COMPARATIVE EVALUATION OF EFFECTS OF DRY ABRASION UPON FABRICS IN THE ACCELEROTOR

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BARBARA WILLETTA SIMONS

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APPROVED:

[redacted]

Assistant Professor of Clothing, Textiles and Related Arts

In Charge of Major

[redacted]

Acting Head of Department of Clothing, Textiles and Related Arts

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

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COMPARATIVE EVALUATION OF EFFECTS OF DRY ABRASION UPON FABRICS IN THE ACCELEROTOR

INTRODUCTION

Throughout history man has continually sought ways and means to improve his circumstances. It seems that the clothes he wears have been one of his concerns. Through experience he has developed a fairly reliable knowledge of the selection, use, and care of the natural fibers, but as the field of textiles broadened manufacturers were not certain what to expect concerning the durability of the new fabrics. A study of the factors causing wear has revealed that abrasion, or wearing away by friction, is a major factor. The urgency for obtaining data about the new fabrics has caused the manufacturer to seek methods of securing this information more quickly than by actual wear. Therefore instruments have been developed to expedite his research in the laboratory.

One of these instruments is the Accelerotor which was developed by the American Association of Textile Chemists and Colorists. The Association adopted tentative operating procedures for the Accelerotor in 1959. To evaluate the results of abrasion in the Accelerotor, they suggested the use of such methods as weight loss of specimen, or change in other characteristics such as strength, air permeability, light transmission, visual appearance, and hand (1, p. 127).

Purpose of Study

Little research has been conducted in order to determine the extent of the ability of the Accelerotor to reproduce actual abrasion damage because the Accelerotor has been recently developed. The purpose of this study has been to investigate the effects of dry abrasion upon fabrics of various fiber content in the Accelerotor, and to determine which methods are the most satisfactory for evaluating these effects. Several methods of evaluation were used to determine the amount and the type of degradation to each fiber, and to determine which methods were the most satisfactory for each fiber.

Statement of Problem

A review of literature revealed that several methods have been used to evaluate the damage to fabrics which were abraded by the Accelerotor and other abrading devices. The methods that were frequently used to indicate the extent and type of damage to fibers were breaking strength, bursting strength, weight loss, appearance, and microscopic study. For this study, therefore, the above mentioned methods were used.

The scope of this study has been limited to fabrics made from wool, cotton, viscose rayon, nylon, Dacron polyester, and Orlon acrylic fibers. Each fabric was white and was woven of one fiber in a plain weave. All of the fabrics woven of man-made fibers were made of continuous filament yarns. The yarn count was balanced or nearly balanced and the construction of the yarns and the fabrics were as comparable as was available.

Certain phases of the abrasion procedure, such as abrasion time, method of finishing the edge, and size of specimen were adapted to the individual fabric because fabrics of different fiber content vary in their thickness, weight, and resistance to abrasion.

REVIEW OF LITERATURE

For many years the information regarding the performance of textile fabrics was passed down from one generation to another. The natural fibers of cotton, linen, silk, and wool were the only fibers available and the selection, use, and care of these fibers was understood by those using them. As the field of textiles changed, manufacturers found it necessary to test fibers and fabrics in order to determine what performance could be expected from them. Many mechanical devices were designed to test certain properties of the natural and man-made fibers. By 1946 more than 50 mechanical devices had been designed to test the resistance of fabrics to abrasion (25, p. 738). The Accelerotor, which was used in this study, was first mentioned in the manual of the American Association of Textile Chemists and Colorists in 1953 (2, p. 88).

The terms serviceability, wear, and abrasion are frequently used interchangeably when describing the service life and durability of a fabric. However, serviceability refers to the ability of a given fabric to fulfill the needs of the intended end use (31, p. 136). Wear refers to the deteriorating actions to which a fabric may be subjected in everyday use (5, p. 751). Kaswell (17, p. 299) stated that wear is the capacity of a fabric to resist abrasion that is caused by such actions as stressing, straining, laundering, dry cleaning, pressing, and creasing. Skinkle (31, p. 137) observed that the general causes of wear are direct force, impact, flexing and friction of fibers and yarns, and abrasion. Abrasion is considered the major factor in wear. He stated that the specific actions of friction between fibers and dust and grit, cloth and cloth, and cloth and external objects cause abrasion. Susich (36, p. 210) indicated that abrasion results from compression, tension, bending, and cutting. Hamburger (11, p. 170) stated that abrasion results from repeated light stress applications occurring frequently during the service life of a fabric. To resist destruction by abrasion a fabric must be able to tolerate the stress applied and also be able to release this stress without causing degradation to the fibers.

Validity of Laboratory Tests

According to Pierce (26, p. 191), the laboratory testing of the resistance of fabrics to wear may be invalid and misleading. He stated, "Imitative tests are a delusion and a snare". Pierce (26, p. 184) expressed the opinion that there is no similarity in the hole worn in a fabric by a given number of rubs against emery paper and the hole worn in a garment as a result of actual wear. Nor does he consider it valid to pull a strip of fabric until it breaks as a result of tension because he believes that these isolated tests give distorted views and should not be accepted as measures of serviceability.

However, Pierce (26, p. 183, 184, 186) goes on to say that we must accept these tests as a part of a more complex picture because the quality of a fabric can be determined by its reaction to the destructive actions which occur during use. Tests used in the laboratory should be those which will bring about the types of destructive action that will be an index to the quality of the fabric. Then the results from several methods of evaluation in the laboratory can be correlated with the results of actual wear to determine the resistance of the fabric to abrasion. Stoll (34, p. 395) believed that it may not be necessary for a specific test action to exactly duplicate a specific wear action, but that the mechanical degradation must be made comparable to the actual wear pattern. Kaswell (17, p. 326) stated that the basic difference between actual wear and laboratory tests is the rate at which destruction takes place. Lester (18, p. P209) reported that when a group of fabrics of varying fiber content was subjected to two abrasives of different degrees of coarseness, those fibers which were the most resistant to the fine abrasive were also the most resistant to the coarse abrasive.

Since it is impossible to imitate all the varied conditions under which wear takes place in everyday use, laboratory tests are usually limited to one factor (32, p. 115). The validity of these laboratory tests depends upon the comparison of the combined results of several individual tests with theory and experience. When used in this manner laboratory testing becomes valid (26, p. 191, 192). The information derived from these tests serves as a basis of comparison to determine whether or not one fabric will last longer than another fabric under specified conditions (32, p. 115).

Macormac and Richardson (20, p. 149) reported that wool fabrics abraded in the Accelerotor had an appearance and texture which was similar to those that were abraded during actual service. Following a study which compared worn cotton garments with fabrics abraded in the laboratory, Clegg (7, p. T473) stated that the microscopic appearance of the fibers which had been abraded in the laboratory were identical to those fibers which had been abraded by actual wear.

A few of the abrasion and wear-testing instruments that have been designed duplicate actual wear patterns sufficiently to warrant their continued use (39, p. 625). Thus far, no one instrument has been developed which can satisfactorily abrade all the fabrics that are available (19, p. P219). For example, different styles of instruments are used to abrade a stiff fabric and a flexible fabric. Because one instrument cannot successfully reproduce all the circumstances for each situation in which wear takes place, the instrument must be limited to the reproduction of the one factor which is responsible for the major portion of the total destructive effect (6, p. 135).

According to the visual and manual evaluations conducted by Macormac and Richardson (20, p. 149), the Accelerotor is one instrument that duplicates actual wear patterns more accurately than any other abrasion instrument available. The instrument has a chamber 5.5 inches in diameter and 2.75 inches deep in which is placed a foam-lined plastic collar with a snuggly fitted abrasive liner made of crocus cloth. Rapid abrasion occurs when the fabric is impelled by means of a blade rotating at a controlled rate of speed. The fabric is driven in a random path and repeatedly strikes the liner and the walls and thereby produces friction throughout the fabric by flexing thread against thread and fiber against fiber (1, p. 127).

Types of Breakdown

The failure of fabrics to withstand abrasion is mainly the result of a weakening of the fiber structure. Clegg (7, p. T454) reported that the three general types of breakdown are transverse cracking, fibrillation and cuticle damage. The type of degradation which occurs as a result of abrasive actions is dependent upon the type and the intensity of the action (25, p. 728). The inherent structure of the fiber also influences the type of degradation which occurs.

McNally and McCord (25, p. 729) expressed the opinion that cracking is a result of the repeated flexing of a fiber. Clegg (7, p. T477) stated that a large proportion of the total breakdown of worn fibers was the result of flexing or bending. Bending creates tensile strain on the outside curvature of the bend and compression on the inside. Since buckling occurs readily, the strain on the outside of the curvature is high and the strain on the inside is relatively small. Fibers with good elasticity, such as nylon and wool, usually show good bending resistance (25, p. 733).

Fibrillation is the separation of one end of a fibril from the main portion of the fiber. It is usually the result of lengthwise degradation which is caused by friction (25, p. 728).

Damage to the cuticle, or outer cover of the fiber, is believed to be the result of stress which chips or pits the cuticle (25, p. 729).

Methods of Evaluation

Various methods have been used to evaluate the resistance of fabrics to abrasion. The methods suggested in the literature are breaking strength, bursting strength, thickness, percentage change in weight, change in appearance, air permeability, light transmission, and the microscopic examination of fibers, yarns, and the detritus. The method that is used is determined by the inherent fiber qualities, the construction of the fabric, and the intended use of the fabric. However, the literature indicates that breaking strength is the most frequently used method because it is the least objectionable criterion for measuring the extent of abrasion damage. Statements to this effect were made by Zook and Mack (40, p. 666) who worked with a Taber abraser. Stiegler and coworkers (33, p. 693) reported similar findings when the Accelerotor was used as the abrading instrument. Hamburger (11, p. 174), Kaswell (17, p. 317), Skinkle (31, p. 114, 140) and others expressed the same opinion when they discussed the subject of abrasion in a general manner.

The ratio of the revolutions per minute to the percentage loss in strength is another means of indicating the ability of a fabric to resist destruction (12, p. 388). For example, when abrading nylon and Dacron of comparable qualities for equal periods of time, nylon has the smaller ratio between the revolutions per minute and the percentage loss in strength.

Breaking strength is also a useful means of comparing fabrics of unlike strengths and varying quality (11, p. 174). The strength imparted to a fabric through the ability of the fibers to cling together is also measured by this method (26, p. P187). If breaking strength were the only criterion used for evaluation it could give a distorted view of those fabrics which have the ability to undergo deformation without damage to the fibers (17, p. 317). But when these results are combined with other tests it becomes a part of a complex picture. It is Matthew's (21, p. T530) opinion that the tensile strength of the cloth was dependent upon the closeness of the weave and the degree of twist in the yarn. However, Tait (37, p. 171) stated that as the length of the float of the warp yarn in twill fabrics increased, the tensile strength increased but the resistance to abrasion was decreased.

Bursting strength was used by Zook and Mack (40, p. 666) to evaluate the strength of woven fabrics that were abraded on a Taber Abraser. They reported that the mean results of the bursting strength method frequently lay between the highest and the lowest loss of strength recorded for the breaking strength method. They are of the opinion that even though the weaker yarns rupture first, the stronger yarns will favorably affect the bursting strength and thus the results will indicate the combined strength of the fabric in the warp and in the filling directions. Matthew (21, p. T531), after using the bursting strength test on linen fabrics, reported that the yarns generally broke in the less extensible direction. He recommended that this method be used to compare fabrics that have the same structure. The bursting strength method has an advantage over the raveled-strip breaking strength method because it requires less preparation of the samples and thereby saves time.

Loss of weight is a valuable means of determining the amount of abrasion on deep pile fabrics, but it is less valid when working with ordinary woven fabrics because lint or abradant may cling to the cloth (11, p. 174). However, Macormac and Richardson (20, p. 150) reported satisfactory results when loss of weight was used to evaluate the damage done to wool fabrics which were abraded in the Accelerotor.

The change in the appearance of the surface texture was suggested by Ball (6, p. 137) as a possible method of evaluation. However, he stated that this method may not be valid because it is influenced by personal opinion. Also the appearance of the surface may vary conversely with the length of the abrasion cycle. Early in the abrasion cycle some fabrics show a greater fuzziness and apparent wear than after the completion of the abrasion cycle because the protruding fibers are broken or sheared off, or pulled out.

Microscopic examinations of the detritus yield valuable, reproducible information concerning the fiber, the yarn, the fabric, and the processing treatments (16, p. 518). This type of study makes it possible to discern the type of degradation that has occurred and the probable steps in the breakdown.

