of Hypotheses Using FAB*LPRO*REP as Error Term			
FAB	2	74192	389.88**
LPRO	2	22835	120.00**
FAB*LPRO	4	17798	46.76**
Test of Hypotheses Using FAB*LPRO*INT*REP as Error Term			
INT	4	2612	9.10**
FAB*INT	8	1867	3.25**
LPRO*INT	8	3961	6.90**
FAB*LPRO*INT	16	2910	2.53**

$*p < .05.$

$**p < .01.$

TABLE III

FOUR-WAY ANOVA FOR WICKING HEIGHT AFTER 10 MINUTES IN FILLING DIRECTION

Source	DF	Sum of Squares	F-Value
Test of Hypotheses Using Residual as Error Term			
FAB	2	35800	696.60**
LPRO	2	16285	316.87**
FAB*LPRO	4	10592	103.05**
INT	4	1713	16.66**
FAB*INT	8	817	3.97**
LPRO*INT	8	1841	8.95**
FAB*LPRO*INT	16	1639	3.99*
REP	1	88	3.42
FAB*LPRO*REP	8	515	2.50**
FAB*LPRO*INT*REP	36	1534	1.66*
RESIDUAL	180	4625	
TOTAL	269	75448	
Test of Hypotheses Using FAB*LPRO*REP as Error Term			
FAB	2	35800	278.28**
LPRO	2	16285	126.58**
FAB*INT	4	10592	41.17**
Test of Hypotheses Using FAB*LPRO*INT*REP as Error Term			
INT	4	1713	10.05**
FAB*INT	8	817	2.40*
LPRO*INT	8	1841	5.40**
FAB*LPRO*INT	16	1639	2.40**

*p < .05.

**p < .01.

TABLE IV

FABRIC ABSORBENCY AS MEASURED BY WICKING HEIGHT (mm) AFTER 10 MINUTES FOR LAUNDERING PROCEDURES AT SELECTED LAUNDERING INTERVALS FOR WARP SPECIMENS

	Laundering	Laundering Proc A	Laundering Proc B	Laundering Proc C
Fabric 1	1	90(5.89)*	70(4.62)	77(6.28)
	3	91(3.38)	51(1.47)	58(11.70)
	5	99(5.40)	51(5.28)	60(7.85)
	10	112(7.94)	52(9.87)	56(3.33)
	20	120(2.88)	54(6.82)	60(5.33)
Fabric 2	1	32(8.94)	28(7.58)	33(7.84)
	2	33(5.92)	24(7.28)	27(5.55)
	5	34(5.43)	25(5.65)	31(4.00)
	10	41(2.23)	28(3.87)	34(3.82)
	20	49(4.43)	35(4.97)	39(7.19)
Fabric 3	1	60(7.89)	57(7.71)	62(6.27)
	3	56(4.24)	49(3.54)	53(11.36)
	5	62(13.08)	46(5.00)	63(5.36)
	10	59(9.14)	45(8.65)	52(7.47)
	20	59(3.43)	56(9.05)	50(6.47)

*Number in parentheses is the standard deviation.

Fabric 1 = cotton; Fabric 2 = 65/35 polyester/cotton; Fabric 3 = polyester.

TABLE V

FABRIC ABSORBENCY AS MEASURED BY WICKING HEIGHT (mm) AFTER 10 MINUTES FOR LAUNDERING PROCEDURES AT SELECTED LAUNDERING INTERVALS FOR FILLING SPECIMENS

	Laundering	Laundering Proc A	Laundering Proc B	Laundering Proc C
Fabric 1	1	73(8.29)*	54(4.62)	59(5.13)
	3	74(4.68)	42(4.15)	45(5.99)
	5	81(4.29)	43(4.80)	47(7.92)
	10	88(4.41)	41(4.17)	48(5.35)
	20	94(2.71)	46(6.85)	47(5.22)
Fabric 2	1	29(10.15)	26(4.10)	31(8.33)
	3	32(7.28)	24(6.47)	28(6.71)
	5	31(4.03)	24(4.08)	31(3.78)
	10	36(4.08)	27(6.59)	31(5.60)
	20	47(2.43)	33(3.95)	35(2.88)
Fabric 3	1	46(7.29)	43(5.48)	39(6.29)
	3	44(4.08)	33(3.66)	40(6.41)
	5	46(4.23)	30(3.37)	46(2.26)
	10	45(2.64)	30(3.98)	43(8.29)
	20	47(2.74)	37(6.36)	43(6.50)

*Number in parentheses is the standard deviation.

Fabric 1 = cotton; Fabric 2 = 65/35 polyester/cotton; Fabric 3 = polyester.

become more absorbent, whereas the 100% polyester tended to remain the same. When laundering with a dryer cycle fabric softener, the wicking heights decreased. The overall effect of dryer cycle fabric softener on absorbency, as measured by wicking height, was to reduce the moisture absorbency.

In Figures 2-7, the wicking height, in millimeters, is plotted against laundering interval for each fabric for each laundering procedure. Examination of these graphs reveals the following.

100% Cotton

Results are shown in Figures 2 and 3 for wicking height in the warp and filling directions, respectively. All data were best fit to quadratic models with the exception of laundering procedure C, in the filling direction only. The data show that for laundering procedure A, without a fabric softener, absorbency in both warp and filling directions increases throughout the range of laundry intervals studied. For laundering procedures B and C the absorbency decreases over the first ten applications of fabric softener, then rises slightly over the last ten applications. An exception to this, previously noted, is procedure C in the filling direction which showed no significant change with laundering interval. The data show that, for 100% cotton, the use of dryer cycle fabric softeners reduced the absorbency of the fabric, as measured by wicking. The slight increase in wicking height over the last ten applications of softener may be a result of the experimental design: the laundry load was smallest over the last ten launderings; since the water level in the washer was not reduced, the

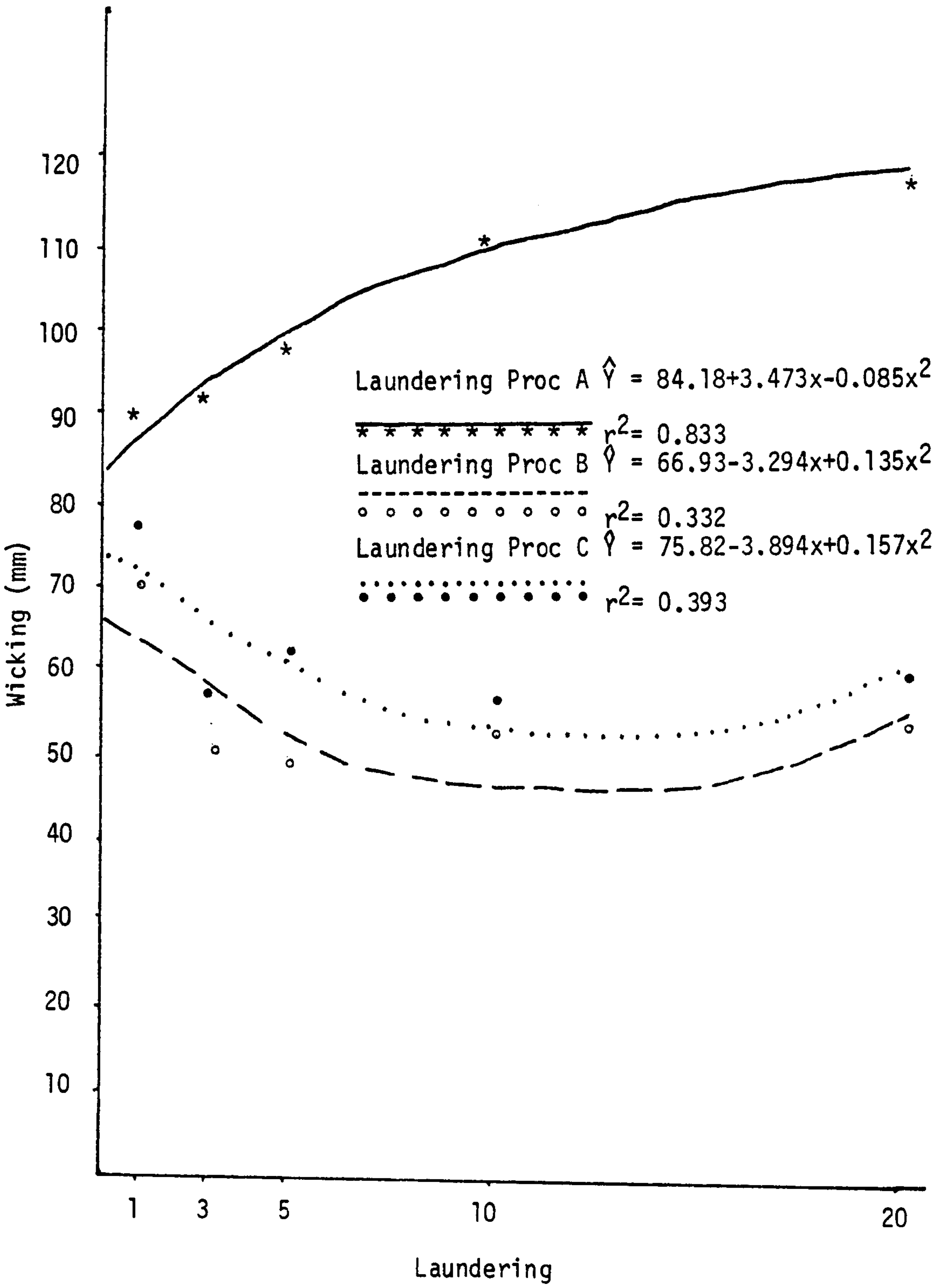


Figure 2. Wicking height (mm) after 10 minutes vs. laundering for fabric 1 (warp)--100% cotton.

