THE EFFECT OF ENVIRONMENTAL FACTORS AND SELECTED LAUNDRY TREATMENTS ON DYED FABRIC WITH FLUORESCENT WHITENING AGENTS

by

Ronda Harris

A Thesis Submitted to the Faculty of the

SCHOOL OF HOME ECONOMICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 7

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Ronda Harris

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Mary Jean Wylie
MARY JEAN WYLIE
Associate Professor of
Home Economics

August 8, 1977
Date

ACKNOWLEDGMENTS

To the following persons, I wish to express my appreciation and gratitude for their support, guidance and assistance in the writing of the thesis and during the course of my graduate work.

Mary Jean Wylie
Dr. Naomi Reich
Dr. Doris Manning
Dr. William Sellers
Dr. David Marx
Paul Johnson

To my parents, Mr. and Mrs. Fred Burt Harris, and my sisters, Geneva and Irene, I owe a special thanks for their assistance and encouragement. I also wish to thank my roommates for their support, particularly Anne Ferguson. To the faculty, staff and my fellow students of the School of Home Economics who assisted and offered encouragement, I say thank you.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--*Continued*

LIST OF ILLUSTRATIONS

ABSTRACT

A 65/35 polyester/cotton blend fabric dyed skipper blue with a disperse/vat color system with the polyester fiber containing a fluorescent whitening agent and with a durable press finish underwent laundry treatments and physical testing. Laundry treatments included temperatures of 140° ± 5° F or 105° ± 5° F; withdrawal after zero, 20 or 40 wash cycles; drying treatments including tumble dried, line dried one hour or four hours. Environmental factors were measured. Control and laundered samples were subjected to laboratory tests, including subjective evaluation, thread count, tear strength, weight calculations, retention of color and fluorescent whitening agents.

Tumble dried samples showed the samllest change in color and tear strength and were less wrinkled. Samples laundered at 105° ± 5° F retained a significantly greater amount of strength and fewer wrinkles than those washed at 140° ± 5° F. The 40th withdrawal samples were lighter in color, weaker and more wrinkled than those removed after the 20th cycle.

Smoothness appearance of fabric samples was rated using the standard AATCC plastic replicas and the replicas painted skipper blue. The judges rated the fabric samples higher using the white replicas.

The fluorescent whitening agent was estimated by subtracting the ultraviolet included _b_ value from the ultraviolet excluded _b_ value. No significant change in fluorescent whitening agents was found.

CHAPTER 1

INTRODUCTION

It is evident that the average consumer has become more conscious of fabric color. As a result, color awareness is one of the first noticeable qualities of a textile product and has become a major influence in salability (Stearns 1974, p. 38; Wingate 1970, p. 217). Many fabrics, however, often lose desirable brightness, whiteness and clearness during processing and maintenance (Joseph 1972, p. 180). In an attempt to counteract these effects, fluorescent whitening agents were developed to improve the whiteness of whites and to maintain the brilliance of colors (Moncrieff 1970, p. 800). Fluorescent whitening agents are applied to fibers as well as being used in detergents to renew brilliance (Joseph 1972, p. 280). An occasional renewing is necessary since over a period of time fluorescent whitening agents lose their effectiveness due to degradation caused by light, heat and chemicals (Blanchard, Harper, Gautreaux and Reid 1971, p. 181).

This investigation has been designed to evaluate the retention of color and fluorescent whitening agents, thread count, weight, tear strength and appearance of 65/35 polyester/cotton blend fabric dyed skipper blue with a disperse/vat color system with the polyester fiber containing a fluorescent whitening agent. A durable press resin finish has been applied to the fabric. The retention of color and fluorescent whitening agents, thread count, weight, tear strength and appearance were evaluated upon exposure to various laundry treatments and environmental factors such as solar radiation, relative humidity, wind velocity, atmospheric and fabric temperature.

Importance of the Investigation

Fluorescent whitening agents are colorless dyes which absorb invisible ultraviolet light and re-emit it as visible blue light. The addition of blue light reflection counteracts the yellow tinge often left on fabrics giving them a better spectral balance (Joseph 1972, p. 280; Weidmann 1957, p. 78). Fluorescent whitening agents not only counteract the yellow tinge left on white goods but they also increase the brilliance of colors (O'Hare 1966, p. 1220; Moncrieff 1970, p. 800).

Fastness of a dyestuff is a major concern not only to the manufacturer but to the consumer as well. Wingate states that "good fibers and yarns, even if durably woven, can be ruined by the use of fugitive dyestuffs crudely applied" (Wingate 1970, p. 218). Fastness properties of the dyestuff are determined by the chemical composition of the dyestuff, affinity of the dyestuff to the fiber and the application method used (Corbman 1975, p. 228; Wingate 1970, p. 197). Although fastness properties have improved since the early development of fluorescent whitening agents, they are still affected to a degree by light, wash conditions, resin treatments, relative humidity and pollutants (Anliker, Hefti, Kasperl and Melicèvič 1969, p. 525; Giles, Haslam and Duff 1976, p. 51). Altherr states that "Although the fastness properties of opticals are gaining in importance, particularly in mass applications, they are still not regarded with the same scrutiny as is common with other dyes." He feels the lack of concern here is due to the use of opticals in household detergent to restore whitening and brightening properties (Altherr 1965, p. 41). The use of optical brighteners or fluorescent whitening agents in detergents was so popular in 1961 that it was virtually impossible to find a household laundry detergent on the market which did not contain one or more of the various types of whiteners (Reinhardt, Fenner, Reid, Furry and Walsh 1961, p. 34). As the researcher of this study checked the 1975 market she also found it impossible to obtain a detergent which did not contain fluorescent whitening agents.

There are a variety of different fluorescent whitening agents on the market from which manufacturers of fibers and detergents may select. It is very crucial that the proper whitening agent be selected according to the fiber type and the end use of the textile product. It has been found that a build-up can occur if the whitening agent has a strong affinity to the textile fiber. This build-up on colored fabric makes color appear duller, causing complaints from the consumer (Hall 1966, p. 58). In a study by Stensby and Findley, it was found that wash water temperature also affects the absorption of fluorescent whitening agents (Stensby and Findley 1972, p. 59).

There is an increasing number and variety of laundry aids and textile products available to the consumer on the market today. With this influx it is difficult for the consumer to choose a laundry product and the proper treatment that will give the greatest acceptance and wear of the textile product.

Objective of the Investigation

This study was designed to investigate the retention of color and fluorescent whitening agents, thread count, tear strength and appearance of disperse/vat dyed skipper blue 65/35 polyester/cotton blend fabric with a built-in fluorescent whitening agent (polyester fiber only) when exposed to various laundry treatments and environmental factors such as solar radiation, relative humidity, wind velocity, and atmospheric and fabric temperature. The purpose of the investigation was to relate color and fluorescent whitening agents retention and care of the fabric to selected home laundry conditions and procedures.

Assumptions

Fabric for this investigation was a 65/35 polyester/cotton blend fabric manufactured by Springs Mills and sold under the trade name "Teeshot". It was a poplin, plain weave rib variation which had been dyed skipper blue with a disperse/vat color system. The polyester fiber had been treated with a fluorescent whitening agent. A durable press finish had been applied to the fabric.

It was assumed that the fabric was uniformly dyed skipper blue with a colorfast disperse/vat color system since it was purchased from one bolt of fabric with this specification.

It was assumed that the fluorescent whitening agent was one which had sufficient affinity for the polyester fiber and was uniformly absorbed.

It was assumed that the fibers and yarns were similar in fineness, twist, length and strength since the fabric was purchased from one bolt of fabric.

It was assumed that the testing equipment was calibrated precisely and that readings and calculations were accurate.

Limitations

The fabric was selected from one fabric store in Tucson, Arizona. Therefore, the fabric was not chosen randomly.

It was not known at what stage of production nor how the fluorescent whitening agent was applied to the polyester fiber.

The stage in which the skipper blue dyestuff was applied was unknown.

Hypotheses

This study was designed to determine the effect of various laundry treatments on 65/35 polyester/cotton blend fabric dyed skipper blue with a built-in fluorescent whitening agent in the polyester fiber and a durable press resin finish applied. Variation in treatments consisted of wash water temperature at $140° \pm 5°$ F or $105° \pm 5°$ F; drying, tumble dried, line dried one hour or line dried four hours; withdrawals, after zero, 20, and 40 wash cycles. All line dried treatments were exposed to environmental factors such as solar radiation, wind velocity, and atmospheric temperature. The following null hypotheses were investigated in the study:

Hypothesis Number One

There will be no significant difference in the retention of color and fluorescent whitening agents, thread count, weight, tear strength and appearance between the fabric samples laundered at 140° $\pm$ 5° F and those laundered at 105° $\pm$ 5° F.

Hypothesis Number Two

There will be no significant difference in the retention of color and fluorescent whitening agents, thread count, weight, tear strength and appearance of samples laundered zero, 20, or 40 times.

Hypothesis Number Three

There will be no significant difference in the retention of color and fluorescent whitening agents, thread count, weight, tear strength and appearance of samples tumble dried, line dried one hour and those line dried four hours.

Hypothesis Number Four

There will be no significant difference in the judges' ratings for smoothness appearance against the white AATCC Test Method Replicas and the same replicas painted blue.

Definition of Terms

AATCC--American Association of Textile Chemists and Colorists.

ASTM--American Society for Testing and Materials.

Blend--Two or more types of fibers combined into one yarn.

Bluing--A coloring agent used to counteract the yellowing of laundered fabrics.

Buffer--Fabric which is the same as that being tested added to the laundry load to maintain a four pound load for each washing and drying cycle.

Constant temperature and controlled relative humidity room--The room where conditioning is conducted, in which the temperature is maintained at 70° ± 2° F and relative humidity is held at 65% ± 2% (ASTM 1974, p. 15). Upon exposure to the standard atmosphere the samples' moisture content is brought to an equilibrium. The constant temperature and controlled relative humidity room is often referred to as merely the constant temperature room.

Control sample--A sample which undergoes no laundering but which is used for subjective evaluation and physical testing.

Durable press--Having the ability to retain substantially the initial shape . . . and unwrinkled appearance . . . after laundering (ASTM 1974, p. 22).

Dye--Soluble color compound which produces relatively permanent color on textile fabric (The American Home Economics Association 1974, p. 58).

Environmental factors--Conditions which are in the environment, such as solar radiation, relative humidity, temperature, and wind velocity.

Epply pyroheliometer--The instrument used by the Weather Bureau and by most outdoor testing stations to measure langley units (Caryl 1960, p. 55).

Fluorescent whitening agents (FWA)--Colorless fluorescent dyes attached to fabric which convert invisible ultraviolet energy to visible light, which results in a whiter and/or brighter-appearing fabric.

Hand anemometer--An instrument used to measure wind velocity.

Hunter Color and Color Difference Meter--The instrument used to measure color and fluorescent whitening agents retention.

Langley units--One langley unit is equal to 1 gram calorie of radiant energy per square centimeter of exposed area (Caryl 1960, p. 55).

Permanent press--Same definition as durable press. Term used interchangeably with durable press.

Resin--A chemical applied to fabric as a monomer solution which penetrates the fabric. Heat curing will then polymerize the monomer, forming cross links between the molecular chains of cellulose (Hollen and Saddler 1973, p. 232).

Sample--A piece of fabric cut 30 inches in length by 33 inches wide for the purpose of laundering and testing.

Sling psychrometer--A hygrometer that uses the difference in readings between two thermometers, one having a dry bulb, the other a wet bulb, which is a measurement of relative humidity or atmospheric moisture.

Solar radiation--The transmission of radiant energy by the sun to the earth's surface.

Solar time--Actual sun time based on the highest point of sun radiation at 12 o'clock noon.

Tear strength--The force required to start or continue a tear in a fabric under specified conditions (ASTM 1974, p. 38).

Thread count--Number of threads per square inch in both the warp and fill directions.

Test specimen--A piece of fabric cut the correct size for a specified test.

Textile expert--A person trained in the field of textiles.

Treatment--Method of washing and drying samples.

UV--Ultraviolet

Weight--Determination of ounces per square yard.

Withdrawal--The number of wash cycles after which samples are removed from the laundry cycle for testing.

CHAPTER 2

REVIEW OF LITERATURE

A faint yellowish cast on textile fabrics due to impurities has been found to make whites less than white and pastel shades to appear dull. A yellowish cast may range in appearance from ivory to yellow. It is the desire of the manufacturer to remove this off-white tinge through scouring and bleaching in order to give textile goods their greatest sales appeal (O'Hare 1966, p. 1220). It is not only desirable to have a whiter white in uncolored fabric but it is also advantageous to begin with a pure white fabric before color application. The whiter the fabric is before dyeing, the more effective the dyeing operation will be in producing clearer, more brilliant pastel shades (Labarthe 1975, p. 286).

In order to improve whiteness, several researchers (Hall 1966, p. 57; Zweidler 1971/3, p. 38; Weidmann 1957, p. 78) have suggested that bleaching with chemicals by oxidation and reduction is necessary to remove impurities in fibers found to cause discoloration. Even after scouring and bleaching, a faint cast often remains. This yellowish cast is due to traces of impurities which are virtually impossible to remove. This last trace of yellow cannot be removed through increased bleaching to give a truly white fiber because an excess of bleaching will cause a weakening of the fiber.

Whiteness is not only a problem for the piece goods manufacturer, but for the consumer of textile articles as well. Yellowing is found to be caused by impurities which are both organic and inorganic. Bleaching during maintenance of textile articles will restore whiteness but it can also damage the fiber and spoil the color of colored fabric (Allen 1971, p. 278). The durable press finish applied to some textile articles may also be ruined by bleaching (Hollen and Saddler 1973, p. 223).

In an attempt to counteract this yellowish cast in textile articles it formerly has been the practice to add bluing through the use of an aqueous solution of ultramarine or a similar dyestuff. Bluing has been found to absorb red and yellow light components which normally would be reflected from the fabric. As these components of light are absorbed, the fabric is given a bluish cast which is accepted by the eye as being whiter (Moncrieff 1970, p. 800; O'Hare 1966, p. 1220). Since the yellow has been covered up, the fabric appears to have a greater whiteness. In actuality, a graying effect has occurred, since bluing causes a reduction in overall reflection of light. A study conducted by Reinhardt and coworkers indicated that yellowing reduces whiteness approximately four times as much as graying (Reinhardt et al. 1961, p. 34).

The overall reduction in the reflection of light caused by bluing made it advantageous to develop a new method of reducing yellow tinge. Much research has been done in the last 50-70 years to develop fluorescent whitening agents as a means of increasing total light reflection. It has been found that as these colorless fluorescent whitening agents are exposed to sunlight they absorb invisible ultraviolet light, which is then reflected as visible blue light (Trotman 1968, p. 145). This visible blue light increases reflection rather than merely masking the yellow tinge.

Not only is it necessary to judge the effect of fluorescent whitening agents on white fabric, but on colored as well. According to a survey of one thousand housewives conducted in 1963, brightness of color is secondary in importance to whiteness and both effects are considered more important than clear color. It has been found that pastel shades owe their bright hue to the effect of fluorescent whitening agents (Zussman 1963, p. 695). The effect of fluorescent whitening agents on deeply colored fabric may be equally important, according to Hall (Hall 1966, p. 60). It is possible that this fact is closely related to the principle of light reflection. With pastel color, a greater amount of light is reflected, whereas with a deeply colored fabric, light is absorbed. Because of this greater reflection of light, the pastel color will appear brighter.