Physical Comparison of Fibers

Susich (36, p. 225, 226) stated that the relative abrasion resistance of multifilament yarns in descending order was nylon, Dacron, viscose rayon, and Orlon. The resistance of the staple fibers in descending order was nylon, Dacron, cotton, wool, Orlon, and viscose rayon. According to a logarithmic scale of relative abrasion damage, developed by Susich, the fibers were rated according to the increase in damage as a result of abrasion. Nylon filament fibers had the least amount of damage and a rating of 1.0; wool was damaged the most and was given a rating of 15.0. The other fibers, in order of increasing damage were Dacron filament with a rating of 1.75, viscose rayon filament with a rating of 5.5, cotton with a rating of 8.5, and Orlon filament with a rating of 10.0. Hicks and Scroggie (14, p. 422) reported that the continuous filament yarns decreased in abrasion resistance in the following order: nylon, polyacrylonitrile, and viscose rayon. Clegg's (7, p. T476) findings showed very little evidence of damage by abrasion to the fibers in continuous filament viscose rayon. Instead, the fibers were pulled out and broken off. Nylon has a high resistance to abrasion as a result of its inherent toughness, natural pliability, and long flex life (23, p. 862). Cook (8, p. 246) stated that nylon has better resistance to abrasion than any other textile fiber. Susich (36, p. 977) reported that of the man-made fibers only the Dacron polyester fiber has a resistance to abrasion that is comparable to nylon. According to laboratory tests, the resistance of Orlon to abrasion is good. The extent of damage by abrasion to the Orlon acrylic fiber is greater than it is to nylon and Dacron fibers. Susich (36, p. 225, 226) stated that the degradation found in Orlon is quite similar to that found in viscose rayon (36, p. 225, 226). McNally and McCord (25, p. 731) reported that cotton has an abrasion resistance that is equal to or is better than wool. The resistance to abrasion of any fabric can be affected by many variables such as the specific type of a given fiber, weave, yarn size, and twist (24, p. 977).

When fabrics of similar fiber content and yarn size were compared, the relative amount of abrasion damage to the spun yarns was always higher than was the damage to the multifilament yarns. The protruding fiber ends of the staple yarns seemed to be more easily pulled out or they were cut off by the abrasive. This loss of fibers permitted a loosening and untwisting of the yarns (36, p. 225, 226).

The appearance of damaged fiber ends varies with the inherent structure of the fiber and with the extent of degradation. Clegg (7, p. T476) found that as a result of abrasion, the cellulosic and protein fibers tended to break at right angles to the fiber axis and that these breaks were often accompanied by fiber distortion. The breaks of the wool were neither at such definite right angles nor were they as sharp as were those breaks in the cotton and viscose rayon. McNally and McCord (25, p. 728) reported that after the fiber sheath of wool had been removed, further abrasion caused fibrillation of the cortex. The breaks in the continuous filament and staple rayon fibers had the appearance of broken glass rods. Some breaks in the rayon were clean and others had irregular jagged edges (7, p. T477). A search of the literature revealed no information concerning the appearance of abraded nylon and Dacron fibers.

Hartsuch (13, p. 251, 252) stated that the strength of the fibers is usually in proportion to the degree of orientation. On this premise, wool is weak, and cotton has medium strength. All of the man-made fibers can be made in a wide range of tensile strengths by subjecting the fibers to varying amounts of stretching in order to align the molecules in a position parallel to the axis of the fiber. One means of determining the crystallinity of a fiber is by means of X-ray diffractions. The patterns of the cross section of a textile fiber are a result of the crystalline structure of the basic chemical elements and the arrangement of these elements within the fiber (26, p. 1149). X-ray diffractions show that Dacron, Orlon, and nylon are highly oriented. The amount of crystallinity in Dacron is between 70 and 80 per cent, which is comparable to nylon (24, p. 1026).

The elongation of the fibers as stated in the literature is given as a basis for comparing their relative resistance to abrasion. A relatively high elongation is found in wool, which has an elongation of 25 to 35 per cent (8, p. 89), and in nylon which has an elongation of 26 to 32 per cent (8, p. 237). A moderate elongation is found in Dacron which elongates from 20 to 30 per cent (8, p. 282) and in Orlon which elongates from 20 to 28 per cent (8, p. 294). Viscose rayon has an elongation of 17 to 25 per cent (8, p. 179) and cotton has an elongation of only 5 to 10 per cent (8, p. 57).

The tensile strength or the tenacity of a fiber may be defined as the amount of tension that is required to break the fiber, yarn, or fabric; it is also defined as the resistance of a fabric to a pulling force (13, p. 107). It is measured in grams per denier, which is a unit of weight that expresses the size of a yarn. The tensile strength of the fibers as stated in the literature is given as a basis for comparing their relative resistance to abrasion. A relatively high tensile strength is found in nylon which has a tenacity of 4.6 to 5.8 grams per denier (8, p. 237) and in Dacron which has a tenacity of 4.5 to 5.5 grams per denier (8, p. 281). A moderate tensile strength is found in cotton which has from 3.0 to 5.0 grams per denier (8, p. 57). Orlon has a tenacity of 2.2 to 2.6 grams per denier (8, p. 294) and viscose rayon has a tenacity of 2.0 to 2.6 grams per denier (8, p. 178), while wool only has a tenacity of 1.0 to 1.7 grams per denier (8, p. 89).

The elasticity of the fibers, as stated in the literature, is given as another basis for comparing the relative resistance of fibers to abrasion. The elasticity, or the return of a fiber to its original length, is the effort of the fiber to oppose pulling and stretching forces (13, p. 113). The recovery from distortion may occur immediately upon the release of stress, but there may be an immediate partial recovery and then the fiber may creep back slowly to its original length. The rate and per cent of recovery varies with the individual fibers. Nylon has 100 per cent recovery at 8 per cent extension (8, p. 237); Orlon has an elastic recovery that is similar to that of nylon (13, p. 354). Wool has 99 per cent recovery at 2 per cent extension (8, p. 89), and Dacron has an elastic recovery similar to that of wool (27, p. 118). Cotton has 74 per cent recovery at 2 per cent extension and 45 per cent recovery at 5 per cent extension (8, p. 58) while viscose rayon has 60 per cent recovery at 2 per cent extension (8, p. 179).

The flex life of a fiber indicates the number of times a fiber can be bent before it will break (25, p. 733). Orlon will withstand over 300,000 flexes, wool fails after 44,000 flexes, and viscose rayon after it has been flexed 2,500 times (13, p. 357). Mauersberger (24, p. 947, 1029) stated that nylon will withstand a high degree of flexing before breakdown and that Dacron has rapid recovery from bending but no specific figures seem to be available in the literature for nylon and Dacron.

The strength of a yarn is dependent upon many factors. When the fabrics in a staple yarn are held in place by contact with adjacent fibers, the strength of that yarn is not only influenced by the strength of the fibers, but also by the length and fineness of the fiber, the shape of the cross section, the surface roughness (25, p. 733), the relative surface area, the amount of entanglement, the changes resulting from friction, and the density of the yarn (24, p. 192). The specific combination of factors that are present in a given fiber determine the ability of the fibers to cling together. However, unless the fibers in the yarns have close contact they will not cling together (13, p. 117). By twisting the fibers together pressure is produced which increases the friction and the yarn density and thus holds the fibers in the yarn. The amount of twist present appears to have two effects on the strength of the yarns. A low twist will produce a weak yarn because the fibers may be easily removed. A high twist can cause shearing effects on the fiber and thus weaken the yarn. Therefore a medium twist yields optimum strength. The amount of twist that is desirable for a yarn that is made from one fiber is not necessarily desirable for a yarn made from another fiber. However, the optimum twist for a given yarn is that amount which yields maximum strength (24, p. 193). Comparisons of strength between filament yarns and staple yarns of similar size, twist, and fiber content indicate that the continuous filament yarns are stronger (23, p. 774). Dull filament yarns are reported to be weaker than bright yarns (23, p. 267).

The Form Factor in Yarn and Fabric

Hamburger (11, p. 173) placed the factors influencing abrasion resistance into two classes: the inherent abrasion resistance of the material, and the geometry of the composite structure which may be classified as the form factor.

One might expect that the larger yarns would yield greater resistance to abrasion (14, p. 421). Tait (37, p. 171) found that a 150 denier yarn was the optimum warp yarn size for rayon lining fabrics. Little gain in resistance to abrasion was shown in larger yarns, and there was a consistent drop in the resistance to abrasion in smaller deniers. Mauersberger (23, p. 767) reported that when yarns having the same denier are compared, those yarns that are composed of a high number of filaments are usually weaker than those composed of a low number of filaments, because the smaller filaments can withstand less strain. Hicks and Scroggie (14, p. 422) found that the maximum resistance to abrasion was obtained by using yarns composed of filaments ranging from three to five denier. Stoll (34, p. 407) reported that the smaller fibers in staple rayon yarns were ruptured across the entire fiber cross section whereas only a portion of the coarser fibers in these yarns were torn away.

The maximum abrasion resistance of 150 denier rayon warp yarn is obtained when the yarn has from six to twelve turns per inch (14, p. 422). Yarns of relatively low twist have a greater portion of the yarn surface exposed to the abradant and there is less binding power for the individual fibers than in highly twisted yarns (4, p. 635). As a result the fibers are more easily removed from the yarn. Yarns of high twist receive severe local abrasion pressure and an early breakdown of the yarn results (4, p. 635).

Another factor influencing the resistance of fabrics to abrasion is the crown height. Crown height is defined as the amount a yarn rises above the plane of the fabric as a result of the crossing of the warp and filling yarns. Variations in the size of the yarns, the twists per inch, and the frequency of the yarn intersections influence the height of the crown. For example, a plain weave fabric having large yarns with a high twist will have a high crown (4, p. 635). There is a direct relationship between the number of crowns per inch and the durability of a fabric. For example, if two fabrics were woven from the same yarn, but had a different number of crowns, the fabric with the higher number of crowns would tend to be more durable because the wear per crown would be less (4, p. 332).

The count or number of yarns per inch in the fabric also influences the resistance to abrasion. The relationship between the count and the size of the yarns determines the closeness of the weave. The compactness of the fabric and the type of weave influence the stiffness of the fabric. Although the compactness of the fabric improves the resistance to abrasion of fabrics which are held in a fixed position, it may have an adverse effect upon the flex abrasion as a result of the increased friction between the fibers. When it is necessary to have a closely woven fabric, those constructed of a twill weave or satin weave permit a closer packing of the yarns with less loss of yarn movement than that which occurs in a plain weave (25, p. 743, 735).

METHODS AND PROCEDURES

Analysis of Fabrics

The fabrics that were used in this study were woven from wool, cotton, viscose rayon, nylon, Dacron, and Orlon. They were selected on the basis of their similarity in count, weave and weight. Each fabric was analyzed to determine its fiber content. The wool and cotton fibers were examined under the microscope, and chemical tests recommended by the American Society for Testing Materials were used to identify the synthetic fibers. The stain differentiation test was used to distinguish between the Orlon and the Acrilan (3, p. 117). The nylon was identified by its solubility in a 6N solution of hydrochloric acid within five minutes, and the Dacron by its solubility in boiling 45 per cent sodium hydroxide within 30 minutes (3, p. 125).

The number of yarns per inch in each fabric was obtained by counting the number of warp yarns per inch and the number of filling yarns per inch with the Suter Counter. The ten places counted in both the warp and in the filling were randomized inside the four inch margin allowed on each fabric. The average of the ten places in each direction was reported.

Yarns from each fabric were untwisted to determine whether the yarns had an S or Z twist. According to the instructions set up by the American Society for the Testing of Materials (3, p. 598, 599, 605), the Direct Counting method was used on the multifilament yarns and the Untwist-Twist Method was used on the staple yarns. Twenty specimens, each ten inches long, were taken from the warp and the filling of each fabric. A tension of 0.25 gram per tex or per unit of linear density, was applied to each yarn. The average of the twenty specimens was divided by the length of the specimen to determine the twists per inch.

The yarn number of each fabric was determined by setting the clamps of the Suter Twist tester at 50 centimeters with a tension of three grams. Ten specimens were measured from the warp and filling of each fabric. Tex was calculated on the basis of the weight of each five meter specimen.

