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Clapp, Anne Calvert

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The University of North Carolina at Greensboro Ph.D. 1984

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by

Anne Calvert Clapp

A Dissertation submitted to
the Faculty of the Graduate School at
The University of North Carolina at Greensboro
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Approved by

Melvin R. Hurwitz
Dissertation Advisor

APPROVAL PAGE

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May 17, 1983

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CLAPP, ANNE CALVERT. A Comparative Ranking of the Severity of Five ASTM Abrasion Test Methods Using Nine Polyester/Cotton Fabrics. (1984)
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This study compared the results of the more commonly used abrasion tests on a series of commercially available fabrics. The test procedures used were those of the American Society for Testing and Materials contained in the 1981 issue of Annual ASTM Standards. The test instruments in the comparison were the Stoll flat, Stoll flex, Schiefer, Taber and Wyzenbeek machines. The test fabrics were polyester and cotton blends ranging in weight from 3.0 to 8.5 ounces per square yard. The fabric constructions included plain, twill and oxford weaves.

The ASTM procedures were modified to provide a common end point for all tests. The end point for each test was half the number of cycles required for the destruction of the weakest fabric. Abrasion resistance was determined by measuring the breaking strength of the fabrics before and after abrasion. Statistical analysis of the data was accomplished by computing the rank order of the fabric strength tests and significance of the rankings was determined using Kendall's Concordance W.

The data from the study indicates that the Stoll flat abrasion test consistently produces the greatest strength loss on the majority of the fabrics studied and that the Taber is the least severe test. There was little difference in the Schiefer, Taber and Wyzenbeek instruments.

There were different patterns in rankings for the fabrics above and below 4.3 ounces. Differences in fabric construction were detected by all tests. In general, oxford and twill fabrics were more abrasion resistant than plain weave fabrics, and the fabrics with a higher polyester content were more abrasion resistant than fabrics with a higher cotton content.

ACKNOWLEDGEMENTS

It is difficult to mention by name all those professional colleagues who have contributed directly and indirectly to this study. A twenty-year career in the textile industry has provided opportunities for the author to discuss abrasion resistance with many of the experts quoted in this study. For the background knowledge they provided, and the curiosity which they provoked, I am most grateful.

The fabrics for the study were provided by Dan River, Inc. and J. P. Stevens. Linwood Wright and Mary Lee Wilkins of those firms helped in the selection of the specific fabrics; their help in that selection is greatly appreciated. The help of the faculty and staff at North Carolina State University where the author is employed and where the laboratory work was performed should be acknowledged. Particular thanks go to Bill Stuckey, Carol Carrere, and Bernard McDougal who kept the equipment going and provided encouragement when things went wrong.

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In any undertaking of this duration, many demands are made on one's family and I appreciate the emotional and tangible support provided by mine. The word processing, which has made the many revisions less formidable, was done by my husband, Allen. For that service, and all the others that he and Ginger have had to perform since June 1977 when I returned to graduate school, I am most grateful.

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CHAPTER I

INTRODUCTION

The statements "it wore out" and "how will it wear" are used by consumers in discussing the properties of textile products. The end point of serviceability described by the consumer in both cases is still a matter of discussion among textile technologists.

In many cases individuals are using the terms "wear" and "abrasion or abrasive wear" synonymously. Some delineation of the terms needs to be made. General dictionary definitions indicate that "to wear" means to consume, to cause to deteriorate, or to be diminished by use, while "abrasion" is a wearing away by friction. American Society for Testing and Materials (ASTM) standard D123 (1981) defines abrasion as the wearing away of any part of a material by rubbing against another surface. It does not define the term "wear".

Kaswell (1946) indicated that wear is a broad term which includes abrasion along with stressing, straining, laundering, drycleaning, pressing, creasing and other factors associated with everyday useage. Taylor (1978) used wear to mean the deterioration of physical and aesthetic properties of textiles in use. He indicated that abrasion is probably the most important component of mechanical wear in textiles.

Abrasion manifests itself in the form of holes in a fabric, changes in color, hand, surface texture, surface appearance or loss of strength. It may be localized to a single point or extend over a large area of a textile product. It can be caused by external rubbing against another surface or by the internal friction of fiber against fiber or yarn against yarn as a fabric is bent or flexed in use.

If durability of fabric is important to consumers, a clearer understanding of procedures for defining and evaluating abrasion is necessary. In the United States the major standard abrasion test methods in use are those published by the American Society for Testing and Materials (ASTM). In their 1981 publication of standards, five procedures are included. The American Association of Textile Chemists and Colorists (AATCC) includes three abrasion colorfastness methods in their 1981 Technical Manual. Many other test procedures have been developed over the years and procedures commonly in use in Europe are not used in the United States. It is generally felt in the United States that the test methods included in the ASTM and AATCC publications of test methods are the most reliable procedures for use in comparing fabrics. The seemingly large number of published standard abrasion test methods would indicate that there is not widespread agreement on a satisfactory test procedure for evaluating fabric abrasion.

Statement of the Problem

It was the purpose of this research to compare results of the standard abrasion tests carried to comparable end points on a series of commercially available polyester/cotton blend fabrics. At present these blends are the predominant fabrics in the apparel market and it is felt they will continue to be a major market segment in the foreseeable future. Since this study is seen as part of ongoing study on fabric wear, it was decided to select fabrics which could be duplicated in commercial constructions in the future.

Galbraith (1975) has stated that researchers have long hoped that abrasion tests could be developed which would predict serviceability or durability of fabric during use. Such hopes have never been realized because no one instrument has been devised to simulate or correlate with all types of abrasive wear and because action other than mechanical stress plays an important part in wear of fabrics in actual use. Most studies have looked at one or two commercially available test methods on limited fabric constructions giving limited information on the ranking of fabrics. It is hoped that this study will allow a broader base for comparison of the test procedures currently in use in the United States.

Objectives

The objectives of this study were the following:

1. To determine the rank order of selected accelerated laboratory tests for abrasion resistance with a series of commercially available polyester/cotton blend fabrics.

2. To determine for each fabric the ranking of tests from most severe to least severe.

3. To determine for each test procedure the ranking of perceived damage to the fabric series from most severely damaged to least severely damaged.

4. To determine whether the current test methods could be grouped to allow some test methods to be used interchangeably.

Hypotheses

The following hypotheses were tested:

1. There is no significant difference in the ordering of abrasion test results for each single fabric from the series of selected test machines.

2. There is no significant difference in the ordering of abrasion test results from each abrasion testing machine for the series of fabrics. Conversely, a single abrasion testing machine will show no significant differences in the rank order of the series of fabrics.

Assumptions

The following assumptions were made:

1. The laboratory equipment, which was operating within the tolerances set forth in the test methods, is representative of equipment currently in use in other testing laboratories.

2. The fabrics selected are representative in fiber content, fabric construction, and finish of the currently available polyester/cotton fabrics in the United States market.

3. The damage measured on each fabric was due solely to the damage sustained during the accelerated abrasion test.

CHAPTER II

REVIEW OF LITERATURE

Two major reviews of the literature on abrasion have been published, one by Hall and Kaswell in 1945, the other by Galbraith in 1975. The former includes articles published between 1924 and 1943, the latter from 1934 to 1973. Neither review is comprehensive.

The first was completed as a portion of the research program on wear resistance of apparel sponsored by the National Research Council and conducted by Massachusetts Institute of Technology (MIT) and Fabric Research Laboratories (FRL). The research program developed from studies undertaken by the office of the Quartermaster General to determine the cause of wear in military uniforms and to find methods to predict which fabrics would provide the longest service in military use. The work by Hall, Harvey, Hamburger, Schiefer, Stoll and Backer used military salvage data as a basis for many of their comparisions.

The second review forms a chapter of a book on the surface characteristics of textiles and reflects the change of emphasis toward consumer issues that has occurred in recent years. There is a great deal of duplication in the articles covered by the two reviews.

In general, basic study of abrasion can be divided into these three major areas: mechanisms of abrasion; the relationship of fiber, yarn, and fabric properties to abrasion; and the methods of simulating end-use abrasion in the laboratory. The major emphasis of this study will be the second two areas. Chronologically, study of abrasion began by finding devices to grind down the surface of a fabric as Myers did in 1912 ("Fabric Wear," 1934) and Schwarz did in 1927. It was later as researchers tried to explain the anomalies in laboratory tests and end use data that major emphasis was placed on mechanisms, textile structures, and the development of a theoretical knowledge base.

Abrasion Mechanisms and Theory

Backer (1951) described abrasion as consisting of three major mechanisms: friction, surface cutting, and fiber plucking. He indicated that the severity of abrasion is determined by the nature of the abradant, the behavior of the fibers in the fabric structure, and the general conditions of rubbing. The interrelationship of viscoelastic properties of fibers and the complex geometry of fabric surfaces serves to make textile abrasion more difficult to analyze than the surface abrasion of solid materials.

Backer's discussion of friction is theoretical, based on work with metals, and is offered as a suggestion for the empirical study of textile materials at a later date. Surface cutting is described as the action of small, sharp protuberances of the abradant in contact with a fiber lying on the surface of a fabric which acts to cut the fiber. Fiber plucking or snagging is said to occur when the fiber works out of the surface of the yarn or fabric under repeated bending stress. Such flexing can cause internal abrasion and attrition even in the absence of an external foreign abrasive substance. The abrasion is caused by the relative movement of fibers within the yarn and yarns within the fabric.

Another author, Hamburger (1945), is also interested in repeated stress in relationship to abrasion resistance. He stated that abrasion is a repeated stress application usually caused by forces of relatively low orders of magnitude which occur many times during the life expectancy of a material. In order to resist destruction, a specimen should be able to absorb energy imparted to it upon stress application and to release the energy after removal of the stress without failing.

In his 1945 study, Hamburger investigated acetate, viscose, and nylon filament yarns, subjecting one series of yarns to a cyclic loading at 90 percent of breaking load and another to a series of Taber abrasion tests. He reported a linear correlation between energy applied in cyclic loading and durability measured by the number of cycles of Taber abrasion. The reader was cautioned that the effect of yarn and fabric construction was not studied; thus, the conclusions reached were not to be extended directly to fabrics made of these fibers and yarns.

Specific strength, initial modulus, and the energy of rupture were determined to be useful predictors of abrasion resistance of a fabric according to Elder and Ferguson in their study of plain weave fabrics in the accelerotor.

The Effects of Textile Properties

The effect of fabric construction on textile geometry was of major concern to Backer and Tanenhaus (1951). The fabric of particular interest was cotton sateen used in Army fatigues. The authors concluded that fabric durability could be altered significantly without a change in fiber content by modifying the structural design of the fabric. In general, they observed that lower rates of fabric destruction would be observed when geometric area of contact between fabric and abradant was increased, although it was pointed out that fabric compliance and yarn mobility had to be preserved at the point of contact between two rubbing surfaces.

The same authors concluded from their data that abrasion resistance of a warp-faced sateen or twill fabric was improved by increasing the number of warp crowns per square inch. At the same time care had to be taken to prevent jamming the warp yarns and markedly reducing the flexibility of the fabric structure or crowding the filling structure to produce warp crowns which became rigid knuckles incapable of absorbing abrasive energy.

Backer and Tanenhaus also pointed to other studies of plain weave fabrics having high warp and low filling crimp which indicate that there is a strong correlation between loss of warp strength and the number of abrasion cycles. Filling strength does not begin to deteriorate until the warp is nearly worn away. In oxford fabrics it was surmised that higher abrasion resistance was attributable to the protective protrusion of longer floats and the higher mobility of yarns in the fabric. It was indicated that at some point a limit of float length would be reached where an increase in snagging potential would overcome the abrasion advantage of long floats.

In 1952 Schiefer and Werntz reported on a series of tests on 16 all-cotton fabrics. Cotton counts of 10/1 and 16/1 for the warp and 8/1 and 12/1 for the filling were woven in plain weave fabrics with 72 or 84 ends and 45 or 55 picks per inch. The fabric showing the best abrasion resistance was the 84x55 with the 8/1 filling while the fabric showing the poorest abrasion resistance was the 72x45 with the 12/1 count.