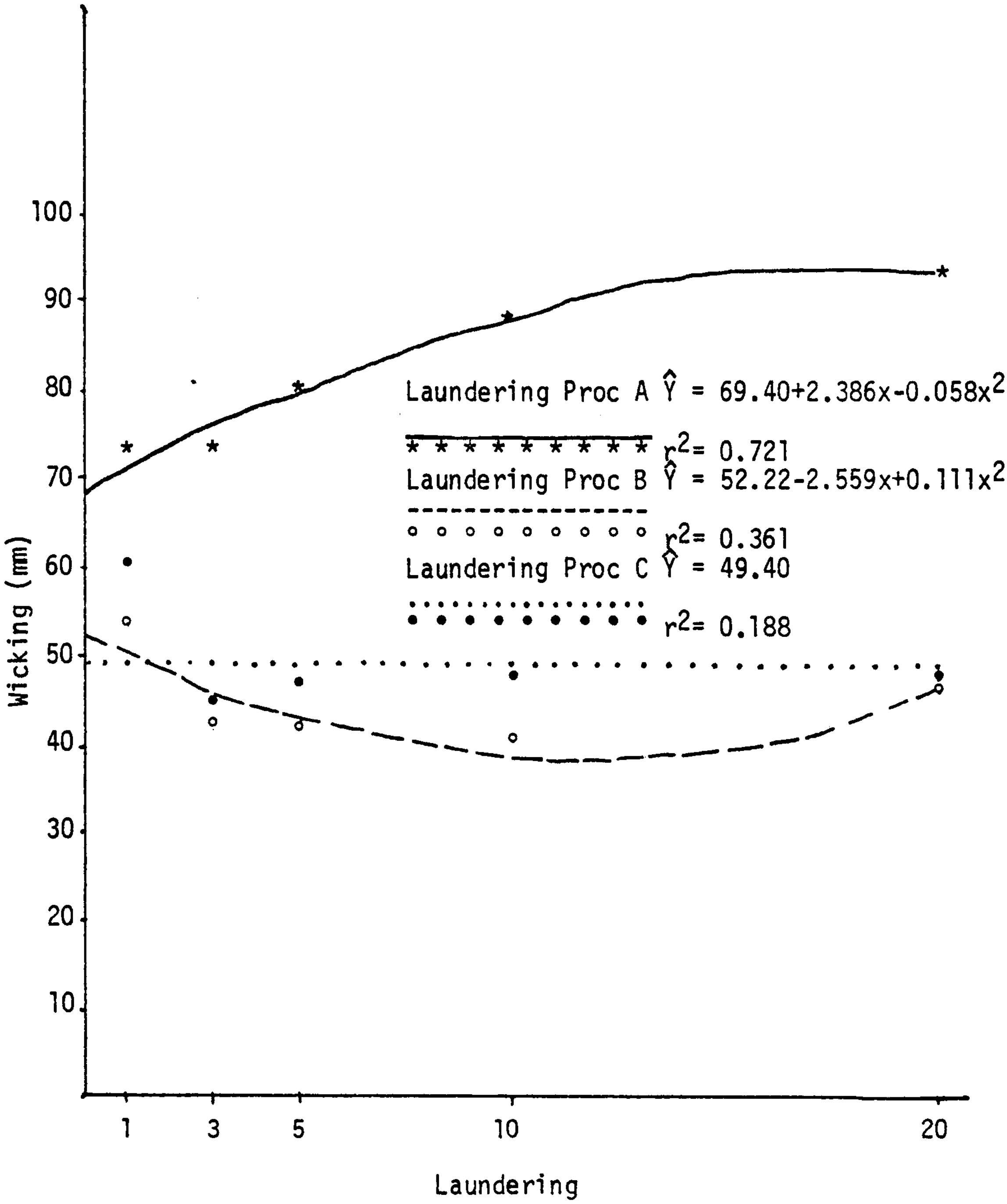


Figure 3. Wicking height (mm) after 10 minutes vs. laundering for fabric 1 (filling)--100% cotton.

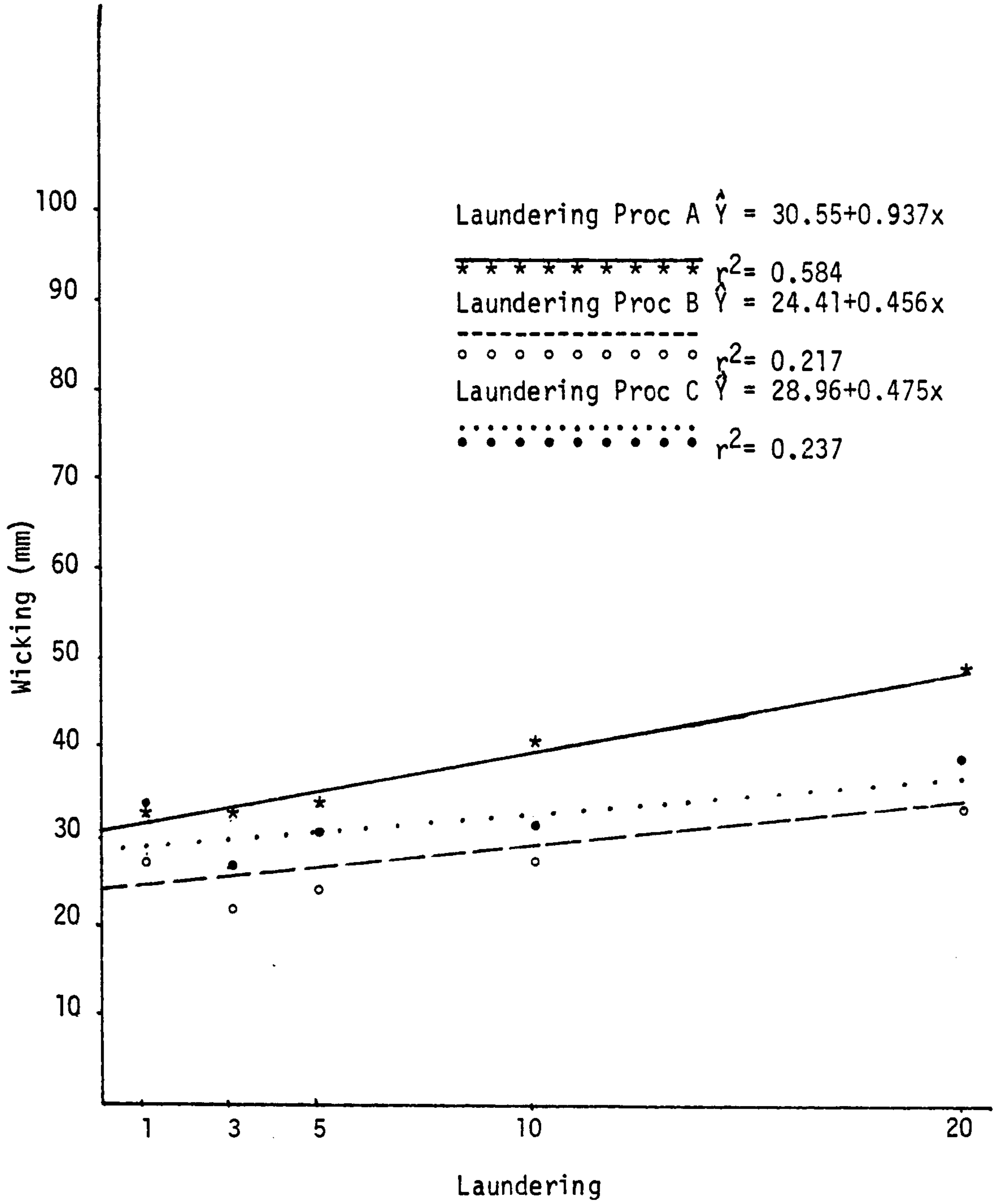


Figure 4. Wicking height (mm) after 10 minutes vs. laundering for fabric 2 (warp)--65/35 polyester/cotton.

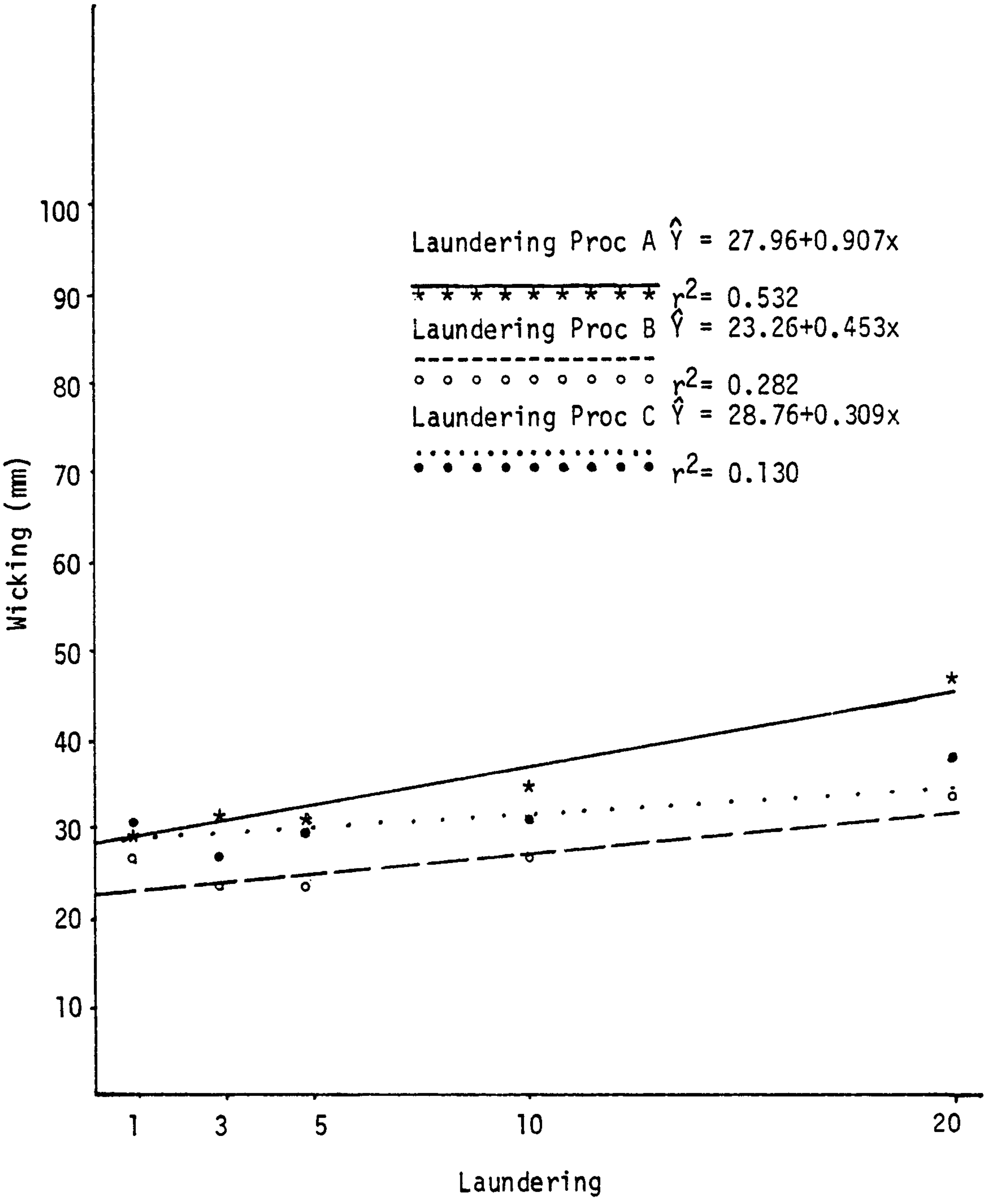


Figure 5. Wicking height (mm) after 10 minutes vs. laundering for fabric 2 (filling)--65/35 polyester/cotton.