Preparation of Specimens

The American Association of Textile Chemists and Colorists (1, p. 128) recommends that the size of the specimens be determined on the basis of the weight per square yard of the fabric. The recommended sizes are as follows:

Weight of Fabric (oz. per sq. yd.)	Dimensions of Specimens (inches)
9 - 12	3.75 x 3.75
6 - 9	4.5 x 4.5
3 - 6	5.25 x 5.25
less than 3	6 x 6

In prior work, the weight of the fabric was determined and specimens were cut to the recommended sizes and abraded to determine the size of specimen that would be suitable for use in the Accelerotor. It was found that all the fabrics could be cut to the recommended size except the one woven of cotton because holes were worn in it before it had been abraded for four minutes. By reducing the size of the cotton specimens from 5.25 to 4.50 inches they could be abraded for at least twelve minutes, the recommended break-in period for the liners, before holes were worn in the specimens.

The amount of fabric that was required for this study was determined by the number of and the sizes of the specimens which were needed. A plan for the cutting of these specimens was developed which included a margin equal to ten per cent of the width of the yardage. The layout of the specimens was randomized in the area inside the margin to avoid distortion which frequently occurs at the edges of the fabric. The control specimens of the unabraded fabric were cut the same size as those that were to be abraded, but the edges of the control fabric were not finished in any way to prevent raveling. The direction of the warp was marked on each specimen by a small arrow made with a ball point pen.

All the fabrics were cut on the grain line. Because of the problems involved when working with pinking shears, the initial cutting was done with plain scissors, allowing 0.25 inch extra on each side for pinking. After pinking two adjacent sides, the square was remeasured from the inside of the pinked edges and cut to the correct dimensions.

When using the Accelerotor as an abrading instrument, it is necessary to employ some means to prevent the raveling of the edges of the specimens. Trial experiments were made to determine which edging would be the most satisfactory for each of the fabrics. Vulcanol adhesive AL 100-5, suggested by the American Association of Textile Chemists and Colorists (1, p. 128), was excellent for wool, and it was found to be satisfactory for cotton if a very small amount was used. When used freely, it tended to stick to itself and to the rotor and thus altered the rate of speed and caused localized abrasion. Experiments were made with a wide variety of glues and cements on the man-made fibers. Edge stitching without turning the edge under was tried, but it raveled out. Although the turned and stitched edge prevented raveling it was felt that the hem would unduly increase the weight of the specimen. Vulcanol and the other adhesives having a rubber type base peeled off, and the cements and glues cracked and chipped. Although the fingernail polish chipped to some extent during abrasion, it proved to be quite satisfactory for all the fibers except wool; therefore, it was used on the cotton, viscose rayon, nylon, Dacron, and Orlon. Vulcanol was used on the wool. The adhesives were applied to a distance of approximately 1/16 inch inside the edge. All adhesive edgings were applied to only one side of all of the specimens except nylon, which raveled so readily that the nail polish was applied to both sides. The specimens were allowed to dry at room temperature.

During the trial experiments some of the particles of the disintegrated fingernail polish clung to the cloth but this fact was not visible to the naked eye because natural colored polish was used. However, when the actual test specimens were edged with bright colored polish redeposition became evident during the study. In order to determine the weight of the fabric without the redeposited polish a second set of samples was prepared with turned and stitched edges. These specimens were cut 0.5 inch larger than the specified finished size, they were pinked on all four edges, turned once, and stitched with two rows of nylon thread 1/16 of an inch apart, using 25 stitches per inch. The first row of stitching was sewed on the first uncut yarn by the pinked edge. This method helped to prevent the long yarns from raveling and catching on the rotor. Because it was difficult to stitch on the grainline it was necessary to clip any long yarns that may have been between the pinked edge and the stitching line.

Abrasion of Specimens

All of the samples were conditions at 70°F ± 2°F and 65 per cent humidity ± 2 per cent for a minimum of eight hours. A moderately coarse abrasive liner, number 180, and the 4.5 inch pitched blade were used in the Accelerotor. The blade rotated 3,000 revolutions per minute. Trial experiments were necessary to determine the length of abrasion time needed to bring about enough degradation to give measurable results. The length of time required was based on the loss of weight and the tensile strength. The nylon and Dacron were each abraded for eight minutes, and the wool, cotton, viscose rayon, and Orlon were each abraded for four minutes.

The abrasive liners were prepared according to the recommendations of the American Association of Textile Chemists and Colorists (1, p. 128). Six samples, one from each fabric, were abraded on one liner in a randomized sequence. After a liner had been used for 16 minutes of abrasion, the liner edge that had been facing the front of the chamber was turned so that it faced the back. Thus the effect of the abrasive liner was more equalized than if the fabrics had all been abraded with the liner facing in one direction.

After the specimens were abraded the weight and breaking strength specimens were prepared and conditioned at 70°F ± 2°F and 65 per cent humidity ± 2 per cent for a minimum of eight hours.

Methods of Evaluation

The loss in breaking strength by the raveled strip method as a result of abrasion was determined by using a Scott Pendulum type tester. Twenty breaking strength strips and seven weight specimens were prepared from each of the six fabrics. To randomize the breaking strength strips and weight specimens among the abraded specimens, one weight specimen and two breaking strength strips were cut from each of the abraded specimens. Since fewer weight specimens than breaking strength strips were needed the remaining breaking strength strips were cut from two abraded specimens. Ten breaking strength strips were cut with the warp yarns running lengthwise in the specimen and ten strips were cut with the filling yarns running the long way of the strip. An equal number of similar specimens were prepared from the control fabric. All the strips were cut 1.25 inch in width and as long as the size of the specimen would allow, they were raveled to 1 inch in width. The specimens that were cut from the abraded pieces were cut no closer than 0.25 inch from the adhesive edging. Each specimen was marked on the crosswise grain with a ball-point pen or pencil to facilitate placing equal stress on the lengthwise yarns. The specimen was placed with the yarns parallel to the edge of the clamp and was centered in clamps having faces 1 by 1.5 inch. The distance between the clamps for the cotton was reduced to two inches because of the smaller size of the specimen.

The breaking strength of each specimen was recorded to the nearest 0.5 pound. The mean breaking strength and the percentage loss in breaking strength were determined for the warp and filling directions.

Another method of testing the strength of a fabric is to burst it by applying a uniform force which is at right angles to a given area of the fabric (31, p. 145). The Scott Tester with the ball-burst attachment was used for determining the bursting strength of the fabrics. Ten specimens of each of the control fabrics and ten specimens of each of the abraded fabrics were tested. The force in pounds required to burst the fabric was read to the nearest

0.5 pound. The mean bursting strength and the percentage loss in bursting strength were calculated.

Seven two-inch squares were cut with a die from each of the control fabrics; a two-inch square was cut from each of the abraded fabrics giving a total of 14 specimens. These specimens were weighed on an analytical balance and compared to the control fabrics to determine the change in weight as a result of abrasion. One weight specimen was cut from each of the seven abraded specimens that were edged with the nail polish. They were cut at least 0.25 inch inside the edging. Breaking strength strips were cut from the remaining portion of the same specimen. Seven weight specimens were cut in the same manner from the specimens of each fabric with the turned and stitched edges. Each specimen was handled with forceps, and weighed to ± 0.0001 gram. The mean weights and the percentage change in weight were determined. Results for both sets of abraded specimens were compared with the specimens cut from the control fabric.

A visual evaluation of the effects of abrasion as indicated by broken or protruding fibers on the surface of the fabrics was conducted by a panel of five judges who were graduate students and staff members. The judges ranked the fabrics according to the apparent increase in the number of damaged fibers. Two sets of unidentified specimens were placed on a table in bright daylight, but not in the direct sunlight. One set of specimens was from the group edged with nail polish or Vulcanol and one set from the group with the turned and stitched edge because it was thought that there might be a difference in appearance as a result of the redeposition and possible abrasion by the fragments of nail polish. Each set was coded from A to F in random order.

Fibers, yarns and fabrics were examined under the microscope. An average of six abraded fibers from each fabric were observed, and a specimen typical of its kind was mounted in glycerine and photographed at 300x magnification so that the type of damage incurred and the possible steps in the breakdown of the fibers could be studied. A comparison was made between the damage found in protruding fiber ends and in the fibers separated from the fabric as a result of abrasion. Warp and filling yarns were removed from each of the abraded fabrics and the control fabrics and were mounted on black paper and photographed at 10x magnification. The abraded and control fabrics of each fiber were folded on the true bias over the edge of thin cardboard and held taut with cellophane tape while they were photographed at 10x magnification.

As much detritus was obtained as was possible from two abrasion cycles. The quantity was compared on a visual basis to determine the approximate loss of fibers from each fabric. It is impossible to determine the amount of fibers which is separated from each fabric, because a little detritus clings to the fabric, and to the abradant, and to the chamber walls. Some fibers also tend to pack together while others retain considerable resilience.

The significance of difference between means for breaking strength, bursting strength and change in weight before and after abrasion was determined by the *t* test.

DISCUSSION OF DATA

Throughout this study the fabrics are divided into two groups according to the length of time that they were abraded. Nylon and Dacron, which were abraded for eight minutes, are in one group and wool, cotton, viscose rayon, and Orlon, which were abraded for four minutes are in the second group.

Effects of Abrasion on Breaking Strength

In all the fabrics the breaking strength in the warp and filling yarns was reduced significantly by the abrasive action (Tables I, II, and Figure 1).

The nylon fabric had 87.7 warp yarns per inch and each yarn had a denier of 76.88, 34 filaments, and 7.97 twists per inch. There were 74.8 filling yarns per inch and each yarn had a denier of 110.52, 34 filaments, and 7.11 twists per inch (Table III). In the nylon fabric there was a 36.40 per cent loss of strength in the warp yarns and a 32.33 per cent loss of strength in the filling yarns. The greater loss of strength in the warp than in the filling may have been the result of a smaller denier in both the individual filaments and in the over-all yarn size. The high degree of toughness, pliability and flexibility present in nylon makes it one of the most durable man-made fibers. Its strength may be attributed to its

Table I

WARP BREAKING STRENGTH BY THE RAVELED-STRIP METHOD

Fiber Composition	Control (pounds)	Abraded (pounds)	Change (per cent)
Nylon	129.55	82.40	-36.40
Dacron Polyester	112.70	30.80	-72.67
Cotton	72.55	58.50	-19.37
Wool	30.05	23.20	-22.80
Viscose Rayon	41.50	18.50	-55.42
Orlon Acrylic	60.70	20.25	-66.64

Table II

FILLING BREAKING STRENGTH BY THE RAVELED-STRIP METHOD

Fiber Composition	Control (pounds)	Abraded (pounds)	Change (per cent)
Nylon	104.25	70.55	-32.33
Dacron Polyester	89.85	21.15	-76.46
Cotton	43.70	32.10	-26.54
Wool	22.05	15.65	-29.02
Viscose Rayon	38.00	17.05	-55.07
Orlon Acrylic	48.95	10.00	-79.57