The 1968 work of Ruppenicker et al. at Southern Regional Research Laboratories looked at the structure of all-cotton durable-press fabrics. They investigated twill, satin, oxford and plain-weave fabrics of suiting weights. It was reported that plain-weave fabrics gave better flex abrasion results than oxford, twill, and sateen but the order of abrasion resistance was reversed when fabrics were sewn into trouser legs and machine washed. They feel that this indicates that yarn mobility is of greater importance when fabrics are unrestrained. They stated that finer yarns were shown to give better flex performance, but the yarns in question were 10/1 and 15/1 cotton yarns spun at twist multipliers of 3.1 and 4.1. No difference in abrasion resistance was attributed to the difference in twist multipliers.

Ruppenicker et al. reported in their 1972 Textile Chemist and Colorist article on the effects of fabric structure on the durability of cotton durable-press fabrics in heavy weights. Eighty fabrics of a nominal 8 ounce per square yard were evaluated after being sewn into pants legs and laundered for 40 cycles. Warp yarns of 15/1 and 18/1 and filling yarns of 9/1 and 12/1 in 3/1, 2/2 and 3/2 twill constructions with the number of ends ranging from 36 to 72 per inch were studied. The twist multiplier for the warp in all fabrics was 4.3; the filling was spun with either 4.3 or 3.3 twist multipliers.

The fabrics showing the least wear were the 3/2 regular twills (45° twill angle). In general, fabrics with the 18/1 warp were more durable than the other fabrics and the 9/1 filling yarn fabrics were more durable. There seemed to be no difference in the two twist multipliers studied. They also felt that durability was increased by increasing the number of ends and decreasing the number of picks per inch.

Aminov (1969) looked at a 100 percent cotton twill fabric and concluded that, under 30x magnification, the warp yarns showed the most severe damage. Wool fabric and carborundum abradant were used on a machine similar to the Martindale Wear Tester. The fabric abradant gave a coefficient of variation (CV) of 2.6% for five tests while the carborundum, which cut the fibers, showed a CV of 20.5% on five tests. It was felt that the fabric abradant was the best material for evaluating the abrasion resistance of fabrics.

Backer and Tanenhaus (1951) also looked at the effect of yarn structure on abrasion resistance. They show that fabric abrasion resistance rises as twist is increased to an optimum point and then decreases as additional twist is inserted. Their data indicates that increasing the twist multiples from 1.5 to 2.3 gives 15% better abrasion resistance. Lower twist multiples give poorer fiber binding and higher ones produce a stiffer yarn which does not dissipate abrasion forces. In general, yarns of larger sizes have better abrasion resistance, primarily because there are more fibers present to rupture before the yarn is destroyed. The Backer study also theorized that there is a better stress distribution over a larger number of fibers in the surface of a large yarn. The authors also felt it was more advantageous to use the larger yarns on the surface of the fabric if a fabric is constructed of yarns of unequal size.

Clegg's 1949 study of the microscopic examination of worn textile articles shows different types of cotton fiber damage in abrasion. The fibers were stained with Congo Red and the fiber damage is shown in drawings by the author. It was her conclusion that firmly held fibers show fibrillation and major abrasive damage or wearing away of the fiber structure. Fibers that are free to move in fabrics are most likely to show transverse cracks from bending and flexing. When there is some rigidity to the structure, the fibers show breaking of the cuticle and some transverse cracks. In general she indicated that there is no difference in the results of the laboratory test-worn fabrics and those which are service-worn when the fabric is held with the same amount of tension.

As Galbraith (1975) indicated, it is difficult to list fibers in a hierarchy of abrasion resistance. Natural fibers vary in length and diameter as a function of their natural growth; manmade fibers are produced in varying forms which change the strength, elongation and abrasion properties. In general, fibers are ranked in broad groups for poor, moderate, good or excellent abrasion resistance.

Needles (1981) stated that the ability of a fiber to absorb shock, recover from deformation, and be generally resistant to abrasion forces is important to its wear characteristics. He defined abrasion resistance as the fiber's resistance to mobile forces or stresses and indicates that a fiber able to absorb and dissipate these forces without damage can be considered abrasion resistant. The toughness and hardness of a fiber related to its chemical and physical structure and morphology will influence abrasion properties, i.e., a rigid, brittle fiber cannot dissipate the forces and fractures or breaks; a tough but more plastic fiber, such as polyester, shows better abrasion resistance.

Galbraith's 1975 review indicated that the fiber considered to have the highest abrasion resistance is nylon. Polyester and olefin are considered to have excellent abrasion resistance. Acrylics and modacrylics have less inherent abrasion resistance than nylon and polyester but are more abrasion resistant than wool, cotton and rayon. Acetate and glass fibers are generally considered to have poor abrasion resistance. Needles (1981) and Hearle et al. (1979) show nylon and olefin as having excellent abrasion resistance; cotton, modacrylic and polyester as good; wool, rayon and acrylic as fair and acetate as poor. Elder (1975) ranks fibers in descending order with nylon as best, followed by polyester, cotton, rayon, acrylic, wool, olefin, and acetate.

Susich (1954) looked at 14 yarns, both staple and filament, of varying fiber contents. The Stoll flex test showed nylon to have the best abrasion resistance, followed by Dacron polyester, Orlon acrylic, wool, cotton, rayon and acetate. He ranked multifilament and staple nylon and Dacron as excellent; Orlon, cotton and wool as good; and viscose and acetate as poor.

Hamburger (1949) discussed the use of fiber stress-strain properties in predicting fabric performance. It is noted that the differences in stress-strain properties of fibers in a blend affect the performance of the final fabric. Using the tenacity in grams per denier of each fiber in a blend, he proposed the use of a formula based on the denier of the complete structure to predict the importance of each fiber's properties in the final blend.

Canter, Jones and Weaver (1968) quoted Hamburger's work on stress-strain predictions in their work on the rupture of cellulosic fibers in durable press blends. The procedures for finding the rupture points for the fibers are essentially the same as Hamburger's. They do indicate the actual results are lower than the predicted values given by the tests on yarns of 100% fiber. In determining blend levels of fibers for durable press, they indicate that care must be taken to balance the toughness and moduli of the fibers to reduce the double rupture.

Galbraith et al. (1971) attempted to explain the "double rupture" phenomenon in their paper on knee burst in boy's jeans. In relating it to the 1968 Canter article, they surmised that the cotton component in the polyester/ cotton blend fractures under stress at a point less than that required to rupture the fabric. The fractured fiber then is "sifted" out of the fabric during wear or laundering so that the final fabric shows less strength due to the lack of interfiber cohesion. The fabrics used in the knee burst experiment were 50/50 polyester/ cotton blends and 75/25 polyester/cotton blends. Fabrics were denim constructed with 77 and 44 ends per inch and 43 and 67 picks.

Part I of the 1977 Elias, Warfield and Galbraith study looked at nylon/cotton and polyester/cotton blends after 20-minute increments of Accelerotor abrasion studies and 24-hour conditioning periods. They also note that fiber damage occurs in the warp yarns of the fabric and that cotton fibers are damaged first. In an analysis of fiber length after abrasion, it was noted that the number of short fibers in the fabrics decreased as abrasion increased, indicating that short fragments are shaken out during abrasion.

Morris and Young (1972) looked at abrasion damage on white polyester/cotton shirts described as 65/35 polyester/ cotton, 3.1 ounces per square yard, with 131 ends and 71 picks. No visible sign of abrasive damage was noticeable to the eye after 24 wear and launderings of the shirts. No strength loss in the fabrics was noted.

Abrasion Testing Machines

On March 24, 1934, the meeting of the United States Institute for Textile Research (USITR) ("Fabric Wear," 1934) focused on methods of measuring fabric wear resistance. At that point it was stated that the best method of developing a test method for abrasion was first to study worn fabrics to determine the causes of damage and then to design a machine that would reproduce those conditions. The consensus was that the points which should be considered in developing the test were temperature and humidity, the use of statistics to interpret data, and the type of abradant used. During the meeting, there were discussions of the abradants being used: emery cloth, bronze wire, and fabrics. A questionaire was given to attendees to determine the type of abrasion studies being performed. In order of descending importance, the following fabrics were being tested: dress goods, linings, carpets, pile fabrics, hosiery, rayon underwear, mechanical fabrics, shoe linings, and miscellaneous fabrics. The machines in use were the Wyzenbeek, the Bureau of Standards Carpet Tester, the MIT Tester, and a series of individual company machines designed for specific purposes.

Following the USITR meeting, the Research Council met and decided to begin two abrasion studies: one at the Bureau of Standards under the direction of Dr. Schiefer; the other at MIT under the direction of Professor Schwarz.

In 1938 Herbert J. Ball, Professor of Textile Engineering at Lowell Textile Institute and a chairman of ASTM D-13, attempted to summarize the work that had been done on abrasion through 1938. Part I of his summary is a listing of machines for abrading fabrics which appeared in the December 1937 issue of the ASTM Bulletin. Those mentioned were Amsler (Switzerland), Bureau or Standards Carpet Wear Tester (USA), T. Eaton and Co. Tester (Canada), Macy's Tester (USA), Matthews' Tester (England), MIT Tester (USA), Perspirator (USA), Schopper (Germany), Shawmut (USA), U.S. Testing Co. Tester (USA), and the Wyzenbeek Precision Wear Tester (USA).

Part II, published in the February 1938 issue of Textile Research, summarized the problems of abrasion testing: standardizing the terminology used for abrasion and wear, development of a universal tester, development of satisfactory laboratory tests, overcoming difficulties in correlating wear ratings and service tests, and standardizing methods of measuring the damage of fabrics caused by abrasion.

In 1932, Harvey reported on the use of the Wyzenbeek Precision Wear Tester on fabrics as an experimental means of predicting the wear life of fabrics for Montgomery Ward, Inc. He suggested the use of 8 ounce oceanic duck, monel screen, and "0" to "0000" grit Barton paper as abradants on the machine. It was his feeling that the "grit" and the screen wire were too harsh as abrasives and provided results in too short a time frame. It was his suggestion that the use of the duck and an abrasion time of 15 hours, with a change of abradant every 10,000 cycles, was a more realistic test. The abrasion resistance of the fabric was determined by using a pendulum tester to compare the breaking strength of the fabric in its original state and at the end point.

Harvey reported the anomaly of fabrics showing increased strength after 10,000 rubs with the duck and at points before the midpoint of tests with other abrasives. No reason is given for the anomaly. In general, he reported general test results where 50% of the test results are within ±5% of the mean while the other results are within ±43%.

The development of the Taber Abraser does not seem to be based on research studies. The machine was developed by Alfred Suter in 1940; the first reference to it appears to be an announcement in the May 1940 issue of Rayon Textile Monthly indicating that the machine would be produced by the Taber Machine Company. In April 1941, the same magazine announced that an improved research model of the Taber Abraser was available. By August 1947, as reported by Russell Armitage of the U.S. Testing Company in a short article in Rayon Textile Monthly, the Taber Abraser was one of the most widely used abrasion testers.

In the 1946 postwar data collection activities of the U.S. government, Schiefer et al. (1948) reviewed the work that had been done in Germany during the war years. Many of the abrasion studies were done on rayon since the textile technologists were trying to find replacement fibers for those unavailable to German industry in the early 1940's. Major emphasis was placed on predicting wear life from fiber and fabric parameters to reduce the amount of testing necessary. Stoll's work in Germany was reported and an attempt was made to review some of the articles printed in the German scientific literature of the times. Drawings, photographs and a discussion of the Stoll flat abrader are included, as well as the announcement that the work in current progress was on a flex abrasion tester. By the time of publication of the Schiefer article in 1948, Stoll was already working on abrasion in the United States.

A mathematical model for uniform abrasion was described by Schiefer in 1947 and a machine which would produce such uniform abrasion was developed on the base of the Bureau of Standards Carpet Tester. The machine, which rotated the abradant and the sample in the same direction with the same angular velocity, was later refined and is described in a later publication by Schiefer, Kream and Krasny (1949).

By 1949 the single unit Schiefer abrasion testing machine had been perfected to the point that a series of metal blades could be used as the abrasive and a contact mechanism had been developed to stop abrasion when the fabric was worn through. In all of Schiefer's work, he indicates that this method of applying abrasive forces gives a more even surface abrasion than the Taber and Wyzenbeek machines and the myriad of testers that had been developed to provide flat abrasion.