There is concern that the use of fluorescent whitening agents on colored fabric may cause a build-up to occur, resulting in a duller-appearing color. It has been found that some types of fluorescent whitening agents show yellow discoloration upon exposure to the sun. This problem could easily be mistaken for poor dye fastness, when in actuality, the effect is due to the fluorescent whitening agent employed in laundering the fabric (Higginbotham and Thomas 1958, p. 1439).

Fluorescent whitening agents were first produced in 1929 by Dr. Paul Krais. He found that when semi-bleached linen was soaked in aesculin, which is a glucoside coumarin derivative of the horse chestnut, a whitening effect occurred. Aesculin, however, had no affinity for fibers and could be washed out with cold water. Another great disadvantage was that it had very poor light fastness (Hall 1966, p. 57).

After Dr. Krais had discovered aesculin, work was begun by Meyer to develop a higher standard product. Meyer discovered that beta-methylumbelliferone could be used for the whitening of textiles and intense research began (Hall 1966, p. 57). It was not until the late 1930's that the first whitening agent appeared on the market commercially (O'Hare 1966, p. 1220). After World War II, whitening agents were incorporated into laundry detergents (Allen 1971, p. 278).

The theme for whitening agents as they have evolved could be described as, "Getting to Know You" during the 1950's; during the 60's "More of a Good Thing", and during the 70's, "Better and Better all the Time" (Stensby and Findley 1972, p. 52). In 1969, 60 per cent of the fluorescent whitening agents produced went into heavy duty detergents (Stensby 1971/2, p. 41). In 1971 it was found that approximately 2,000 fluorescent whitening agent patents existed with some 200 manufacturers and distributors marketing about 2,000 various products (Zweidler 1971/3, p. 38). During the 70's there has been extensive use of fluorescent whitening agents by industrial and domestic consumers alike.

Note that fluorescent whitening agents are known by a variety of names, such as optical brighteners, optical whitening agents, optical bleaching agents or optical bleaches, fluorescent bleaching agents, whiteners, brighteners and fluorescent brightening agents (Sarkar 1971, p. 1). Joseph indicated that the term "bleaching" is inappropriate since no bleaching actually occurs (Joseph 1972, p. 280). To prevent confusion, ASTM has adopted the term "Fluorescent Whitening Agents", and this is the term which will be used throughout the remainder of this investigation ("Wanted: New Name for White Dyes." 1968, p. 75). For the sake of convenience, the abbreviation "FWA" will be used in this study.

Light Perception

Light consists of several components which are either visible or invisible. Electromagnetic radiation starts at the invisible end of the spectrum with the short wavelengths, which include X-ray, gamma ray and ultraviolet. The visible color band portion of the spectrum bridges the gap between the shortest and the longest invisible wavelengths. Infrared and radio wavelengths represent the longest invisible wavelengths (Koller 1965, p. 3). Ultraviolet wavelengths range from 300 to 400 millimicrons (Fig. 1). The short invisible ultraviolet rays are absorbed by FWA, converting this energy into visible blue light. This addition of blue light counteracts the yellow tinge of impurities, giving a better spectral balance which increases whiteness and brightness of textile products (Weidmann 1957, p. 78; Trotman 1968, p. 145).

The color of a fabric is determined by the wavelength reflected as white light strikes its surface. White light as seen by the human eye contains the various color components of the spectrum. This can

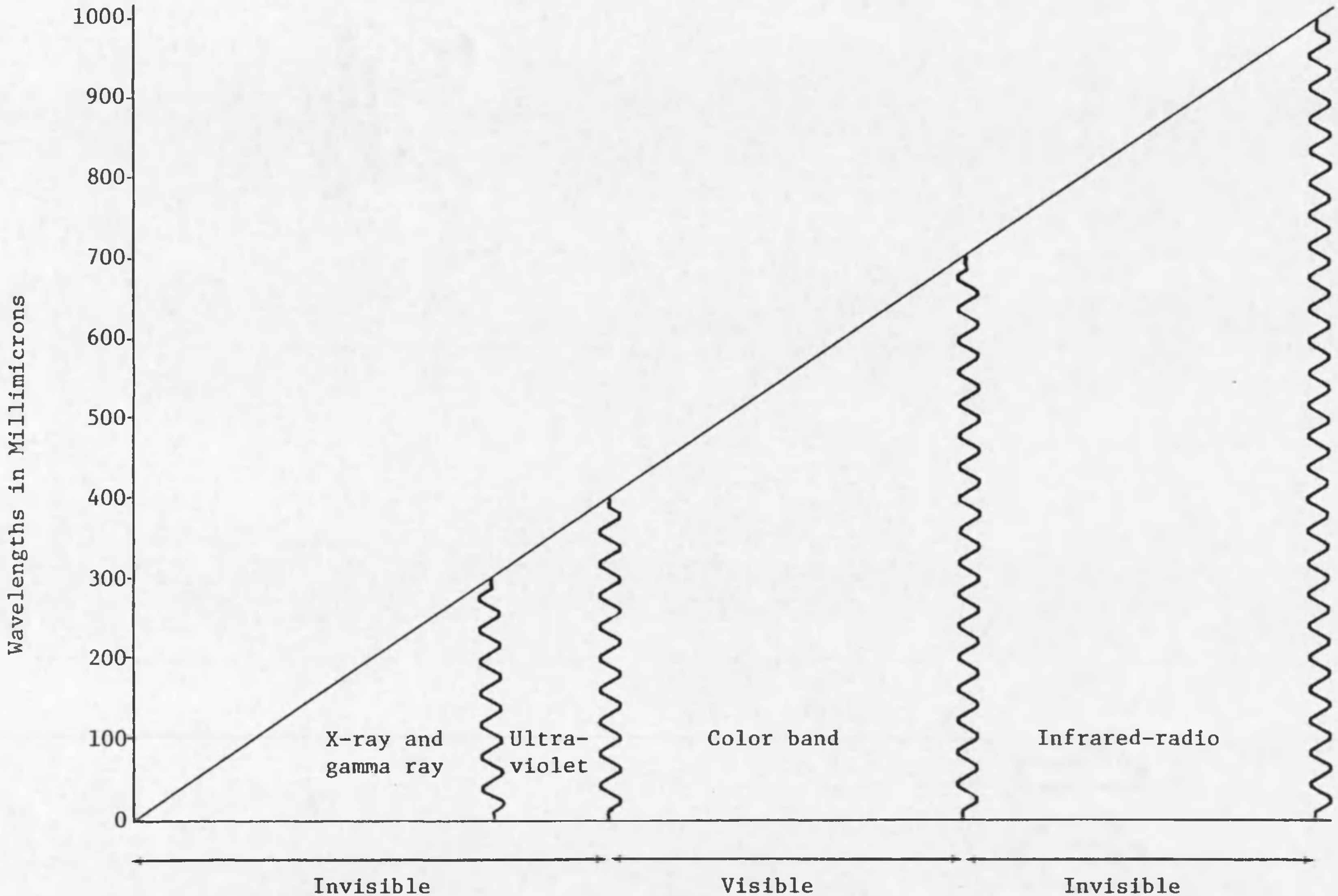


Fig. 1. The Electromagnetic Spectrum

be demonstrated as light is allowed to pass through a prism breaking the light down into color bands (violet, blue, green, yellow, orange and red). The visible white light is the portion of the electromagnetic spectrum to which the eye is sensitive. Visible wavelengths range from approximately 360 to 400 millimicrons, which are the shortest, to 700 to 760 millimicrons, which are the longest ("Introduction." 1973/1, p. 2; Labarthe 1975, p. 326; Koller 1965, p. 3). The shortest visible wavelengths are perceived as violet, ranging to red, which represents the longest visible wavelength, as shown in Fig. 2. However, the range of the visible spectrum has not been defined sharply since it varies from individual to individual (Koller 1965, p. 3).

Color Properties

Color is a very prominent constituent of our everyday environment and has long been considered an essential component of textiles. Color is one of the key factors considered when the consumer selects and purchases any textile product (Hollen and Saddler 1973, p. 208).

Color is produced when an interfering agent such as a dye absorbs all color components of white light except that of the color reflected (Weidmann 1957, p. 78). Chemical composition of the dye determines which components of light will be absorbed and which will be reflected (Judd 1952, p. 26). Color is perceived as a three dimensional system: hue, saturation and lightness, which are often referred to as being tridimensional. Hues are the colors of the rainbow (red, yellow, green and blue and their variations). Saturation refers to the vividness of a color. For example, a deep blue colored fabric is

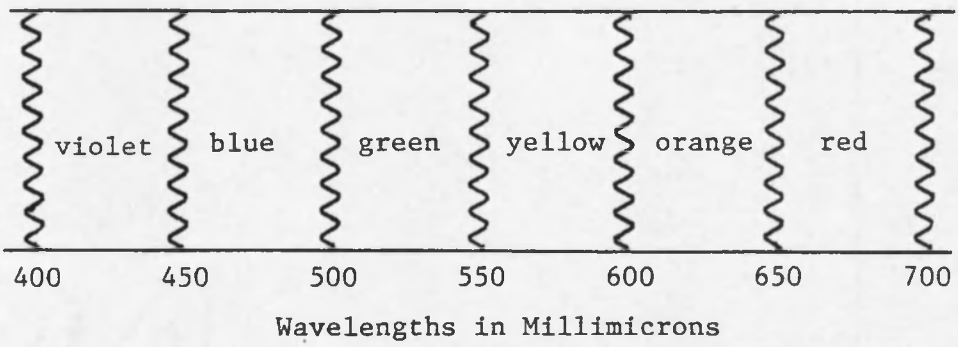


Fig. 2. Color Range of the Visible Spectrum

considered to be more saturated than a light blue colored fabric. Lightness refers to the ability of a colorant to reflect visible light as it strikes the surface of the fabric (Hunter 1972, p. 3; "Introduction." 1973/1, pp. 2-3).

Dyes

Color is very important to the consumer and Joseph alludes to this fact by saying that "Color speaks louder than words. Its appeal is universal, and it repeatedly serves as a common language. In the modern marketplace, consumers are usually more concerned with the 'just right' color than they are with consideration for other fiber and fabric characteristics" (Joseph 1972, p. 318). For this reason it is essential that the dyer use discretion in the selection of an appropriate colorant to be applied if the color is to remain desirable throughout the life of the textile product. For color fastness properties to exist the dyer must take into account the chemical nature of the fiber and colorant as well as the colorant's resistance to washing, chemicals and sunlight (Judd 1952, p. 26). It has been stated that "Dyes are generally considered fast when they resist the deteriorating influences to which they will be subjected in the use for which the fabric is intended" (The American Home Economics Association 1974, p. 61).

Early dyes presented one major drawback in that they were not colorfast. This problem was partially corrected, however, by the discovery and use of mordants. Mordants are metallic salt compounds which bond the dyestuff, metal and fiber together, thus improving fastness properties (The American Home Economics Association 1974, p. 59).

The history of dyeing dates back to at least 3500 B.C. as indicated by a piece of fabric dyed indigo blue which was found in Thebes and which dates from that period of history. Later, pieces of fabric dyed yellow were found which were more uniform in color and which had greater color fastness properties than they would have had with the use of natural dyes. Because of the advantages demonstrated by these specimens and the fact that they are more economical to produce on a large scale basis than natural dyes, synthetic dyes have dominated the market since their discovery (Allen 1971, p. 7).

Dyes can be classified in several different ways. Four classifications which are useful are: 1) hue produced by the dye, 2) chemical class of the dye, 3) method of application, and 4) the types of fibers to which the dye can be successfully applied (Joseph 1972, p. 321).

Dyes used on cotton fibers include reactive, direct, azoic, vat and sulfur dyes. Cationic, disperse and azoic have an affinity for polyester fibers to a limited extent (The American Home Economics Association 1974, pp. 58-60; Joseph 1972, p. 322). Disperse and vat dyestuffs are the systems which will be discussed in this study.

Disperse Dyes

Disperse dyes were first developed for dyeing acetate fibers. In 1923 when they were manufactured they were called acetate dyes because of their purpose (Joseph 1972, p. 324; Allen 1971, p. 275).

Disperse dyes consist of small molecules which contain amino groups, and are considered to be insoluble in water, although they do disperse without difficulty throughout the solution. As dyeing takes place the dispersed dyestuffs diffuse into the hydrophobic polyester fiber after being dissolved by a carrier which forms a film covering the surface of the fiber. It is believed that the carriers cause the polyester fiber to swell, moving the polymer chains apart so that dye molecules can penetrate. High pressure, high temperature dyeing is also successful, giving a wide range of shades. The Thermosol process as developed in 1949 by duPont was designed for continuous operation, taking away the need for carriers (Allen 1971, p. 277). This process involves padding the dyestuff to the fiber and then passing it through a heat zone. Thermofixation occurs in ten seconds when infrared heat is used, and in 30 seconds when dry air is used (Joseph 1972, p. 324).

Disperse dyes are found to have good colorfastness to light, laundering and dry cleaning (Joseph 1972, p. 324). They are not found to exhibit the same fastness qualities as the vat dyes. They have one major drawback in that they are susceptible to fume fading by nitrous oxide in the atmosphere, which causes a gradual fading to a pink color, particularly the blue shades (Corbman 1975, p. 226). This is especially the case when used in articles exposed to the atmosphere for long periods of time. The problem, however, is not as serious and does not occur as rapidly on nylon and polyester fibers as it does on acetate fibers.

Vat Dyes

The major use of vat dyes is on cellulosic fibers, cotton in particular. Some of the various types of vat dyes can also be used on synthetic fibers as well. Their use on protein fibers is limited due to the alkaline nature of the dye solution required to dissolve the dyestuff (The American Home Economics Association 1974, p. 59).

Indigo dye was the first vat dye known to man. The vat dye process was developed when it was observed by accident that natural dye's color was destroyed as it fermented, but that upon exposure to air, oxidation caused the color to be restored. In 1883 the structure of indigo was determined and in 1897 the first synthetic dye was produced commercially (Allen 1971, p. 150). The name "vat dyes" was derived from the large vessel or vat used in the process of dyeing (Joseph 1972, p. 326).

Vat dyes have been divided into two chemical classes: 1) anthraquinone and 2) indigoid dyes (The American Home Economics Association 1974, p. 59). Both groups are insoluble in water but are converted to a product which is soluble in an alkaline solution. This solution is said to be "leuco" or colorless. After application, this leuco compound is reoxidized to its original form by air or an oxidizing agent (Joseph 1972, p. 326).

The continuous pad-steam process has been found to be the superior method for the application of vat dyes. In this process a fine spray of a suspended insoluble solution is applied to the fabric, which is then padded with alkali and a reducing agent, steamed to fix the dye, then soaped and rinsed. This method gives a uniform distribution of the dyes. It is colorfast, which makes it less likely that alkaline sensitive fibers will be harmed (The American Home Economics Association 1974, p. 60; Joseph 1972, p. 326).

Vat dyes are considered to possess colorfastness properties which range from good to excellent (The American Home Economics Association 1974, p. 59). They are generally considered to be colorfast to light, washing and bleaching (Hollen and Saddler 1973, p. 216). It has been found that dyes of this type exhibit variation in colorfastness according to their chemical structure. For this reason it is important that the dyeing process be carefully controlled to prevent colors which fade rapidly (Joseph 1972, p. 325).