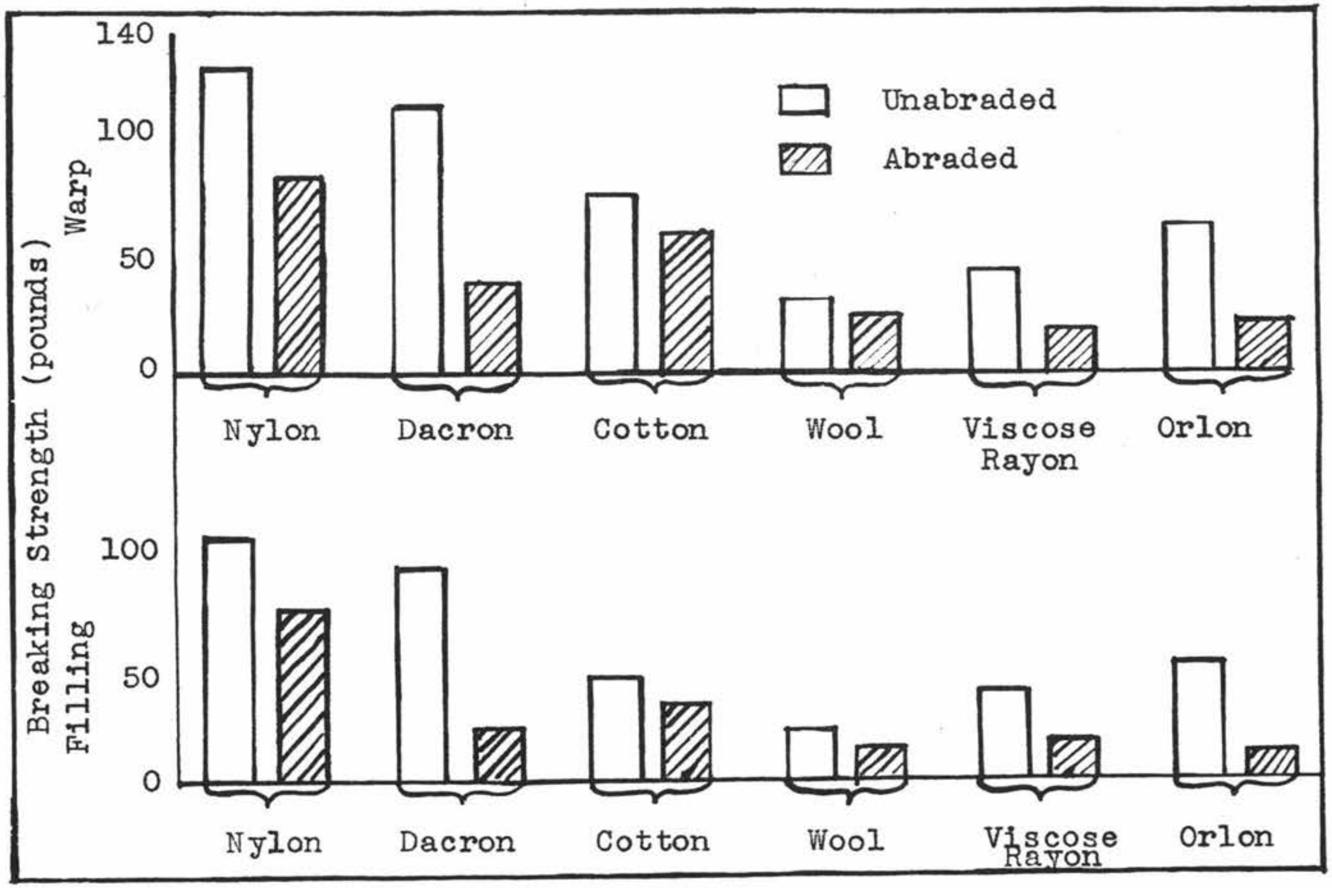

Figure 1. BREAKING STRENGTH BEFORE AND AFTER ABRASION

Table III

CHARACTERISTICS OF THE YARNS AND FABRICS

Fiber Composition	Weight per Square Yard (ounces)	Count per Inch Warp (number)	Count per Inch Filling (number)	Yarn Twist per Inch Warp (number)	Yarn Twist per Inch Filling (number)	Yarn Number Warp (denier)	Yarn Number Filling (denier)
Nylon	2.8747	87.7	74.8	7.97	7.11	76.68	110.52
Dacron	3.2167	77.9	66.3	6.03	6.72	167.04	173.52
Cotton	3.2139	86.4	78.3	20.87	24.86	159.48	126.72
Wool	4.1534	56.6	45.5	16.54	17.60	310.86	301.14
Viscose Rayon	2.6926	97.8	65.6	3.15	3.02	104.40	160.74
Orlon	1.9767	86.8	63.8	3.65	4.34	103.32	108.00

extremely long, highly oriented molecular chains in which the molecules are closely packed (21, p. 861, 862). The ability to stretch 20 per cent before breaking and the excellent elastic recovery make it possible for the fibers to undergo large amounts of distortion before degradation takes place (13, p. 253). The smoothness and the cylindrical shape of the filaments reduces the friction between the fibers, the yarns, and the abradant and thus reduces abrasion as a result of friction (23, p. 861, 862).

The Dacron fabric had 77.9 warp yarns per inch and each yarn had a denier of 167.04, 34 filaments, and 7.11 twists per inch. The filling yarns had a denier of 173.52, 34 filaments, and 6.72 twists per inch (Table III). In the Dacron fabric there was a 72.67 per cent loss of strength in the warp yarns and a 76.46 per cent loss of strength in the filling yarns. The greater loss in strength in the filling than in the warp may have been the result of a lower count and a smaller denier. The Dacron fibers, although comparable to nylon in toughness and smoothness, are not as strong (31, p. 225, 226). Dacron also has highly oriented long chain molecules, but the benzene ring in the Dacron reduces the flexibility in the chains so that the fiber has an inherent stiffness which resists bending. Dacron is incapable of being distorted as much as nylon as a result of this resistance to bending and the fibers being weaker than nylon.

The percentage of loss in the breaking strength of the Dacron in both the warp and the filling yarns was at least twice as great as was the strength of the nylon yarns (Figure 2). The Dacron warp yarns had 1.94 twists per inch less than the nylon and the Dacron filling yarns had .39 twists per inch less than the nylon. The warp and filling yarns of both fabrics had 34 filaments each, but the denier of the warp yarns in the Dacron was twice as large as those in the nylon fabric; the filling yarns were one-third larger than those in the nylon fabric. The Dacron fabric had 9.8 less yarns per inch in the warp and 8.5 less yarns per inch in the filling than did the nylon. However, the strength of the Dacron control fabric was 16.8 pounds less in the warp and 14.40 pounds less in the filling than the nylon. The review of literature indicated that the strength of the Dacron is comparable to that of nylon but it is not equal to it (36, p. 225, 226). Nylon has been known for its outstanding strength and the findings in this study coincide with the literature. Although the Dacron lost at least twice as much strength as the nylon, 25.64 per cent of its strength remained after eight minutes of abrasion.

The Orlon fabric had 80.8 yarns per inch and each yarn had a denier of 103.32, 40 filaments, and 3.65 twists

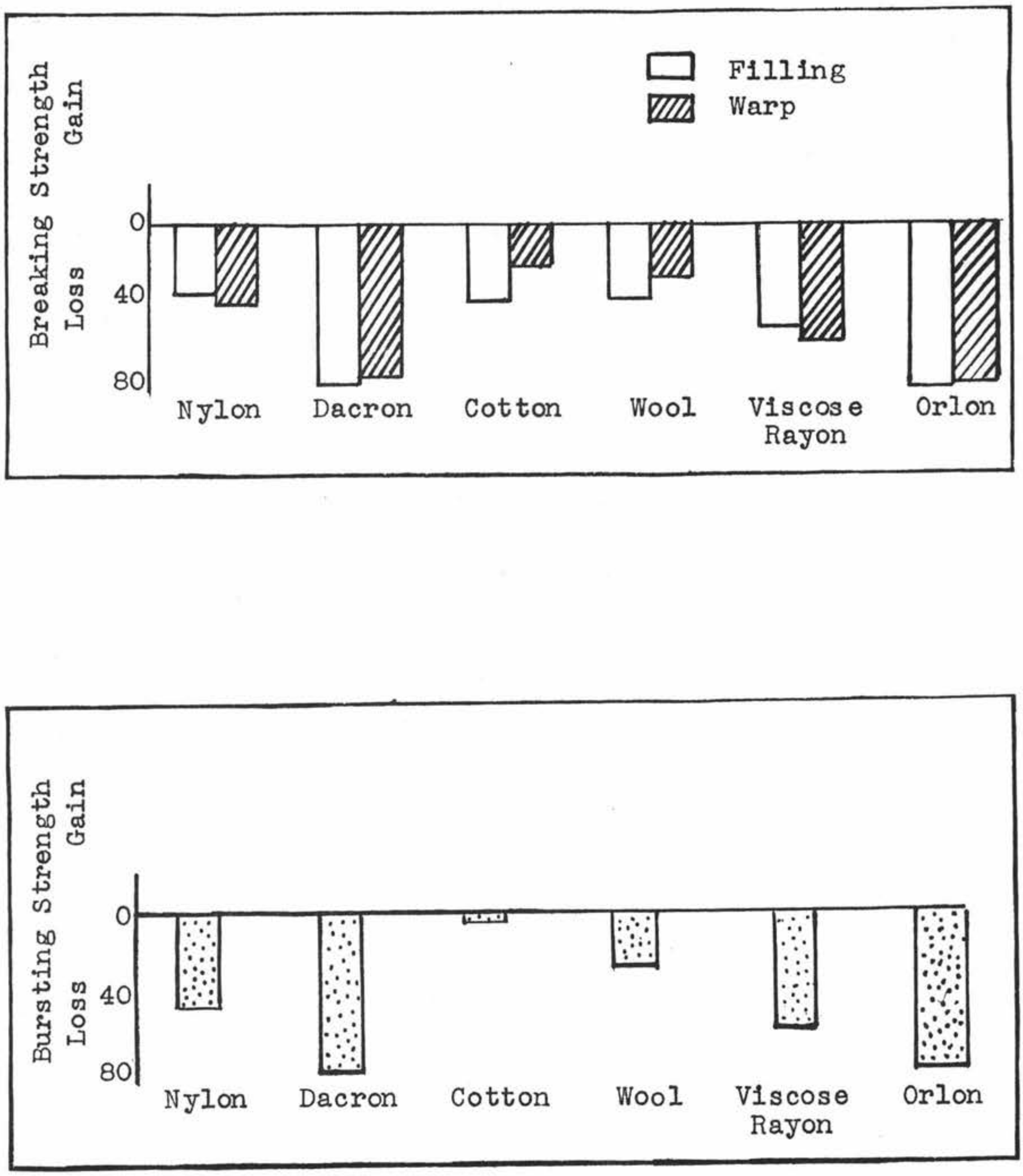

Figure 2. PERCENTAGE LOSS IN STRENGTH AFTER ABRASION

per inch. The filling had 63.8 yarns per inch and each yarn had a denier of 108.00, 41 filaments, and 4.34 twists per inch. In the Orlon fabric there was a 66.64 per cent loss of strength in the warp and a 79.57 per cent loss of strength in the filling. Therefore it would seem that the greater loss of strength in the filling may have been the result of the lower yarn count. Orlon was much weaker than the other synthetic fibers that were studied (36, p. 225). Orlon can be flexed 300,000 times before it ruptures (13, p. 357), but it lacks the ability to stretch (35, p. 225, 226). The inability to stretch would reduce its ability to prevent degradation by distortion. It would seem that its strong tendency to form fibrils, which was evidenced in this study, would lower its resistance to abrasion and reduce its durability. A contributing factor to this fibrillation may be the structure of the fiber into two parts, the cuticle and the cortex.

The viscose rayon fabric had 97.8 warp yarns per inch and each yarn had a denier of 104.40, 60 filaments, and 3.15 twists per inch. The filling had 65.6 yarns per inch and each yarn had a denier of 160.70, 85 filaments, and 3.02 twists per inch. In the viscose rayon there was a 55.42 per cent loss of strength in the warp yarns and a 55.07 per cent loss of strength in the filling yarns. It may be that the larger denier of the filling yarns and the higher count in the warp made it possible for both sets of yarns to withstand equal amounts of abrasion damage. Viscose rayon has much less inherent strength than does nylon and Dacron (Figure 1). Sometimes Orlon is weaker than viscose rayon, but this depends upon the degree of orientation present. It has the ability to stretch 18 per cent before breaking, which is comparable to nylon, but it has a low elastic recovery. It can be flexed only 2,500 times before it ruptures (13, p. 253, 357). The serrated cross section of the fiber tends to increase the friction between the fibers and between the fibers and the abrasive.

The percentage of loss in the breaking strength of the Orlon was 11.22 per cent greater in the warp and 24.50 per cent greater in the filling than the viscose rayon (Figure 2). The Orlon warp yarns had .50 twists per inch less than the viscose rayon and the Orlon filling yarns had 1.32 twists per inch more than the viscose rayon. Each of the warp and filling yarns of the Orlon had 40 filaments. The warp of the viscose rayon had 1/3 more filaments than the Orlon and the filling had over twice as many filaments as the Orlon. The denier of the warp yarn in both fabrics was almost the same but the denier of the viscose rayon filling was 1/3 larger than that of the Orlon. The count of the filling was almost the same in both fabrics, but the warp of the Orlon was 18 per cent smaller than that of the viscose rayon. The review of literature indicated that Orlon is usually more resistant to abrasion than is viscose rayon. However, the strength of the fibers in both fabrics is influenced by the degree of orientation present. Both fibers have a smooth surface with an irregular shape. The amount of friction between the fibers would be less than that of cotton and wool but greater than that of nylon and Dacron. While the viscose rayon has greater ability to stretch than does the Orlon, its ability to recover from elongation is much less than that of the Orlon. The flex life of the Orlon is 120 times greater than that of the viscose rayon. Although the Orlon had nearly twice as much strength as the viscose rayon before abrasion, the rayon retained 44.74 per cent of its strength and the Orlon retained 25.50 per cent of its strength after four minutes of abrasion.