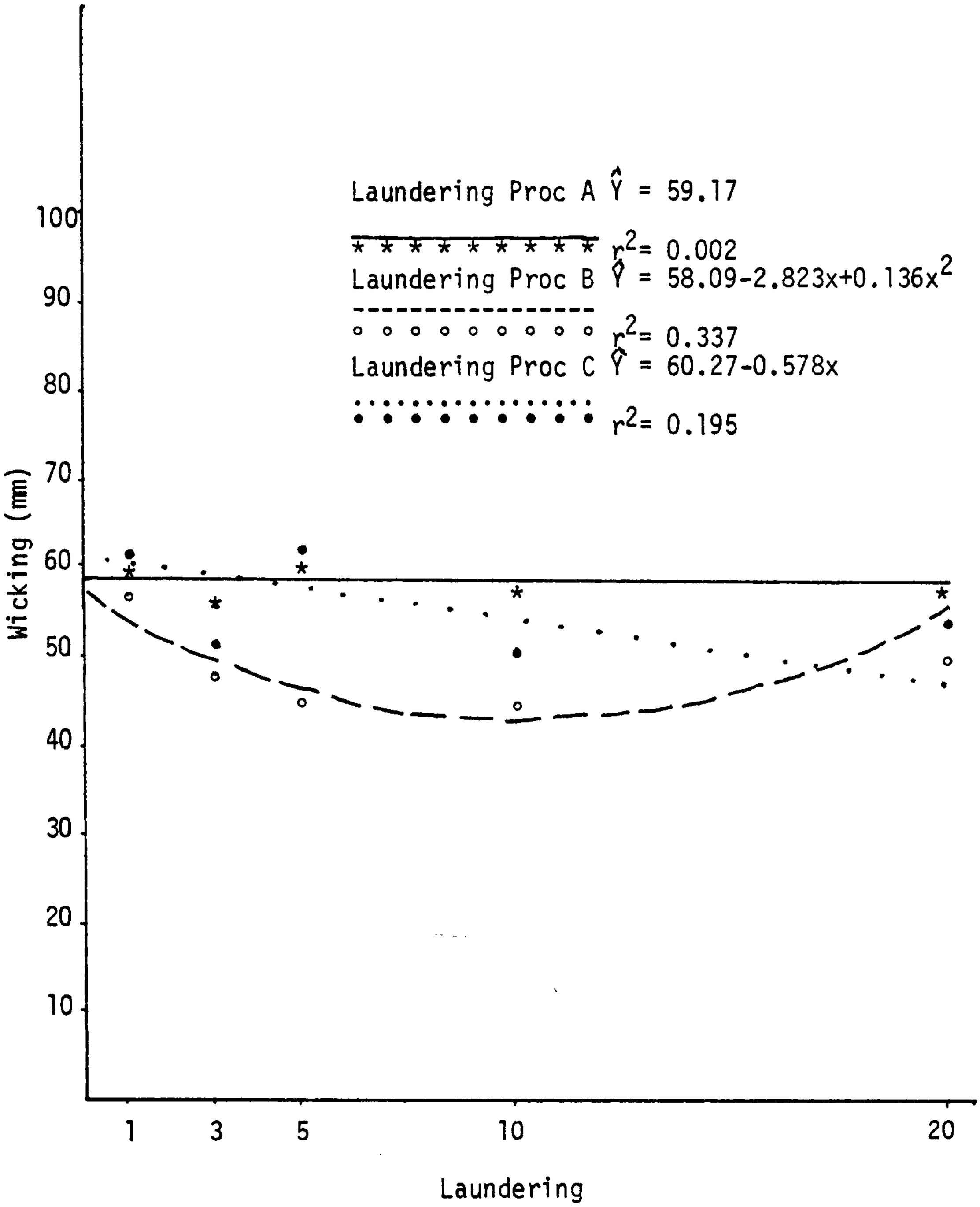


Figure 6. Wicking height (mm) after 10 minutes vs. laundering for fabric 3 (warp)--100% polyester.

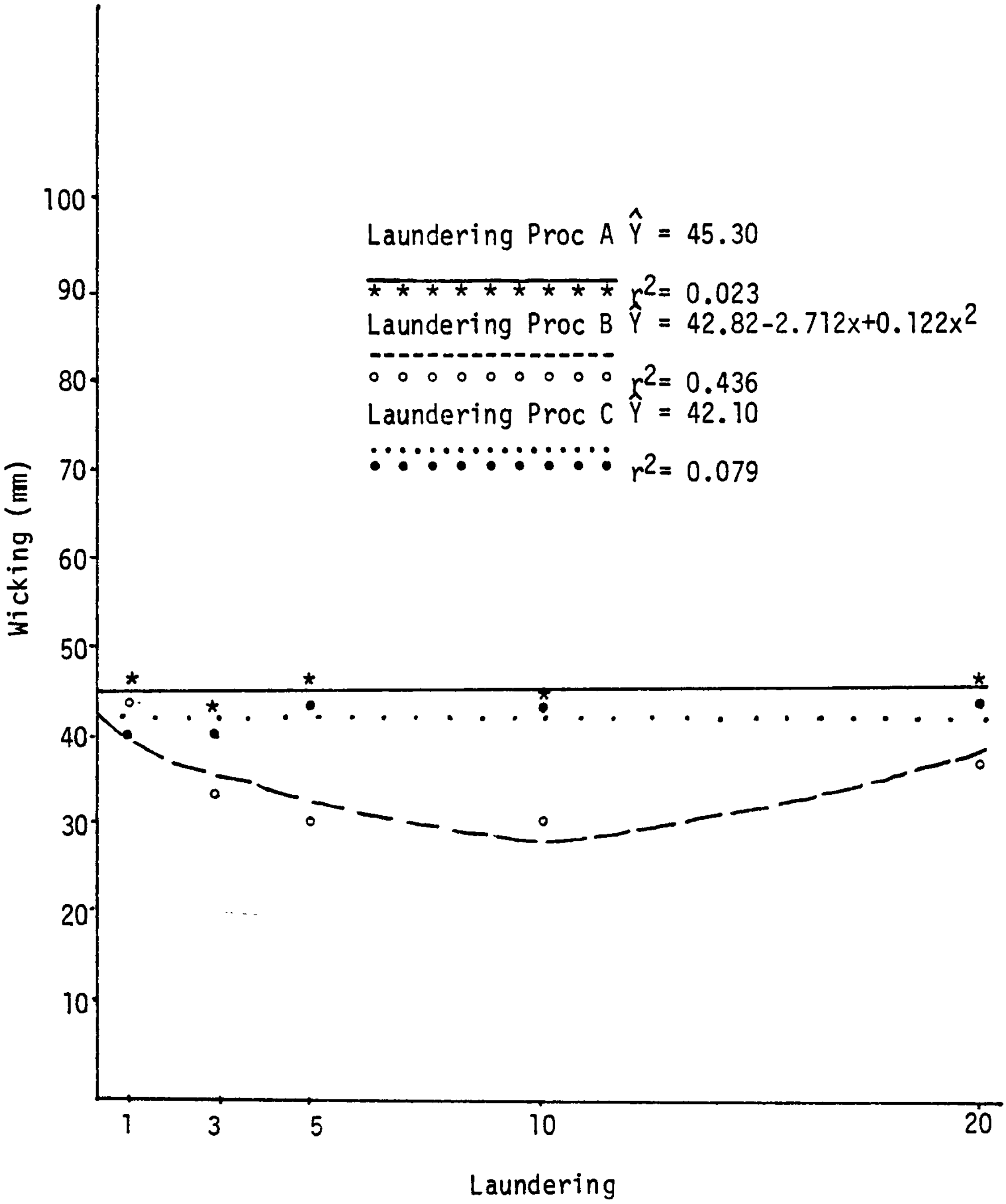


Figure 7. Wicking height (mm) after 10 minutes vs. laundering for fabric 3 (filling)--100% polyester.

higher liquid/cloth ratio for the last ten launderings might have given more efficient removal of previously deposited softener.

65/35 Polyester/Cotton

Results are shown in Figures 4 and 5 for wicking height in both the warp and filling directions, respectively. All data were best fit to linear models in both the warp and filling directions. The positive slopes indicate that absorbency increased with laundry interval for all laundering procedures. The slopes for laundering procedure A, without fabric softener, were significantly higher than the slopes for procedures B and C, showing that the use of dryer cycle fabric softeners partially negated the increase due to laundering alone. These data show that, for this blend fabric, absorbency as measured by wicking increases with laundering with or without dryer cycle fabric softener, but that softened fabrics are less absorbent than unsoftened fabrics at each interval.

100% Polyester

Results are shown in Figures 6 and 7 for wicking heights in both warp and filling directions, respectively. Laundering procedure A, without fabric softener, shows no change in wicking height over the 20 laundering intervals. Laundering procedure B gives results best fit to quadratic models showing a decrease in wicking over the first 10 launderings followed by an increase over the last 10 launderings. The increase may be caused by the experimental design, as previously discussed for the cotton fabric. Laundering procedure C showed a linear decrease in absorbency in the warp direction and no change in the fill direction. The change in wicking of this fabric was slight, and each procedure gave somewhat different results. The effect of dryer cycle fabric softeners on the 100% polyester was to give lower absorbency than no use of fabric softener.

Since each main effect, laundering procedure and fabric, was found by ANOVA to be significant, Duncan's Multiple Range post hoc comparison test was applied to establish significant differences among these effects. Tables VI and VII illustrate Duncan's Multiple Range post hoc test for wicking heights in the warp and filling directions. The 100% cotton has the highest values, followed by the 100% polyester, then the 65/35 polyester/cotton. The 100% polyester shows higher wicking than the 65/35 polyester/cotton blend because of the larger yarns used and the fewer yarns per inch.

For each fabric, there was a significant difference between each laundering procedure. The order remained the same across the fabrics; laundering procedure A had higher wicking values than laundering procedure C, which had higher wicking values than laundering procedure B. This leads us to believe that a film adheres to the fabric's surface when using a dryer cycle fabric softener, thus reducing moisture absorbency.