Blended Fabrics and Their Properties

A blended fabric has been defined by The American Home Economics Association as a "combination of two or more types of fibers in one yarn used in various fabric construction" (The American Home Economics Association 1974, p. 67). Fabrics are blended for several reasons. They are blended in order to obtain cross dyeing effects, to improve spinning, and to increase weaving and finishing efficiency. Blending also improves texture, hand and appearance characteristics. The blending of expensive fibers with inexpensive fibers is beneficial for economical reasons. To improve performance is, however, considered the single most important reason for blending fibers (Hollen and Saddler 1973, pp. 103-104).

Note that polyester/cotton blends are generally blended to improve their performance (Joseph 1972, p. 259). Cotton has excellent absorbency, static and pilling resistance while polyester, on the other hand, is deficient in these particular properties. Polyester has excellent wrinkle recovery and strength, while cotton is deficient in wrinkle recovery and its strength is considered to be only good. By blending these fibers at an appropriate percentage level, the properties of each fiber complement each other, giving a performance unachievable using either fiber alone.

Fluorescent Whitening Agents

Five per cent of the sun's radiation reaches the earth's surface as invisible ultraviolet light. Depending upon the chemical nature of the substance struck by radiant energy, it will be either partially or fully absorbed. The increased energy absorption causes the electrons of the atom struck by this energy to become excited, moving them from one sublevel of the atom to another. As the atom returns to its unexcited or ground state, the extra energy is emitted as heat or ultraviolet light, depending upon the structure of the absorbing compound (Sarkar 1971, p. 6).

A compound's ability to fluoresce depends on its chemical nature. A non-fluorescent molecule can be made to fluoresce by chemically changing its spatial arrangement. Double conjugated bonds of the aromatic nuclei tend to exhibit fluorescent properties. Stilbene is a typical representative of this composition. Pi electron systems tend to fluoresce to a greater extent than sigma electrons because they require less energy to excite the less stable bond (Dünnenberger 1960, p. 15).

Rigid aromatic structures emit an intense fluorescence. This rigid structure controls lost energy as molecules return to a grounded state (Sarkar 1971, p. 8). The configurations of the isomers designated as cis and trans fluoresce differently. Cis-isomers, with atom groups found on the same side of the carbon double bond tend to fluoresce less or sometimes not at all, while trans-isomers, with atom groups found on opposite sides of the carbon-carbon double bonds tend to fluoresce.

Stilbene

In 1974, stilbene derivatives were the largest group of chemical compounds used as FWA (Schulze, Polcaro and Stensby 1974, p. 46). The general formula for stilbene is illustrated in Fig. 3.

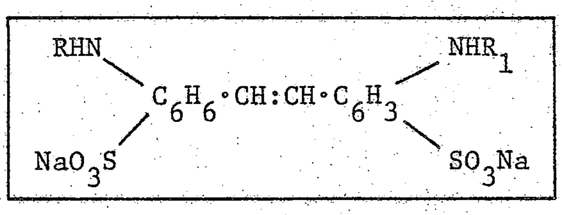


Fig. 3. General Formula for Stilbene

Higginbotham and Thomas state that groups R and R_1 have an important effect on such properties as light stability and substantivity, which is defined as the ability of FWA to attach themselves to textile fibers so that they are not easily removed in washing (Higginbotham and Thomas 1958, p. 1438; Villaume 1958, pp. 560-561).

The 4:4'-diamiono stilbene-2:2' disulphonic acid (shown in Fig. 4) is sometimes referred to as DAS. It is considered to be one of the most important stilbene derivatives (Sarkar 1971, p. 12).

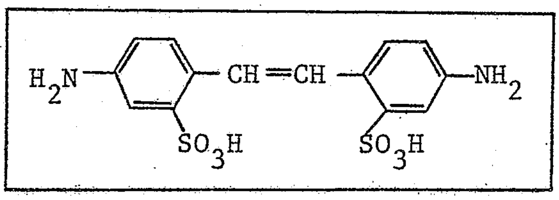


Fig. 4. Cotton Whitener DAS Structure

Benzoxazole and Benzimidazole

Benzoxazole and benzimidazole are included in a major group of heterocyclic five ring compounds. These compounds and their derivatives can be linked to one another or with ethylene, phenyl or other aromatic or heterocyclic ring systems. The major groups benzoxazole and benzimidazole were first marketed according to the formula shown in Fig. 5.

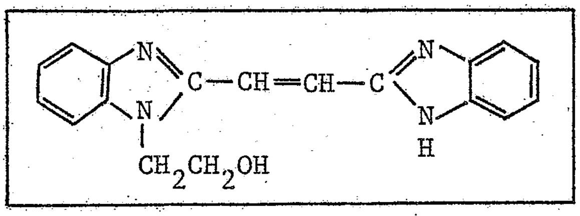


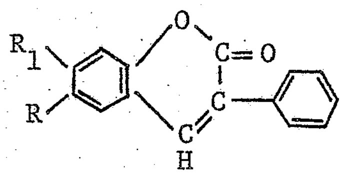
Fig. 5. General Formula for First Marketed Heterocyclic Five Ring Compounds

The compound has an affinity to cellulosic fibers. It fluoresces a greenish blue hue which is accepted by the eye as being whiter and/or brighter. It is incorporated into detergent because it is resistant to hypochlorite (Sarkar 1971, p. 35).

Coumarin

The 7-dialkylamino-4-methyl-coumarins, despite their poor lightfastness, are still in use as FWA. Their wide use is a result of their intense brightening effect, especially on animal fibers

(Dünnenberger 1960, p. 17). Fig. 6 illustrates the structure Sarkar gives for coumarins (Sarkar 1971, p. 54).



R = H or alkyl
R_1 = $-SR_2$ where R_2 = alkyl

Fig. 6. Structure for Coumarins

Application of FWA

FWA can be applied to cotton fibers by the exhaust method because of the absorbent quality of the cotton fibers. The brightener can be applied at room temperature, requiring about one quarter to one half an hour in either hard or soft water. If brightening is done in soft water it is necessary to add Glauber's salt to promote uptake of brightener in the fabric. Exhaustion is the usual method of application of brighteners to cotton unless the process is combined with a finishing agent requiring heat. If this is the case, the pad-method of applying the agent and then the heat would be used.

Because polyester fiber has a low degree of swelling, the exhaustion method cannot be used in brightening it unless heat is applied. An alternative to heating the solution is treatment with a carrier.

The pad-method was developed especially for the application of FWA to polyester fibers. In many countries and particularly in North America, where increasing amounts of polyester materials are being used, the FWA are being applied at the melt-spin stage of manufacture (Sarkar 1971, p. 73).

It has been found that treating cellulosic fibers with FWA in the finishing bath formulation and treating man-made fibers in the polymer melt are the most effective ways of improving initial garment whiteness, but will not insure long-term whiteness. Since FWA are sensitive to light, heat and chemicals it is necessary to renew fluorescent properties in the wash bath during maintenance (Blanchard et al. 1971, p. 181).

In determining the best type of FWA for use in home laundry detergents several factors must be taken into consideration. Variables involved in the selection process include fiber composition, wash water temperature and properties of brightness.

Although there has been an increase of man-made fibers in wash load composition, the need for FWA in the wash liquor has declined as a result of treatment of the fibers at the mills during production. This is an important factor, particularly in the case of polyester fibers because of their hydrophobic nature. Low wash water temperatures of the 1970's limit possible penetration of FWA since a higher wash water temperature is required to cause swelling of the polyester fiber. Therefore, it is necessary that polyesters be treated during production to retain a high degree of the FWA.

Manufacturers of detergent must take into consideration the ratio of white, pastel and printed goods to be laundered as they determine requirements for whiteners. The outcome of this production might be judged by determining whether manufacturers produce detergents which will give consumers the standard of whiteness they desire, while also producing clear, bright colors (Stensby and Findley 1972, p. 55).

A FWA should possess the ability to build up on the fiber being treated. The capability of a FWA to affix itself to the fiber is affected by washing time, temperature, cloth-to-wash liquor ratio, type of detergent used, and pH level. It should exhibit fastness properties, meaning that the FWA is capable of retaining fluorescent properties when exposed to bleaching compounds, sunlight, alkali and acid. It should also be substantive.

CHAPTER 3

METHODS AND PROCEDURES

A 65/35 polyester/cotton blend fabric called "Teeshot", manufactured by Springs Mills was chosen for this study. The fabric was selected from a fabric store in Tucson. The fabric is a poplin, plain weave rib variation dyed skipper blue with a disperse/vat color system. The color system did not contain a FWA (Appendix A). The polyester fiber had been treated with a FWA. A permanent press resin finish had also been applied to the fabric.

Fabric Preparation

A total of 39 samples was used. Each sample was cut 30 inches in the warp direction by 33 inches in the fill direction. Eighteen buffers were also cut 30 inches in the warp direction and from selvage to selvage (44-45 inches) in the fill direction. The raw edge of each sample and buffer was zig-zagged at 20 stitches per inch to prevent raveling from occurring. A small pocket with two buttonholes sewn in it was zig-zagged to the upper left-hand corner of the line dried samples to hold the thermometer for temperature readings. Each sample was coded in the upper left-hand corner for identification purposes. Appendix B lists the coding system used for the study. This coding system will be referred to throughout the text. After preparation the samples were hung on hangers with clothes pins and covered with plastic to prevent soiling.

Washing Procedures

Laundering of the fabric samples was done under controlled conditions. Control samples were not laundered but remained hanging under a plastic cover during the duration of the washing period. Withdrawal for the washed samples occurred after the 20th and 40th wash cycles. Before starting the wash cycle each wash day the buffers were wet down so that their moisture content was equal to that of the samples after washing, so that the rate of drying would be constant for each dryer. Buffers for the first load were placed in the dryer and those to be used in the drying of the second load were placed in the constant temperature room to maintain moisture content.

Each wash day the samples were sorted into water temperature groups. Each sample was then marked with a wash-fast pen in the upper left-hand corner near the pocket according to a tally system to indicate the wash cycle number. The two wash treatments were rotated each wash day to allow similar sun exposure of the line dried samples. A one day rest period was allowed between each wash cycle. Eighteen samples coded C were washed using wash water temperature maintained at $140° \pm 5°$ F with a warm rinse. The remaining eighteen samples coded D were washed with a water temperature maintained at $105° \pm 5°$ F, cold rinse. After the 20th withdrawal seven buffers were added to the wash load to maintain the four pound wash load weight.

Water for washing was taken from The University of Arizona well system. A water sample was taken and cooled from the washer fill tap during each wash week and analyzed for water hardness. Water hardness test results appear in Appendix C. The BKH Total Water Hardness Test, Catalog No. 66140, by Van Waters and Rogers, Incorporated was used for this test.

Washing was done in a Whirlpool Imperial Mark XII Model LSA 9920 washer. A durable press wash cycle was selected with high agitation, low spin, and high water level. Wash procedures included filling the tub to within ten to eleven inches from the top of the tub and agitating one minute. Wash water temperature was then taken and recorded to make sure that the appropriate temperature level was reached, after which one third cup heavy duty Tide detergent containing a FWA was added and the wash liquor was allowed to agitate one additional minute. The type of FWA in the detergent was not identified. After agitation, samples were added and the wash cycle was completed.

Upon completion of each cycle samples were sorted for dryer or line drying. Thermometers were placed in the pocket of the line dried samples.

Drying Procedures

Three various drying procedures were used in the investigation. Treatments included tumble dried, line dried one hour and line dried four hours. Withdrawal of the samples occurred after the 20th and 40th drying treatments.

Tumble drying was done in a Whirlpool Imperial Mark XII dryer, Model LSE 9920. Samples and buffers to be tumble dried were taken immediately from the washer and placed into the dryer. The dryer was set on automatic durable press regular cycle setting and the speed selector set on super. The samples were dried for 25 minutes with the last five minutes serving as a cool down period.

After the drying cycle was completed the samples were removed and immediately hung and covered with plastic. The lint filter was cleaned after each dry cycle.

Line drying was done on the roof of the Home Economics Building at The University of Arizona. Each laundry day it was necessary to rotate the two wash cycles: 1) $140° \pm 5°$ F, and 2) $105° \pm 5°$ F to maintain equal langley units. The first wash cycle of line dried samples was hung on the line at 10:00 A.M. ± five minutes solar time and the second wash cycle at 10:55 A.M. ± five minutes solar time. Solar time was actual sun time based on the high point of the sun radiation at high noon.

Samples were hung at random on the line. The warp grain of the samples ran in a vertical position with the fill yarns running in a horizontal direction. Each sample was hung with the area to be tested facing South and the six inch area with the thermometer and code folded over the line facing North. Samples were secured with clothes pins; one at each end of the sample and one on either side of the thermometer. On very windy days, an extra pin was placed at the midpoint of each sample. The one hour samples were exposed for one hour ± five minutes and the four hours samples for four hours $\pm$ five minutes. After removing samples from the line they were checked for damage, then hung on hangers with clothes pins and covered with plastic until the next wash day.

Environmental Factors

At designated times on each wash day, various components of the environment were measured and recorded. The temperature of each individual sample was read from the thermometer placed in the pocket. The thermometers were hung on the North side so that they would not be in the direct sunlight. Wind velocity was recorded by using the hand anemometer. The sling psychrometer was used to measure relative humidity. Readings were taken at the initial hanging, midpoint, and take down. The amount of solar radiation received by each sample was recorded on an Epply pyroheliometer at the Environmental Research Laboratory at The University of Arizona. Solar radiation data was collected weekly from the laboratory.

Laboratory Testing Methods

Six laboratory tests were conducted on the treatment and control samples. Tests included: 1) subjective evaluation, 2) thread count, 3) tear strength, 4) weight calculations, 5) retention of color and FWA. Each test was conducted according to standardized procedures.

Subjective Evaluation

Each sample was subjectively evaluated for smoothness appearance by three textile students from The University of Arizona. The three judges had previous experience in rating samples in a similar project using white fabric samples. Prior to evaluation of the test samples a training session was conducted using the blue buffers. Each of the judges compared the samples for fabric smoothness appearance after repeated launderings to the AATCC Test Method Replicas and assigned each a DP (Durable Press) rating. The replica ratings ranged from DP-1, poorest in appearance, to DP-5, smoothest in appearance (Table 1). Samples were conditioned in the constant temperature and controlled relative humidity room overnight before being evaluated.

After rating the samples to the AATCC Test Method Replicas, the plastic replicas were painted skipper blue with tempera paint to match the sample color. A training session using the painted replicas and buffers was conducted. The samples were then reevaluated under the same conditions and by the same judges. This was done on the basis of a previous study conducted here at The University of Arizona in which it was found at the 0.01 level of significance that the judges recorded poorer ratings for colored samples compared to the white replicas than those compared with the painted replicas (McPherson 1972, p. 33). Under each condition the results were recorded and the ratings given by the three trained experts were averaged for each sample.

Thread Count

Thread count was taken according to Federal Specification Method 50-50 (U.S. National Bureau of Standards, 1951). Five thread counts were taken on each sample, in both the warp and fill direction. Counting was done from the lower left-hand corner. A three inch margin was

Table 1. Fabric Smoothness Ratings

Rating	Description
DP-5	An appearance equivalent to the DP-5 Replica.
DP-4	An appearance equivalent to the DP-4 Replica.
DP-3.5	An appearance equivalent to the DP-3.5 Replica.
DP-3	An appearance equivalent to the DP-3 Replica.
DP-2	An appearance equivalent to the DP-2 Replica.
DP-1	An appearance equivalent to the DP-1 Replica.