The cotton fabric had 86.4 yarns per inch and each yarn had a denier of 159.48, and 20.87 twists per inch. The filling had 78.3 yarns per inch and each yarn had a denier of 126.72 and 24.86 twists per inch. There was a 19.37 per cent loss of strength in the warp yarns of the cotton fabric and a 26.54 per cent loss of strength in the filling yarns. The greater loss of strength in the filling yarns may have been the result of the smaller denier of the filling yarn. Cotton has a fibrillar structure that is held together with an amorphous cement (13, p. 166). This structure plus the presence of a lumen allows the fibrils to move slightly in relation to each other thus making possible a good reversible bending strength. The medium degree of orientation of the molecules provides a good tensile strength (24, p. 260). Cotton has a low percentage of elongation, is relatively inelastic, and it has a strong tendency to fibrillate. The convolutions of the fibers cause them to cling to each other but at the same time they increase the friction between the fibers.

The wool fabric had 56.6 warp yarns per inch and each yarn had a denier of 310.86 and 16.54 twists per inch. The filling had 45.5 yarns per inch and each yarn had a denier of 301.14 and 17.60 twists per inch. The wool fabric had a 22.80 per cent loss of strength in the warp yarns and 29.02 per cent loss of strength in the filling yarns. The greater loss of strength in the filling yarns than in the warp yarns may have been the result of the lower count and the smaller denier in the filling yarns.

The individual wool fibers have a low degree of orientation which results in a weak fiber (13, p. 251, 252). However, it can be stretched 30 per cent before it will break, it can be flexed 44,000 times before it ruptures, and it has excellent elastic recovery (13, p. 357).

The epidermal scales on the wool fiber increase the ability of the fibers to cling together and in this way give added strength to the fabric. These scales show no tendency to form fibrils, however the spindle-shaped cells in the cortex will fibrillate after the scales have been removed. Clegg (7, p. T475) found that much of the damage to wool fibers was by transverse cracking without fibrillation.

The percentage loss of strength of the wool filling yarns was 3.43 per cent greater than were those of the cotton filling yarns (Figure 2). The wool warp yarns had 4.33 twists per inch less than the cotton and the filling yarns had 7.26 twists per inch less than the cotton. The denier of the wool warp was twice as large as the cotton warp and the denier of the wool filling was 1-1/6 times larger than that of the cotton warp. The count of the wool warp was 2/3 less than that of the cotton and the count of the wool filling was 3/5 less than that of the cotton. The review of literature indicated that cotton usually has better resistance to abrasion than wool and the findings of this study coincide with the literature. The breaking strength of the cotton appeared to be a little stronger than it should have been because the distance between the clamps was shorter when the cotton strips were broken. The strength of these fibers may vary according to the conditions under which they were grown, and the processing treatments to which they were subjected during textile manufacture.

The results of the breaking strength tests indicated that of the six fibers used in this study nylon had more resistance to abrasion than any of the other fibers. Nylon retained 65.42 per cent of its strength after it was abraded; Dacron retained 25.65 per cent of its strength. Both of these fibers are more resistant to abrasion than the other four fibers because they were able to withstand twice as much abrasion. Of the fibers abraded for four minutes only the cotton exceeded the Dacron in strength retained. Of the fibers abraded for four minutes cotton retained 60.73 per cent of its total strength, wool retained 74.57 per cent, viscose rayon retained 44.75 per cent, and Orlon retained 27.59 per cent of their total strength.

Effects of Abrasion on Bursting Strength

All of the abraded fabrics except those woven of cotton decreased significantly in their bursting strength (Table IV and Figure 3). All of the fabrics broke in a straight line along the weakest yarn except the cotton specimens which broke in an arc. The cotton warp yarns appeared to have less strength when the bursting strength method was used than when the breaking strength method was

Table IV

BURSTING STRENGTH

Fiber Composition	Control (pounds)	Abraded (pounds)	Change (per cent)
Nylon	239.95	135.50	-43.53
Dacron Polyester	232.35	49.05	-78.87
Cotton	53.70	52.30	- 2.61
Wool	62.90	46.80	-25.60
Viscose Rayon	71.05	32.60	-54.17
Orlon Acrylic	120.05	26.50	-77.93

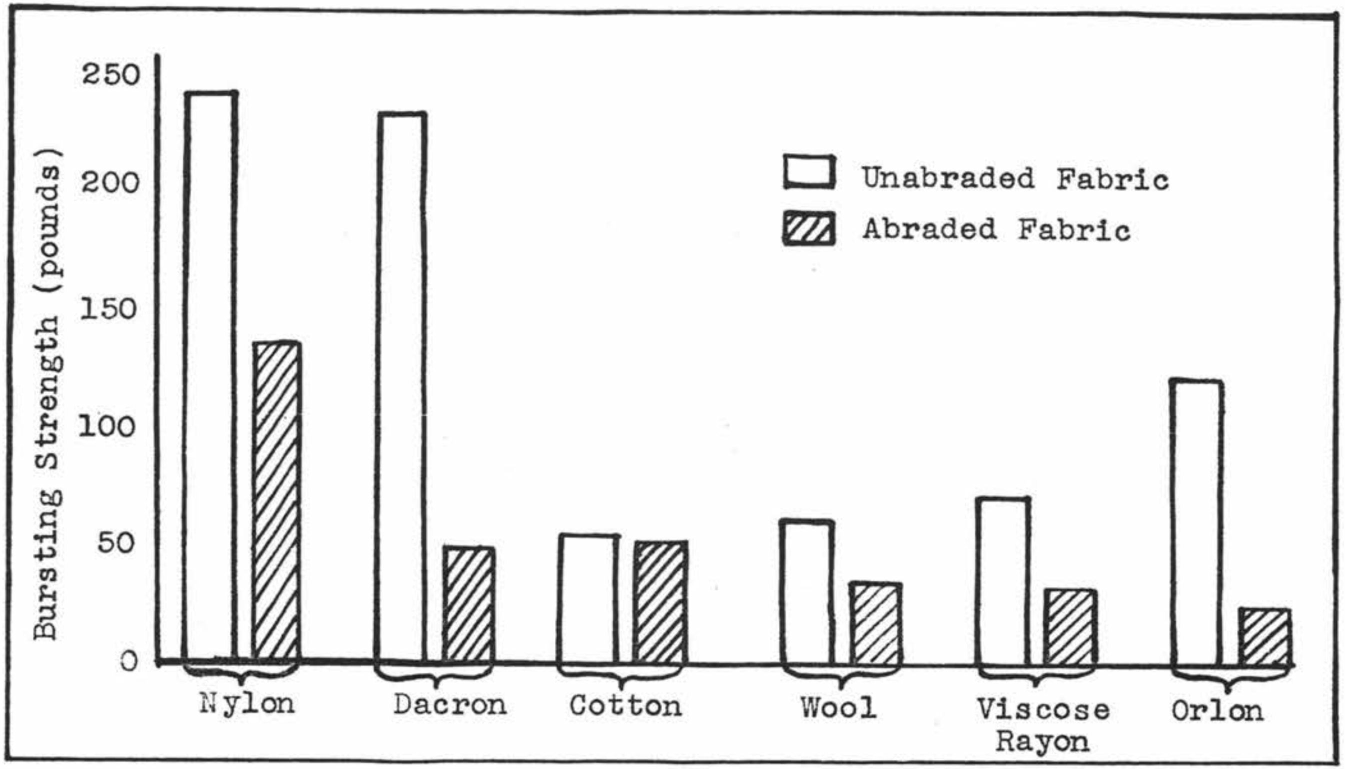

Figure 3. BURSTING STRENGTH BEFORE AND AFTER ABRASION

used. It was expected that the bursting strength of the cotton control fabric would be as high as the combined strength of the unabraded warp and filling yarns (Table V). The combined warp and filling strength was not as high in most of the control fabrics as was the bursting strength. Except for the cotton, the per cent of strength retained by the fabrics after abrasion was very similar to that indicated by the breaking strength method. The strength retained was as follows: nylon 56.47 per cent, Dacron 21.13 per cent, cotton 97.39 per cent, wool 74.40 per cent, rayon 45.83 per cent, Orlon 22.07 per cent.

Comparison of Breaking Strength and Bursting Strength

When the loss of strength of the fabrics that were abraded for eight minutes was compared with those fabrics that were abraded for four minutes, all of the fibers arranged themselves in the same order for bursting strength as they did for breaking strength (Figure 2). The bursting strength tended to be greater than either the warp or the filling breaking strength but less than the combined strength of the warp and filling yarns except for the wool (Table V). These results would support the theory that the stronger yarns favorably influence the total bursting strength of the fabric (40, p. 666). However, the bursting strength for both the control and the abraded cotton specimens was less than the warp breaking strength of the

Table V

TOTAL STRENGTH RETAINED AFTER ABRASION
AS INDICATED BY BURSTING AND BREAKING STRENGTHS

Fiber Composition	Breaking Strength Combined Warp and Filling (pounds)	Bursting Strength (pounds)	Difference (per cent)
Nylon	152.95	135.50	11.41
Dacron Polyester	51.95	49.05	5.58
Cotton	90.60	52.30	25.92
Wool	38.85	*46.80	*16.99
Viscose Rayon	35.55	32.60	8.30
Orlon Acrylic	30.25	26.50	12.40

* Only wool showed an increase when tested by bursting strength.

cotton. The bursting strength of the abraded wool was greater than the combined strength of the abraded warp and filling yarns. This may be the result of the tendency of wool fibers to cling together. The difference between the strength retained by the bursting strength and the combined warp and filling breaking strengths is shown in Table V. This analysis seems to indicate that there is a closer relationship between the total warp and filling breaking strength and the bursting strength for fabrics composed of filament yarns than there is for those fabrics made from staple yarns. In all of the fabrics woven of continuous filament yarns, the bursting strength of the abraded fabric was greater than was the breaking strength of the abraded warp yarns, but it was less than the combined breaking strength of the warp and filling yarns (Tables I, V).

Effects of Abrasion on Weight

In the review of literature it was noted that fabrics having little bulk did not lose enough weight to provide a valid measurement and in some instances there was a gain in weight. The findings of this study coincided with the literature. Two means were calculated for each of the six fabrics. Nine of the twelve means showed a gain in weight; both wool and one Orlon mean showed a loss in weight (Table VI).

Table VI

WEIGHT PER SPECIMEN OF FOUR SQUARE INCHES

Fiber Composition	Control (grams)	Edged with Adhesive: Abraded (grams)	Edged with Adhesive: Change (per cent)	Edge Turned and Stitched: Abraded (grams)	Edge Turned and Stitched: Change (per cent)
Nylon	0.2523	0.2600	+3.05	0.2594	+2.81
Dacron	.2816	.2851	+1.24	.2867	+1.81
Cotton	.2817	.2872	+1.95	.2907	+3.19
Wool	.3644	.3283	-9.91	.3382	-7.19
Viscose Rayon	.2377	.2386	+ .38	.2413	+1.51
Orlon	.1731	.1715	- .92	.1735	+ .23

A greater gain in weight was anticipated for those weight specimens cut from the specimens that were edged with the nail polish than from those cut from the specimens with the stitched edge because of the redeposition of the nail polish upon the specimens. However, only the nylon fabric gained more weight when it was edged with nail polish than when it was edge stitched (Figure 4). The attraction of the nail polish to the nylon by static electricity may have been greater than the attraction of the detritus to the nylon. All of the fabrics except wool showed an insignificant loss when they were edged with the nail polish as compared with those that were stitched. Thus it would seem that either the nail polish may have caused some abrasion to the fabric, or the fibers from the turned edge redeposited on the fabric and caused it to weigh more than the redeposited nail polish. The fabrics gained in weight, whether they were edged with nail polish or were stitched. Cotton and Dacron gained the most weight, viscose rayon less, and Orlon the least. Orlon lost weight when the edges were stitched. The amount of weight gained by those fabrics edged with nail polish was not in proportion to the gain in weight of those fabrics with the stitched edge.