II. SOFTNESS

Drape was used to evaluate the softness of the fabrics tested. The drape coefficient (percent drape) is representative of the percentage of the total area of a specimen that is covered as the specimen is draped from a platform. A fabric with a high drape coefficient

TABLE VI

DUNCAN'S MULTIPLE RANGE TEST FOR WICKING HEIGHT AFTER 10 MINUTES IN WARP DIRECTION

Fabric--Laundering Procedure	Mean (mm)*	Duncan Grouping
1 - A	102.20	A
1 - C	62.20	B
1 - B	55.70	C
3 - A	59.17	B
3 - C	55.77	C
3 - B	50.60	D
2 - A	37.87	E
2 - C	32.67	F
2 - B	27.97	G

*N = 30 for means; Alpha level = .05; DF = 180; MS = 38.06. Means with the same letter are not significantly different.

TABLE VII

DUNCAN'S MULTIPLE RANGE TEST FOR WICKING HEIGHT AFTER 10 MINUTES IN FILLING DIRECTION

Fabric--Laundering Procedure	Mean (mm)*	Duncan Grouping
1 - A	81.80	A
1 - C	49.40	B
1 - B	45.16	C
3 - A	45.30	C
3 - C	42.10	D
3 - B	34.73	E
2 - A	35.03	E
2 - C	31.17	F
2 - B	26.80	G

*N = 30 for means; Alpha level = .05; DF = 180; MS = 25.70. Means with the same letter are not significantly different.

would not drape freely; it would be a stiff fabric. On the other hand, a fabric with a low drape coefficient would drape freely. Therefore, the lower the drape coefficient, the softer the fabric.

The four-way ANOVA for drape coefficient, Table VIII, reveals that there were no significant differences between laundering procedures. Fabric, interval and their interaction were found to be highly significant. Thus dryer cycle fabric softeners do not appreciably change the softness of the fabric, as measured by drape.

In Figures 8-10, the drape coefficient is plotted against laundering intervals for each of the fabrics and each laundering procedure. Examination of these graphs reveals the following.

100% Cotton

Results are shown in Figure 8. The data show that laundering without a fabric softener had no effect on the drape coefficient throughout the range of laundry intervals studied. Laundering procedure A is, therefore, best fit to a straight line. When a fabric softener was introduced the drape coefficient decreased slightly. For laundering procedure B, the drape coefficient decreased over the first 10 launderings, then leveled out. These data were best fit to a quadratic model. The data for laundering procedure C were best fit to a linear model. The negative slope indicates a decrease in the drape coefficient as the laundering proceeds.

65/35 Polyester/Cotton

Results are shown in Figure 9. The data show that the drape coefficient decreased as the number of launderings increased, whether

TABLE VIII

FOUR-WAY ANOVA FOR DRAPE COEFFICIENT

Source	DF	Sum of Squares	F-Value
Test of Hypotheses Using Residual as Error Term			
FAB	2	1808	731.78**
LPRO	2	6	2.29
FAB*LPRO	4	9	1.77
INT	4	216	43.73**
FAB*INT	8	289	29.24**
LPRO*INT	8	19	1.95
FAB*LPRO*INT	16	49	2.48**
REP	1	4	3.23
FAB*LPRO*REP	8	27	2.71**
FAB*LPRO*INT*REP	36	73	1.64*
RESIDUAL	180	222	
TOTAL	269	2723	
Test of Hypotheses Using FAB*LPRO*REP as Error Term			
FAB	2	1808	270.51**
LPRO	2	6	0.85
FAB*LPRO	4	9	0.65
Test of Hypotheses Using FAB*LPRO*INT*REP as Error Term			
INT	4	216	26.72**
FAB*INT	8	289	17.80**
LPRO*INT	8	19	1.19
FAB*LPRO*INT	16	49	1.51

*p < .05.

**p < .01.

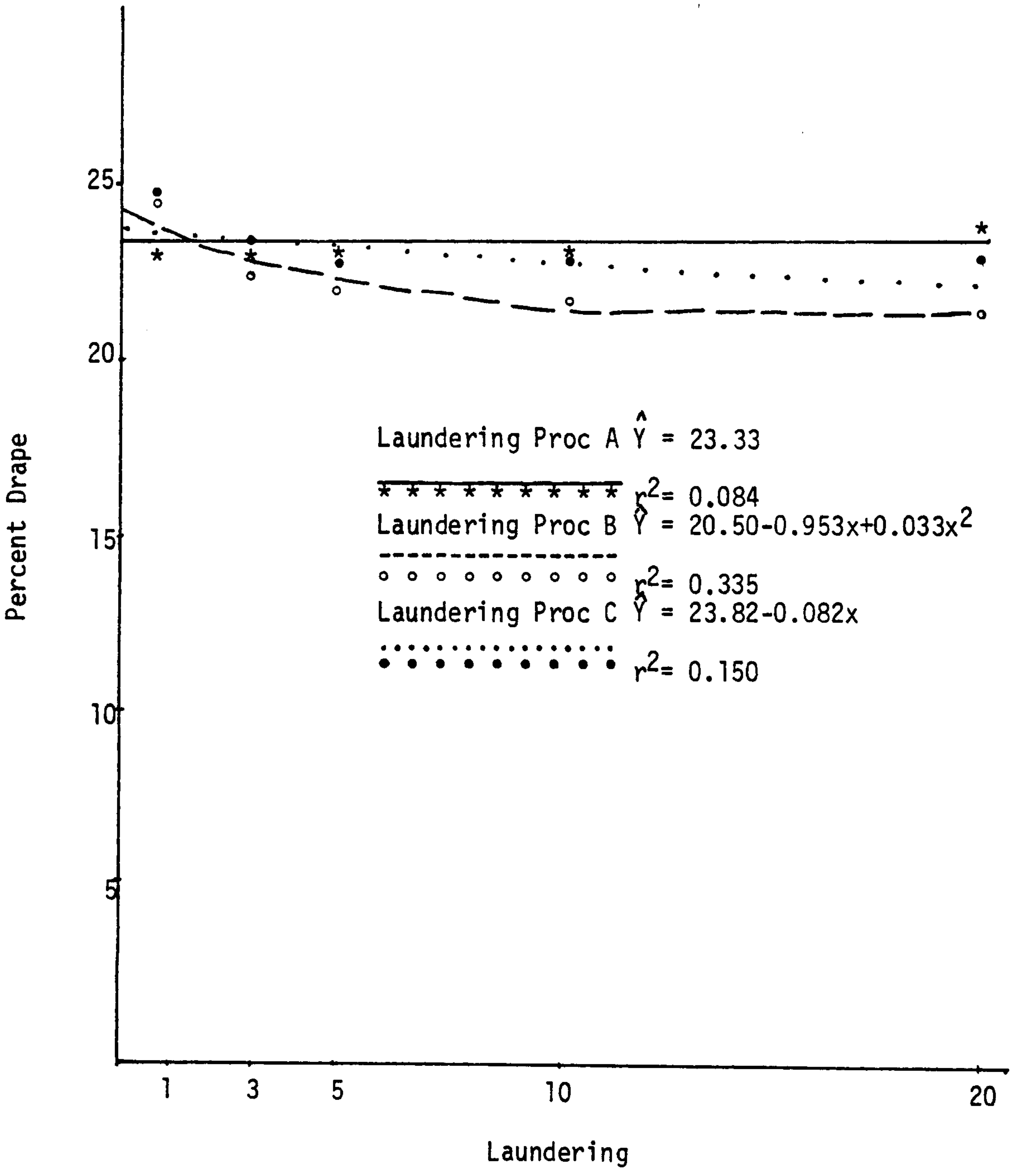


Figure 8. Percent drape (drape coefficient) vs. laundering for fabric 1--100% cotton.

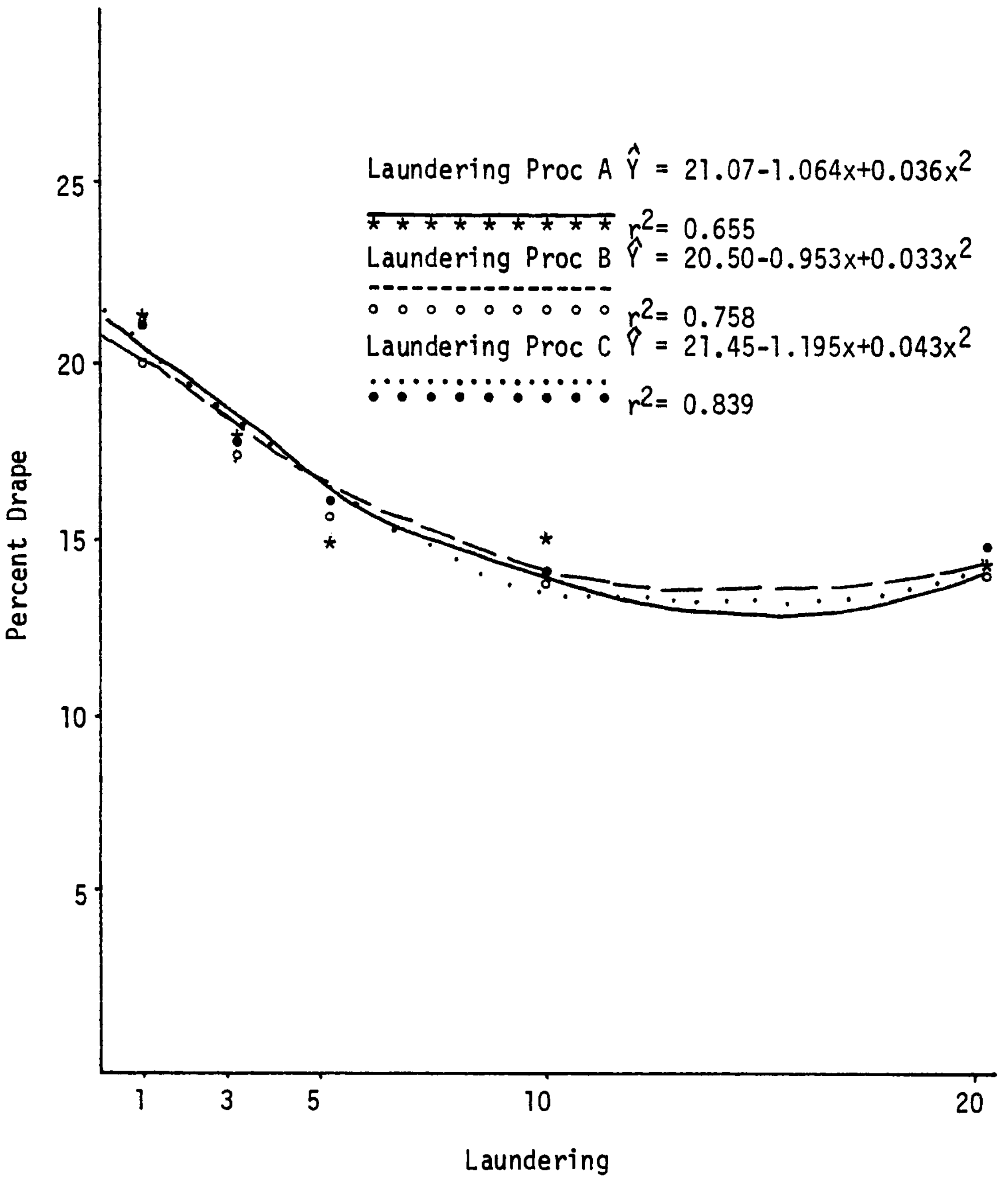


Figure 9. Percent drape (drape coefficient) vs. laundering for fabric 2--65/35 polyester/cotton.