Reproduced from American Association of Textile Chemists and Colorists 1975, p. 176.

left on the bottom and sides of each sample and a six inch margin was left on the top of the line dried samples. The three inch margin was left to meet the specifications required by the test procedures and the six inch margin was left to avoid taking counts in the area of the fabric which had received less exposure to the sun. Thread count was recorded and averaged for each sample.

After subjective evaluation and thread count tests were completed, the samples were cut in an orderly fashion. Cutting was done according to a pattern prepared before the cutting of the samples as outlined in Fig. 7.

Weight Caclulation

Weight of the fabric specimens, cut four inches by four inches, was measured in grams on the Mettler balance. Weighing of the fabric specimens was done in order to justify change due to shrinkage or build-up of FWA. The method set up by United States Testing was used for this test. The method had been modified in previous studies conducted at The University of Arizona since it was impossible to move the Mettler balance into the constant temperature room (Portouw 1971, p. 30). Modification was accomplished by conditioning the weighing bottles. Each bottle was weighed ten times to establish an accurate standard weight so that the bottles would not have to be reweighed each time the fabric specimens were weighed. The fabric test specimens were conditioned 24 hours before weighing.

The test specimens were removed from the conditioning rack and each was placed into one of the preweighed bottles. Lids were placed

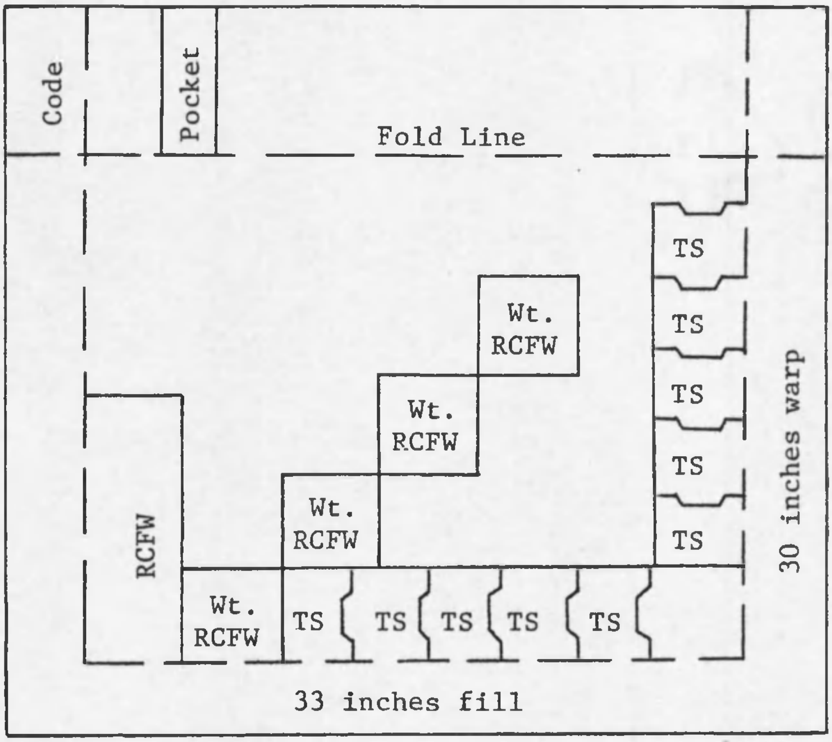


Fig. 7. Diagram of Thermometer Pocket and Laboratory Tests Outline for Samples

Abbreviations: Wt. = weight
RCFW = retention of color and fluorescent whiteness
TS = tear strength

on the bottles. Each bottle and test specimen was transferred to a chamois lined box, placed on a cart and transported to the adjoining testing laboratory to be weighed on the Mettler balance. To prevent excess weight due to finger prints, tongs and chamois were used to aid in moving the bottles and placing the lids. The test specimen weight was determined by subtracting the known weight of its bottle from the total weight of the bottle and test specimen.

Tear Strength

Tear strength test specimens were cut with a cutting die 102 millimeters long by 75 millimeters wide. Five specimens were cut with the long dimension of the die parallel to the warp yarn and five were cut with the long dimension parallel to the fill yarn. Each fabric specimen was conditioned before testing. Tear strength in grams was measured and averaged for each fabric specimen in both warp and fill direction. Tear strength was measured in grams on the Elmendorf falling pendulum apparatus. The standard method followed was ASTM D 1424-63 (R 1970) (ASTM 1974, p. 276).

Retention of Color and FWA

Color retention was measured on the Hunter Color and Color Difference Meter. The instrument was calibrated to the blue hitching-post. Color difference readings were taken from a strip cut four by eleven inches and from the four weight specimens. The strip was folded in such a manner that four layers were placed under the viewing window. The four weight samples were stacked in the same order for each specimen, giving a thickness of four layers of fabric.

The specimens were placed under the viewing window and color difference measurements L, a, and b were taken. The L measurement indicates lightness, with 100 representing perfect white, ranging to zero, which represents black. The a reading indicates the amount of redness present when it has a positive value and green when zero or a minus value. The b reading indicates yellowness when in the plus region, gray when zero, and blueness when the minus region as illustrated in Fig. 8.

After one reading was taken, the specimen was turned 90° and a second reading was taken. The specimen was then set aside while five readings were taken on five other specimens. The third and fourth readings were then taken in order to ensure accuracy and to make sure the instrument had not drifted (Hunter Associates Laboratory, Incorporated 1970).

After this procedure was completed on all the specimens, the ultraviolet absorbing filter was rotated into position. "The UV filter makes it possible to measure color excluding fluorescence excited by ultraviolet light which normally strikes the specimen" (Hunter Associates Laboratory, Incorporated 1970). The readings were then taken excluding fluorescence following the same procedure as used in the readings including fluorescence.

The mean of each pair of readings was computed to determine the average reading for the specimens. Total color difference between the control mean and the specimen means were computed. The three components

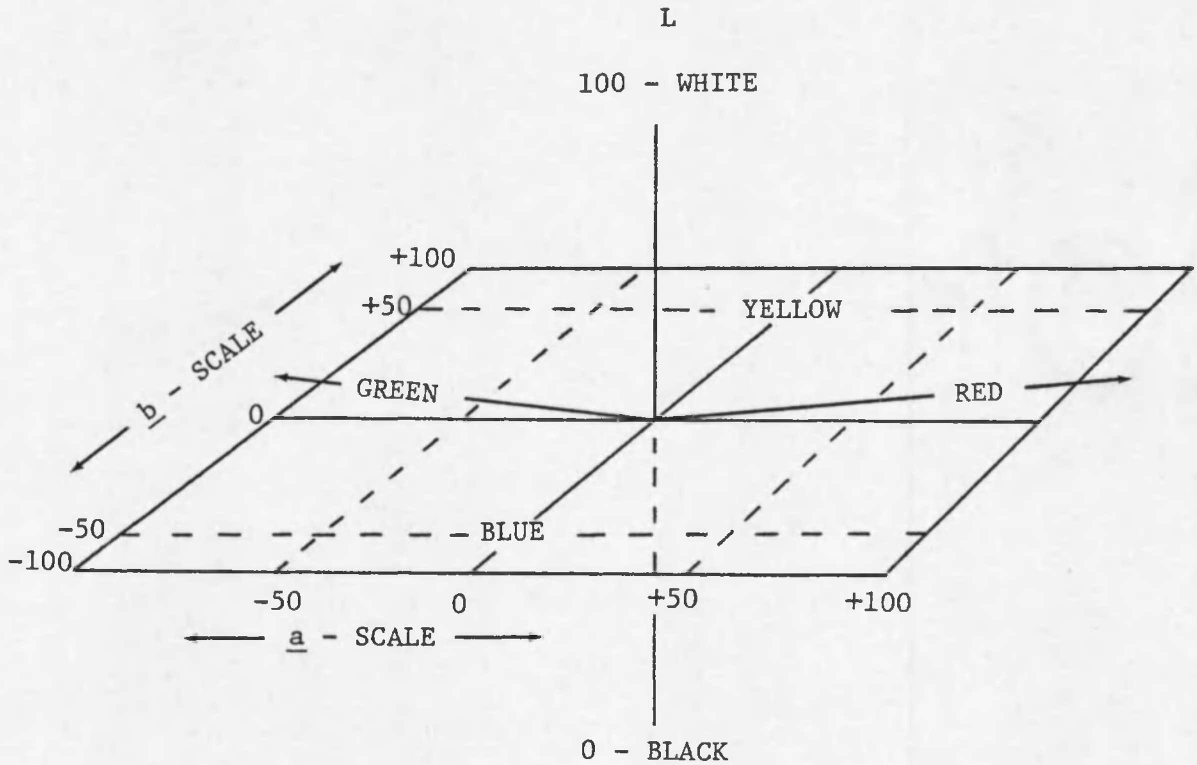


Fig. 8. L, a, b Dimensional Graph of Colors

Reproduced from Hunter Associates Laboratory, Incorporated 1970.

of color difference, $\Delta\underline{L}$, $\Delta\underline{a}$, and $\Delta\underline{b}$ were used to compute total color difference. The formula used in claculating total color difference in chromaticity and reflectance is illustrated in Fig. 9.

$$\Delta E = \sqrt{(\Delta \underline{L})^2 + (\Delta \underline{a})^2 + (\Delta \underline{b})^2}$$

Fig. 9. Formula for Total Color Difference

Analysis of Data

Data for analysis was collected from environmental factors recorded and tests run on the 65/35 polyester/cotton blend fabric dyed skipper blue with a disperse/vat dye system. Data was collected and coded for the computer program Statistical Package for Social Sciences (SPSS), Version 6.0.5, developed by Vogelback Computing Center, Northwestern University (Nie, Hull, Jenkins, Steinbrenner, and Bent 1975).

Environmental factor means were calculated for statistical evaluation. A Pearson-product moment correlation coefficient utilizing the SPSS was used for evaluation. The analysis was used to determine whether the environmental factors had an effect on the physical testing of the line dried samples at the 0.05 level of significance. Physical tests, including thread count, tear strength, weight calculations, retention of color and FWA were evaluated.

Water for washing was analyzed weekly using the BKH Total Water Hardness Test. Readings were recorded but were not analyzed statistically.

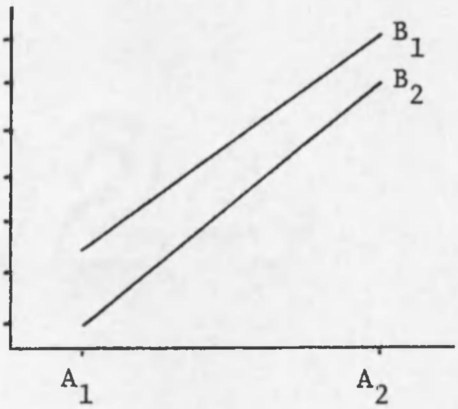
A 3 X 2 X 2 factorial design was used to determine interactions of the three variables at various levels (Steel and Torrie 1960, p. 194). All sample groups were utilized except the control group. Variables and levels involved in this study were as follows: Variable 1, drying treatment; levels consisted of one hour line dried, four hours line dried and tumble dried; Variable 2, temperature; with two levels, 140° ± 5° F and 105° ± 5° F; Variable 3, withdrawal; levels consisting of 20 and 40 wash cycles, as shown in Table 2.

The factorial experimental design was developed to provide information about interaction when two or more factors are involved at various levels (Anderson and Bancroft 1952, p. 267). An interaction is defined by Steel and Torrie as being the differential response which occurs when simple effects for a factor differ by more than can be attributed to chance (Steel and Torrie 1960, p. 197). When a significant interaction is being described, the factors are dependent on each other and will be represented in a response scale by a change in magnitude or direction (Fig. 10a, 10b). When the interaction is non-significant, the variables are independent of one another. That is, factor A is not affecting factor B (Steel and Torrie 1960, p. 199). In this case, the response values lie parallel to each other (Fig. 10c).

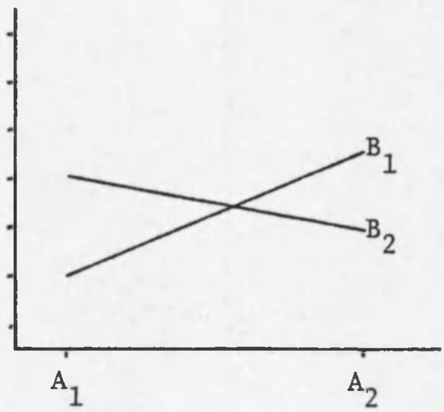
The analysis of variance method (Steel and Torrie 1960, p. 110) was utilized to perform statistical analysis between the means at the 0.05 level of significance. Dependent variables for the study were subjective evaluation, thread count, tear strength, weight calculation, retention of color and FWA. A five-way ANOVA (Analysis of Variance) 45, was utilized to make a comparison of the subjective evaluation of the

Table 2. A 3 X 2 X 2 Factorial Design Utilized to Determine Interaction of Three Variables

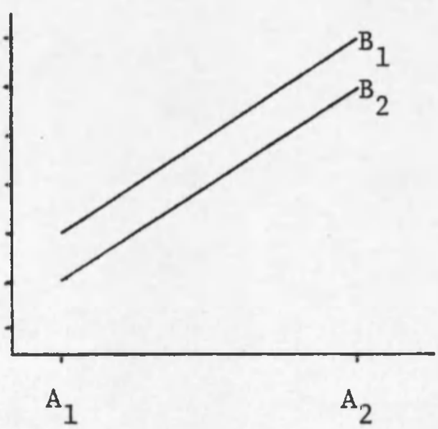
	Factors	Levels
A =	Drying Treatment	1. one hour
		2. four hours
		3. tumble dried
C =	Temperature	1. 140° ± 5° F
		2. 105° ± 5° F
B =	Withdrawal	1. after cycle number 20
		2. after cycle number 40



a. Significant interaction difference in magnitude



b. Significant interaction difference in direction



c. Non-significant interaction responses parallel

A_1 and A_2 = independent variable, a factor level

B_1 and B_2 = independent variable, b factor level

Fig. 10. Interaction of Factors

white three dimensional DP plastic replicas and the replicas painted to match the fabric color. The Student-Newman-Keul's procedure for multiple range comparison of means was used to evaluate sample groups where one-way analysis of variance results were positive (Hicks 1973, pp. 36, 37).

CHAPTER 4

RESULTS

The data were evaluated by the analysis of variance method. Difference between means was set at the 0.05 level of significance. The Student-Newman-Keul's procedure, a multiple range test, was used to determine the significance of sets of differences at the 0.05 level of significance. A linear Pearson-product moment correlation coefficient at the 0.05 level of significance was used to determine whether there was a relationship between the environmental factors and the physical testing.

Environmental Factors

Environmental factor means were calculated for statistical evaluation. Fabric temperature, air temperature, and relative humidity means were calculated for each line dried sample at the beginning, midpoint, and end of the line drying period, as shown in Appendix D, Tables D.1, D.2, and D.3. Wind passage in miles per hour was determined for each sample group by multiplying the average wind velocity by the number of hours (one hour or four hours) the samples were on the line as shown in Appendix D, Table D.4.