There was a significant loss in the weight of the wool specimens. This result agrees with the findings of

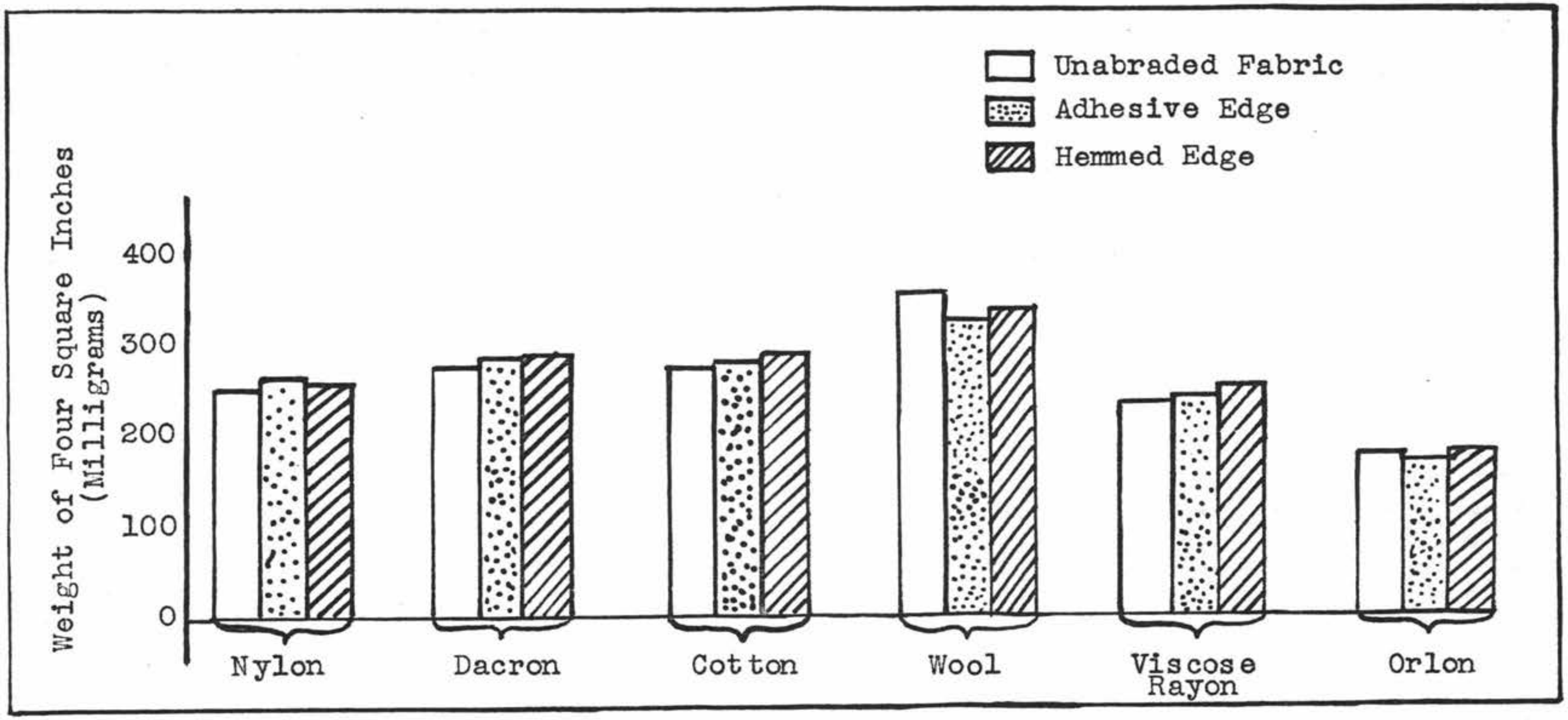

Figure 4. WEIGHT OF FOUR SQUARE INCHES BEFORE AND AFTER ABRASION

Macormac and Richardson (20, p. 150) in their experiments on wool fabrics abraded in the Accelerotor. It appears that the bulk of the wool fabric was sufficiently greater than that of the other fabrics to cause a significant loss in weight. Also the wool yarns had a lower twist than the cotton yarns so the fibers would not have been bound as tightly in the wool yarns as in the cotton yarns. Although the wool was edged with Vulcanol some fragments of the nail polish clung to the wool when some of the specimens that were edged with the nail polish were abraded with the same liner and preceded the abrasion of the wool. There was a greater loss in the weight of the wool when the preceding fabrics were edged with nail polish rather than stitched (Figure 5). Those weight specimens cut from the specimens edged with Vulcanol lost 7.19 per cent while those cut from specimens with the stitched edge lost 9.91 per cent. The percentage loss in strength of the wool fabric, as given in Tables I, II, and III, pages 35 and 37, was considerably greater than the percentage loss in weight (Table VI). This difference may be partly the result of the redeposition of the detritus, although it did not appear to redeposit on the wool to the extent that it redeposited on the other fabrics. Because the wool was the only fabric that lost a significant amount of weight it is not possible to compare the loss of weight

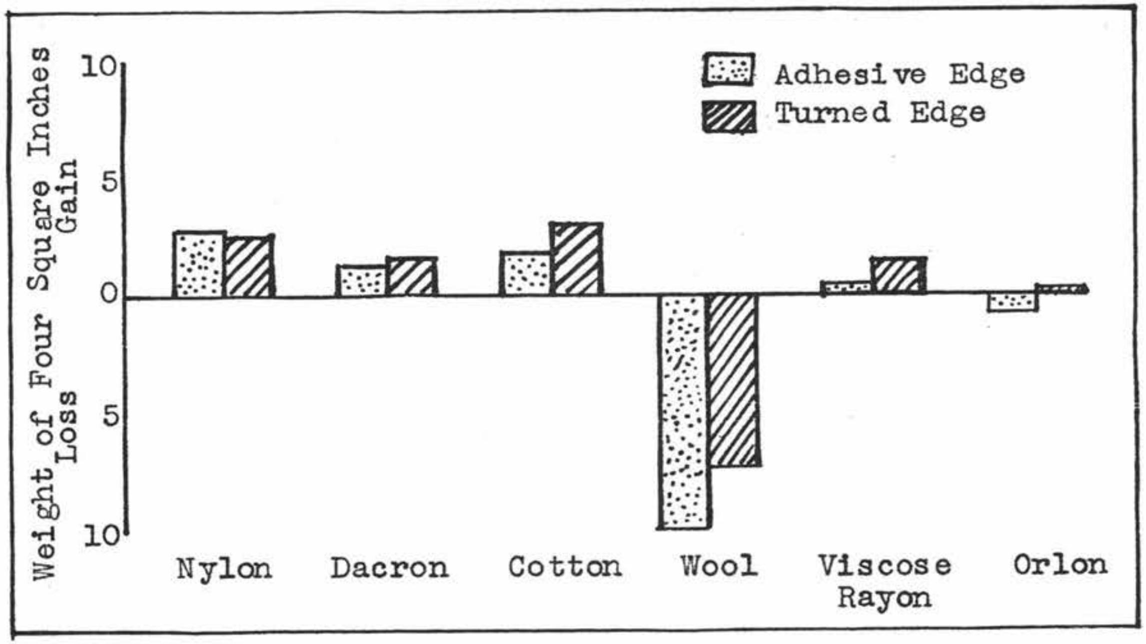

Figure 5. PERCENTAGE CHANGE IN WEIGHT AFTER ABRASION

to the loss of strength of the fabrics used in this study. It may be that if a longer period of abrasion had been used there would have been significant losses in weight for all of the fabrics, because sometimes a decrease in weight follows the increase that may occur during the earlier portion of the abrasion cycle (5, p. 751).

Effects of Abrasion on Appearance

It was the opinion of those who evaluated the fabrics that there was a marked change in the appearance of most of the fabrics as a result of abrasion. The nylon showed very few broken fibers in comparison with the Dacron. Of the other four fabrics, the wool appeared to have the least amount of distorted fibers, but the panel of judges differed in their opinions about the change of the cotton, Orlon, and viscose rayon. The length of the fibers on the surface may have influenced the opinion of the judges. Since the cotton and viscose rayon had longer protruding fibers than the Orlon they appeared to have a greater quantity of broken fibers. The Orlon had very short, greatly fibrillated ends which were not readily seen but they produced a suede-like effect. The Orlon had the greatest percentage loss of strength and the viscose rayon fabric was weakened considerably more than the wool and cotton (Figure 2), but these changes were not evidenced by the quantity of broken fibers on the surface. There does not seem to be a reliable, consistent correlation between the apparent amount of distorted fibers and the remaining strength of these fabrics after abrasion.

Effects of Abrasion on Microscopic Characteristics

Damage to the individual fibers apparently can be placed into two categories, fibers which appear to have been broken because of bending and those which show a gradual breakdown before their separation. Of the fibers used in this study, nylon, Dacron and viscose rayon fall in the first category and the cotton and Orlon into the second (Plates I, II, III). Wool seemed to fit into both categories, but more fibers were classed in the first category than in the second. Some of the Dacron and nylon fibers were enlarged at the breaking point (Plate I). The viscose rayon appeared to break without enlargement (Plate II). Most of the viscose rayon, Dacron, nylon and wool fibers broke straight across. Occasionally an irregular end was found among the man-made fibers similar to that in the photomicrograph of the nylon fiber (Plate I). Clegg (7, p. T477) reported that the viscose fibers generally break transversely although fiber distortion was often present. The Dacron showed very little fibrillation, the nylon even less. In a few instances the ends of the wool fibers were fibrillated. The nylon appeared to have been pitted as a result of abrasion, however the presence of large quantities of the delustering agent in the Dacron, Orlon, and viscose rayon made it impossible to determine if pitting had occurred.

The breakdown of the cotton fiber took place by means of fibrillation (Plate III). Clegg (7, p. T456) concluded that gentle abrasion caused breakdown of the cuticle, or outer covering, on cotton. This effect on the cuticle plus flexing resulted in the eventual transverse breakdown of the fiber.

The epidermal scales on the abraded wool fiber were much less obvious than were those on the unabraded fiber, which would indicate that there was a gradual wearing action. Occasional localized abrasion was evidenced by short longitudinal cracking, which resulted in fibrillated ends (Plate III). McNally and McCord (25, p. 728) reported that after the fiber sheath was removed by abrasion the cortex fibrillated.

The abraded Orlon had both fibrillated and smooth ends, with a predominance of the fibrillated. Fibrillation occurred at random along the cuticle of the fiber, and lengthwise splits in the fiber were present (Plate II). These splits seemed to occur most frequently at the thinnest portion of the cross section of the fiber.

The yarns had a general tendency to broaden when they were abraded (Plate IV, V, VI). Of the continuous filament yarns, the Orlon and viscose rayon fibers showed a greater tendency to broaden than did the nylon and Dacron. The variation is probably partly the result of the number of twists per inch because the lower twists provide less binding power for the fibers. The nylon and Dacron yarns had six to eight turns per inch, and the Orlon and viscose rayon had three to four turns per inch (Table III).

The photomicrographs of the fabrics (Plate VII, VIII, IX) show the relationship of the abraded fibers and yarns to the fabric as a whole and the extent of degradation that took place. Those yarns which broadened closed the interstices between the yarns. Those fibers which broke off or pulled loose at one end have produced distorted fibers on the surface of the fabric. The Orlon appeared to have the greatest change in appearance because of the numerous broken fibers with fibrillated ends and the many loose fibrils along the fibers. The Dacron and Orlon had broken fibers of similar length, but the Dacron had a fewer number of broken fibers and very few short fibrils. When the long extended fibers were removed from the viscose rayon and nylon fabrics, a similar type of damage occurred but the extent of damage was much less in the nylon. The cotton and wool fabrics had an increased number of short fiber ends after abrasion. It appeared that the cotton fabric had shorter protruding fibers than the wool.

Effects of Abrasion as Indicated by the Detritus

It is impossible to give an accurate account of the quantity of detritus formed by each fabric because some probably clings to the fabric as is indicated by the increased weight, and some clings to the abrasive liner and to the walls of the abrasion chamber. As judged by a visual, subjective test, the nylon appeared to lose a negligible amount of fibers, the Dacron, viscose rayon, and Orlon lost a greater amount and the wool and cotton lost much more than did the filament fibers. Of the fibers abraded eight minutes there was a correlation between fiber loss and the percentage loss in strength. The Dacron lost the most fibers and had the greatest loss in strength (Tables I, II, III). Two of the fabrics that were abraded for four minutes were woven of continuous filament fibers and two were woven of staple fibers. Those fabrics that were woven of the staple fibers showed the greatest loss of fibers, but they had the smallest percentage loss of strength. The fabrics that were woven of continuous filament fibers showed a smaller loss in fibers but a greater percentage loss in strength. Therefore, it would appear that there was no definite correlation between the amount of fibers lost and the loss of strength. It was not possible to determine the length of the fibers broken or sheared off by abrasion since some of the fibers in the detritus were separated from the pinked edge of the cloth.

The microscopic appearance of the detritus showed that the degradation present in the detritus was the same type as that which was produced on the broken fibers that were manually removed from the fabric; however, the extent of damage to the fiber in the detritus was much greater than in the fibers remaining in the fabric. A microscopic evaluation of the detritus was conducted by Stiegler (33, p. 693). He stated that an evaluation of the detritus often provides valuable information about the reactions of the fibers to abrasion, the nature of the fiber fracture, and the fibril formation, and the type of action causing the degradation.