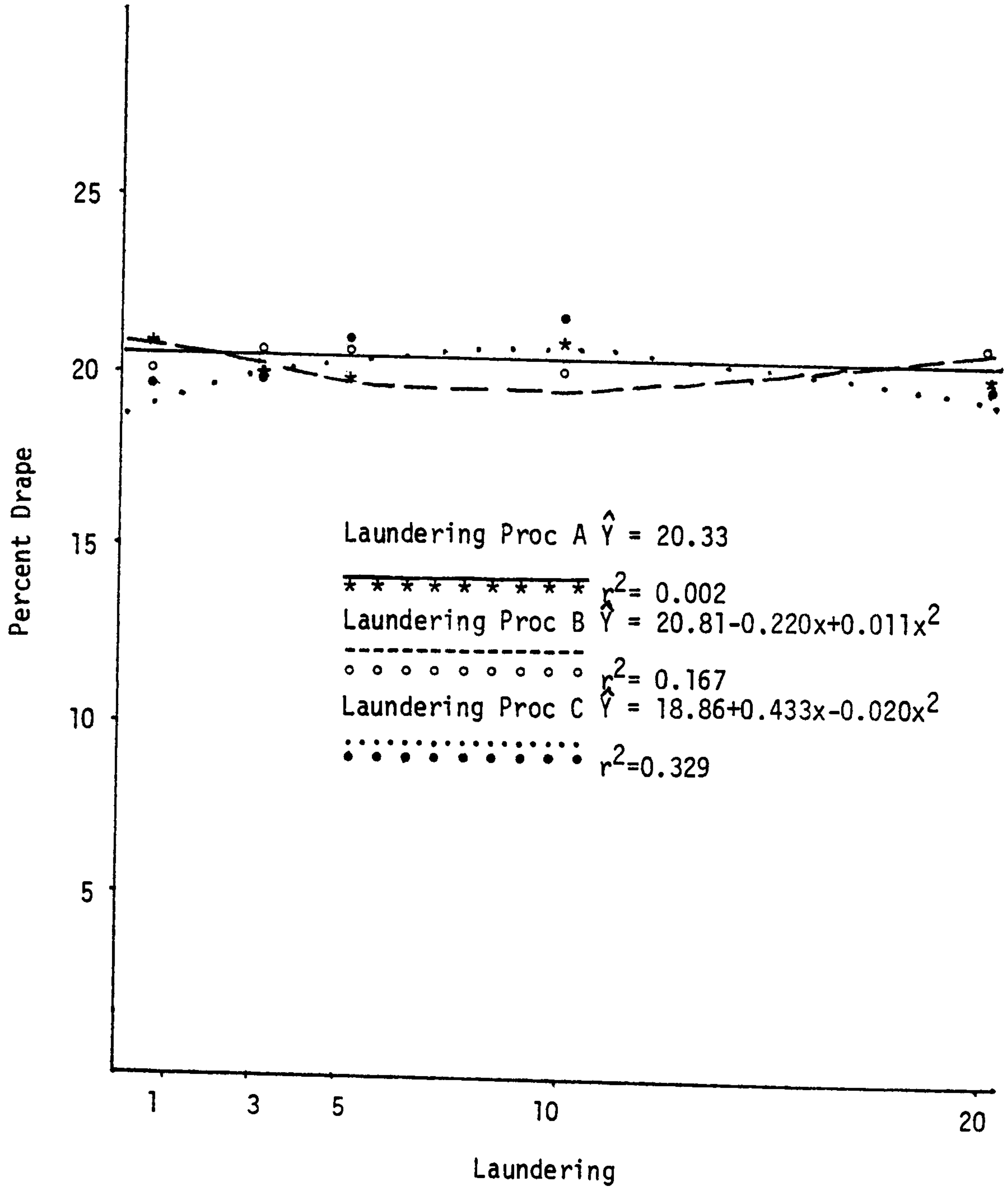


Figure 10. Percent drape (drape coefficient) vs. laundering for fabric 3--100% polyester.

or not a fabric softener was applied. All data were best fit to quadratic models. For each laundering procedure, the drape coefficient decreased sharply over the first 10 launderings, then rose slightly over the last 10 launderings. The curves are so similar it is hard to distinguish one laundering procedure from another. The 65/35 polyester/cotton fabric illustrates a natural increase in softness with repeated laundering. This increased softness may be the result of the fabric's finish being removed during laundering.

100% Polyester

Results are shown in Figure 10. The drape coefficient remained relatively the same throughout the entire study. The data for laundering procedure A was best fit to a straight line. For laundering procedures B and C the data were best fit to quadratic models. Laundering procedure B shows a decrease in drape coefficient over the first 10 launderings followed by an increase over the last 10 launderings. Laundering procedure C illustrates an increase in drape coefficient over the first 10 applications of fabric softener, then a slight decrease over the last 10 applications. The change in the softness of this fabric was slight, with each laundering procedure giving somewhat different results.

The average drape coefficients for the fabrics can be seen in Table IX. As previously mentioned, there was no significant difference between laundering procedures. Each fabric had different drape coefficients which remained relatively the same throughout the entire study. The figures in Table IX show that the 100% cotton fabric had

TABLE IX

DRAPE COEFFICIENT (PERCENT DRAPE) FOR LAUNDERING PROCEDURES AT SELECTED LAUNDERING INTERVALS

	Laundering	Laundering Proc A	Laundering Proc B	Laundering Proc C
Fabric 1	1	23(0.88)*	24(1.98)	25(1.69)
	3	23(1.55)	23(0.65)	23(1.43)
	5	23(1.58)	22(1.29)	23(1.30)
	10	23(1.57)	22(1.01)	23(0.89)
	20	24(1.70)	22(1.11)	22(1.43)
Fabric 2	1	21(1.76)	20(1.82)	21(1.12)
	3	17(1.37)	17(0.90)	18(0.54)
	5	15(1.05)	16(1.10)	16(0.64)
	10	15(1.41)	15(0.98)	15(1.00)
	20	14(1.21)	14(0.55)	15(0.44)
Fabric 3	1	21(1.38)	20(0.73)	19(1.23)
	3	20(0.97)	21(0.70)	20(1.09)
	5	20(1.09)	21(1.08)	21(0.64)
	10	21(1.42)	19(0.93)	21(1.31)
	20	20(1.24)	21(0.95)	19(0.91)

*Number in parentheses is the standard deviation.

Fabric 1 = cotton; Fabric 2 = 65/35 polyester/cotton; Fabric 3 = polyester.

the highest drape coefficients, followed by the 100% polyester, then the 65/35 polyester/cotton blend. If ranked according to softness the order would be reversed. The use of dryer cycle fabric softeners did not affect the softness of the fabrics, as measured by drape.

III. STATIC CLING

Static cling was evaluated by measurement of the electrical resistivity of the fabric specimen, in accordance with test method AATCC 76-1975 Electrical Resistivity of Fabrics using the Custom Scientific Resistance Tester. For each fabric, testing was done in the warp direction. Electrical resistivity was measured in megohms resistivity then converted to terms of 10^8 ohms. A decrease in electrical resistivity indicated a decrease in the static cling.

The four-way ANOVA for electrical resistivity, Table X, show fabric and laundering procedure and their interaction are highly significant in accounting for the variance in the data. From Table XI one can see that laundering with a dryer cycle fabric softener decreases the electrical resistivity for each of the fabrics. During laundering procedure A static electricity was evidenced on the fabrics by the crackling sounds accompanied by flashes. When a fabric softener was introduced, there were no apparent signs of static electricity. The overall effect of the dryer cycle fabric softener was to reduce electrical resistivity, thus reducing static cling.

In Figures 11, 12 and 13 electrical resistivity, in 10^8 ohms, is plotted against laundering intervals for each of the fabrics and each laundering procedure. As the laundering proceeded without a

TABLE X

FOUR-WAY ANOVA FOR ELECTRICAL RESISTIVITY
(10^8 OHMS)

Source	DF	Sum of Squares	F-Value
		Test of Hypotheses Using Residual as Error Term	
FAB	2	11980188035164	844.55**
LPRO	2	7641617100513	538.70**
FAB*LPRO	4	13925997876213	490.86**
INT	4	30574099339	1.08
FAB*INT	8	26925923760	0.47
LPRO*INT	8	41640432810	0.73
FAB*LPRO*INT	16	93708680316	0.83
REP	1	22091151737	3.11
FAB*LPRO*REP	8	150543443590	2.65**
FAB*LPRO*	36	227458774665	0.89
RESIDUAL	180	1276681271073	
TOTAL	269	35417426789180	
		Test of Hypotheses Using FAB*LPRO*REP as Error Term	
FAB	2	11980188035164	318.32**
LPRO	2	7641617100513	203.04**
FAB*LPRO	4	13925997876213	185.01**
		Test of Hypotheses Using FAB*LPRO*INT*REP as Error Term	
INT	4	30574099338	1.21
FAB*INT	8	26925923760	0.53
LPRO*INT	8	41640432810	0.82
FAB*LPRO*INT	16	93708680315	0.93

*p < .05.