The average amount of solar radiation each sample was exposed to was determined and expressed in langley units. Average number of langley units per sample group for the line dried samples appears in Appendix D, Table D.5.

A linear Pearson correlation coefficient analysis utilizing the SPSS was performed to determine the correlation between environmental factors and physical testing. No correlation was found to exist at the 0.05 level of significance between environmental factors (fabric temperature, air temperature, relative humidity, wind velocity and solar radiation to which the fabric was exposed) and physical testing variables (thread count, tear strength, weight, and color retention values: _L_, _a_, _b_, ultraviolet included and ultraviolet excluded, and retention of FWA). A total of 148 separate correlations were run. Sample group means appear in Table 3.

Laboratory Testing Methods

Each sample was subjected to laboratory testing procedures, then means for each test were calculated for statistical evaluation. Results of laboratory testing included subjective evaluation, thread count, weight calculation, tear strength and retention of color and FWA.

Subjective Evaluation

Each of the treated and control samples was compared and rated against six three-dimensional AATCC plastic standardized replicas to determine its actual smoothness or wrinkled state. The rating of the replicas ranged from DP-1, indicating the poorest retention of the original appearance to DP-5, indicating the smoothest retention of the original appearance.

Table 3. Means of Environmental Factors Line Dried Samples were Exposed to by Sample Group

Sample Group	Environmental Factors* A.T.	F.T.	R.H.	W.V.	S.R.
L_1-20-C	92.7	93.3	18.8	2.6	1627.80
L_1-20-D	92.6	94.2	21.1	2.7	1609.90
L_1-40-C	86.3	88.6	18.9	2.7	4494.17
L_1-40-D	86.3	88.1	18.5	3.0	1609.90
L_4-20-C	94.0	95.0	18.5	14.2	6159.80
L_4-20-D	92.0	93.9	19.4	14.6	6054.70
L_4-40-C	88.0	89.2	16.3	13.6	11148.80
L_4-40-D	88.3	88.8	16.3	13.9	11027.50

*Environmental factors include air temperature (A.T.), fabric temperature (F.T.) in degrees Fahrenheit, relative humidity (R.H.) in percentage, wind velocity (W.V.) in miles per hour and solar radiation (S.R.) expressed in langley units.

Rating of the samples was done by three trained judges. Rating was first done against the standard white replica. After each sample had been rated against the white replicas, the replicas were painted blue to match the fabric color and the samples were rerated.

Means of each of the sample treatment groups and control group were calculated and compared collectively as well as by replica color. Means appear in Appendix E, in Table E.1. Control samples were judged along with the treatment samples but were not included in the analysis of variance procedure.

A significant difference in appearance was found to exist among the line dried one hour, line dried four hours and tumble dried samples compared to both the white and painted replicas. In both cases the tumble dried samples were given the highest rating, indicating that they were less wrinkled than samples line dried one hour or four hours. The one hour line dried treatment group was given the poorest rating, appearing the most wrinkled when compared to both the white replica and the painted replica.

In utilizing the Student-Newman-Keul's test with the white replicas it was found that the one hour line dried samples received a significantly lower rating in smoothness appearance than the four hours line dried samples and the tumble dried samples. The difference between the four hours line dried and the tumble dried sample groups was non-significant. Against the blue replicas a significant difference was found to exist between the one hour line dried and the tumble dried sample groups, and between sample groups line dried four hours and those tumble dried. A non-significant difference was found between the one hour line dried and four hours line dried sample groups (Table 4). Note that groups for which a non-significant difference was found were different after the replicas were painted blue to match the sample color. This indicates to the investigator that color affects the perception of the wrinkled state of fabric.

Table 4. Subjective Evaluation Ratings for Drying Treatments

	Means*	
Drying Treatment	White Replica	Blue Replica
One Hour Line Dried	3.556^{a}	3.236^{a}
Four Hours Line Dried	3.736^{b}	3.375^{a}
Tumble Dried	3.806^{b}	3.542^{b}

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

A significant difference was found to exist between treatment groups washed at 140° ± 5° F and those washed at 105° ± 5° F when compared to both the white and blue replicas. Fabric samples washed at 140° ± 5° F appeared to be significantly more wrinkled than those washed at 105° ± 5° F as indicated in Table 5. Possibly some of the durable press finish was lost at the higher temperature, causing more wrinkles to appear.

Table 5. Subjective Evaluation Means by Wash Temperature

	Means*	
Temperature	White Replica	Blue Replica
140° ± 5° F	3.380[a]	3.040[a]
105° ± 5° F	4.018[b]	3.722[b]

*Means within the same column having the same exponential letter are not significantly different at the 0.05 level.

There was also a significant difference between the withdrawal treatments compared with both the white and blue replicas. The samples withdrawn after the 20th wash cycle were found to be significantly less wrinkled than those withdrawn after the 40th cycle as illustrated in Table 6. Possibly some of the finish was lost as the number of cycles increased. This could account for the increased number of wrinkles as the number of wash cycles increased.

Table 6. Subjective Evaluation Means by Withdrawal

	Means*	
Withdrawal	White Replica	Blue Replica
20	3.796[b]	3.518[b]
40	3.602[a]	3.250[a]

*Means within the same column having the same exponential letter are not significantly different at the 0.05 level.

The Student-Newman-Keul's test of multiple means comparisons was utilized to determine whether a significant difference existed among the control, the 20th withdrawal and the 40th withdrawal groups. The control group was found to be significantly less wrinkled than the treatment groups when compared with both the white AATCC plastic replica and the replica painted blue, as shown in Table 7.

The judges' ratings were also analyzed. There was no significant difference among the three judges' ratings of the fabric against the blue replicas. Utilizing the Student-Newman-Keul's test at the 0.05 level of significance against the white replica, judges one and three gave significantly different ratings (Table 8). These results indicate to the investigator that judging a blue fabric against a white replica does affect the judges' rating.

As illustrated in Fig. 11, there was a two-way interaction between wash temperature and withdrawal when compared with both the white and blue replicas. In both cases it was found that as the wash water temperature increased at the 20th withdrawal, the appearance of the sample became more wrinkled. As the number of cycles increased from 20th to 40th withdrawals, the 105° ± 5° wash temperature treatment rating remained the same. With the higher wash temperature, 140° ± 5° F, as the withdrawals increased, the appearance of the samples became more wrinkled. These results indicate that it is possible that the higher wash temperature creates a greater loss of the durable press finish, causing the samples to appear more wrinkled.

Table 7. Subjective Evaluation Mean Ratings against the White and Blue AATCC Plastic Replicas for Smoothness

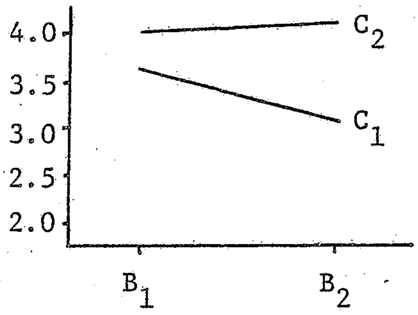
	Means*	
Sample Group	White Replica	Blue Replica
C	4.933^{k}	4.544^{jk}
TD-20-C	$3.500^{cdefghi}$	3.333^{cdefg}
TD-20-D	4.167^{ij}	3.889^{ghi}
TD-40-C	$3.500^{cdefghi}$	3.111^{bcde}
TD-40-D	4.056^{hij}	3.833^{fghi}
L_1-20-C	3.611^{efghi}	3.167^{bcdef}
L_1-20-D	3.722^{efghi}	3.667^{efghi}
L_1-40-C	2.944^{abc}	2.556^{a}
L_1-40-D	3.944^{ghi}	3.556^{defghi}
L_4-20-C	3.667^{efghi}	3.444^{cdefgh}
L_4-20-D	4.111^{hij}	3.611^{efghi}
L_4-40-C	3.056^{abcd}	2.667^{ab}
L_4-40-D	4.111^{hij}	3.778^{efghi}

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

Table 8. Subjective Evaluation Means by Judges

	Means*	
Judge	White Replica	Blue Replica
1	3.885[a]	3.467[a]
2	3.769[ab]	3.292[a]
3	3.697[b]	3.389[a]

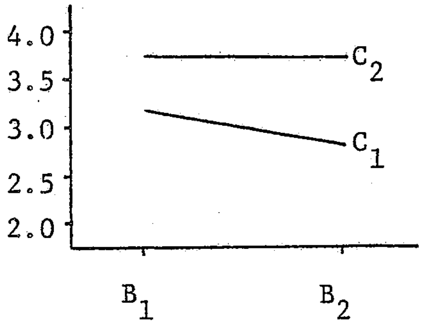
*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.



Wash temperature vs. withdrawal against the white replica

C_1 = wash temperature 140° ± 5° F
C_2 = wash temperature 105° ± 5° F

B_1 = 20th withdrawal
B_2 = 40th withdrawal



Wash temperature vs. withdrawal against the blue replica

Fig. 11. Two-way Interaction with Appearance

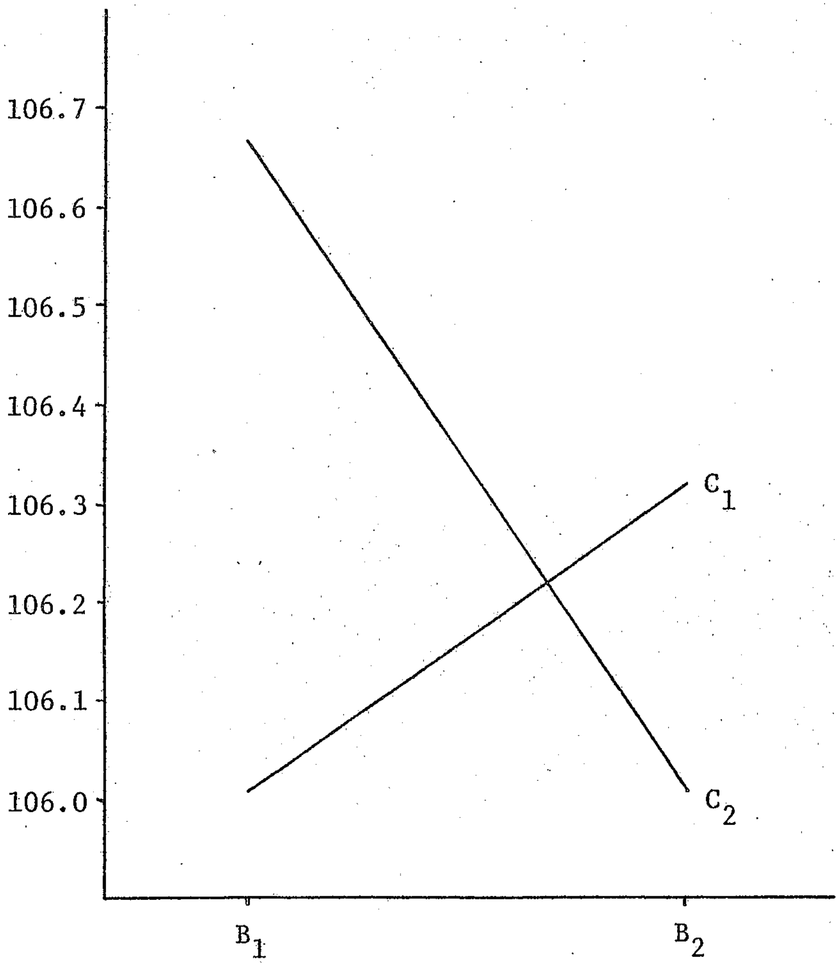
Thread Count

Thread counts for both warp and fill were taken for each sample by counting the number of yarns per inch in five separate positions not adjacent to each other. Readings were averaged for each of the sample groups and the control group. Mean readings appear in Appendix E, in Table E.2.

No significant difference existed among the one hour line dried, four hours line dried and tumble dried samples in either the warp or fill direction. Nor was there a significant difference between samples withdrawn after the 20th and 40th cycles or between the samples washed at 140° ± 5° F and those washed at 105° ± 5° F.

In the warp direction there existed a two-way interaction involving wash temperature and withdrawal as indicated in Fig. 12. The interaction indicates that the warp yarns of the sample groups washed at 140° ± 5° F became more dense as the number of cycles increased while the samples washed at 105° ± 5° F became less dense at the 40th withdrawal. The change in yarn denseness indicates to the investigator that a relaxing of the warp yarns occurred at the lower temperature at the 20th withdrawal. The increase in denseness of the samples washed at 140° ± 5° F at the 40th withdrawal indicates a shrinkage of the warp yarn between the 20th and 40th withdrawals.

The results of the Student-Newman-Keul's test of multiple mean comparisons indicates that the thread count in the warp direction of the control group is significantly less dense at the 0.05 level of significance than the sample group line dried four hours, wash water



C_1 = wash water temperature 140° ± 5° F
C_2 = wash water temperature 105° ± 5° F

B_1 = 20th withdrawal
B_2 = 40th withdrawal

Fig. 12. Two-way Interaction with Warp Thread Count

temperature 105° ± 5° F, at the 20th withdrawal. No significant difference was found to exist among group means in the fill direction. Means are given in Table 9.

Weight Calculation

Four weight specimens for each sample were cut, then weighed on the Mettler balance. Weights were averaged to obtain the sample group means, which appear in Appendix E, Table E.3. The means were compared using a one-way analysis of variance method to determine whether a significant difference existed among means of drying treatments (line dried one hour, line dried four hours and tumble dried), between wash water temperature (140° ± 5° F and 105° ± 5° F), and between the 20th and 40th wash cycle periods. There was no significant difference found to exist at the 0.05 level of significance.

The Student-Newman-Keul's test of multiple mean comparisons was also run at the 0.05 level of significance to determine whether there was a significant difference among the sample groups and the control group means. No significant difference was found.

Tear Strength

The Elmendorf instrument was used to measure the amount of force in grams required to propagate a tear previously started. Tear strength mean readings in grams for each of the treatment groups and the control group appear in Appendix E, Table E.4.

Among the drying treatments there was a significant difference between all the groups: the one hour line dried, four hours line dried

Table 9. Thread Count Warp Means

	Means*	
Sample Group	Warp	Fill
C	105.3[a]	53.3[a]
TD-20-C	106.3[ab]	54.0[a]
TD-20-D	106.3[ab]	54.0[a]
TD-40-C	106.3[ab]	54.0[a]
TD-40-D	106.0[ab]	54.0[a]
L_1-20-C	106.0[ab]	54.0[a]
L_1-20-D	106.3[ab]	54.0[a]
L_1-40-C	106.3[ab]	54.0[a]
L_1-40-D	106.0[ab]	54.3[a]
L_4-20-C	106.0[ab]	54.3[a]
L_4-20-D	107.0[b]	54.0[a]
L_4-40-C	106.3[ab]	54.0[a]
L_4-40-D	106.0[ab]	54.0

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

and tumble dried treatment groups, in both the warp and fill directions (Table 10). Tumble dried samples were found to be the strongest while the four hours line dried samples were the weakest in both the warp and fill directions. This indicates to the investigator that environmental factors did affect the tear strength of the samples.

A significant difference existed between the samples washed at 140° ± 5° F and those washed at 105° ± 5° F in both the warp and fill directions. Samples washed at 105° ± 5° F were found to be significantly stronger than those washed at 140° ± 5° F. See Table 11.

A significant difference in both the warp and fill directions existed between the 20th and 40th withdrawal groups as illustrated in Table 12. This indicates that as the number of cycles increases the fabric becomes significantly weaker in strength.