CONCLUSIONS AND RECOMMENDATIONS

The results of the resistance of some commonly used fibers to dry abrasion were determined by five methods of evaluation. A comparison was made of the results to determine which methods were the most satisfactory for determining the amount and the type of degradation to each fiber.

The results of this study seem to indicate that the breaking strength method was satisfactory for each of the fibers which were evaluated. According to the literature, breaking strength seems to be the most frequently used method to determine the strength retained after abrasion. The raveled-strip breaking strength method can measure the rate at which degradation occurs, it can indicate the relative durability of a given fabric, it can indicate the strength retained after dry abrasion, and the strength imparted to a fabric because fibers and yarns tend to cling together. It provides a basis for comparing the effects of dry abrasion upon fabrics of unlike strengths and quality; it is possible to obtain several specimens from a limited amount of material.

The disadvantages of the raveled-strip breaking strength method are the amount of time that is required to prepare specimens and the possibility of obtaining a distorted viewpoint when it is used as the only criterion for the resistance to abrasion of fibers which are capable of undergoing high distortion without breaking.

The bursting strength method can be used to evaluate the same properties as does the raveled-strip breaking strength method. However, the bursting strength method usually has been used to evaluate knit fabrics. Zook and Mack (40, p. 666) had used it to evaluate woven fabrics and they considered it to a satisfactory method. Therefore, the bursting strength method was used in this study and compared with the breaking strength method to determine whether or not it would be a satisfactory method of evaluation for the fibers studied. In addition to the foregoing advantages, preparation of the specimens requires less time after the abrasion; it measures the combined effects of the strength of the warp and the filling yarns which resemble actual wear, and it measures the ability of the fibers to cling to each other within the yarns and between the yarns.

There are several disadvantages to the bursting strength method of evaluation. It requires a larger quantity of fabric than does the breaking strength method in order to obtain an equal number of evaluations, because only one bursting strength evaluation can be made on each specimen that is abraded in the Accelerotor; it does not provide information concerning the strength of the warp and the filling yarns separately.

Little use has been made of bursting strength as a means of measuring the damage incurred to woven fabrics by abrasion. One reason for this may be that many abrasion devices incur damage primarily in only one direction of a given piece of fabric. When the Accelerotor is used the degradation of the filling and the warp yarns tends to be uniform to the extent that the fibers, yarns, and weave of the fabric are uniform. In this study all of the fabrics which were evaluated by the bursting strength method arranged themselves in the same order of resistance to abrasion as when they were evaluated by the raveled-strip breaking strength method.

It was noted in the review of literature that the percentage of weight lost during abrasion can only be of value when the fabric is thick enough to lose more weight through the loss of fibers than it gains through redeposition of the detritus. The results of this study concur with this theory. The wool was the only fabric that showed a significant loss. All of the other fabrics showed a significant gain or a loss that was too small to be significant. Macormac and Richardson (20, p. 150) also reported a significant loss of weight when working with wool abraded in the Accelerotor.

When the appearance of the fabrics was evaluated by the panel of judges, the apparent amount of protruding fibers on the surface of the fabric did not seem to be a reliable criteria. Those fabrics that had long protruding fibers appeared to have a larger quantity of broken ends, whereas the shorter fibers were less obvious and gave the impression of less damage. There was no reliable correlation between the percentage loss in strength and the appearance of the fabric.

The microscopic evaluation of the type and extent of damage as a result of abrasion was very valuable. By high magnification it was possible to ascertain the probable steps in the breakdown of the individual fibers, the type of damage incurred in the breakdown, and the extent of damage to the individual fibers. Under low magnification it was possible to determine the effects of the damage to the yarn and how this damage affected the fabric.

The three types of damage incurred to the fibers in this study were breaking because of bending, wearing through before separation, and the pitting of the cuticle. The nylon, Dacron, and viscose rayon had either a clean or jagged break as a result of bending; the Orlon and cotton had fibrillated ends. The wool had a clean break in most instances, but a few fibrillated ends were found. There was frequent fibrillation along the length of the cotton and the Orlon fibers.

An attempt was made to collect the detritus so that the amount of fibers that were lost by abrasion might be determined. In the increasing order of loss of those fabrics which were abraded for eight minutes, nylon lost the least amount of fibers and Dacron the most. Of those fabrics which were abraded for four minutes, the viscose rayon and Orlon lost about the same amount as did the Dacron and the cotton and wool lost much more. There seemed to be little correlation between the amount of fibers which were lost and their percentage loss in strength. However, when the quantity of fibers lost was compared, a greater percentage loss in strength was noted among the continuous filament yarns than among the staple yarns. Therefore, it would seem that the loss of fibers is more weakening to the continuous filament yarns than it is to the staple yarns. This loss may be the result of the continuous filament yarns having a lower twist than the staple yarns.

The ability of the various fibers to resist abrasion is related to a combination of toughness, smoothness, flexibility, and elasticity (13, p. 326). Of the fibers evaluated in this study, the nylon and Dacron were able to withstand eight minutes of abrasion and still retain considerable strength. The nylon proved to be superior to the Dacron. Of the fabrics abraded for four minutes, the cotton and wool retained moderate amounts of strength, and the viscose rayon and Orlon retained the least strength.

Although fabrics of a similar construction were used in this study, there were variations in the count, twist, and denier which were unavoidable. In addition, several types of nylon, Dacron, Orlon, and viscose rayon are manufactured, and there are varying degrees of quality in all of the natural and man-made fibers. These factors could, to some extent, be responsible for the rate of destruction and durability of these fabrics.

Of those methods of evaluation used in this study, breaking strength, bursting strength, and the microscopic evaluation of the fibers proved to be the most satisfactory.

The Accelerotor has the advantage of combining such abrasive actions as flexing, shock, compression, stretching, rubbing fiber against fiber, yarn against yarn, fabric against fabric, and fabric against abradant in one operation on a minimum of fabric. It would seem that the end result produced by this instrument would more nearly resemble the abrasive patterns of actual service than those produced by instruments which tend to isolate the various actions.

There was an increase in temperature in the abrasion chamber of the Accelerotor and this may have been a disadvantage when abrading those fibers which are affected by heat. However, it was not observed that the rise in temperature had any appreciable effect upon the fibers which were evaluated in this study.

Many attempts were made in this study to find one adhesive edging that would be suitable to all the fibers. The recommended Vulcanol adhesive was suitable to the natural fibers but peeled off of the man-made fibers. Fingernail polish was the most suitable adhesive found for the man-made fibers but it tended to chip and redeposit on the fabrics. It was not suitable for wool. Turning and stitching the edge as described in chapter III was satisfactory for all of the fibers but the preparation of the specimens was a tedious process.

Because time was limited, the scope of this study included only a portion of those fibers which are commonly used. However, there are many more fibers in use for which little information has been published. Therefore, it is recommended that evaluations be made on additional types of fibers and that the results of laboratory evaluations be compared with fabrics that have been abraded during actual wear in order to determine the accuracy with which the Accelerotor reproduces actual wear patterns.

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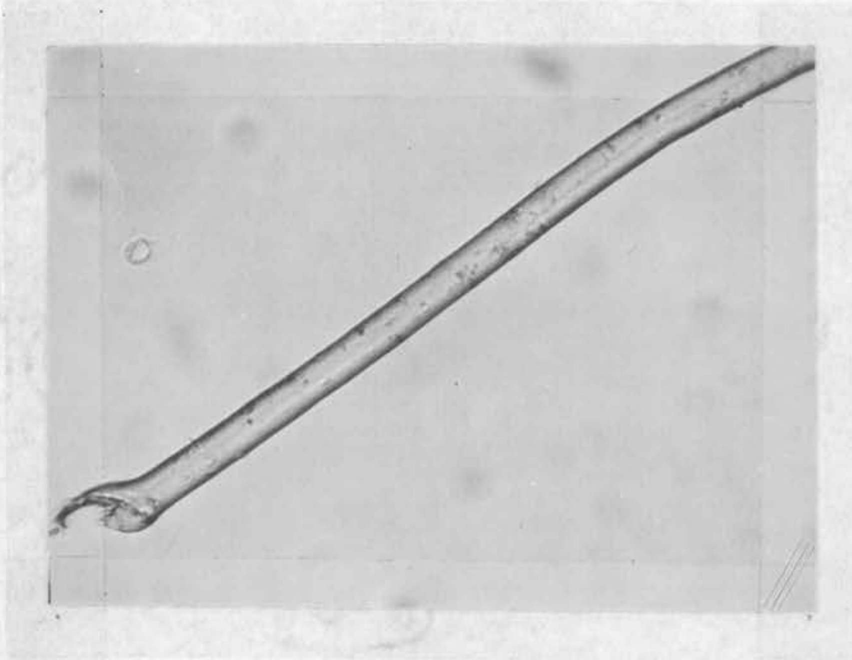
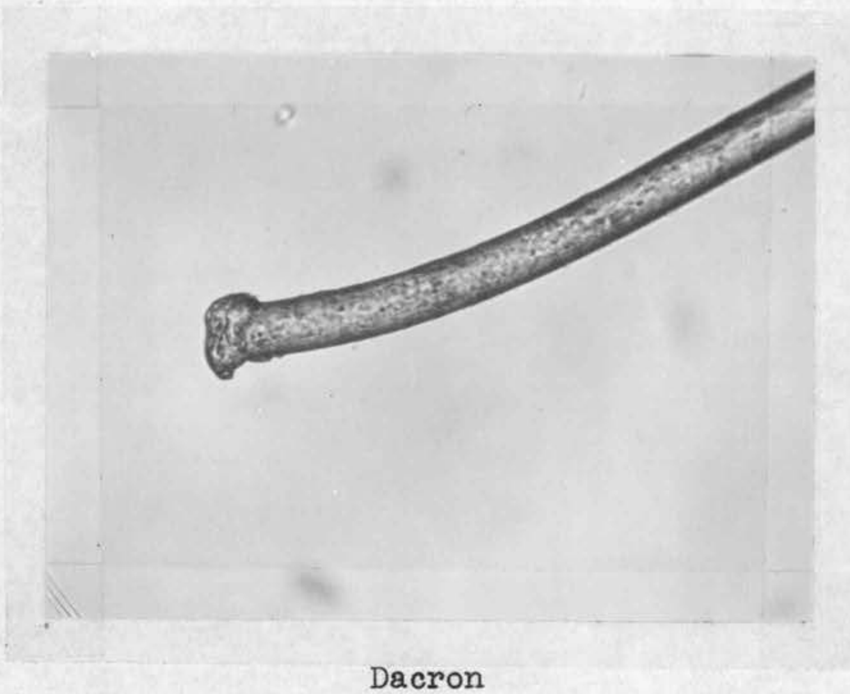
A P P E N D I C E S

APPENDIX A

Photomicrographs

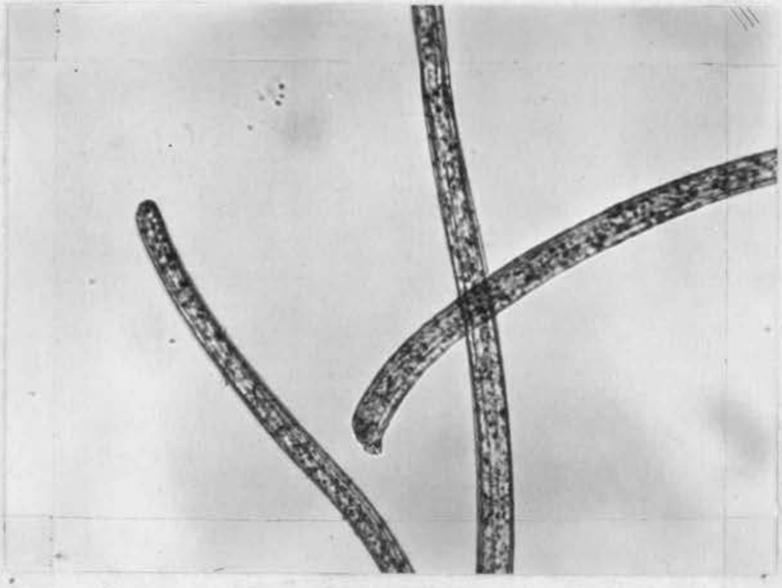


Nylon

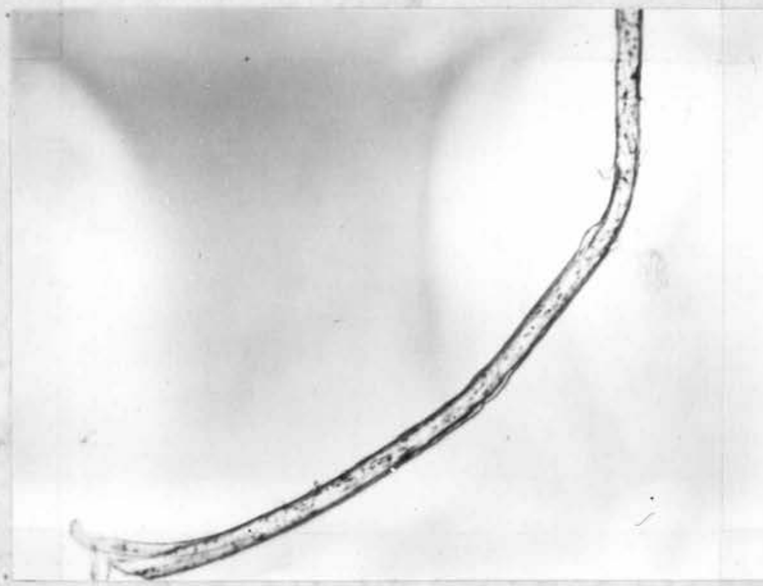


Dacron

Plate I. Photomicrographs of abraded fibers. Magnification 300x.