Also in 1949, Stoll reported on an improved multipurpose abrasion tester which included elements for looking at both plane and flex abrasion. He described salvage studies of U.S. Army uniforms which show garment damage to be composed of 30% plane abrasion, 20% flex abrasion, 20% edge abrasion, 20% tear strength and 10% from other miscellaneous causes. Since the major cause of discard is abrasion, he suggested that the new abrasion tester would screen fabrics for military use. He felt that a test should produce a mechanical disintegration comparable to the actual wear pattern noted in garment use.

Stoll stated that mineral abrasives cut fibers and should be avoided since fibers in actual wear do not appear to be cut. He also felt that the methods of breaking up individual fibers with fine emery was not characteristic. He suggested that care be taken to study the cohesive forces in abrasion: the reaction between fibers and abrasive, the fiber to fiber relationship, and what happens to the structural parts of a fiber during abrasion.

Skinkle indicated in his 1949 book, <u>Textile Testing</u>, that the MIT tester and the Taber Abraser are the most satisfactory abrasion testers. No data is provided as a basis for the statement. It was pointed out that the Taber was useful in preliminary screening of fabrics to eliminate the poorest fabric. The machine was also deemed satisfactory in determining the effects of finishes on a fabric or comparing different lots of the same fabric. The test results were only useful in intralaboratory comparison.

Weiner and Pope indicated in a 1963 "letter to the editor" that a study was being conducted at Natick Laboratories on 15 fabrics with 12 fibers using a Stoll Flex, Taber Abraser, and a sand abrader. Only the strengths in the warp directions of the fabrics were tested. In general, the CV is 32-54% for the tests which had been completed at the time of writing. The test results indicated both adhesive and abrasive wear as would be expected with the types of testers used. They noted a correlation coefficient of

Discussions between representatives of six British textile research associations at the Shirley Institute in the early 1960's (Committee 1964) revealed some uneasiness about experimental data on which abrasion or "wear" tests relied for support. It was agreed that tests were put to a use for which they were unsuitable. A study was originated by the directors of these textile research organizations to compare several fabrics and several abrasion testers in a series of interlaboratory tests. The fabrics were cotton and rayon with durable press finishes; the test machines included the AATCC Accelerotor, the Courtalds BFT, the Lester Ring Wear, the LINRA, the Martindale, the Schiefer, the Shirley BOSS and the Stoll (Universal).

In all tests there was a discussion about the determination of a suitable endpoint. In all cases the tests were run to destruction which could be the cutoff of the machine or until visual inspection determined that a yarn had been severed. In general, the between laboratory correlation for all tests was deemed poor. They did conclude that similar results were given by the following groups of testers:

1. LINRA, Schiefer (with wool abrasive), Martindale (hole endpoint);
2. Shirley BOSS (loomstate abradant), Stoll Flex Martindale (weight loss);
3. Stoll Flat, BFT Flex, BFT Ball, Accelerotor, and Schiefer (steel abrasive).

The North Central Regional Research Project reported by Galbraith et al. in 1969 compared Schiefer and Stoll inflated diaphragm tests on 100% cotton and 100% nylon fabrics. Nine levels of abrasion from slight distortion to total rupture were tried. The Schiefer test showed the least amount of yarn and fabric deterioration and the damage occurred at a slower rate. They indicated that the Stoll test accelerates abrasion at low cycles because pressure is localized in the center of the abraded area.

Kawamura and Ikeda (1968) did not present data to support their claims that the Schiefer abrasion more closely resembles actual wear. They merely reported that the log values of the number of cycles to destruction rather than the raw data are used for comparison.

Colledge (1966, 1968) used three test procedures to determine the differential abrasion in cross-dyed fabrics in blends of polyester/cotton and polyester/wool. He concluded that there was no correlation between the three tests. The Modern Textiles and Canadian Textile Journal articles report the same research study which was conducted using the Stoll inflated diaphragm test and the two AATCC frosting tests using screen wire and emery cloth as abradants. The evaluation was based on color change.

During the 1969 Textile Institute Conference, Newton discussed the problem of abrasion testing in Australia. He suggested that two abrasion tests be used in each evaluation: a flat test and a flex test. The Wyzenbeek, Schiefer and Stoll tests were the U.S. machines suggested as possible choices. Problems still exist with controlling abradant, tension, pressure, method of evaluation of the end point, and machine variables.

In his study correlating the results of laboratory abrasion tests with combat course tests, Kaswell (1946) states that the determination of the end point in a test is the major difficulty. He felt that the relationship between original and abraded tensile strength was the best means of comparing test results. To that end, a destructive test index was calculated by setting a percentage of stress loss on the vertical axis of a graph and the number of cycles to produce that loss on the horizontal axis and then calculating the area under the curve as the destructive index.

In Kaswell's laboratory tests, the MIT tester and the Taber Abraser were used. Twill, sateen, and herringbone fabrics were subjected to units of incremental abrasion. The Taber was run for 200 cycles or revolutions and in increments of 200 cycles from 200 to 1800 cycles. In determining the serviceability of the fabric for use, the following weighting system for test results was used:

1. abrade the warp and test the warp for strength-70%
2. abrade the filling and test the warp for strength-5%
3. abrade the filling and test the filling for strength-20%
4. abrade the warp and test the filling for strength-5%

Tyrer (1966) is also concerned with the problems of abrasion resistance testing and indicates that other tests of strength should be carried out if the results are to used meaningfully. The difficulty of consistently finding the end point of tests is emphasized. The procedures of reduction in tensile strength, weight, thickness and air flow are not really as related to consumer wear as pilling and color change which are noted long before the fabric is destroyed.

Germans (1951) also pointed out the difficulty in determining the end point of abrasion tests. The method he favors is weight loss; he indicated that extended abrasion does reduce the amount of fiber present in the fabric. In the test he described, the fabric is held rigid and is abraded by a continuous belt of abrasive cloth.

While the 1968 Kemp study used wool fabrics in the correlation of laboratory and use tests, she does point out a major problem of using weight loss as a means of measuring the degree of abrasion. Fabrics which show a high degree of pilling have been abraded but the fibers are still present on the surface of the fabric so a weight loss is not detected or recorded in the laboratory.

Sarma et al. (1974) have also been concerned with the correlation of laboratory tests and service wear life. They concluded that flex abrasion is the best predictor of service wear life in India, but state that the magnitude of differences between the number of flex cycles is not a prediction of the magnitude of differences in abrasion wear.

Kemp's 1968 study resulted from a consumer protection group in England that was concerned with the wear life of school blazers. Nine fabrics of unreported construction were made into blazers which were worn by school children for a two-year period. Abrasion resistance of the garments was judged visually and the unworn fabrics were subjected to a Martindale abrasion test. In the actual wear tests, the author indicated there was a .16 correlation of warp tensile strength to actual wear, a .87 correlation of warp tensile strength to Martindale testing, a .33 correlation of weft tensile strength to actual wear, and a .82 correlation of weft tensile strength to Martindale testing. Strength tests seem to correlate better with laboratory tests than with actual wear.

The scanning electron microscope (SEM) has been used in numerous studies in recent years to observe morphological characteristics of fibers in fabrics subjected to abrasion tests and actual wear. Kirkwood (1974) reported on studies of garments tested on the Fort Lee Wear Course and lab tests conducted on the Schiefer, Stoll Flex and Taber instruments. The fabrics studied were nylon and cotton blends in several constructions. He reported the presence of nylon in a 70/30 nylon/cotton blend had a range of influences on the morphology and extent of damage to the cotton. It was noted that the Schiefer instrument did not damage the nylon fiber while the other machines did.

Dweltz and Sparrow (1978) used the SEM to determine whether the Stoll flex tester produced the same fiber damage in cotton fabrics that is produced by actual wear and laundering. They concluded that laboratory tests did not produce the same microview as wear-tested fabrics. Hearle (1973) also indicated that accelerated tests showed more cutting action rather than the fibrillation that occurred in wear and laundering.

A method for comparing results of a series of tests of fabrics in a series of abrasion tests was reported by Beck et al. (1966). In all tests, a series of samples was run to destruction, then a second series was run for half the number of cycles required for destruction. The weight loss of the samples run to half-destruction was determined and a ratio of change was calculated as follows:

$$\frac{\text{Weight Loss (in mg)}}{\text{\# of Cycles to Produce Change}}$$

The difficulty of using normal distributions in analyzing abrasion tests carried to the end point of destruction was first discussed by Tanenhaus in 1947. At that time he noted that, in plotted frequency distributions of breaks, the distributions were positively skewed, thus indicating that the means calculated therefrom were atypical. He proposed that the median, which is more independent of the extremes of the distribution, is more representative of the end point than the mean.

Prevorsek, Lyons and Whitwell (1963) discussed the statistical treatment of data in cyclic rupture tests. It was their conclusion that the use of central measure of lifetime to characterize fatigue data is misleading. More emphasis should be placed on early failures and expected minimum life. They suggested the use of the third asymptotic distribution, further described by Weibull and Gumbel, as being appropriate for the analysis of textile fatigue data.

The use of statistics to study the results of abrasion and pilling tests has been a major concern of Barella (1966, 1967) who believes that abrasion is a fatigue phenomenon of textiles which cannot be dealt with using the usual statistical techniques, since their distributions are not Gaussian. He also pointed out that minimum, rather than mean values, are of greater importance in predicting wear life.

In yarn abrasion studies where tests produce breakage of the yarns, Barella feels that it is possible to fit a Weibull distribution to the results. His 1967 article on pilling and wear studies indicated the use of the early fatigue rates may correlate more easily with use studies.

CHAPTER III

OUTLINE OF PROCEDURES

Fabrics

Nine polyester/cotton blend fabrics were included in the study. All are commercially available fabrics representative of the polyester/cotton apparel fabrics on the market during 1981-1982. The details of their construction are given in Table 1.

The construction characteristics of the fabrics were determined by the following ASTM procedures:

D1422-76	Twist in Single Spun Yarn by the Untwist-Retwist Method
D1910-64	Construction Characteristics of Woven [For counted number of warp yarns (ends) and filling yarns (picks) and for fabric weight.]

Yarn count or size was determined by direct weighing of five one-yard lengths on an O'Haus automatic yarn numbering balance. Fiber content is listed as the information on the label provided by the manufacturers.

Fabrics A-E, considered by the trade as light weight or top weight fabrics, were supplied by one manufacturer. The fabrics were yarn dyed and received the mill's standard

TABLE 1

PHYSICAL CHARACTERISTICS OF FABRICS USED IN THE STUDY

	FABRIC								
	A	B	C	D	E	F	G	H	I
FIBER CONTENT									
% Polyester	65	65	60	20	80	65	50	65	65
% Cotton	35	35	40	80	20	35	50	35	35
YARN COUNT									
Warp	37/1	37/1	37/1	40/1	37/1	15.5/1	15.5/1	15.5/1	15.5/1
Filling	37/1	37/1	14.5/1	40/1	150d	10.5/1	12/1	10.5/1	10.5/1
YARN TPI									
Warp	24	24	24	32	24	20	20	20	20
Filling	24	24	14.5	32	15	12.5	8.5	12.5	12.5
YARN TM									
Warp	3.9	3.9	3.9	3.9	3.9	5.0	5.0	5.0	5.0
Filling	3.9	3.9	3.9	3.9	—	3.9	2.5	3.9	3.9
BREAKING STRENGTH									
Cut (Pounds)									
Warp	76	55	43	43	62	165	104	146	175
Filling	38	31	51	27	61	88	58	97	63
Ravel (Pounds)									
Warp	80	59	46	44	62	168	128	159	186
Filling	40	32	51	27	64	90	63	97	64
FABRIC WEIGHT									
(Oz./Yard^2)	3.25	3.0	4.25	3.5	3.0	8.5	7.0	7.75	7.25
FABRIC COUNT									
Ends	101	88	97	119	85	103	86	86	104
Picks	64	56	42	70	60	47	46	46	34
WEAVE									
2/1 Twill	*						*	*	
3/1 Twill						*			
Plain		*		*	*				
Oxford			*						*

permanent press finish. Fabric E is constructed with a polyester/cotton spun yarn warp and a 100% polyester texturized filament filling. Fabric D has a 100% cotton warp and a polyester/cotton spun yarn filling. All other fabrics were constructed of intimate blended yarns in the warp and filling directions. Fabrics F-I, considered heavy or bottom weight fabrics, were supplied by a second manufacturer. These fabrics were piece dyed and given a permanent press finish.