**p < .01.

TABLE XI

ELECTRICAL RESISTIVITY (10^8 OHMS) FOR LAUNDERING PROCEDURES AT SELECTED LAUNDERING INTERVALS

	Laundering	Laundering Proc A	Laundering Proc B	Laundering Proc C
Fabric 1	1	5128(2683)*	3771(468)	4398(1426)
	3	5949(1034)	5860(841)	3833(476)
	5	5053(1637)	3508(711)	3568(612)
	10	5426(635)	3843(789)	5040(565)
	20	3364(446)	3149(434)	4041(806)
Fabric 2	1	126725(115469)	71888(11449)	70125(25892)
	3	102000(44167)	41650(4688)	82700(22595)
	5	106000(82197)	66500(10251)	59556(33033)
	10	75650(23834)	46513(9349)	65915(34903)
	20	37850(3564)	35553(17360)	46718(25870)
Fabric 3	1	1121563(289898)	147431(43294)	161188(171716)
	3	1215000(56920)	89938(22283)	122238(43539)
	5	1215000(188785)	60778(29538)	234350(50296)
	10	1155000(239248)	83710(77659)	247563(108617)
	20	1140000(257196)	31828(14718)	174925(79988)

*Number in parentheses is the standard deviation.

Fabric 1 = cotton; Fabric 2 = 65/35 polyester/cotton; Fabric 3 = polyester.

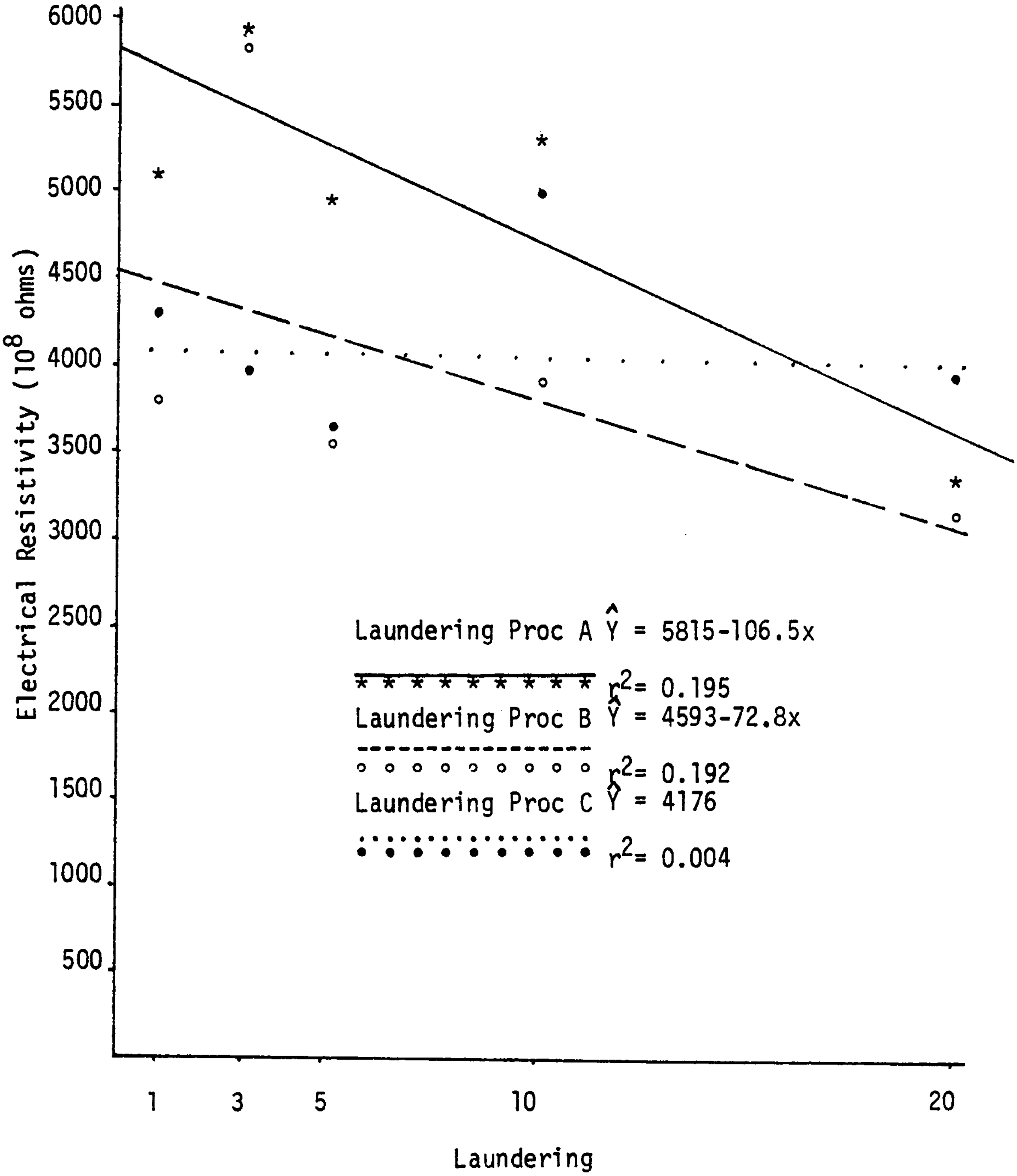


Figure 11. Electrical resistivity (10^8 ohms) vs. laundering for fabric 1--100% cotton.

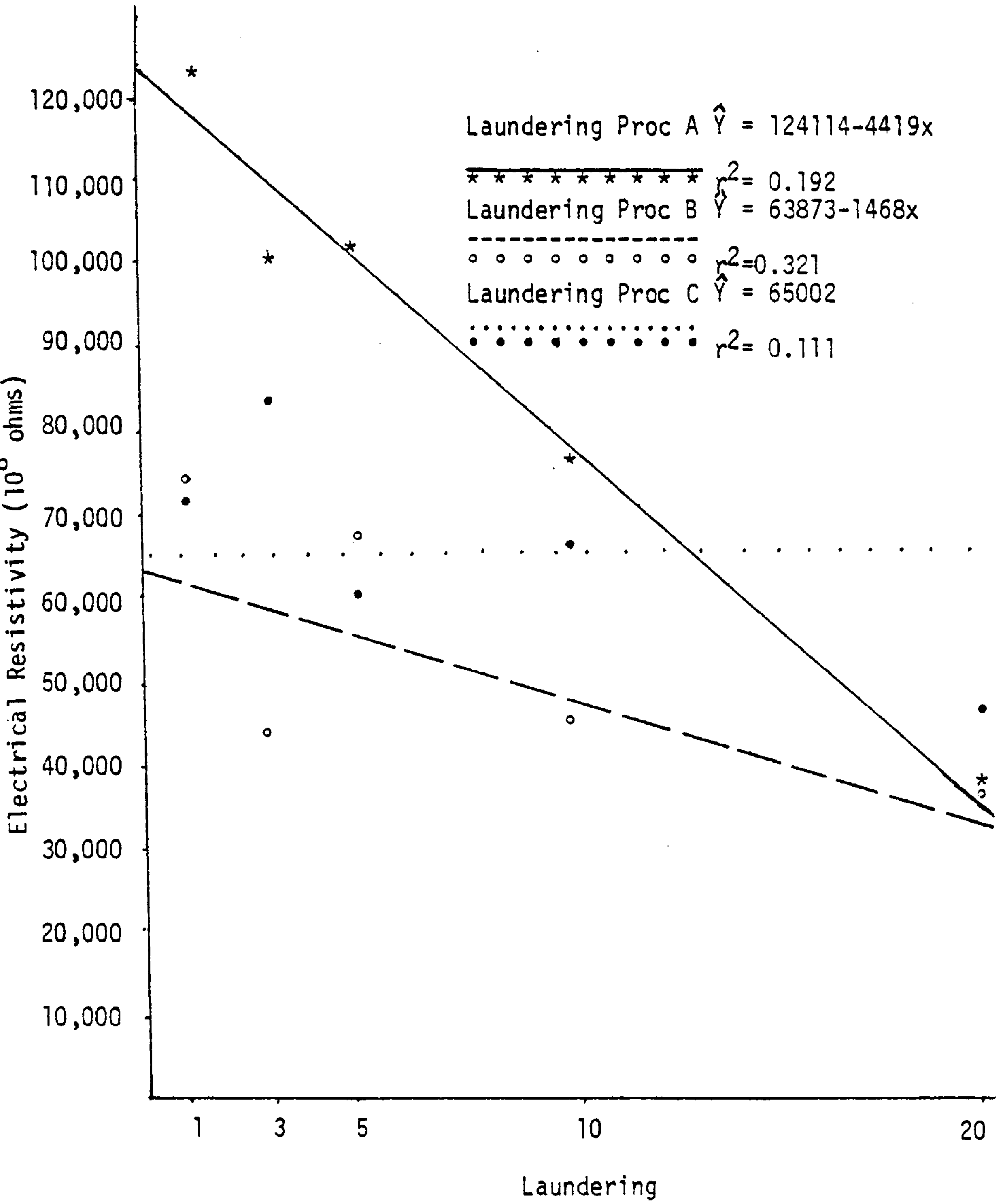


Figure 12. Electrical resistivity (10^8 ohms) vs. laundering for fabric 2--65/35 polyester/cotton.