A two-way interaction was found to exist between wash water temperature and drying treatment in the fill direction as shown in Fig. 13. Samples washed at 140° ± 5° F were considerably weaker than those washed at 105° ± 5° F. The difference in the increased wash water temperature had a greater effect on the tumble dried samples.

The Student-Newman-Keul's test of multiple range mean comparisons was used to determine whether a significant difference existed between the sample groups and the control group. The control group was significantly stronger than the treatment groups in both the warp and fill directions. From the treatment groups, the tumble dried, 20th withdrawal group which had wash water temperature of 105° ± 5° F was

Table 10. Tear Strength Means in Grams by Drying Treatment

Drying Treatment	Means *	
	Warp	Fill
One Hour Line Dried	2118.33[b]	1168.00[b]
Four Hours Line Dried	1005.00[a]	1091.67[a]
Tumble Dried	2239.17[c]	1260.91[c]

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

Table 11. Tear Strength Means in Grams by Wash Temperature

Wash Temperature	Means*	
	Warp	Fill
140° $\pm$ 5° F	1978.89[a]	1107.22[a]
105° $\pm$ 5° F	2256.11[b]	1247.22[b]

*Means within the same column having the same exponential letter are not significantly different at the 0.05 level.

Table 12. Tear Strength Means in Grams by Withdrawal

	Means*	
Withdrawal	Warp	Fill
20	2198.89[b]	1222.22[b]
40	2036.11[a]	1126.11[a]

*Means within the same column having the same exponential letter are not significantly different at the 0.05 level.

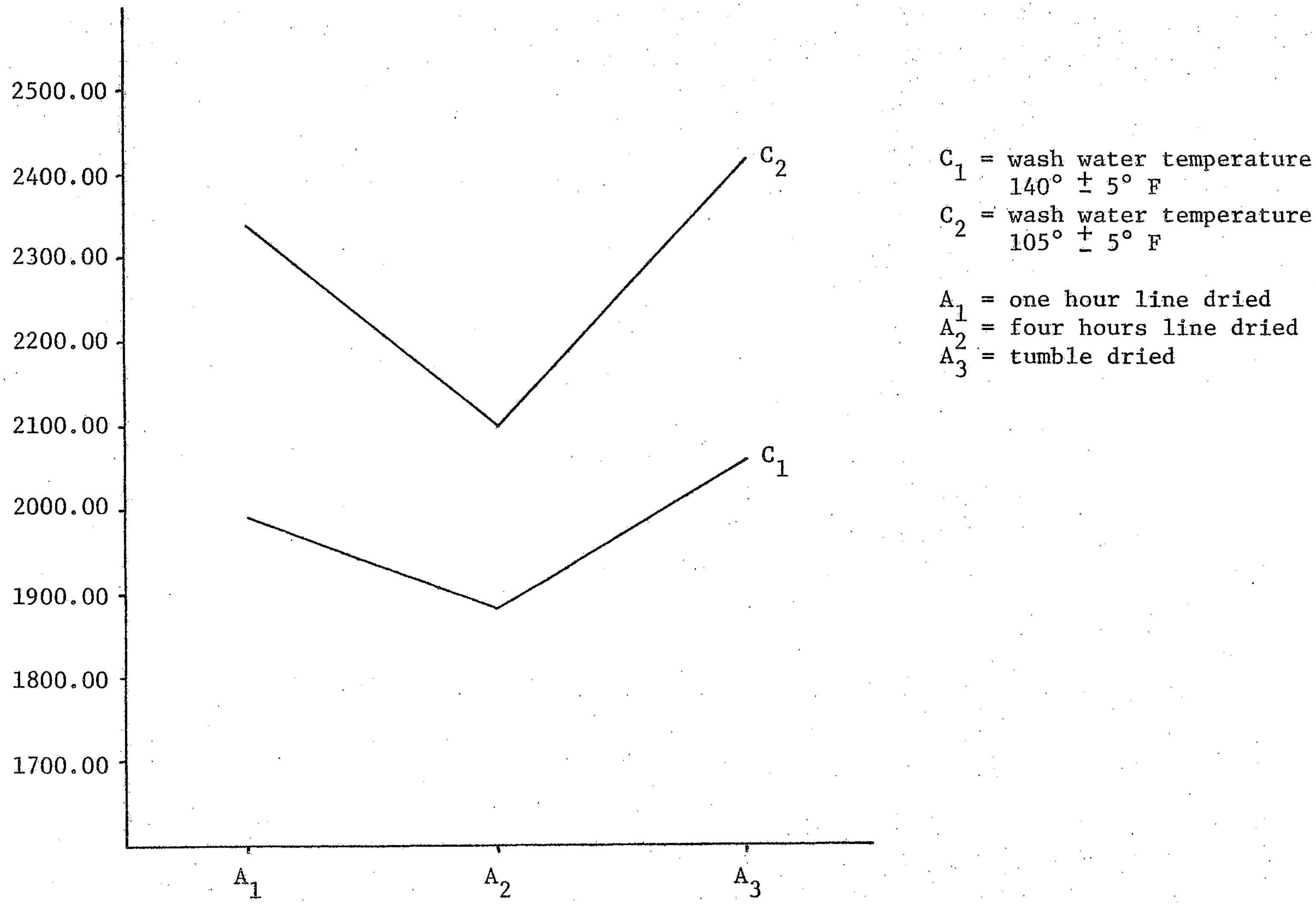


Fig. 13. Two-way Interaction with Fill Tear Strength

significantly stronger than the rest of the groups in both the warp and fill directions, as illustrated in Fig. 14.

Retention of Color and FWA

Total color difference and FWA difference were computed by measuring the components of color with and without excited fluorescence. Means including ultraviolet appear in Appendix E, Table E.5 and ultraviolet excluded values appear in Table E.6.

Color Difference

Total color difference (Delta E) was determined by using the formula illustrated in Fig. 9. A one-way analysis of variance was used to analyze total color difference of fabric samples including ultraviolet light at the 0.05 level of significance. A significant difference in color change was found to exist among treatment groups: tumble dried, line dried one hour and line dried four hours. Utilizing the Student-Newman-Keul's test it was determined that each drying treatment group was significantly different from the others. The tumble dried samples changed the least amount, with the greatest change occurring in the four hours line dried samples as illustrated in Table 13.

Between the treatment groups withdrawn at the 20th and 40th cycles a significant difference was found to exist at the 0.05 level of significance. As the number of cycles increased the fabric color was significantly lighter (Table 14).

A two-way interaction was found to exist for color difference between drying treatment factor and withdrawal factor (Fig. 15). A

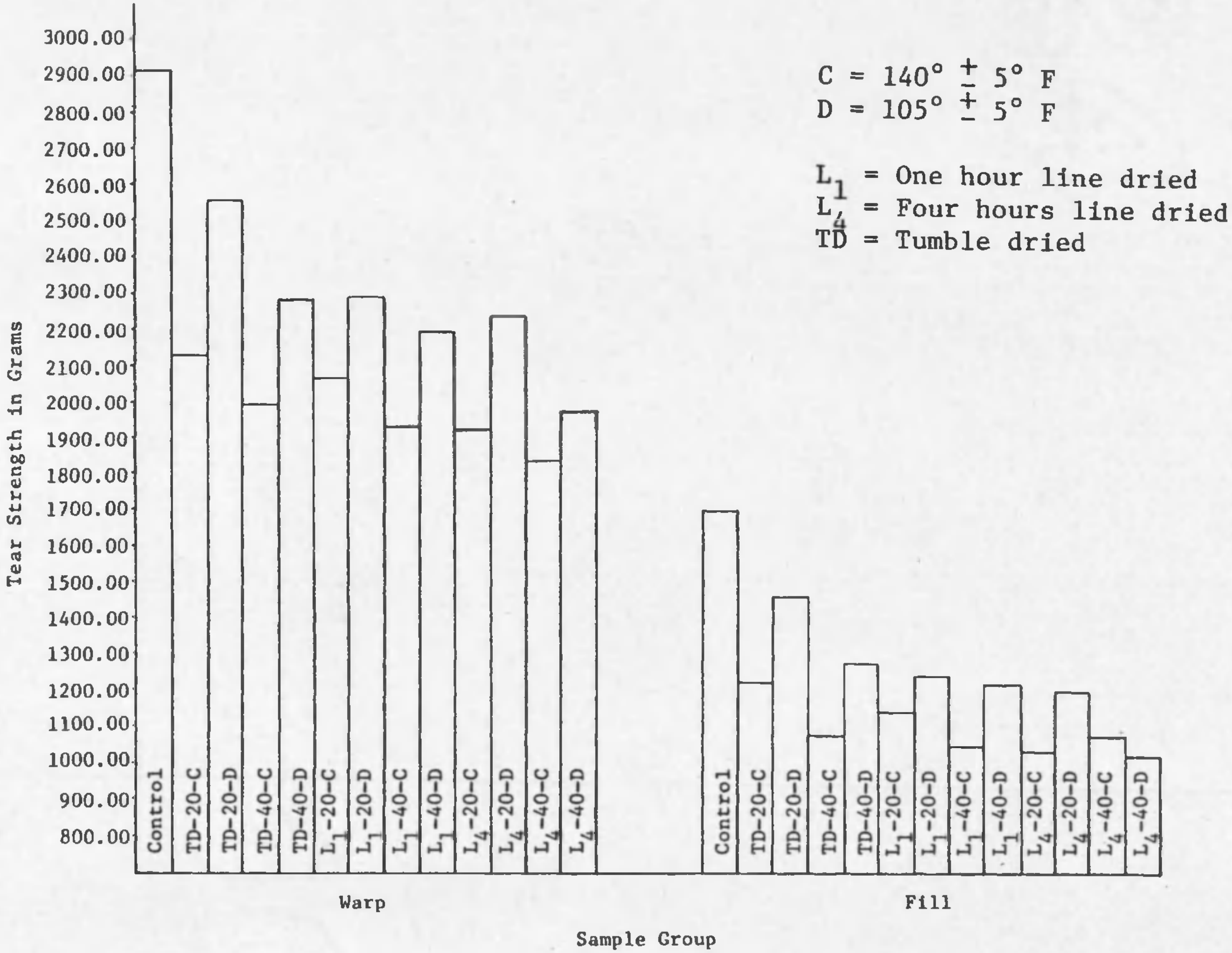


Fig. 14. Tear Strength in Grams by Sample Group for Warp and Fill Directions

Table 13. Drying Treatment Ultraviolet Means

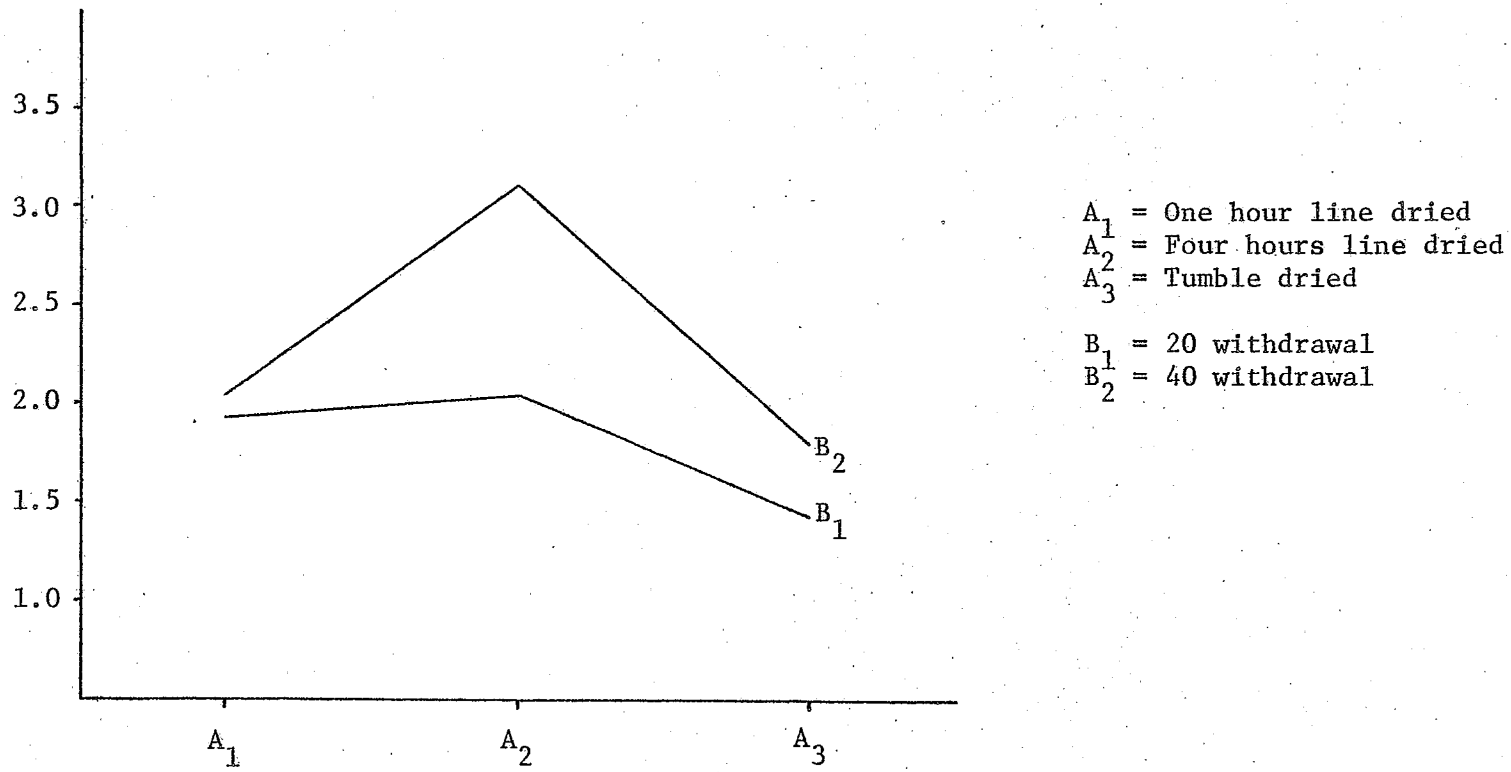
Sample Group	Means*
One Hour Line Dried	1.9789[b]
Four Hours Line Dried	2.6623[c]
Tumble Dried	1.5872[a]

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

Table 14. Withdrawal Ultraviolet Means

Sample Group	Means*
20 Withdrawal	1.8094[a]
40 Withdrawal	2.3429[b]

*Means within the same column having the same exponential letter are not significantly different at the 0.05 level.



Delta E ultraviolet included
drying treatments vs. withdrawal

Fig. 15. Two-way Interaction Color Difference

significant difference was found to exist among the three drying treatment groups between the 20th and 40th withdrawals, with the greatest difference occurring in the treatment group line dried four hours.

Total color difference was analyzed including the control utilizing the Student-Newman-Keul's test at the 0.05 level of significance. The treatment groups: tumble dried, line dried one hour, and line dried four hours were found to have a significantly greater color change than the control. Among the treatment groups a significant difference was found to exist between the line dried four hours, 40th withdrawal sample group and the other sample groups as shown in Table 15.

Ultraviolet Included b Minus Ultraviolet Excluded b Value

The brightness effect on the substrate due to the fluorescence excited by ultraviolet light was estimated by subtracting the difference between the b value ultraviolet included and b value ultraviolet excluded. This value was used since FWA generally fluoresce in the blue region, which the b value represents, adding to a substrate total reflectance in this region.