Specimen Preparation

Test method notes on sample preparation for both breaking strength and abrasion tests caution the technician to avoid cutting specimens which would contain the same warp and filling yarns. This assures that a series of tests will contain a random selection of warp and filling yarns more representative of the fabric. In preparing the specimens for this study care was taken to assure that a single series of tests did not contain the same yarns but that samples for the different test methods did contain duplicates of yarn combinations used to determine the original fabric breaking strength. The outer five inches of fabric at either selvage was removed to reduce variability of results due to fabric construction. The samples were then cut by starting at the left corner, moving across the fabric in five-inch increments and up the fabric in one inch increments in a pattern which allowed duplication of warp yarns in fabrics tested in the warp direction and duplication of filling yarns tested in the filling direction. Thus, for instance, one was assured in comparing original breaking strength, Stoll flex, Stoll flat, Wyzenbeek, Taber and Schiefer test results that the same five sets of yarns were being tested in a comparison of each fabric.

Physical Tests

The 1981 Annual Book of ASTM Standards, Part 32, contains the five standardized abrasion test methods used in this study. The "Uses and Significance" section of ASTM D1975 points out the major limitations of abrasion testing. It is indicated there that the measurement of the relative amount of abrasion in the tests may be affected by the method of evaluation and may be influenced by the judgement of the operator. To remove some of the operator bias in determining the endpoint of the tests it was decided a similar method of measuring abrasive damage for all tests would be used. Some modifications in the tests, therefore, were necessary to allow comparison of results from the various tests. The ASTM procedures used were the following:

D1175-80	Standard Test Method for Abrasion Resistance of Textile Fabrics (Oscillatory Cylinder and Uniform Abrasion Methods)--Wyzenbeek and Schiefer

D3884-80	Standard Test Method for Abrasion Resistance of Textile Fabrics (Rotary Platform, Double Head Method)--Taber
D3885-80	Standard Test Method for Abrasion Resistance of Textile Fabrics (Flexing and Abrasion Method)--Stoll flex
D3886-80	Standard Test Method for Abrasion of Textile Fabrics (Inflated Diaphragm Method)--Stoll flat

Residual breaking strength was used as the common method of evaluating the effects of the various tests. All tests were run for a specified number of cycles; then the samples were tested for breaking strength according to the procedures outlined in ASTM D1682. An Instron 1130 CRE tester operating at a crosshead speed of 50 millimeters per minute to give a break in approximately 20 seconds was used for all tests. Samples abraded following ASTM D3884, D3886 and D1175 (Schiefer Uniform Abrasion Method) produced a small sample for breaking strength testing and required the use of a one-inch gauge length on the Instron and a die-cut strip sample size of one by two inches. Abrasion tests conducted by the procedures of ASTM D3885 and D1175 (Oscillatory Cylinder) permitted the use of a standard one by six inch ravel strip breaking strength test.

The order of testing was to run all abrasion tests, prepare the breaking strength samples from the abraded samples, then run all breaking strength samples. All testing was completed in standard conditions of 65% relative humidity and 70°F. All abraded samples were allowed to condition at least 18 hours before they were tested for retained strength.

Wyzenbeek abrasion

The oscillatory cylinder procedure described in ASTM D1175, Sections 8-15, is more commonly referred to as the Wyzenbeek abrasion test. As specified by the test procedure, each test specimen was abraded for 250 cycles using "0" emery paper as the abradant and a dead-weight loading of two pounds, 16 samples abraded in the warp direction, and 16 samples abraded in the filling direction. The residual breaking strength of the specimens, raveled to a 1-inch width, was used as a means of evaluating the effects of abrasion. No modification of the test was necessary.

Schiefer abrasion

The uniform abrasion test described in ASTM D1175, Sections 16-24, is usually referred to as the Schiefer test in the literature. A spring steel abradant and head weight of ten pounds were used in all tests. Rather than carrying the tests to a destructive end point, as specified in the test method, all samples were abraded for 1,500 cycles and retained strength was used as a means of comparison. The

1,500 cycle end point was determined in preliminary testing which indicated that approximately 2,800 cycles on the weakest fabric would produce the damage necessary to automatically stop the machine. Ten samples from each fabric were abraded and one breaking strength specimen was cut from each sample.

Taber abrasion

The double-head rotary platform machine referred to in ASTM D3884 is more commonly called the Taber Abraser. For the purposes of this testing, the CS 15 rubber-base wheels and 500-gram head weights were used. After 600 abrasion cycles, at least one fabric appeared to have a broken yarn and the abraded track could be found on all fabrics. Each sample was abraded for 600 cycles and the wheels were resurfaced after each 600 cycles as specified in the test. Ten samples from each fabric were abraded and four breaking strength specimens (two warp, two filling) were cut from each sample. The analysis of the data later indicated that additional samples of Fabrics A, B, D and I were needed; an additional 15 samples of those fabrics were abraded and tested.

Stoll flex

The flexing and abrasion method described in ASTM D3885 is also referred to as the Stoll flex abrasion test.

Samples 1.5x8 inches were raveled to 1x8 inches and abraded using the flex bar on the machine. Ten samples in the warp direction and ten samples in the filling direction were abraded using a two-pound bar weight and a half-pound head weight. Warp samples were abraded for 500 cycles and filling samples for 1,500 cycles. These cycle times were determined in preliminary testing which indicated that the weakest warp allowed the machine to cut off after 1,100 cycles and the weakest filling ruptured after 2,800 cycles. Evaluation was based on breaking-strength results obtained after abrasion.

Stoll flat

The same Universal Wear Test Machine was used for the Stoll flex and Stoll flat abrasion tests. The Stoll flat tests were performed according to the specifications of ASTM D3886 for inflated diaphragm testing. The abradant used was "0" grit emery polishing paper. The air pressure was 4 PSI and the head weight load was one pound. The test was run using the rotation mechanism on the machine to provide multidirectional abrasion. In a preliminary test, samples were run until all fibers in the center section were worn enough to activate the electrical stop mechanism. The earliest failure was at 860 cycles.

To compare results with other samples, a variation of Section 11.1.2 was selected in which the samples for all tests were abraded for 500 cycles. The abradant paper was changed for each specimen. Twenty specimens from each fabric were abraded and each specimen was cut to provide one breaking-strength sample for further testing.

Statistical Tests

A One-Way Analysis of Variance (ANOVA) was used to analyze the data for each fabric to see if differences in the strength noted after the various abrasion tests were significant. If these differences had not been significant, there would have been no purpose in ranking the procedures to determine differences between machines on different fabrics.

The procedure used for determining the significance of the rankings was Kendall's Coefficient of Concordance W. A Chi-square test was used to test the hypotheses since the values for number of objects to be ranked and the number of methods for ranking exceeded the published tables. The procedure used is that described in Daniel's Applied Nonparametric Statistics using the computation formula:

$$W = [12(\Sigma_{j=1}^{n} R_j^2) - 3m^2n(n+1)^2]/[m^2n(n^2-1)]$$

where m = number of sets of rankings

n = number of items to be ranked

R_j = sum of ranks assigned to the j^{th} object

The number of samples tested was not the same for all tests. The number of samples required for each test was determined in preliminary testing of breaking strength. The number of samples required was calculated from the mean and standard deviation of the breaking strengths using the formula of ASTM D2905-81:

$$n = (ts/E)^2$$

where t = 1.96 (Student's t for infinity at 95% Confidence Level)

s = standard deviation of sample

E = error rate of .05 of mean

CHAPTER IV

RESULTS

The original breaking strengths of the fabrics were determined on the Instron 1130. A printout of the data was used instead of calculations from a drawn curve in order to report the strength of the specimens. As samples were run, jaw breaks were noted and the data collected from such specimens were rejected when calculating the mean and standard deviation for the test series.

Fabric B exhibited a higher degree of variability of strength than the other samples. Using the ASTM calculation to determine the number of specimens required at the 95% confidence level and allowing a 5% error, it was found that additional breaking strength tests for Fabric B should be run to provide the desired statistical reliability. Table 2 shows the mean, standard deviation, coefficient of variation (CV) and number of tests run for all warp-strength tests and all filling-strength tests. From these figures it is noted that the fabrics showing the least variability in original strength were Fabrics E and H, while the one with the greatest variability was Fabric B. Fabric G also produced highly variable strength tests.

TABLE 2

MEAN, STANDARD DEVIATION, COEFFICIENT OF VARIATION AND NUMBER OF TESTS FOR ALL STRENGTH TESTS

Fabric Warp		Cut	Ravel	Stoll Flat	Stoll Flex	Wyzen-beek	Schiefer	Taber
A	$\overline{X}$	76.45	79.88	33.73	55.88	75.87	72.51	73.12
	s	2.085	1.547	1.818	2.918	3.374	1.912	4.120
	CV	2.72	1.94	5.40	5.22	4.45	2.64	5.63
	n	10	10	16	8	9	5	20
B	$\overline{X}$	55.34	58.98	26.15	41.78	33.11	41.34	42.03
	s	4.108	1.894	3.820	3.070	3.750	9.185	5.250
	CV	7.42	3.21	15.00	7.00	11.30	22.20	13.00
	n	10	10	16	14	15	5	18
C	$\overline{X}$	42.87	45.64	51.17	42.07	47.42	44.98	47.77
	s	2.149	1.125	2.457	1.852	1.490	2.676	1.608
	CV	5.01	2.46	4.84	4.40	3.14	5.95	3.36
	n	10	10	5	5	5	5	5
D	$\overline{X}$	42.56	44.10	18.77	16.71	16.37	17.50	40.43
	s	2.682	2.022	2.310	3.585	2.490	3.330	2.621
	CV	6.30	4.59	12.00	21.50	15.20	19.10	6.48
	n	10	10	9	21	16	5	20
E	$\overline{X}$	61.54	62.00	34.69	57.22	57.06	62.07	57.63
	s	2.662	2.002	2.510	2.020	2.163	3.597	5.335
	CV	4.32	3.23	7.23	3.53	3.79	5.79	9.30
	n	10	10	10	5	11	5	22
F	$\overline{X}$	165.2	168.0	86.48	168.1	143.5	126.2	134.3
	s	3.409	6.067	5.310	6.183	4.092	8.369	5.240
	CV	2.10	3.60	6.00	3.68	2.28	6.63	3.90
	n	10	10	14	5	5	5	5
G	$\overline{X}$	103.9	128.1	62.44	128.2	100.3	117.8	119.2
	s	6.608	4.731	4.240	3.360	3.551	10.37	5.478
	CV	6.36	3.69	7.00	2.62	3.54	8.80	4.60
	n	10	10	11	5	5	5	5
H	$\overline{X}$	145.5	159.1	105.9	158.9	138.6	141.6	127.5
	s	5.026	2.890	5.590	4.041	4.569	6.167	15.09
	CV	3.46	1.82	5.00	2.54	3.29	4.36	11.80
	n	10	10	5	5	5	5	18
I	$\overline{X}$	175.1	185.9	116.8	186.2	151.6	149.6	161.3
	s	7.868	4.245	3.856	4.280	7.936	2.545	5.605
	CV	4.49	2.28	3.30	2.30	5.23	1.70	3.47
	n	10	10	5	5	5	5	16