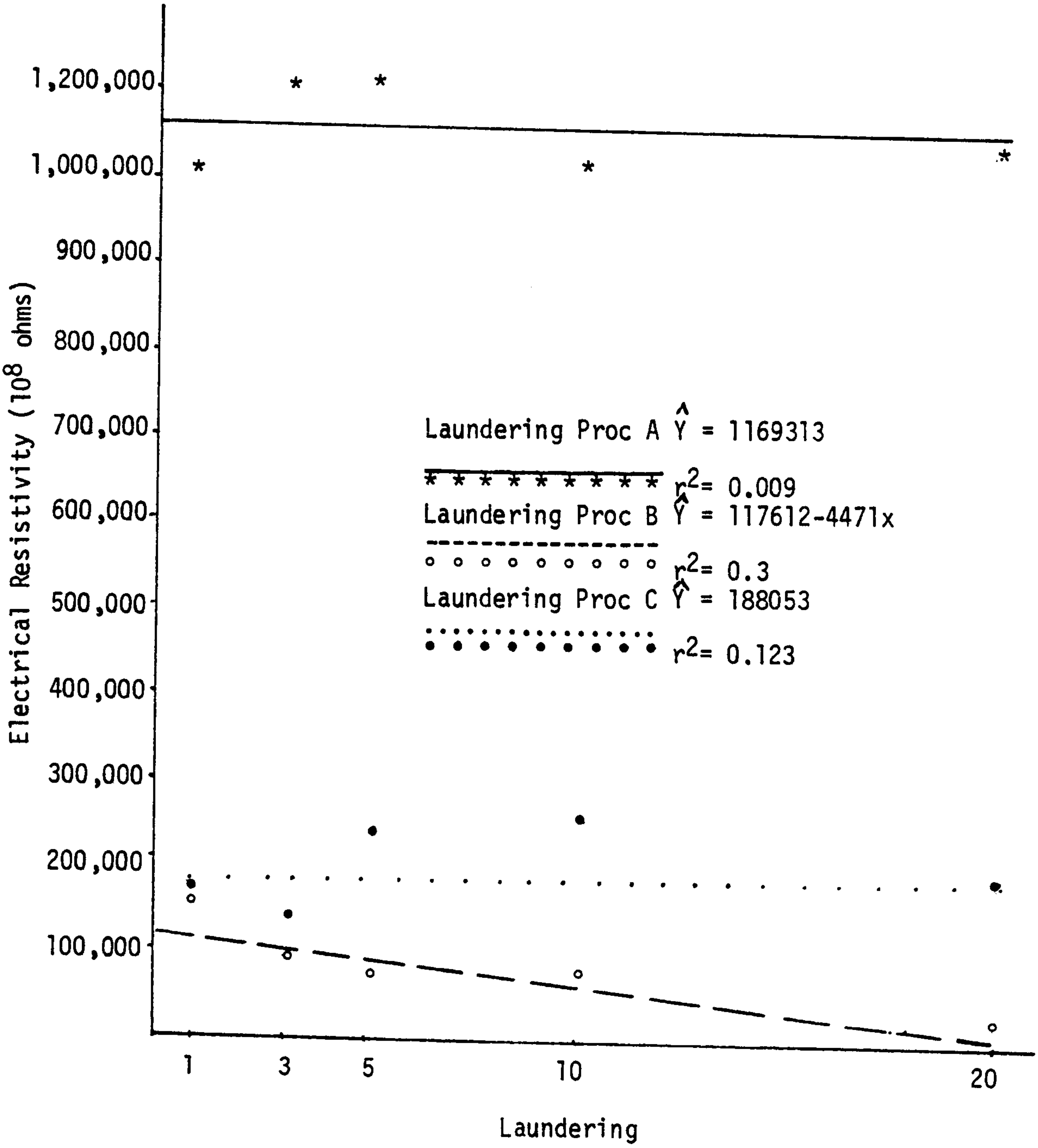


Figure 13. Electrical resistivity (10^8 ohms) vs. laundering for fabric 3--100% polyester.

softener the 100% cotton and the 65/35 polyester/cotton show a reduction in electrical resistivity, whereas the 100% polyester remained the same. Laundering with dryer cycle fabric softeners reduced the electrical resistivity for each of the fabrics.

The largest reduction in electrical resistivity was observed in the 100% polyester fabric. The unsoftened polyester had a mean electrical resistance of 1,170,000 x 10^8 ohms, whereas the softened polyester had a mean electrical resistivity of 188,000 x 10^8 ohms for laundering procedure C and 82,700 x 10^8 ohms for laundering procedure B.

Duncan's Multiple Range post hoc test for electrical resistivity can be seen in Table XII. The 100% polyester had the highest electrical resistivity, followed by the 65/35 polyester/cotton, and then the 100% cotton fabric. There is a significant difference between laundering procedures for the 100% polyester fabric only. Laundering procedure B decreased the electrical resistivity more than laundering procedure C.

This further develops the idea of a film adhering to the fabric's surface when using a dryer cycle fabric softener. The film on the fabric's surface provides a means for the dissipation of any charge, thus reducing static cling. It seems apparent that laundering procedure B provides a thicker film on the fabric's surface than laundering procedure C, as indicated by electrical resistivity.

TABLE XII

DUNCAN'S MULTIPLE RANGE TEST FOR ELECTRICAL RESISTIVITY (10^8 OHMS)

Fabric--Laundering Procedure	Mean*	Duncan Grouping
3 - A	1169312	A
3 - C	188053	B
3 - B	82737	C
2 - A	89645	C
2 - C	65003	C
2 - B	52421	C
1 - A	4984	D
1 - C	4176	D
1 - B	4024	D

*N = 30 for means; Alpha level = .05; DF = 180; MS = 7092673728. Means with the same letter are not significantly different.

IV. FLAMMABILITY

Fabric flammability was evaluated by measurement of maximum heat transfer rate and ignition time, in accordance with the proposed Mushroom Apparel Flammability Test. The ignition time is the minimum time required for a specimen to ignite (8). The proposed standard designates 1/2 second and 1 second to be the time intervals at which the fabrics are to be tested. Table XIII illustrates the ignition time of each fabric after 1 and 20 launderings for each laundering procedure. The table reveals no changes in ignition time at the different intervals for any of the fabrics. Dryer cycle fabric softeners did not alter the ignition time of the fabrics tested.

Maximum heat transfer rate is the greatest rate at which heat is transferred from a burning specimen to the test apparatus (8). If a fabric has a maximum heat transfer rate of greater than 0.40 $J/(cm^2 \cdot s)$, then it is classified according to its ignition time. (See definitions on page 6.) Maximum heat transfer rates for each of the fabrics, as measured in $J/(cm^2 \cdot s)$, are shown in Table XIV. Although a fluctuation is observed, the fabric softeners did not change the maximum heat transfer rate appreciably.

Each fabric was classified according to the MAFT classification system. This was done by incorporating the results for a fabric from the maximum heat transfer rate and ignition time for each interval of a laundering procedure. In Table XV the MAFT Classifications for the fabrics are shown. This table reveals that there were no differences in fabric classification for any of the fabrics. It was thought that

TABLE XIII

IGNITION TIME OF FABRICS AFTER 1 AND 20 LAUNDERINGS FOR EACH LAUNDERING PROCEDURE

Fabric*	Laundering Proc A 1	Laundering Proc A 20	Laundering Proc B 1	Laundering Proc B 20	Laundering Proc C 1	Laundering Proc C 20
1	ignition time greater than 1 second					
2	ignition time greater than 1/2 second, but less than 1 second					
3	ignition time greater then 1 second					

*Fabric 1 = cotton; Fabric 2 = 65/35 polyester cotton; Fabric 3 = polyester.

TABLE XIV

MAXIMUM HEAT TRANSFER RATE OF FABRICS [J/(cm^2·s)] AFTER 1 AND 20 LAUNDERINGS FOR EACH LAUNDERING PROCEDURE

Fabric*	Laundering Proc A 1	Laundering Proc A 20	Laundering Proc B 1	Laundering Proc B 20	Laundering Proc C 1	Laundering Proc C 20
1	1.08	.98	1.13	1.01	1.09	1.04
2	1.17	1.32	1.07	1.28	1.06	1.34
3	.16	.14	.15	.14	.16	.16

*Fabric 1 = cotton; Fabric 2 = 65/35 polyester cotton; Fabric 3 = polyester.

TABLE XV

MAFT CLASSIFICATION OF FABRICS AFTER 1 AND 20 LAUNDERINGS FOR EACH LAUNDERING PROCEDURE

Fabric*	Laundering Proc A 1	Laundering Proc A 20	Laundering Proc B 1	Laundering Proc B 20	Laundering Proc C 1	Laundering Proc C 20
1	2	2	2	2	2	2
2	3	3	3	3	3	3
3	1	1	1	1	1	1

*Fabric 1 = cotton; Fabric 2 = 65/35 polyester cotton; Fabric 3 = polyester.

the added build-up on the fabric's surface might change a fabric to a higher (less safe) classification, but these findings reveal no change. Therefore, repeated laundering with dryer cycle fabric softeners did not adversely affect the flammability of the fabrics tested.

CHAPTER V

SUMMARY AND CONCLUSIONS

There were three objectives of this study: (1) To determine the effects of dryer cycle fabric softeners on the moisture absorbency, softness, and static cling of 100% cotton, 65/35 polyester/cotton, and 100% polyester fabrics, (2) to determine whether repeated use of a dryer cycle fabric softener would cause a fabric to change fabric classifications according to the MAFT fabric classification system, and (3) to determine whether differences exist between two dryer cycle fabric softeners, both of the solid flexible substrate type.

It was assumed that a mixed load was representative of a typical consumer laundering practice. Therefore each laundering procedure contained samples of all three fabrics. The fabrics were randomly assigned into groups for laundering. Each group of fabrics was subjected to one of the three laundering procedures. Laundering procedure A served as a control since no fabric softener was introduced. Laundering procedures B and C both utilized dryer cycle fabric softeners of different brands. Each laundering procedure was carried out for 20 launderings.

After 1, 3, 5, 10 and 20 launderings, the fabrics were tested for the evaluation of moisture absorbency, softness and static cling. Wicking heights after 10 minutes in both the warp and filling direction were used to evaluate moisture absorbency. Drape coefficient (percent drape) was used as a measure of softness. Static cling was measured in terms of electrical resistivity. After the initial and final launderings, each fabric was evaluated for flammability. Ignition time and maximum heat transfer were used to classify the fabrics according to the MAFT fabric classification system.

I. NULL HYPOTHESIS 1

A dryer cycle fabric softener will not decrease the absorbency of fabrics, as measured by wicking. Statistical analysis revealed fabric, laundering and the interaction of these variables to be highly significant for the wicking height after 10 minutes in both the warp and filling directions. This led to the rejection of Hypothesis 1. A dryer cycle fabric softener will decrease the absorbency of fabrics, as measured by wicking.

II. NULL HYPOTHESIS 2

A dryer cycle fabric softener will not increase the softness of fabrics, as measured by drape. The drape of the fabrics was not significantly affected by the use of dryer cycle fabric softeners; therefore Hypothesis 2 was accepted.

III. NULL HYPOTHESIS 3

A dryer fabric softener will not decrease the static cling of fabrics, as measured by AATCC 76-1975 Electrical Resistivity of Fabrics. Statistical analysis revealed fabric, laundering and the interaction of these variables to be highly significant for electrical resistivity; therefore Hypothesis 3 was not accepted. A dryer cycle fabric softener will decrease the static cling of fabrics, as measured by AATCC 76-1975.

IV. NULL HYPOTHESIS 4

A dryer cycle fabric softener will not increase the flammability of fabrics, as measured by the MAFT rate of heat transfer and ignition time. This hypothesis was accepted because no fabric changed classification after repeated laundering with or without a dryer cycle fabric softener.