Ultraviolet b value included and b value excluded were measured on the Hunter Color and Color Difference Meter. Estimation of the sample group means difference appear in Appendix E, Table E.7.

Sample group means were compared according to the Student-Newman-Keul's test at the 0.05 level of significance. A non-significant difference was found to exist among the control and treatment groups tumble dried, line dried one hour and line dried four hours at both

Table 15. Total Color Difference Value Means Ultraviolet Included

Sample Group	Means* 140° ± 5° F	105° ± 5° F
C	0.120[a]	0.120[a]
TD-20	1.522[bc]	1.310[b]
TD-40	1.833[bcd]	1.683[bcd]
L_1-20	1.894[bcd]	1.943[bcd]
L_1-40	2.213[cd]	1.865[bcd]
L_4-20	2.282[d]	1.904[bcd]
L_4-40	3.241[e]	3.222[e]

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

wash water temperatures as illustrated in Table 16. This indicates to the investigator that FWA do not affect the appearance of colored fabric significantly.

Table 16. b Value Ultraviolet Included Minus b Value Ultraviolet Excluded Sample Group Means

	Means*	
Sample Group	140° ± 5° F	105° ± 5° F
C	0.1000[a]	0.1000[a]
TD-20	-0.0497[a]	0.0210[a]
TD-40	0.1040[a]	-0.1330[a]
L_1-20	0.2540[a]	0.1583[a]
L_1-40	-0.5457[a]	0.2083[a]
L_4-20	-0.0920[a]	0.2460[a]
L_4-40	0.2457[a]	-0.0330[a]

*Means within the same column with the same exponential letter are not significantly different at the 0.05 level utilizing the Student-Newman-Keul's test.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study was performed to investigate the effects of various laundry treatments and environmental factors on the appearance, thread count, weight, tear strength and retention of color and FWA on disperse/vat dyed skipper blue 65/35 polyester/cotton blend fabric with a built-in FWA (polyester fiber only) and a permanent press finish. Results of the laboratory tests were statistically analyzed to ascertain the effects of laundry treatments and environmental factors.

Results of Hypotheses

Hypothesis Number One

There will be no significant difference in the retention of color and FWA, thread count, weight, tear strength and appearance of samples laundered at 140° ± 5° F and those laundered at 105° ± 5° F.

The data indicate a partial rejection of the null hypothesis. A significant difference was found between the samples washed at 140° ± 5° F and those washed at 105° ± 5° F for physical tests of tear strength and appearance. The samples washed at 105° ± 5° F were found to be significantly stronger than samples washed at 140° ± 5° F. Samples washed at 140° ± 5° F were significantly more wrinkled in appearance than those washed at 105° ± 5° F. A non-significant difference between wash water temperature sample groups was found for physical tests for retention of color and FWA, thread count and weight.

Hypothesis Number Two

There will be no significant difference in the retention of color and FWA, thread count, weight, tear strength and appearance of samples laundered zero, 20 or 40 times.

The data indicate a partial rejection of the null hypothesis. Control samples were found to have significantly higher values than those laundered 20 and 40 times for the physical tests for retention of color and FWA, tear strength, and smoothness appearance. Samples laundered 40 times were found to be significantly lighter in color, weaker in tear strength and more wrinkled in appearance than those laundered 20 times. A non-significant difference existed between the 20th and 40th withdrawal for retention of FWA. Differences in values for samples laundered zero, 20 and 40 times for thread count and weight were found to be due to chance alone.

Hypothesis Number Three

There will be no significant difference in the retention of color and FWA, thread count, weight, tear strength, and appearance of samples tumble dried, line dried one hour, and those line dried four hours.

The data indicate a partial rejection of the null hypothesis. A significant difference was found to exist among samples tumble dried, line dried one hour and those line dried four hours for physical tests of retention of color, tear strength and appearance. There was a significant difference in color among all three treatment groups with the greatest change occurring with the samples line dried four hours. The samples line dried four hours also had the weakest tear strength. The tumble dried samples had the least change in color and tear strength. The smoothness appearance of the samples was significantly different, with the tumble dried samples receiving the highest rating, indicating that they were less wrinkled when compared against both the white and blue test replicas. Differences in means of physical tests for retention of FWA, thread count and weight were found to be due to chance alone.

Hypothesis Number Four

There will be no significant difference in the judges' ratings for smoothness appearance against the white AATCC Test Method Replicas and the same replicas painted blue.

The data indicate a partial rejection of the null hypothesis. The ratings by judges one and three against the white replicas were significantly different, while against the replicas painted blue the judges' ratings of appearance were not significantly different.

Conclusions

Samples washed at 140° ± 5° F were found to wrinkle to a greater extent than samples washed at 105° ± 5° F. Samples washed at the lower temperature were significantly less wrinkled than those washed at the higher temperature.

The ability of a fabric to maintain a minimum amount of wrinkling during laundering is important to the consumer in the purchase of a durable press fabric. Fabrics which become less wrinkled when washed at the lower wash water temperature setting also have the advantage of eliminating the extra energy used to heat the wash water to the higher temperature.

The fabric samples also proved to be significantly stronger when washed at the lower wash water temperature. This indicates to the investigator that the serviceability of the fabric would be greater when it is washed at the lower wash water temperature.

As the number of wash cycles increased, it was found that the fabric samples became significantly lighter in color. They also became significantly weaker and more wrinkled.

Tumble drying proved to be the most satisfactory method of drying the fabric. The degree of color change was significantly less than for the other two drying treatment groups. Fabric samples tumble dried were also significantly stronger and less wrinkled than those in the other treatment groups.

In evaluating the retention of color and FWA it was determined that color change was affected by various laundry treatments, while there was no significant effect on FWA. The degree of color change was affected significantly by withdrawal and drying treatments. The smallest degree of color change was obtained by tumble drying the samples.

A previous study by Higginbotham and Thomas indicates that a build-up of FWA may occur, causing discoloration upon exposure to the sun. This is often mistaken for poor dye fastness (Higginbotham and Thomas 1958, p. 1439). In this study, however, it can be concluded that a build-up of FWA did not occur. This can be supported by the data indicating that there was no significant change in FWA among the samples using the various laundry treatments, nor were the samples significantly heavier, as would have been the case had there been a build-up of FWA. The data support the statements of several authors that disperse/vat color systems are generally fast to light (Hollen and Saddler 1973, p. 216; Joseph 1972, p. 324).

It can also be concluded that the color of the test replicas does affect the judges' ratings when judging smoothness appearance of fabric samples. This supports McPherson's finding that judges give colored fabric a poorer rating when comparing it to a white replica than they do when comparing it to replicas painted to match the fabric color (McPherson 1972, p. 33). There was a non-significant difference in the judges' ratings against the blue replicas while against the white test replicas the judges' ratings differed significantly.

It can be concluded that tumble drying will cause the smallest degree of color change. It was also noted that the smaller the number of wash cycles the less the degree of color change; however, it would be impractical to be able to wash a textile product only a few times in order to maintain quality.

Recommendations

Replicating this study using a larger number of fabric samples would increase the power of the tests. This possibly could have an effect on the results of such a study.

Experimentation will be required to determine whether a precolored plastic replica could be produced. A precolored replica would avoid uneven distribution of color in painting the replicas, and therefore eliminate much possible inaccuracy during subjective evaluation of fabric samples.

Increasing the number of AATCC plastic replica standards would reduce the chance of inaccurately rating the appearance of a sample which should receive a value between two standards. This increase in the number of replicas would lessen the chance of an invalid test.

Repeating this study in a location where relative humidity reaches a higher level than in Tucson may result in different effects on fabric samples. For this same reason, it would also be informative to repeat the study in an area which experiences lower atmospheric temperatures.

To determine effects of FWA on colored fabric dyed blue it would be beneficial to repeat this study using an intense blue and a pastel blue colored fabric. A comparison of the effects of environmental factors and different laundry treatments using these two colors of fabric would illustrate the difference in change of FWA as a result of variation in color intensity.

In 1977, with concern focused on an energy shortage, a duplication of the study using a cold wash and cold rinse would be appropriate. This variation could result in the build-up of FWA on samples tested.

The study indicates to the consumer that the tumble drying procedure is the most satisfactory drying method. However, due to the energy shortage, line drying for one hour is recommended, as it will produce similar results.

APPENDIX A

CORRESPONDENCE WITH MANUFACTURER

Springs Springs Mills, Inc.

Research and Development Center
Fort Mill, S. C. 29715
803/547-2901

April 17, 1975

Ms. Rhonda Harris
Teaching Assistant
University of Arizona
Tucson, Arizona 85721

Dear Ms. Harris:

We are pleased that you have selected "Teeshot" for your work.

The yellow shade, which we call Lemon Peel, is dyed with a fiber reactive/dispersed color system. The Skipper Blue shade is dyed with a vat/dispersed color system. Neither color system contains an optical brightener.

If we can be of further help, let us know.

Sincerely yours,

SPRINGS MILLS, INC.

L. V. McMackin

L. V. McMackin
Group Leader
Finishing Research

pr

cc: Mr. Bob Slough

APPENDIX B

CODING FOR SAMPLE GROUPS

Description	Symbol
Three control samples--unlaundered	C-1, C-2, C-3
Three samples, washed 20 times, wash water 140° F, tumble dried	$TD-20-C_1$, $TD-20-C_2$, $TD-20-C_3$
Three samples, washed 20 times, wash water 105° F, tumble dried	$TD-20-D_1$, $TD-20-D_2$, $TD-20-D_3$
Three samples, washed 40 times, wash water 140° F, tumble dried	$TD-40-C_1$, $TD-40-C_2$, $TD-40-C_3$
Three samples, washed 40 times, wash water 105° F, tumble dried	$TD-40-D_1$, $TD-40-D_2$, $TD-40-D_3$
Three samples, washed 20 times, wash water 140° F, line dried one hour	L_1-20-C_1, L_1-20-C_2, L_1-20-C_3
Three samples, washed 20 times, wash water 105° F, line dried one hour	L_1-20-D_1, L_1-20-D_2, L_1-20-D_3
Three samples, washed 40 times, wash water 140° F, line dried one hour	L_1-40-C_1, L_1-40-C_2, L_1-40-C_3
Three samples, washed 40 times, wash water 105° F, line dried one hour	L_1-40-D_1, L_1-40-D_2, L_1-40-D_3
Three samples, washed 20 times, wash water 140° F, line dried four hours	L_4-20-C_1, L_4-20-C_2, L_4-20-C_3
Three samples, washed 20 times, wash water 105° F, line dried four hours	L_4-20-D_1, L_4-20-D_2, L_4-20-D_3
Three samples, washed 40 times, wash water 140° F, line dried four hours	L_4-40-C_1, L_4-40-C_2, L_4-40-C_3
Three samples, washed 40 times, wash water 105° F, line dried four hours	L_4-40-D_1, L_4-40-D_2, L_4-40-D_3

APPENDIX C

WATER HARDNESS TEST

Date	Parts per Million	Grains Hardness
6/05/75	164	9.512
6/14/75	142	8.236
6/18/75	136	7.888
6/26/75	134	7.772
7/03/75	126	7.308
8/27/75	124	7.192
9/04/75	144	8.352
9/11/75	118	6.844
9/18/75	152	8.816
9/27/75	154	8.932
10/04/75	166	9.628
10/09/75	178	10.324
10/25/75	142	8.236
11/06/75	152	8.816
11/13/75	158	9.164

APPENDIX D

ENVIRONMENTAL STATISTICAL DATA OF LINE DRIED SAMPLES
FROM MAY 28, 1975 TO NOVEMBER 13, 1975

Table D.1. Sample Mean Fabric Temperature of Line Dried Samples

	Average Fabric Temperature in °F		
Sample	Beginning	Midpoint	End
L_1-20-C_1	70.5	101.7	106.5
L_1-20-C_2	71.2	105.0	105.1
L_1-20-C_3	70.8	104.3	104.6
L_1-20-D_1	77.2	104.4	104.6
L_1-20-D_2	71.4	103.8	105.0
L_1-20-D_3	71.6	104.7	105.3
L_1-40-C_1	67.6	98.7	99.3
L_1-40-C_2	67.9	99.0	99.7
L_1-40-C_3	68.1	98.4	98.7
L_1-40-D_1	66.6	97.8	98.7
L_1-40-D_2	68.0	97.1	99.5
L_1-40-D_3	68.2	97.8	99.5
L_4-20-C_1	70.4	106.7	101.7
L_4-20-C_2	80.4	107.8	105.1
L_4-20-C_3	71.2	107.3	105.0
L_4-20-D_1	72.3	105.0	104.4
L_4-20-D_2	71.8	105.6	104.5
L_4-20-D_3	71.7	105.4	104.4
L_4-40-C_1	67.6	100.8	98.8
L_4-40-C_2	67.5	101.7	98.5
L_4-40-C_3	67.5	101.1	99.4
L_4-40-D_1	67.8	99.7	98.6
L_4-40-D_2	67.9	100.0	98.3
L_4-40-D_3	67.9	100.4	99.0

Table D.2. Mean Air Temperature Readings

	Air Temperature in °F		
Sample Group	Beginning	Midpoint	End
L_1-20-C	92	92	94
L_1-20-D	92	92	94
L_1-40-C	85	86	88
L_1-40-D	86	86	88
L_4-20-C	92	94	96
L_4-20-D	92	94	90
L_4-40-C	85	89	90
L_4-40-D	86	89	90

Table D.3. Mean Relative Humidity Readings

Sample Group	Per Cent Relative Humidity Line Dried Period Beginning	Midpoint	End
L_1-20-C	22.2	21.7	20.6
L_1-20-D	21.6	22.2	19.6
L_1-40-C	20.1	18.9	17.8
L_1-40-D	19.1	19.0	16.9
L_4-20-C	22.2	18.2	15.2
L_4-20-D	22.0	19.4	16.7
L_4-40-C	19.8	15.5	13.7
L_4-40-D	19.3	15.5	14.1

Table D.4. Wind Velocity Readings for Line Dried Samples

	Wind Velocity in M.P.H.			
	Water Temperature 140° ± 5° F		Water Temperature 105° ± 5° F	
Date	L_1	L_4	L_1	L_4
5/28/75	1.67	22.67	5.00	22.67
5/30/75	1.67	4.00	0.67	0.00
6/03/75	0.67	17.32	3.33	24.00
6/05/75	2.33	10.67	0.33	17.33
6/07/75	9.33	42.67	10.00	40.00
6/10/75	3.00	22.67	0.33	22.67
6/12/75	0.67	9.33	2.00	1.33
6/14/75	4.00	18.67	2.67	2.67
6/16/75	2.67	18.67	5.33	34.67
6/18/75	12.00	56.00	11.33	42.66
6/26/75	0.00	2.67	0.67	2.67
7/01/75	0.33	8.00	0.33	2.67
7/03/75	0.67	5.33	0.33	14.67
8/27/75	0.67	2.67	2.00	10.67
9/04/75	1.67	2.00	0.67	2.00
9/09/75	0.67	5.33	0.33	4.00
9/11/75	1.67	10.67	1.67	14.67
9/13/75	4.67	8.00	4.67	17.33
9/16/75	0.67	5.33	0.33	6.67
9/18/75	3.00	10.67	2.00	9.33
9/23/75	9.33	40.00	12.00	42.67
9/25/75	6.00	17.33	6.00	12.00
9/27/75	0.00	6.67	0.67	12.00
9/30/75	0.00	9.33	0.00	1.33
10/02/75	6.67	21.33	5.33	32.00
10/04/75	1.00	6.67	0.67	5.33