TABLE 2--Continued

Fabric Filling		Cut	Ravel	Stoll Flat	Stoll Flex	Wyzen-beek	Schiefer	Taber
A	$\bar{X}$	38.08	39.67	24.39	18.17	37.05	38.36	37.98
	s	2.606	1.810	2.107	1.750	2.577	1.241	2.178
	CV	6.85	4.56	8.60	10.00	6.96	3.23	5.76
	n	10	10	17	18	5	5	5
B	$\bar{X}$	31.31	31.92	17.93	18.30	28.88	28.44	25.59
	s	2.785	3.290	2.920	1.750	2.756	4.603	2.498
	CV	8.89	10.30	16.00	9.60	9.50	16.19	9.80
	n	10	27	24	18	14	5	18
C	$\bar{X}$	50.51	51.36	30.32	34.84	51.02	28.94	39.87
	s	2.712	2.001	1.274	0.800	1.134	1.188	3.680
	CV	5.37	3.90	4.20	2.29	2.22	4.10	9.20
	n	10	10	5	5	5	5	10
D	$\bar{X}$	27.08	27.40	13.51	15.85	25.25	30.70	28.62
	s	1.096	0.974	0.466	1.590	1,199	1.192	1.451
	CV	4.04	3.55	3.45	10.00	4.70	3.88	5.07
	n	10	10	5	20	10	5	20
E	$\bar{X}$	61.38	64.07	39.44	63.92	63.52	58.42	57.77
	s	1.682	1.033	1.612	1.879	1.117	3.685	3.294
	CV	2.74	1.61	4.08	2.94	2.80	6.30	5.70
	n	10	10	5	5	5	5	10
F	$\bar{X}$	88.15	90.03	93.86	93.17	87.17	83.06	88.83
	s	3.273	3.908	3.508	2.845	1.432	7.249	4.542
	CV	3.71	4.34	3.74	3.05	1.64	8.73	5.11
	n	10	10	19	5	5	5	5
G	$\bar{X}$	58.04	63.71	73.02	64.85	63.59	68.22	68.17
	s	3.632	3.171	3.960	2.277	2.214	4.098	2.348
	CV	6.26	4.98	5.42	3.51	3.48	6.00	3.44
	n	10	10	5	5	5	5	5
H	$\bar{X}$	96.55	97.13	98.48	94.36	93.80	101.7	94.27
	s	2.718	3.347	5.103	3.125	3.669	4.993	3.284
	CV	2.81	3.45	5.18	3.31	3.91	4.91	3.48
	n	10	10	5	5	5	5	5
I	$\bar{X}$	62.89	64.21	73.14	62.64	64.05	70.24	68.37
	s	2.664	3.402	2.326	2.330	0.949	1.889	2.970
	CV	4.24	5.65	3.18	3.72	1.48	2.69	4.34
	n	10	10	5	5	5	5	19

To determine whether the differences between abrasion tests on a single fabric were significant, a series of one-way ANOVA was computed to compare the five test means for each fabric. The results of those tests for both the warp and filling tests are shown in Tables 3 and 4. All comparisons indicated that the differences were significant. Since specific comparisons between selected pairs of means were not desired, the least significant differences were calculated for each of the comparisons as an aid in ranking tests for later analysis.

Tables 5, 6 and 7 report the rank order of abrasion test results on each of the nine fabrics. The combined test results reported in these tables were obtained by adding the warp strength and filling strength, then ranking the resulting additive results to provide a means of describing total fabric performance. The rank of "1" indicates the strongest test and "5" indicates the weakest.

The warp rankings reported in Table 5 indicate that for seven of the nine fabrics the Stoll flat abrasion test produced the greatest amount of abrasion. The least amount of abrasive damage was produced by the Stoll flex on four fabrics, by the Taber on two fabrics, by the Wyzenbeek on one and by the Schiefer on one fabric.

Kendall's Concordance W is the measure used to test the null hypothesis that the warp abrasion tests are assigning ranks to the fabrics independently and at random.

TABLE 3

SYNOPSIS OF ONE-WAY ANOVA COMPUTATIONS FOR BREAKING STRENGTH RETAINED IN THE WARP DIRECTION AFTER FIVE ASTM ABRASION TESTS ON NINE FABRICS

FABRIC	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
TESTS									
Stoll Flat	33.73	26.14	51.17	18.75	34.69	86.48	62.44	105.94	116.82
Stoll Flex	55.88	41.78	42.07	16.71	57.22	168.12	128.24	158.94	186.16
Wyzenbeek	75.78	33.11	47.42	16.36	56.14	143.48	100.30	138.60	151.62
Taber	73.28	42.70	48.66	40.43	57.77	133.35	117.20	127.46	161.32
Schiefer	72.51	41.32	44.98	18.86	62.07	126.18	117.80	141.54	149.62
F-Ratio	429.05	36.60	14.99	217.05	67.86	158.89	182.60	15.50	115.55
Total DF	57	62	29	70	40	38	34	37	25
Prob >F	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
LSD*	2.874	3.306	2.736	2.185	3.741	7.659	6.189	14.581	6.779

***LSD:** least significant difference calculated at $t_{.05}$ using the Snedecor Method

TABLE 4

SYNOPSIS OF ONE-WAY ANOVA COMPUTATIONS FOR BREAKING STRENGTH RETAINED IN THE FILLING DIRECTION AFTER FIVE ASTM ABRASION TESTS ON NINE FABRICS

FABRIC	A	B	C	D	E	F	G	H	I
TESTS									
Stoll Flat	24.39	17.93	29.72	13.51	39.44	93.86	73.02	98.47	73.12
Stoll Flex	21.24	18.17	34.83	15.84	64.93	93.17	64.66	94.36	62.64
Wyzenbeek	37.05	28.62	51.02	25.26	63.52	87.17	63.59	93.81	64.05
Taber	35.71	25.88	40.51	28.62	57.77	90.54	68.82	93.80	68.06
Schiefer	38.36	28.44	29.70	30.70	58.42	83.06	68.22	101.74	70.24
F-Ratio	69.96	56.60	55.60	313.50	62.40	9.13	8.93	3.28	12.94
Total DF	69	74	29	59	29	43	33	29	39
Prob >F	.0000	.0000	.0000	.0000	.0000	.0000	.0001	.0272	.0000
LSD*	3.148	2.317	3.517	1.228	3.738	3.750	3.258	5.992	3.436

***LSD:** least significant difference calculated at $t_{.05}$ using the Snedecor Method

TABLE 5

RANK ORDER OF BREAKING STRENGTH RETAINED IN THE WARP DIRECTION FOR FIVE ASTM ABRASION TESTS ON NINE FABRICS

FABRIC	A	B	C	D	E	F	G	H	I
TESTS									
Stoll Flat	5	5	1	2	5	5	5	5	5
Stoll Flex	4	2	5	5	3	1	1	1	1
Wyzenbeek	1	4	3	4	4	2	4	2	3
Taber	2	1	2	1	2	3	2	4	2
Schiefer	3	3	4	3	1	4	3	3	4

TABLE 6

RANK ORDER OF BREAKING STRENGTH RETAINED IN THE FILLING DIRECTION FOR FIVE ASTM ABRASION TESTS ON NINE FABRICS

FABRIC	A	B	C	D	E	F	G	H	I
TESTS									
Stoll Flat	4	4	5	5	5	2	1	2	1
Stoll Flex	5	5	3	4	2	1	5	4	4
Wyzenbeek	2	1	1	3	1	4	4	5	5
Taber	3	3	2	2	3	3	3	3	3
Schiefer	1	2	4	1	4	5	2	1	2

TABLE 7

RANK ORDER OF COMBINED BREAKING STRENGTH RETAINED IN THE WARP AND FILLING DIRECTIONS FOR FIVE ASTM ABRASION TESTS ON NINE FABRICS

FABRIC	A	B	C	D	E	F	G	H	I
TESTS									
Stoll Flat	5	5	3	5	5	5	5	5	5
Stoll Flex	4	4	5	4	1	1	1	1	1
Wyzenbeek	1	3	1	3	2	2	4	3	4
Taber	2	2	4	1	4	3	2	4	2
Schiefer	3	1	2	2	3	4	3	2	3

TABLE 8

COMPUTED VALUES OF KENDALL COEFFICIENT OF CONCORDANCE (W) FOR RANK ORDER OF FIVE TESTS BY NINE FABRICS AS REPORTED IN TABLES 5, 6, AND 7

	W	x^2	df
ALL FABRICS			
Warp (Table 5.)			
Pounds	.249	8.96	4
Filling (Table 6.)			
Pounds	.086	3.10	4
Combined Warp and Filling (Table 7.)			
Pounds	.402	14.47**	4
FABRICS A, B, C, D AND E			
Warp (Table 5.)			
Pounds	.304	6.08	4
Filling (Table 6.)			
Pounds	.568	11.36*	4
Combined Warp and Filling (Table 7.)			
Pounds	.496	9.92*	4
FABRICS F, G, H AND I			
Warp (Table 5.)			
Pounds	.894	14.30**	4
Filling (Table 6.)			
Pounds	.500	8.00	4
Combined Warp and Filling (Table 7.)			
Pounds	.809	12.94*	4

* Significant at the .05 level
** Significant at the .01 level

Table 8 shows that the W value is 0.249 and the corresponding Chi Square (x^2) value is 8.964. The p-value is between .10 and .05. In this case, the null hypothesis is accepted and it is noted that, while there is a tendency for the Stoll flat test to give the more severe abrasion, there is little agreement among the other rankings.

The same tests on the filling direction samples resulted in a W value of 0.086 and a x^2 of 3.096. The resulting x^2 value of 3.096 has a p-value greater than .01, so the null hypothesis that the tests are assigning ranks to the fabrics independently and at random is accepted.

By combining warp and filling results and then ranking the combined strengths and calculating W and x^2, a x^2 of 14.47 is obtained. The calculated x^2 value has a p-value less than .01 so the null hypothesis is rejected. Inspection of the data for trends in rankings indicates that, in all but one of the fabrics, the Stoll flat abrasion test produced the most abrasion. In five of the nine fabrics the Stoll flex test produced the least damage. No other test ranked more than four fabrics at the same level.

Of the five fabrics ranked as the least damaged by the Stoll flex test, four were bottom weight fabrics. The rankings for the top and bottom weight fabrics were separated and analyzed separately. The analyses of the rankings of those tests are also reported in Table 8.

For fabrics A-E, the x^2 table was used to establish the significance of the W values calculated. For tests with four degrees of freedom, the table indicates that a x^2 value of 9.488 for a .05 probability and 13.277 for a .01 probability is needed to reject the null hypothesis that the tests are assigning ranks to the fabrics independently and at random.

The data for top weight fabrics reported in Table 8 show that the warp values do not exceed the 9.488 value and thus indicate no discernible pattern to those rankings. The values for the filling and the combined data are significant at the .05 level. Inspection of the data for patterns to the rankings shows that, in the filling tests, the Stoll flat tests rank three fabrics in fifth place and two fabrics in fourth place, thus indicating that it is the more severe test. In the combined data, the Stoll flat test ranks four of the five fabrics as class 5 or most severely damaged.

The results for the bottom weight fabrics in Table 8 show x^2 values of 14.3 for the warp tests, 8.0 for the filling tests and 12.94 for the combined tests. The filling test results are not significant at the desired levels; however, the warp and combined data are significant: the warp significant at the .01 level and the combined data at the .05 level of significance. For four out of five tests, the Stoll flat tests are ranked a "5" and the Stoll flex tests are ranked a "1". This indicates that the flat test is the more severe and the flex test the least severe. The same results are noted on the combined data. Rankings for the other tests in both data sets are fairly dispersed with no other tests receiving more than two rankings that were the same.

The raw data for computing the preceding rankings were strength in pounds because only a single fabric was being ranked with five tests. Since comparing a series of fabrics of widely varying original strengths is more difficult, three methods of making the comparisons were used: (a) reporting the data in pounds as collected on the Instron, (b) reporting it as percentage of strength retained following abrasion and (c) reporting it as strength per yarn in an attempt to reduce the data to some common denominator. The mean values used to produce the rankings are reported in Table 2. The resultant rankings are reported in Table 9.