V. NULL HYPOTHESIS 5

Two different dryer cycle fabric softeners will not differ in their effects on the fabric characteristics. Duncan's Multiple Range post hoc test indicated a significant difference to exist between the two dryer cycle fabric softeners. Laundering procedure B decreased the moisture absorbency and static cling significantly more than laundering procedure C. The film deposited on the fabric's surface by fabric softener B was evidently thicker than fabric softener C. This was also evidenced by feel or by holding the fabric up to a light. These results indicate that Hypothesis 5 must be rejected. Two different dryer cycle fabric softeners will differ in their effects on the fabric characteristics.

Manufacturers claim that fabric softeners reduce static cling, impart a clean fresh smell, and leave clothes really soft. This research confirmed the first claim, dryer cycle fabric softeners do reduce static cling. The clean fresh smell was also evidenced during the laundering procedure. This research contradicted the claim that dryer cycle fabric softeners leave clothes really soft, if drape is a true measure of softness.

VI. RECOMMENDATIONS FOR FURTHER STUDY

Recommendations for further investigation ensuing from the results of the study include:

1. Investigating additional properties or fabric characteristics affected by the use of dryer cycle fabric softeners.

2. Conducting a study comparing wash cycle or rinse cycle fabric softeners to dryer cycle fabric softeners.

3. Conducting a similar study testing static cling at two or more levels of lower humidity.

4. Conducting a similar study using different fabrics.

5. Conducting a similar study washing each fabric type independently.

6. Developing a test procedure for determining fabric softener build-up.

7. Conducting a study evaluating the new detergent on the market which contains a built-in fabric softener.

LIST OF REFERENCES

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1. American Association of Textile Chemist and Colorist, 1976. AATCC Technical Manual. Research Triangle Park, N. C.: American Association of Textile Chemist and Colorist, 1976.

2. American Society for Testing Materials. Annual Book of ASTM Standards. Part 24, Textile Materials--Yarns, Fabrics and General Methods. Philadelphia, Penn., 1977.

3. Armstrong, Dr. W. R. "Fabric Softeners," Home Laundering '65--Update for Excellence. Chicago: The American Home Laundry Manufacturers' Association. 1964. pp. 51-52.

4. Blake, Dr. Jules. "How A Detergent Is Evaluated," Detergents in Depth. New York: The Soap and Detergent Association. 1974. pp. 32-37.

5. Blanchard, Eugene J., Robert J. Harper, Jr., Joseph S. Bruno, and J. David Reid. "Reactive Softeners Can Improve All-Cotton DP," Textile Industries (October 1967), pp. 98, 100, 102, 104, 114, 116, 194.

6. Bogarty, H., N.R.S. Hollies, and M. Harris. "The Judgment of Harshness of Fabrics," Textile Research Journal (May 1956), pp. 355-360.

7. Collins, Sandra Holland. "The Effects of Fabric Softeners on Flame Retardant Cotton Flannette." Unpublished Master's Thesis, Texas Woman's University, Denton. August 1975.

8. Consumer Products Safety Commission. Part 1633--Proposed Standard for the Flammability of General Wearing Apparel. Draft 4, September 27, 1976.

9. Cook, Alton A. "Fabric Softeners--Chemistry of the Soft Touch," American Dyestuff Reporter (September 1973), pp. 24-26, 87.

10. Defosse, T. C. and P. P. Carfagno. "The Effects of Laundering Practices on the Flame Retardance of Fabrics," Textile Chemist and Colorist (January 1974), pp. 25-29.

11. Drake, G. L. "Flammability: Yesterday, Today, Tomorrow," Textile Chemist and Colorist (December 1976), pp. 17-23.

12. Dubrow, Paul L. and Werner M. Linfield. "Cationic Fabric Softeners," Soap and Chemical Specialties (April 1957), pp. 89-97.

13. Dvorkovitz, V. "Cationic Surface Active Agents," Soap and Sanitary Chemicals (May 1952), pp. 41-43.

14. Egan, R. R. "Cationic Surface Active Agents as Fabric Softeners," Journal of the American Oil Chemists' Society (January 1978), pp. 118-121.

15. Evans, W. P. "Cationic Fabric Softeners," Chemistry and Industry (July 5, 1969), pp. 893-903.

16. "Fabric Softeners," Consumer Reports (January 1960), pp. 22-23.

17. "Fabric Softeners," Consumer Reports (May 1969), pp. 254-257.

18. "Fabric Softeners," Consumer Reports (May 1974), pp. 419-421.

19. Gantz, G. M. "Surfactant Structure and Performance," American Dyestuff Reporter (November 4, 1968), pp. 34-41.

20. Ginn, M. E., T. A. Schenach and Eric Jungermann. "Performance Evaluation of Selected Fabric Softeners," Journal of the American Oil Chemists' Society (December 1965), pp. 1084-1088.

21. Hallows, Dr. H. B. "Softening Agents," International Dyer and Textile Printer (September 17, 1965), pp. 443-447.

22. Hearle, John W. S. "Shear and Drape of Fabrics," from John W. S. Hearle, Percy Grosburg and Stanley Bucker, Structural Mechanics of Fibers, Yarns, and Fabrics, Vol. 1. New York: John Wiley and Sons, 1969. Chapter 12, pp. 371-410.

23. Hughes, Graham K. and Sherril D. Koch. "Evaluation of Fabric Softeners," Soap and Chemical Specialties (December 1965), pp. 109-112.

24. Hughes, Leonard, Larry H. Hsing, Brenda L. Simmons, Jane M. Leiby, and Marvin L. Deviney. "Radiotracer and Colloidal Study of Fabric Softener Action," Textile Chemist and Colorist (May 1978), pp. 20-25.

25. Hughes, Leonard, Jane M. Leiby and Marvin Deviney. "Detergents' Effect on Fabric Softeners," Soap, Cosmetics and Chemical Specialties (October 1976), pp. 44, 46, 48, 50, 52, 66.

26. Hughes, Leonard, Jane M. Leiby and Marvin Deviney. "Fabric Softener Adsorption Studies," Soap, Cosmetics and Chemical Specialties (October 1975), pp. 56-62.

27. Johnson, Keith. Antistatic Compositions for Textiles and Plastics. Park Ridge, New Jersey: Noyes Data Corporation, 1976. pp. 182-235.

28. Kasem, M. A. and H. K. Rouette. "Flammability and Flame Retardancy of Fabrics: A Review," Journal of Fire and Flammability (October 1972), pp. 316-328.

29. Kennedy, Doris F. "Effect of Laundering Flame Retardant Children's Sleepwear with a Fabric Softener." Unpublished Doctoral Dissertation, The University of Tennessee, Knoxville, December 1975.

30. Koehler, Naomi. "Cationic Softeners for Home Laundry," Home Laundry Conference Report. Chicago: Home Laundry Division of the Association of Home Appliances Manufacturers, 1966. pp. 58-62.

31. Linfield, Werner M., Joseph C. Sherrill, Gerard A. Davis, and Robert M. Raschke. "Fabric Treatment with Cationic Softeners," Journal of the American Oil Chemists' Society (November 1958), pp. 590-593.

32. Linton, George E. Modern Textile Dictionary. New York: Duell, Sloan and Pearce, 1963. (6th edition)

33. Mallison, Peter. "Textile Softeners--Properties, Chemistry, Application and Testing," Journal of Society of Dyers and Colourists (February 1974), pp. 67-72.

34. Markezich, Anthony R. and Marilyn M. Smith. "Softeners Applied in Home Laundering," American Dyestuff Reporter (May 19, 1969), pp. 26-27.

35. Midwest Section, AATCC. "A New Abrasion Method for Evaluating the Effects of Cationic Fabric Softeners," Textile Chemist and Colorist (February 1973), pp. 49-54.

36. Northern New England Section, AATCC. "An Inquiry into the Influence of Application Conditions on Softener Efficiency--Part 1," American Dyestuff Reporter (January 17, 1966), pp. 33-38.

37. Northern Piedmont Section, AATCC. "The Effect of Repeated Application of Home Softeners upon Absorbency and Other Properties of Terry Towels," Textile Chemist and Colorist (January 1972), pp. 16-21.

38. Pacheco, J. F. and P. P. Carfagno. "How Laundering Practices Influence the Flame Retardancy of Fabrics," Textile Chemist and Colorist (November 1972), pp. 45-50.

39. Perkins, R. M., G. L. Drake, Jr., and W. A. Reeves. "The Effect of Laundering Variables on the Flame Retardancy of Cotton Fabrics," Journal of the American Oil Chemists' Society (July 1971), pp. 330-333.

40. Philadelphia Section, AATCC. "Cationic Softeners--Their Secondary Effects on Textile Fabrics," American Dyestuff Reporter (January 28, 1957), pp. 41-57, 64.

41. "Sales Spurt Puts New Zip into Fabric Softeners," Chemical Week (December 30, 1961), pp. 36-37.

42. Schick, M. J. (Ed.). Surface Characteristics of Fibers and Textiles--Part 1. New York: Marcel Dekker, Inc., 1975.

43. Shenai, V. A. and A. H. Mulla. "Evaluation of Cationic Softeners," International Dyer and Textile Printer (August 4, 1972), pp. 151, 152, 154, 155.

44. Shields, G. "The Soft Touch in Home Laundering," Detergents in Depth--Update '76. New York: The Soap and Detergent Association, 1976. pp. 30-35.

45. Silvernale, Carolyn Cawley. "Effects of Laundering Flame Retardant Cottons with Fabric Softeners." Doctoral Dissertation, Texas Woman's University, Denton, August 1973.

46. Simpson, Harold A. and Carolyn C. Silvernale. "How Laundering with Fabric Softener Affects Flame Retardant Cotton Fabrics," American Dyestuff Reporter (January 1976), pp. 36-42, 58.

47. Stock, C. R. and A. Hvizdak. "Tactual and Instrumental Ranking of Softeners on Starched and Unstarched Cottons," Textile Research Journal (March 1953), pp. 186-196.

48. Suchecki, S. M. "FR Still Needed--Realistic Test Method," Textile Industries (February 1977), pp. 19, 21, 28.

49. Tickle, Anna Reida. "The Evaluation of Three Types of Fabric Softeners." Unpublished Master's Thesis, Texas Tech, August 1974.

50. Wachter, Kathleen. "An Evaluation of Selected Commercial Cationic Fabric Softeners on the Flammability and Absorbency of Selected Flame Retardant Fabrics." Unpublished Master's Thesis, The University of Tennessee, Knoxville, December 1975.

51. Ward, Howard L. "Textile Softeners for Home Launderings," Journal of Home Economics (February 1957), pp. 122-123.

VITA

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