Table D.4. Continued

	Wind Velocity in M.P.H.			
	Water Temperature 140° ± 5° F		Water Temperature 105° ± 5° F	
Date	L_1	L_4	L_1	L_4
10/07/75	7.33	29.33	7.33	24.00
10/09/75	2.67	8.00	4.00	10.67
10/11/75	0.00	8.00	0.00	8.00
10/14/75	0.67	6.67	0.00	4.00
10/16/75	0.00	1.33	0.00	0.00
10/23/75	4.00	18.67	7.33	24.00
10/25/75	0.67	6.67	0.67	2.67
10/28/75	0.33	1.33	0.33	0.00
10/30/75	3.33	24.00	6.67	32.00
11/01/75	0.00	2.67	0.00	2.67
11/04/75	6.00	18.67	8.00	28.00
11/06/75	0.66	9.33	0.33	5.33
11/08/75	1.33	6.67	0.67	2.67
11/13/75	4.33	18.67	5.33	13.33

Table D.5. Solar Radiation of Line Dried Treatments Expressed in Langley Units

Date	Solar Time 10 A.M.	11 A.M.	12 Noon	1 P.M.	2 P.M.	3 P.M.
5/28/75	67.2	68.7	90.1	90.1	40.8	30.4
5/30/75	74.3	86.5	91.4	89.4	84.5	75.9
6/03/75	75.9	88.4	91.9	92.1	87.0	75.4
6/05/75	74.6	87.5	92.9	90.9	87.0	76.4
6/07/75	69.3	83.0	87.8	89.9	83.5	65.7
6/10/75	72.3	83.5	87.5	91.3	84.3	75.7
6/12/75	76.9	86.5	71.6	92.1	84.8	69.0
6/14/75	74.3	84.8	91.4	91.6	85.3	74.6
6/16/75	73.6	85.5	92.9	90.6	85.3	78.4
6/18/75	72.8	84.5	91.6	67.0	47.7	57.9
6/26/75	76.7	86.5	90.6	94.2	88.6	74.8
7/01/75	72.8	83.5	87.0	88.7	82.0	58.1
7/03/75	70.8	75.4	68.2	73.6	77.2	31.2
8/27/75	65.4	66.7	85.8	76.0	75.5	64.7
9/04/75	56.8	68.6	77.2	41.4	5.8	17.4
9/09/75	61.8	71.7	78.1	79.5	74.0	61.8
9/11/75	60.8	71.3	77.6	79.5	72.8	61.8
9/13/75	60.4	70.4	63.6	69.9	51.3	64.0
9/16/75	58.1	70.4	75.5	76.0	71.7	59.0
9/18/75	55.9	67.4	74.2	76.8	50.0	44.5
9/23/75	60.4	70.1	77.8	78.7	72.8	60.8
9/25/75	57.9	69.2	76.0	78.2	71.3	59.0
9/27/75	54.7	66.9	73.3	74.4	68.1	56.8
9/30/75	32.1	45.9	53.1	62.7	63.8	56.3
10/02/75	54.7	67.2	72.2	73.3	66.5	55.9
10/04/75	55.2	66.5	73.7	74.4	69.7	56.8
10/07/75	53.1	66.3	71.3	73.5	68.6	55.2

Table D.5. Continued

	Solar Time					
Date	10 A.M.	11 A.M.	12 Noon	1 P.M.	2 P.M.	3 P.M.
10/09/75	53.6	66.3	70.8	72.3	66.7	52.8
10/11/75	52.2	64.2	69.7	69.5	65.8	54.1
10/14/75	52.9	64.7	69.9	71.1	65.4	54.3
10/16/75	47.7	61.3	67.6	68.8	62.2	51.8
10/23/75	33.0	52.7	53.6	56.8	57.7	45.2
10/25/75	45.9	59.0	66.7	65.1	60.8	48.5
10/28/75	45.4	57.0	64.0	64.7	57.7	47.9
10/30/75	43.6	54.5	61.5	62.4	58.3	45.9
11/01/75	31.6	36.1	40.9	44.5	57.7	20.1
11/04/75	45.2	55.4	62.2	62.9	56.1	44.3
11/06/75	42.7	53.3	59.2	61.5	54.5	44.5
11/08/75	42.3	53.6	60.4	60.6	54.7	44.5
11/13/75	41.1	53.6	59.2	59.9	52.9	42.7

APPENDIX E

STATISTICAL DATA FOR PHYSICAL TESTING

Table E.1. Subjective Evaluation Sample Group Means by DP Rating

Sample Group	White Replica	Blue Replica
C	4.933	4.544
TD-20-C	3.500	3.333
TD-20-D	4.167	3.889
TD-40-C	3.500	3.111
TD-40-D	4.056	3.833
L_1-20-C	3.611	3.167
L_1-20-D	3.722	3.667
L_1-40-C	2.944	2.556
L_1-40-D	3.944	3.556
L_4-20-C	3.667	3.444
L_4-20-D	4.111	3.611
L_4-40-C	3.056	2.667
L_4-40-D	4.111	3.778

Table E.2. Thread Count Sample Means for Warp and Fill

Sample Group	Warp	Fill
C	105.33	53.33
TD-20-C	106.33	54.00
TD-20-D	106.67	54.00
TD-40-C	106.33	54.00
TD-40-D	106.00	54.00
L_1-20-C	106.00	54.00
L_1-20-D	106.33	54.00
L_1-40-C	106.33	54.00
L_1-40-D	106.00	54.33
L_4-20-C	106.00	54.33
L_4-20-D	107.00	54.00
L_4-40-C	106.33	54.00
L_4-40-D	106.33	54.00

Table E.3. Weight Sample Group Means in Grams

Sample Group	Mean
C	1.65
TD-20-C	1.59
TD-20-D	1.52
TD-40-C	1.56
TD-40-D	1.56
L_1-20-C	1.59
L_1-20-D	1.50
L_1-40-C	1.56
L_1-40-D	1.51
L_4-20-C	1.56
L_4-20-D	1.49
L_4-40-C	1.58
L_4-40-D	1.55

Table E.4. Tear Strength Sample Group Means for Warp and Fill in Grams

Sample Group	Warp	Fill
C	2910.00	1703.33
TD-20-C	2130.00	1223.33
TD-20-D	2550.00	1463.33
TD-40-C	1993.33	1083.33
TD-40-D	2283.33	1280.00
L_1-20-C	2063.33	1150.00
L_1-20-D	2286.67	1246.67
L_1-40-C	1926.67	1060.00
L_1-40-D	2196.67	1216.67
L_4-20-C	1920.00	1046.67
L_4-20-D	2243.33	1203.33
L_4-40-C	1840.00	1080.00
L_4-40-D	1976.67	1036.67

Table E.5. L, a, and b Value Sample Group Means with Ultraviolet Included

Sample Group	L Value	a Value	b Value
C	34.417	3.563	-39.612
TD-20-C	35.513	3.333	-40.641
TD-20-D	35.504	3.287	-40.213
TD-40-C	35.863	3.283	-40.675
TD-40-D	35.754	3.246	-40.571
L_1-20-C	35.937	3.575	-40.704
L_1-20-D	35.575	3.679	-41.167
L_1-40-C	36.275	3.575	-40.775
L_1-40-D	36.175	3.325	-40.084
L_4-20-C	36.592	3.225	-39.129
L_4-20-D	36.283	3.292	-39.517
L_4-40-C	37.046	2.954	-37.842
L_4-40-D	37.087	2.800	-37.987

Table E.6. L, a and b Value Sample Group Means with Ultraviolet Excluded

Sample Group	L Value	a Value	b Value
C	34.359	3.763	-39.712
TD-20-C	35.512	3.483	-40.592
TD-20-D	35.400	3.270	-40.234
TD-40-C	35.641	3.3137	-40.779
TD-40-D	35.817	3.1420	-40.438
L_1-20-C	35.579	3.650	-40.958
L_1-20-D	35.387	3.717	-41.325
L_1-40-C	36.383	3.358	-40.229
L_1-40-D	36.012	3.312	-40.292
L_4-20-C	36.363	3.154	-39.037
L_4-20-D	36.058	3.338	-39.763
L_4-40-C	36.896	3.109	-38.088
L_4-40-D	37.192	2.746	-37.954

Table E.7. b Value Included Minus b Value Excluded Sample Group Means

Sample Group	Means
C	0.1000
TD-20-C	-0.0497
TD-20-D	0.0210
TD-40-C	0.1040
TD-40-D	-0.1330
L_1-20-C	0.2540
L_1-20-D	0.1583
L_1-40-C	-0.5457
L_1-40-D	0.2083
L_4-20-C	-0.0920
L_4-20-D	0.2460
L_4-40-C	0.2457
L_4-40-D	-0.0330

LIST OF REFERENCES

Allen, R. L. M. Colour Chemistry. New York: Meredith Corporation, 1971.

Altherr, E. "Optical Brighteners." American Dyestuff Reporter. 54, (March 20, 1965), 38-43.

American Association of Textile Chemists and Colorists. AATCC Technical Manual, Vol. 51. Research Triangle Park, N.C.: AATCC, 1975.

The American Home Economics Association. Textile Handbook. 5th ed. Washington, D.C.: AHEA, 1974.

American Society for Testing and Materials. 1974 Annual Book of the American Society for Testing and Materials. Philadelphia, Pennsylvania: ASTM, 1974.

Anderson, R. L. and T. A. Bancroft. Statistical Theory in Research. 1st ed. New York: McGraw-Hill Book Company, Incorporated, 1952.

Anliker, R., H. Hefti, H. Kasperl and B. Milicèvič. "Some Theoretical and Practical Aspects of Polyester Whitening from the Wash Bath." Journal of the American Oil Chemists' Society. 46, (October 1969), 523-528.

Blanchard, Eugene J., Robert J. Harper, Jr., Gloria A. Gautreaux and J. David Reid. "Optical Brightener Absorption by Polymer-Treated Fabrics." Chemical Technology. (March 1971), 181-184.

Caryl, C. R. "The Langley as a Unit for Timing Outdoor Exposures." ASTM Bulletin. (January 1960), 55-59.

Corbman, Bernard P. Textiles: Fiber to Fabric. 5th ed. New York: McGraw-Hill Book Company, Incorporated, 1975.

Dünnenberger, M. "Luminescence." CIBA Review. 12, (October 1960), 13-17.

Giles, Charles H., Ronald Haslam and David G. Duff. "An Examination of the Cause of the Humidity Sensitivity of the Lightfastness of Dyed Material" Textile Research Journal. (January 1976), 51-54.

Hall, A. J. Textile Finishing. 3rd ed. New York: American Elsevier Publishing Company, Incorporated, 1966.

Hicks, Charles Robert. Fundamental Concepts in the Design of Experiments. 2nd ed. New York: Holt, Rinehart and Winston, Incorporated, 1973.

Higginbotham, R. S. and F. W. Thomas. "Fluorescent Whitening Agents." Nature. 181, (May 24, 1958), 1437-1439.

Hollen, Norma and Jane Saddler. Textiles. 4th ed. New York: Macmillan Publishing Company, Incorporated, 1973.

Hunter Associates Laboratory, Incorporated. Instructions for Hunterlab Model D25 Color-Difference Meter. Fairfax, Virginia: Hunter Associates Laboratory, Incorporated, 1970.

Hunter, Richard S. "Appearance Analysis and Its Uses." Hunterlab Reflections and Transmissions. (May 1972), 1-5.

"Introduction." CIBA Review. (1973/1), 2, 3.

Joseph, Marjory L. Introductory Textile Science. San Francisco: Holt, Rinehart and Winston, Incorporated, 1972.

Judd, Deane B. Color in Business, Science, and Industry. New York: John Wiley and Sons, Incorporated, 1952.

Koller, Lewis R. Ultraviolet Radiation. 2nd ed. New York: John Wiley and Sons, Incorporated, 1965.

Labarthe, Jules. Elements of Textiles. New York: Macmillan Publishing Company, Incorporated, 1975.

McPherson, Bonnie Jean. "A Comparative Evaluation of Drying Techniques of Dyed 65-35 Polyester-Cotton Blend Fabric with a Durable Press Finish." Unpublished Master of Science Thesis, The University of Arizona, 1972.

Moncrieff, R. W. Man-Made Fibres. 5th ed. New York: John Wiley and Sons, Incorporated, 1970.

Nie, Norman H., C. Hadlai Hull, Jean G. Jenkins, Karin Steinbrenner and Dale H. Bent. Statistical Package for the Social Sciences. 2nd ed. New York: McGraw-Hill Book Company, Incorporated, 1975.

O'Hare, B. J. "Optical Bleaching Agents." Chemistry and Industry. (July 9, 1966), 1220-1224.

Portouw, Shirley Jean. "The Wearing and Appearance Qualities of 50-50 Polyester-Cotton, Durable Press, Elementary Age Boys' Shirts under Home Laundry Conditions." Unpublished Master of Science Thesis, The University of Arizona, 1971.

Reinhardt, Robert M., Terrance W. Fenner, J. David Reid, Margaret S. Furry and Mary Walsh. "Fluorescent Whitening Agents in 'Wash-Wear' Finishing of Cotton." American Dyestuff Reporter. 50, (October 2, 1961), 34-41.

Sarkar, A. K. Fluorescent Whitening Agents. Watford: Merrow Publishing Company, Limited, 1971.

Schulze, Janos, Terrance Polcaro and Per Stensby. "Analysis of Fluorescent Whitening Agents in U.S. Home Laundry Detergents." Soap/Cosmetics/Chemical Specialties. 50, (November 1974), 46-52.

Stearns, E. I. "Measurement of Color and Color Difference." Textile Chemist and Colorist. 6, (February 1974), 38-49.

Steel, Robert G. D. and James H. Torrie. Principles and Procedures of Statistics. New York: McGraw-Hill Book Company, Incorporated, 1960.

Stensby, Per S. "Modern Trends in Printing, Dyeing and Finishing." CIBA Review. (1971/2), 41-47.

Stensby, Per S. and W. R. Findley. "Whiteners in the 1970's." Soap/Cosmetics/Chemical Specialties. (October 1972), 52-64.

Trotman, Edward Russell. Textile Scouring and Bleaching. London: Charles Griffin Company, Limited, 1968.

U.S. National Bureau of Standards. Textile Testing Methods. Washington, D.C.: U.S. Government Printing Office, 1951.

Villaume, F. G. "Optical Bleaches in Soaps and Detergents." The Journal of the American Oil Chemists' Society. 35, (October 1958), 558-566.

"Wanted: New Name for White Dyes." American Dyestuff Reporter. (April 22, 1968), 75.

Weidmann, Charles J. "Making White Whiter." American Fabrics. 39, (1957), 78, 79.

Wingate, Isabel B. Textile Fabrics and their Selection. 6th ed. New Jersey: Prentice-Hall, Incorporated, 1970.

Zussman, H. W. "Fluorescent Agents for Detergents." The Journal of the American Oil Chemists' Society. 40, (November 1963), 695-698.

Zweidler, R. "Why and How Fluorescent Whiteners Work." CIBA Review. (1971/3), 38-44.