Using retained strength in pounds as the method of comparison to rank the warp tests resulted in a W value of 0.968 with a corresponding x^2 of 38.72 as shown in Table 10. With 8 degrees of freedom in the comparison, the probability of a x^2 greater than 21.95 is .005; the null hypothesis is therefore rejected. In analyzing the fabric rankings it may be noted that the ranking of Fabric D in ninth place by all five tests indicates that it is the weakest fabric in all tests. Fabric I is ranked first by all tests, indicating it is the strongest fabric. Fabric G is ranked fourth by all

TABLE 9

RANKINGS FOR FIVE ABRASION TESTS FROM STRENGTH RETAINED AS CALCULATED BY THREE METHODS

ABRASION TEST	FABRIC NUMBER	WARP			FILLING			COMBINED		
		LBS.	% RET.	LBS. PER END	LBS.	% RET.	LBS. PER PICK	LBS.	% RET.	LBS. PER YARN
STOLL FLAT	A	7	8.5	7	7	5.5	7	7	7.5	7
	B	8	7	8	8	8	8	8	7.5	8
	C	5	1	5	6	7	5	5	1	5
	D	9	8.5	9	9	9	9	9	9	9
	E	6	5	6	5	5.5	6	6	6	6
	F	3	6	3	2	3	3	3	4.5	3
	G	4	4	4	4	1	4	4	4.5	4
	H	2	2	1	1	4	1	1	2	1
	I	1	3	2	3	2	2	2	3	2
STOLL FLEX	A	6	8	6	7	9	7	7	8	7
	B	8	7	7	8	8	8	8	7	8
	C	7	5.5	8	6	6	6	6	6	6
	D	9	9	9	9	7	9	9	9	9
	E	5	5.5	5	3	3	5	5	5	5
	F	2	2.5	3	2	1.5	3	1	1.5	3
	G	4	2.5	4	4	1.5	2	4	1.5	4
	H	3	2.5	1	1	5	1	2	4	1
	I	1	2.5	2	5	4	4	3	3	2
WYZENBEEK	A	5	2	5	7	7	7	6	3	7
	B	8	8	8	8	9	8	8	8	8
	C	7	1	7	6	3	5	7	1	6
	D	9	9	9	9	8	9	9	9	9
	E	6	3	6	5	4	6	5	2	5
	F	2	5	3	2	5	3	2	4.5	3
	G	4	7	4	4	1	4	4	7	4
	H	3	4	1	1	6	1	1	4.5	1
	I	1	6	2	3	2	2	3	6	2
TABER	A	5	3	5	7	6.5	7	6	2	6
	B	8	9	8	9	8	8	9	9	8
	C	7	2	7	6	9	5.5	7	5	7
	D	9	4	9	8	3	9	8	6	9
	E	6	5	6	5	6.5	5.5	5	3.5	5
	F	2	8	4	2	4	3	3	8	3
	G	4	1	3	3	1	4	4	1	4
	H	3	7	2	1	5	1	2	7	1
	I	1	6	1	4	2	2	1	3.5	2
SCHIEFER	A	5	5	6	6	5	7	6	4	6
	B	8	8	7	9	8	8	8	7.5	8
	C	7	2	8	8	9	6	7	7.5	7
	D	9	9	9	7	2	9	9	9	9
	E	6	3	5	5	6	5	5	3	5
	F	3	7	4	2	7	3	3	6	4
	G	4	1	3	4	1	4	4	1	3
	H	2	4	1	1	4	1	1	2	1
	I	1	6	2	3	3	2	2	5	2

TABLE 10

COMPUTED VALUES OF KENDALL COEFFICIENT OF CONCORDANCE (W) FOR RANK ORDER OF NINE FABRICS BY FIVE TESTS AS REPORTED IN TABLE 9

	W	x^2	df
ALL FABRICS			
Warp			
Pounds	.968	38.72**	8
% Retained	.492	19.68**	8
Pounds/End	.949	37.96**	8
Filling			
Pounds	.948	37.92**	8
% Retained	.642	25.68**	8
Pounds/Pick	.962	38.48**	8
Combined Warp and Filling			
Pounds	.955	38.20**	8
% Retained	.417	16.68*	8
Pounds/Yarn	.979	39.14**	8
FABRICS A, B, C, D AND E			
Warp			
Pounds	.856	17.12**	4
% Retained	.676	13.52**	4
Pounds/End	.776	15.52**	4
Filling			
Pounds	.820	16.42**	4
% Retained	.256	5.12	4
Pounds/Pick	.950	19.00**	4
Combined Warp and Filling			
Pounds	.872	17.44**	4
% Retained	.408	8.16	4
Pounds/Yarn	.904	18.08**	4
FABRICS F, G, H AND I			
Warp			
Pounds	.904	13.56**	3
% Retained	.208	3.12	3
Pounds/End	.840	12.60*	3
Filling			
Pounds	.904	13.56**	3
% Retained	.060	0.00	3
Pounds/Pick	.648	9.72*	3
Combined Warp and Filling			
Pounds	.712	10.68*	3
% Retained	.212	3.18	3
Pounds/Yarn	.936	14.04**	3

* Significant at the .05 level

** Significant at the .01 level

tests and Fabric B is ranked eighth by all tests. Four tests rank Fabric C in seventh place, Fabric F in second place and Fabric H in third place. The most common ordering of fabrics is from Fabric I as strongest to F, H, G, A, E, C, B and D as weakest after abrasion. The Wyzenbeek and Taber tests were the two procedures that ranked them in exactly that order.

Dividing the strength after abrasion by the original strength provides information on the percentage of its original strength retained by a fabric. Table 9 indicates the rankings of fabrics by percent strength retained. Table 10 shows the resulting W value of 0.492 with a corresponding x^2 of 19.68, thus indicating the null hypothesis may be rejected at the .01 level of significance. Three tests clearly rank Fabric D as the weakest, or in 9th place, and a fourth test ranked it at 8.5, indicating that Fabric D is generally considered the weakest fabric. Three tests rank Fabric I in fourth place. Fabric B is ranked among the top three by all tests and Fabric E is ranked fifth or seventh. No other patterns appear evident.

In order to state the strength in a comparable unit for each sample, the strength per end was calculated. The W value of 0.949 shown in Table 10 and the corresponding x^2 of 37.96 indicates there is agreement between rankings by the various tests. Fabric D is again the weakest fabric by all five tests. Four tests rank Fabric H as the strongest and the same four tests rank Fabric I in second place. The Taber test reverses these later rankings and places Fabric I as strongest. Fabric F is ranked in third place and Fabric G in fourth place by the two Stoll tests and the Wyzenbeek; the Taber and Schiefer tests reverse these rankings. Fabrics A and E are in fifth and sixth place and Fabrics B and C are in seventh or eighth place in the rankings. The general ordering of the fabrics in strength per end after abrasion is Fabric H as strongest and, in decreasing order of strength, Fabrics I, F, G, A/E, B/C and Fabric D as weakest. The Wyzenbeek test ranks them in that order.

Filling strengths were calculated in the same manner. The x^2 values of all three sets of data indicate there is a concensus ranking at the .005 level. In comparing pounds breaking strength retained, all five tests rank Fabric H in first place and Fabric F in second place; four tests rank Fabric G in fourth place, Fabric E in fifth place, Fabric C in sixth place and Fabric A in seventh place. Three tests rank Fabric I in third place, Fabric B in eighth place and Fabric D in ninth place. From strongest to weakest the fabrics are H, F, I, G, E, C, A, B and D; the Stoll flat test and the Wyzenbeek test rank the fabrics in that order. By original strength they were ranked H, F, I, E, G, C, A, B and D.

The data for percentage of strength retained indicate that Fabric G retains a greater portion of its strength after abrasion than the other fabrics do. The Stoll flex rankings produced a tie for first place between Fabric F and G. The other tests ranked Fabric G in first place. Fabric B was ranked in eighth place by four tests and in ninth place by the fifth. There was not agreement on the weakest or ninth place ranking. Fabric A is ranked from fifth to ninth place, Fabric C from third to ninth and Fabric D from second to ninth.

Evaluation based on strength retained per pick shows a more general agreement. All five tests produced the same ranking order for Fabrics A, B, D and F. Four tests produced the same ordering for Fabrics G, H and I. From strongest to weakest, the Fabrics were ranked H, I, F, G, C/E, A, B and D. The Stoll flex test is the only one that deviates from that general order.

Combining the warp and filling strength and comparing rankings for pounds strength, percentage of strength retained and pounds strength retained per yarn results in calculated W values of 0.955, 0.417 and 0.979 respectively, as shown in Table 12. The data for percentage of strength retained are significant at the .05 level and the calculated x^2 for the pounds strength values and strength per yarn values exceed the .005 level of the x^2 Table. Thus, all three comparisons indicate support for the hypothesis that there is agreement between the test methods in their ability to rank fabrics.

The data in Table 9 show that, when comparing pounds strength retained, four of the tests rank Fabric D in ninth place, Fabric B in eighth place, and Fabric E in fifth place. All five tests place Fabric G in fourth place. Three tests rank Fabric A in sixth place, Fabric C in seventh place, Fabric F in third place and Fabric H in first place. No fabric received a plurality of second place ranks. In general, the ranking of the abraded fabrics from strongest to weakest is from H to I, F, G, E, A, C, B and D. The Schiefer test ranked them in that order and the Wyzenbeek test reversed on the order for second and third place.

Using percentage of strength retained for comparison it is more difficult to detect a pattern to the rankings. Fabric D is weakest with four tests ranking it in ninth place but the Taber places it in sixth place. Fabric G seems to have the highest rankings being ranked first by two tests and tied for first by the Stoll flex test; however, it is ranked sixth by the Wyzenbeek test. Fabric C was ranked eratically being placed first by the Wyzenbeek and Stoll flat tests, fifth by the Taber, sixth by the Stoll flex and seventh by the Schiefer. No general order of ranking is apparent.

The strength per yarn data produced the highest W value. All five tests ranked Fabric H in first place, Fabric I in second place, Fabric B in eighth place and Fabric D in ninth place. Four tests ranked Fabric F in third place, Fabric G in fourth place and Fabric E in fifth place. Fabric A was ranked in seventh place by three tests and in sixth place by two tests. In general the ranking from the strongest to the weakest would be from H to I, F, G, E, C, A, B and D. The Stoll flex and Wyzenbeek tests place them in that order.

The data for Fabrics A-E and F-I were compared separately to see if there was greater consistency in rankings with top weights and bottom weights. The ranking significances are reported in Table 10. The calculated W values and x^2 values for percentage of strength retained for the filling direction in top and bottom weights, for warp strength in bottom weights, and for combined percentage of strength retained in top and bottom weights are all below their respective .05 probability levels. For these tests, then, the data indicate that the rankings assigned are random.

For the top weight fabrics, the abrasion tests of filling strength in pounds all rank Fabric E in first place; four rank Fabric C in second place, Fabric A in third place, Fabric B in fourth place, and Fabric D in fifth place. From weakest to strongest the fabrics are D,B,A,C and E. The Schiefer test was the only one that did not rank them in that order.

When ranking the same fabrics for strength in pounds per pick, the reversals between first and second rankings by the tests on Fabrics C and E indicate that these fabrics tie for strongest. All five tests rank Fabric A third, Fabric B fourth and Fabric D fifth.

The warp strength tests for the top weight fabrics, regardless of the method for calculating strength, produced significant rankings. The pounds of strength retained after abrasion produced abrasion rankings of 1 (strongest) for Fabric A, 2 for Fabric E, 3 for Fabric C, 4 for Fabric B and 5 (weakest) for Fabric D. The rankings for Fabric A were the most varied with three first-place rankings, one second-place ranking and one third-place ranking.

Percentage of strength retained calculations produced rankings that were less obvious. Fabric C is ranked as retaining the most strength and Fabric D is ranked as retaining the least. Fabric E tends to be ranked in second place.

In comparing strength per end, Fabrics A and E split the first and second place ranks. Fabric D is the weakest. Fabrics B and C split the third and fourth rankings.

For the bottom weight fabrics, the rankings for percent strength retained were not significant. The rankings for filling strength in pounds show Fabric H is strongest, Fabric F is ranked in second place, and G and I split the third and fourth place ranks. Comparing pounds per pick, Fabric H is again strongest, Fabric I is second, Fabric F is third and Fabric G is fourth. The Stoll flex test reverses the rankings for Fabrics G and I.

The warp tests comparing strength in pounds ranked Fabric I as strongest, Fabrics F and H split the second and third ranks, and Fabric G was in fourth, or weakest, place.

The combined warp and filling strengths were also separated into top and bottom weight rankings. The rankings for percentage of strength retained were not significant for either top or bottom weights. For the top weight fabrics ranked by pounds of strength, Fabric E is strongest after abrasion, Fabric A is second, Fabric C is third, Fabric B is fourth and Fabric D is weakest; this was the order of ranking of the Wyzenbeek and Schiefer tests. The strength per yarn test ranks Fabric E as strongest, Fabric C in second place, Fabric A as third, Fabric B as fourth and Fabric D as weakest; this was the exact order shown by the Stoll flex and Wyzenbeek tests.

Inspection of the rankings for bottom weight fabrics by pounds strength shows that all five tests rank Fabric G as the weakest. Fabrics F and I are erratic and were ranked in first, second, or third place by one or more tests. Fabric H is always ranked in first or second place. In general, the fabrics could be ranked H, I, F, and G. Using pounds per yarn as a measure of performance, all five tests rank Fabric H as strongest and Fabric I in second place. Four tests rank Fabric F in third place and Fabric G as weakest. Thus, the consensus ranking from the procedures is H, I, F and G.

CHAPTER V

CONCLUSIONS

General Conclusions

This study compared the results of the more commonly used abrasion tests on a series of commercially available fabrics. The procedures included in the study were those contained in the currently available edition of the ASTM standards. In most laboratories the selection of the test method used is dictated by the type of test equipment owned by the laboratory and comparison of test results from a variety of test machines is not possible. We have shown that all five of the tests were able to discern differences between the fabrics, but we have also shown that the five tests do not all rank the nine fabrics in precisely the same order. As discussed in more detail below we have shown that some abrasion tests are more severe than others.

The data from this study indicate that the Stoll flat abrasion test consistently produces the greatest strength loss in the majority of the fabrics studied. The rankings in Tables 5, 6, and 7 show in 20 out of 27 cases that the Stoll flat test produced a rank of 4 or 5, indicating a high strength loss. Four rankings of 1 or 2 were produced by the tests on the filling yarns of twill weave fabrics. Since these fabrics were abraded on the face of the fabric and the filling floats appeared on the back of the fabric, we would not expect the filling yarns to be severely abraded by the Stoll flat test. The one fabric which consistently showed less damage from the Stoll flat abrasion was the top weight oxford cloth. It was felt that the mobility of the yarns in this particular construction produced a fabric which was more resistant to the abrasion damage produced by this particular test.

When the total ranked scores in Tables 5, 6, and 7 are used as a measure of severity, the least severe test is the Taber; there is little difference in the Stoll flex, Wyzenbeek and Schiefer tests. If the rankings are separated into those for the top weight and the bottom weight fabrics, an anomoly appears in that ranking system. For the top weight fabrics, the Stoll flex test is the most severe of the four procedures; for the bottom weight fabrics, it is the least severe.

For the top weight fabrics, the Stoll flat test is shown to produce the most fabric degradation, followed closely by the Stoll flex test. There was little difference in the amount of damage produced by the Wyzenbeek, Schiefer and Taber instruments. The bottom weight fabrics were affected in a different pattern. The Stoll flat and Wyzenbeek produced similar results. The Stoll flat produced the highest strength loss but the Wyzenbeek produced a similar abrasion pattern. It should be remembered that both tests used the same sandpaper as an abrasive. Again, there was little difference between the Taber and Schiefer tests.

Differences in fabric constructions were detected by all five tests. Tables 9 and 10 both show that comparing data on a pounds strength basis is more conclusive than using a percentage of strength retained comparison. Fabric differences were also easier to detect when we separated the data into rankings for top and bottom weight fabrics. Fabrics A-E were considered the top weight fabrics and Fabrics F-I were considered the bottom weight fabrics.

Using fiber content as a predictor of abrasion resistance we would expect Fabric D, a 20/80 polyester/cotton blend with a 100% cotton warp, to be the least abrasion resistant fabric. All five tests produced the greatest strength loss on the Fabric D warp. In 27 of 30 tests, Fabric D was ranked in ninth place, the weakest fabric. The Taber test produced more damage in Fabric B in the filling direction. The filling yarns in the two fabrics were of similar fiber content and the Taber test may have been able to discern some other differences in fabric construction.

Fabric E was an 80/20 polyester/cotton blend with a 100% polyester filling which we would expect to be the most abrasion resistant in tests of top weight fabrics. In 7 of 10 comparisons our predicted behavior was observed. For those cases where our predicted behavior was not observed we note that Fabric C was ranked ahead of Fabric E. The Stoll flex, Taber and Schiefer tests produced the expected rankings. The Stoll flat and Wyzenbeek tests, on a pounds per pick basis, produced a lower than expected ranking for fabric E and a corresponding higher ranking for Fabric C, the oxford cloth fabric.

Fiber content for the bottom weight fabrics was more uniform. Fabric G was a 50/50 polyester/cotton blend. The warp yarn constructions for Fabrics G and H were the same and the fabric construction was the same for the two fabrics. We would expect Fabric G to be the weaker fabric due to its higher cotton content. In all comparisons this was the case. In not all cases, however, was Fabric G the weakest of the four fabrics. Both the Taber and Schiefer tests produced more damage on a per end basis on Fabric F, a 3/1 twill with more warp yarns exposed on the surface of the fabric. For pounds retained in the filling, the Taber test produced more abrasion on Fabric I, the oxford cloth.

The oxford construction in Fabric I was expected to produce good abrasion resistance. The warp test results were as expected; the original warp strength was higher than that of the other fabrics and it retained that strength rank in all tests. The filling for Fabric I also ranked as the lowest strength for the bottom weight fabrics. After abrasion, the Stoll flat, Wyzenbeek and Schiefer tests produced higher strengths than would be expected, just as the Stoll flat and Wyzenbeek did on the top weight oxford cloth.

A more detailed description of these general conclusions, some more specific ones, and some recommendations for further work are discussed in the following sections. The major contribution of these results is to provide a framework for additional study on the phenomena of fabric wear.

The First Hypothesis

The first hypothesis of the study, that there is no significant difference in the ordering of abrasion test results for each individual fabric from the series of selected test methods, must be rejected. The ANOVA computations shown in Tables 3 and 4 indicate there are significant differences between the five test methods for each and every one of the nine selected fabrics. The Kendall Concordance W and corresponding x^2 values reported in Table 8 indicate that, for the combined warp and filling data, there appears to be an ordering of the severity of the abrasion tests. On inspection of the assigned ranks, it is noted that the Stoll flat abrasion test is the most severe for 8 out of 9 fabrics. The fabric which is not as severely damaged is the light-weight oxford cloth.

When comparing the test rankings for the top-weight fabrics in Table 8, it is noted that the rankings for the filling and combined data are significant at the 0.05 level of significance. Again, the Stoll flat test is the more severe. The Stoll flex test ranks closely to the Stoll flat in severity; the Wyzenbeek seems to be the least severe test. The results from abrasion with the Schiefer instrument seem close to those for the Wyzenbeek. These data do not appear to support the 1964 conclusion of the Committee of Directors of Textile Research Associations that the Stoll Flat and Schiefer instruments give similar results. They do support the conclusions of Galbraith et al. (1969) that the Schiefer abrasion test was less damaging than the Stoll flat test.

While Weiner and Pope (1963) reported coefficient of variations of 32-54%, the data in this study had CV's of 2-22%. Of the 90 sets of test data reported in this study, only 16 sets had CV's of 10% or greater. Weiner and Pope also reported a correlation coefficient of 0.64 between the Taber and Stoll flex tests. The current study shows the Stoll flex test to be more severe than the Taber test for the top-weight fabrics and less severe than the Taber test for the bottom-weight fabrics.

The largest W value reported in Table 8 was the 0.894 value for the warp strength of the bottom-weight fabrics ranked in Table 5. While there is some agreement in the ranking of the abrasion tests among those four fabrics, it should be noted that the agreement is only for the most severe and the least severe tests. There appears to be little differentiation among the Wyzenbeek, Taber and Schiefer tests; the fact that the Schiefer test did not receive any Number 2 rankings tends to place it closer to the Stoll flat test in the rankings.

The rank orders of bottom-weight fabrics reported in Table 7 indicate that Fabrics G and I produced identical rankings for the five tests. For those two fabrics, the Stoll flat test is the least severe test, followed by the Taber, Schiefer, Wyzenbeek and Stoll flat tests in order of increasing severity.

In general, the data reported in Tables 3-8 tend to indicate that there are differences between the five abrasion tests studied and that the Stoll flat test appears to be the most severe test in 18 of 27 comparisons.

The Second Hypothesis

The data in Tables 9 and 10 support the decisions to reject the second hypothesis of the study, that a single abrasion testing machine will show no significant differences in the rank order of the series of nine fabrics. Since the end point of all abrasion tests was measured as pounds strength retained, the rank orders of the original strength and the abraded strength after each test should be the same for all comparisons. Table 11 presents some of the data from Tables 9 and 10 in a slightly different manner in order to make that comparison more clearly.

The x^2 values reported in Table 10 with eight degrees of freedom in the comparison all exceeded the 15.51 value for the 0.05 probability level for critical values of x^2. The same Table 10 reports the separate comparisons for top-weight and bottom-weight fabrics. In general, the x^2 values for percentage of strength retained tend to be below the selected critical values thus indicating that rankings based upon percentage of strength retained are being assigned independently and at random.

TABLE 11

RANK ORDER OF FABRIC STRENGTH IN POUNDS BEFORE AND AFTER ABRASION

	1	2	3	4	5	6	7	8	9
WARP:									
Original	I	F	H	G	A	E	B	C	D
Stoll Flat	I	H	F	G	C	E	A	B	D
Stoll Flex	I	F	H	G	E	A	C	B	D
Wyzenbeek	I	F	H	G	A	E	C	B	D
Taber	I	F	H	G	A	E	C	B	D
Schiefer	I	H	F	G	A	E	C	B	D
FILLING:									
Original	H	F	E	G	I	C	A	B	D
Stoll Flat	H	F	G	I	E	C	A	B	D
Stoll Flex	H	F	G	I	E	C	A	B	D
Wyzenbeek	H	F	G	I	E	C	A	B	D
Taber	H	F	G	I	E	C	A	D	B
Schiefer	H	F	G	I	E	A	D	C	B

NOTE: A rank of "1" is strongest; "9" is weakest.

These data indicate that using percentage of strength retained is not the best method for comparing damage from abrasion. If all fabrics in the study had similar original strengths, such comparisons might have been more meaningful, but if original strengths had been similar, such computations would not have been necessary.

If factors such as fiber content, yarn construction and fabric construction did not alter the abrasion characteristics of the fabrics, one would expect that one could rank a series of fabrics from strongest to weakest, apply the same abrasion treatment to all of them, retest them for strength and have them ranked in the same order. Table 11 indicates that this was not the case.

Fabric D is expected to be the weakest fabric, based on fiber content. The warp is 100% cotton and the filling is 65/35 cotton/polyester, producing a fabric which is 80/20 cotton/polyester. Fabric D is consistently ranked as weakest in tests of the warp, but the Schiefer and Taber tests for the filling reverse Fabrics B and D in the rankings. The fiber content of the filling yarns for Fabrics B and D was identical indicating that the two tests in question could have been more sensitive to changes in yarn or fabric construction.

Fabric E, constructed with a textured filament polyester filling and a 65/35 polyester/cotton warp, would be expected to show higher strength than other similar weight fabrics and to retain that strength after abrasion. The filling performance was as expected. The warp yarns for Fabric E were of the same construction as the warp for Fabrics A, B, and C, indicating that fabric construction could account for the placement in the rankings for the warp of Fabric E. Of those four fabrics, Fabric A had the highest original strength. Fabric A had the highest number of ends and was constructed in a twill weave.

Fabric A ranked higher than Fabrics B, C and E in original warp strength and retained that ranking for the Wyzenbeek, Taber and Schiefer tests. In the Stoll flat test, Fabric C, the oxford cloth, ranked higher than Fabrics E, A and B, confirming the conclusions of Backer and Tanenhaus (1951) that oxford constructions have greater abrasion resistance which they attributed to the mobility of yarns in the structure.

Fabric A was a twill weave; Fabric B, a plain and Fabric C, an oxford. Only when tested by the Stoll flat test did the oxford construction outperform the plain and twill weaves. In original strength, Fabric B ranked higher than Fabric C. However, after all tests, Fabric C ranked higher than Fabric B, indicating again that an oxford construction may outperform a plain construction when subjected to abrasive forces.

In rankings of original strength and abraded strength, the only "crossover" from lightweight to bottom-weight fabrics occurred with the filament polyester in Fabric E, that fabric having an original strength comparable to Fabrics I and G. The Stoll flex and Wyzenbeek tests failed to differentiate between fabrics but the Stoll flat, Taber and Schiefer tests did so differentiate.

The warp strength data of Table 11 indicate that Fabrics I and G were strongest and weakest, respectively, both before and after abrasion. Fabric G was expected to be the weaker and less abrasion resistant because of its higher cotton content. Fabrics F, H and I were constructed from the same warp yarns. Fabrics F and I could be expected to have a higher original strength than Fabric G because of the number of ends per inch. Fabric I was an oxford cloth and Fabric F was a 3/1 twill; thus the difference in ranking of the two fabrics could be attributed to the fabric construction. The oxford construction produced the strongest fabric before and after abrasion.

Fabric F was originally stronger than Fabric H and retained that relationship after Stoll flex, Wyzenbeek and Taber abrasion. The Stoll flat and Schiefer tests reversed those rankings. Again, as with Fabric C, the Stoll flat test seems to be sensitive to the shifting of yarns, producing higher strength than one would expect on yarns that have more mobility.

Ranks for the filling strengths are virtually unchanged after abrasion. Fabric H is the strongest and Fabric I is second; Fabrics G and I are quite similar, as shown by the raw data in Table 2, although Fabric G could be ranked fourth in original strength.

On a pounds per pick basis, Fabric H remains strongest and Fabric B weakest of the bottom-weights. By original strength, Fabric F is stronger than Fabric I. Only the Stoll flex abrasion test retains that relationship. The Stoll flat, Wyzenbeek, Taber and Schiefer reverse the rankings by showing Fabric I as the stronger after abrasion. Fabric I was the oxford cloth, and on a per-yarn basis in the filling direction, it performed better than expected on all tests except the Stoll flex. This behavior was similar to that exhibited by the other oxford in the study, Fabric C.

The methodology for determining the end point in this series of abrasion tests may have caused some of the difficulties in interpreting the results. The series of nine fabrics was treated as a single series so that all nine fabrics received the same amount of abrasion. Inspection of the data in Table 2 indicates one problem, the anomaly of fabrics showing greater strength after abrasion than their original strength. A second problem was the overlapping of rankings with the bottom-weight fabrics.

Separating the fabrics into two series and subjecting the bottom-weights to a longer abrasion test, based on the behavior of Fabric G, might produce additional information. There are other implications for additional study, as well.

Recommendations for Further Study

In addition to the change in end point recommended above, there are four other areas where further study is advised. The major recommendation is to perform a garment or household fabric end-use wear trial on which to base decisions. The current study indicates that the Stoll flat test is the most severe of the procedures and indicates some fabrics where the test reverses rankings achieved by other tests. Further exploration of the correlation between fabric wear under actual use and under abrasion testing would increase confidence in relative test results.

This study did indicate some of the problems of using percentage of strength retained as a means of comparing test results. When there are wide variations in original strengths of materials, and percentage of strength retained is used as a means of comparison, one tends to forget that a 20 percent strength loss in a fabric with 40 pounds original strength produces a considerably weaker fabric than a 40 percent strength loss in a fabric with 100 pounds original strength. The percentage of strength loss data do not seem useful; actual pounds strength data are more meaningful. Data analysis in further studies could be simplified by using pound and pound-per-yarn measurements only.

Some verification of results from testing the lightweight fabrics needs to be made. Additional fabrics similar to Fabrics A and C should be tested to see if the Stoll flat test consistently ranks oxford cloths higher than twills while the other tests do not. Also, some plain-weave fabrics similar to Fabrics B and D should be studied to see whether the Taber and Schiefer tests continue to rank the fabrics in one order while the other three tests rank them in the order of their original strength.

BIBLIOGRAPHY

American Association of Textile Chemists and Colorists (AATCC). 1981. Technical Manual 57. Research Triangle Park, N.C.: AATCC.

American Society for Testing and Materials (ASTM). 1981. Annual Book of Standards 32. Philadelphia: ASTM.

Aminov, K. A. 1969. Analysis of the wear of cotton fabrics in service and in abrasion tests under laboratory conditions. Technology of the Textile Industry USSR 2: 10-13.

Armitage, Russell. 1947. Textile testing. Rayon Textile Monthly, May 1947, p.54.

Backer, Stanley and Tanenhaus, S. J. 1951. The relationship between the structural geometry of a textile fabric and its physical properties: the mechanics of fabric abrasion. Textile Research Journal 21: 635-654.

Ball, H. J. 1937. News notes. ASTM Bulletin: December 1937, p.63.

Ball, H. J. 1938. Problems which abrasion in wear testing present. Textile Research 9: 134-137.

Barrella, A. 1966. The application of the Weibull distribution to describe fatigue phenomena in textile materials. Annals Science Textiles Belges 3: 73-79.

Barrella, A. 1967. A contribution to the application of Weibull's distribution in the testing of textile materials. Journal of the Textile Institute 58: 78-82.

Beck, L.; Belleli, J.; and Sieberichs, F. 1966. Evaluation and compilation of the international investigation into abrasion resistance testing carried out by the technical committee of the Association Internationale de la Teinture Textile. Melliand Textilber 46: 1095-1104, 1221-1226, 1346-1354.

Canter, Clyde T.; Jones, G. D.; and Weaver, J. W. 1968. Rupture of cellulosic fibers in durable press blends. American Dyestuff Reporter 57: 45-49.

Clegg, Gladys G. 1949. Microscopical examination of worn textile articles. Journal of the Textile Institute 40: T449-480.

Committee of the Directors of Textile Research Associations. 1964. Final report on the interlaboratory abrasion tests. Journal of the Textile Institute 55: P1-P12.

Colledge, R. 1966. Polyester blends: How they react to flat abrasion. Modern Textiles Magazine 47: 23, 26, 35-36.

Colledge, R. 1968. The evaluation of differential abrasion effects in polyester blend fabrics. Canadian Textile Journal 85: 61-65.

Daniel, Wayne W. 1978. Applied Nonparametric Statistics. Boston: Houghton Mifflin Co.

Dweltz, N. E.; and Sparrow, J. T. 1978. SEM study of abrasion damage to cotton fibers. Textile Research Journal 48: 633-637.

Elder, H. M. 1978. Wear of textiles. Journal of Consumer Studies and Home Economics 2: 1-13.

Elder, H. M.; and Ferguson, A. S. 1969. The abrasion resistance of some woven fabrics as determined by the Accelerotor abrasion tester. Journal of the Textile Institute 60: 251-267.

Elias, D. K.; Warfield, C. L.; and Galbraith, R. L. 1977. Incremental frictional abrasion: effect on fiber characteristics. Textile Research Journal 47: 294-303.

Fabric wear resistance and methods of measuring it. 1934. Textile Research 4: 348-351.

Galbraith, Ruth L. 1975. "Abrasion of Textile Surfaces." In Surface Characteristics of Fibers and Textiles, pp. 193-224. Edited by M. J. Schick. New York: Marcel Dekker.

Galbraith, Ruth L.; Boyle, M.; Cormany, E.; Davison, S.; Ginter, A.; Ericson, J.; Lapitsky, M.; Lund, L.; and Cooper, M. 1969. Changes in cotton and nylon fabrics caused by increments of Accelerotor, Schiefer and Stoll abrasion. Textile Research Journal 39: 329-338.

Galbraith, Ruth L.; Sproul, C. N.; and Paklin, C. E. 1971. Predicting knee burst in boys' jeans. Textile Chemist and Colorist 3: 144-148.

Germans, F. H. 1951. The abrasion test as a criterion to determine the wear of textiles. Journal of the Textile

Institute 42: T185-T193.

Hall, Harry S.; and Kaswell, E. R. 1945. Wear resistance of apparel textiles: A literature survey. Textile Research Journal 15: 178-186.

Harvey, Ellery H. 1932. Wyzenbeek precision wear meter. American Dyestuff Reporter 21: 177-179.

Hamburger, Walter J. 1945. Mechanics of abrasion of textile materials. Textile Research Journal 15: 169-177.

Hamburger, Walter J. 1949. The industrial application of stress-strain relationships. Journal of the Textile Institute 40: P700-P718

Hearle, J. W. S. 1973. An atlas of fiber fracture: Abrasion testing and user trials. Textile Manufacturer 100: 44-45.

Hearle, J. W. S.; Buckley, C. P.; and Lomas, B. 1979. "Fracture, fatigue and wear of man-made fibers", paper presented at Internationale Chemiefasertagung in Dornbirn, 22 June 1979.

Kaswell, Ernest R. 1946. Wear resistance of apparel fabrics: Laboratory evaluation of military fabrics and correlation with combat course tests. Textile Research Journal 16: 502-521.

Kawamura, M; and Ikeda, S. 1968. Abrasion of fabrics. Journal of the Textile Machinery Society of Japan 14: 204-214.

Kemp, S. 1968. A comparison between laboratory abrasion test results and a wear trail on blazer cloths. The Textile Institute and Industry 6: 69-74.

Kirkwood, B. H. 1974. Scanning electron microscope investigation of morphological characteristics of laboratory and field wear in military fabrics. Textile Research Journal 44: 545-555.

Morris, M. A.; and Young, M. A. 1972. Performance of durable press shirts: Laboratory evaluations for color changes and abrasion. Textile Chemist and Colorist 4: 65-68.

Needles, Howard L. 1981. Handbook of Textile Fibers, Dyes and Finishes. New York: Garland STPM Press.

News notes. 1940. Rayon Textile Monthly, May 1940, p.90.

News notes. 1941. Rayon Textile Monthly, April 1941, p. 96.

Newton, H. E. 1969. Discussion of abrasiveness and wearability. *Textile Journal of Australia* 44: 12-14, 34-42.

Prevorsek, Dusas; Lyons, W. J.; and Whitwell, J. C. 1963. Statistical treatment of data and extreme value theory in relation to fatigue in textiles. *Textile Research Journal* 33: 969-973.

Ruppenicker, G. F.; Kyame, G. J.; and Little, H. W. 1968. The influence of yarn parameters and weaves in durable press performance of cotton fabrics. *Proceedings of the Eighth Cotton Utilization Research Conference*, New Orleans: 111-122.

Ruppenicker, G. F.; Rhodes, P. L.; and Kingsberry, E. C. 1972. The effect of structure on the properties of cotton durable press work trouser fabric. *Textile Chemist and Colorist* 4: 229-232.

Sarma, G. V. 1974. Statistical interpretation of results of laboratory abrasion tests. *Journal of the Textile Association* 35: 147-155.

Schiefer, Herbert F. 1947. Solution of the problem of producing uniform abrasion and its application to the testing of textiles. *Textile Research Journal* 17: 360-368.

Schiefer, Herbert F.; Cream, Lawrence; and Krasny, John. 1949. Improved single-unit Schiefer abrasion testing machine. *Textile Research Journal* 19: 259-269.

Schiefer, Herbert F.; Fourt, Lyman; and Kropf, Richard T. 1948. Textile testing in Germany: Serviceability evaluation. *Textile Research Journal* 18: 18-38.

Schiefer, Herbert F.; and Werntz, C. W. 1952. Interpretation of tests for resistance to abrasion of textiles. *Textile Research Journal* 22: 1-12.

Skinkle, John H. 1949. *Textile Testing*, 2nd Edition. Brooklyn: Chemical Publishing Co.

Snedecor, George W.; and Cochran, W. G. 1967. *Statistical Methods*, 6th Edition. Ames, Iowa: The Iowa State University Press.

Stoll, R. G. 1949. An improved multipurpose abrasion tester: Its application for the evaluation of wear resistance of textiles. *Textile Research Journal* 19: 394-415.

Susich, George. 1954. Abrasion damage of textile fibers. Textile Research Journal 24: 210-228.

Tanenhaus, S. J. 1947. The median as a typical value for Walker Yarn Abrader data. Textile Research Journal 17: 281-286.

Taylor, H. M. 1978. Abrasion in fabrics. Textiles 7: 36-41.

Tyrer, J. 1966. Some observations on the evaluation of the abrasion resistance of textile fabrics. Textile Institute and Industries 4: 330-331.

Weiner, L. T.; and Pope, C. J. 1963. Correlation of laboratory abrasion testers. Textile Research Journal 33: 761-764.