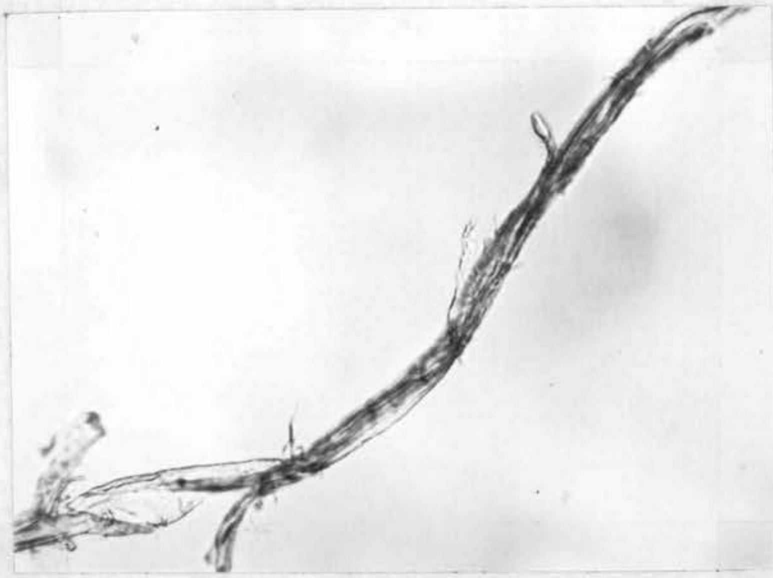


Viscose Rayon

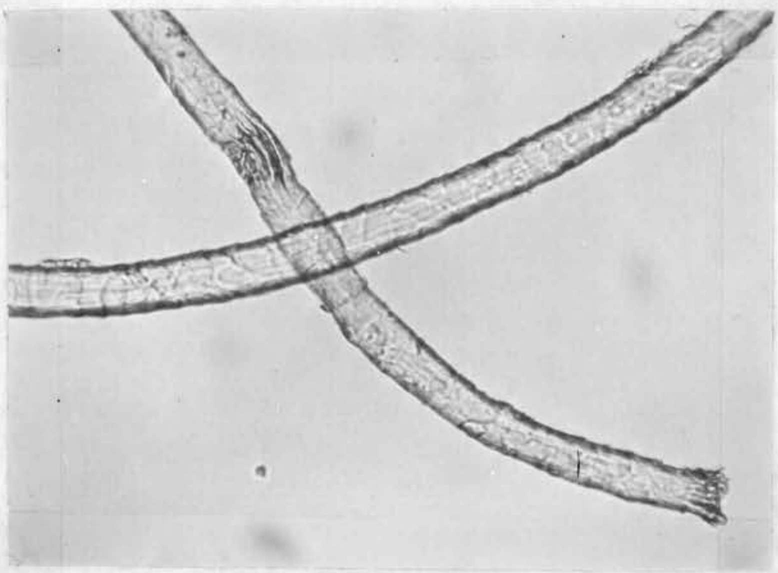


Orlon

Plate II. Photomicrographs of abraded fibers. Magnification 300x.

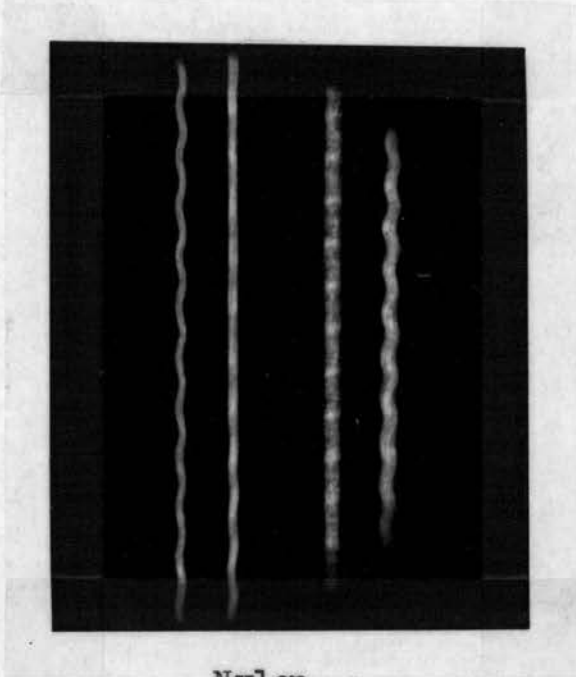


Cotton

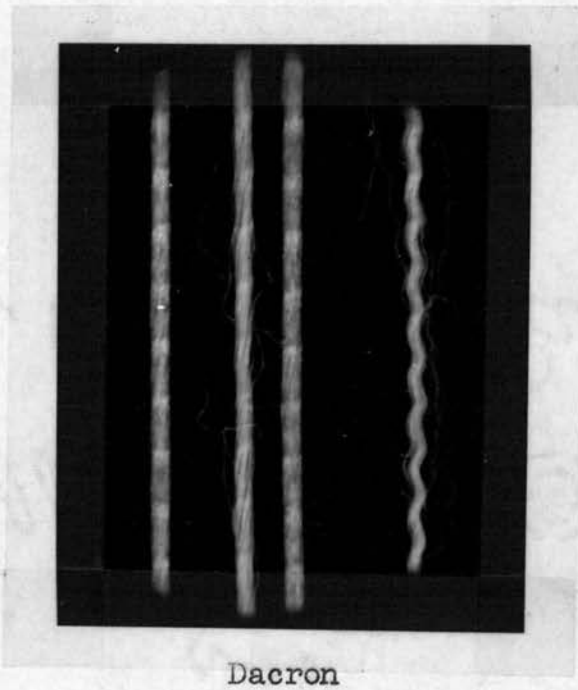


Wool

Plate III. Photomicrographs of abraded fibers. Magnification 300x.

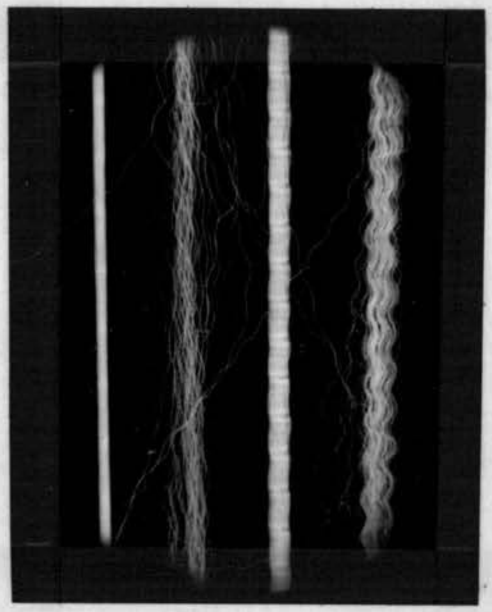


Nylon

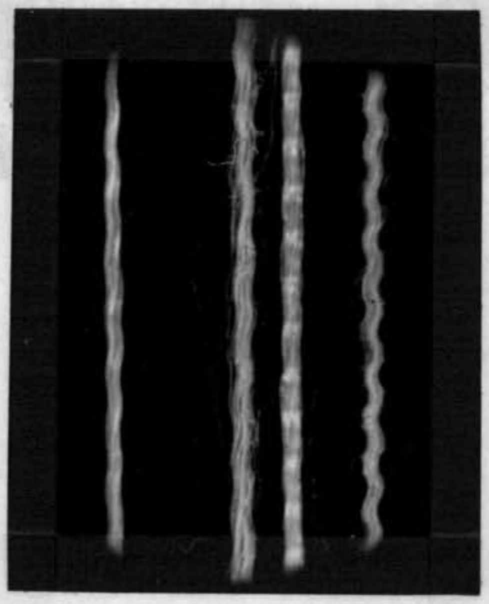


Dacron

Plate IV. Photomicrographs of unabraded and abraded yarns. Order for each photomicrograph from left to right, warp unabraded and abraded, filling unabraded and abraded. Magnification 10x.

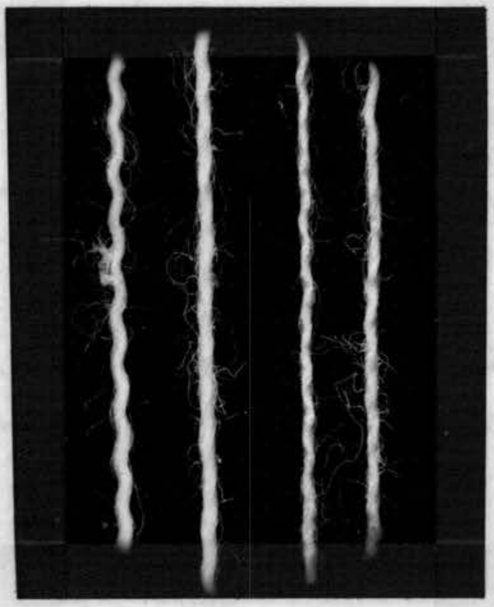


Viscose Rayon

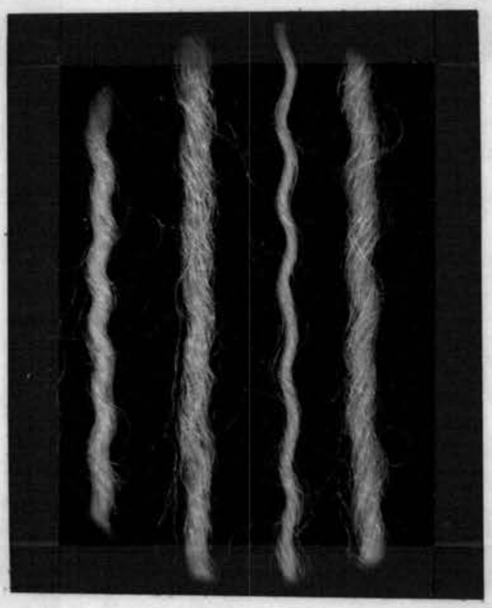


Orlon

Plate V. Photomicrographs of unabraded and abraded yarns. Order for each photomicrograph from left to right, warp unabraded and abraded, filling unabraded and abraded. Magnification 10x.

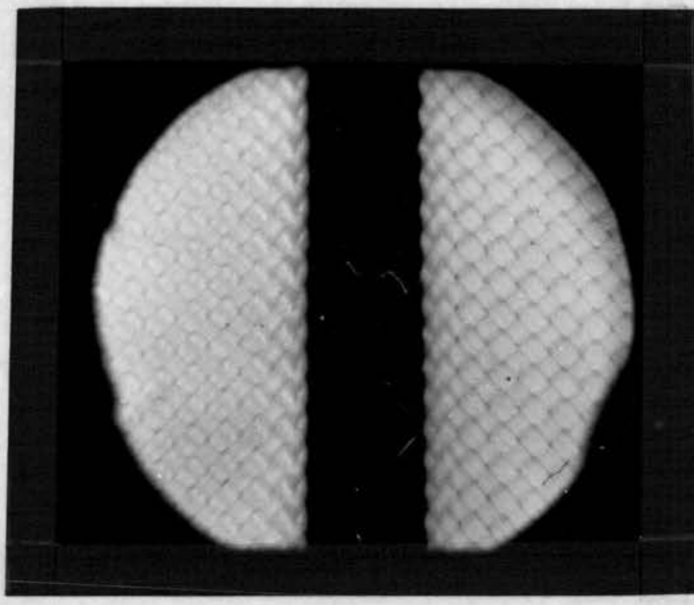


Cotton

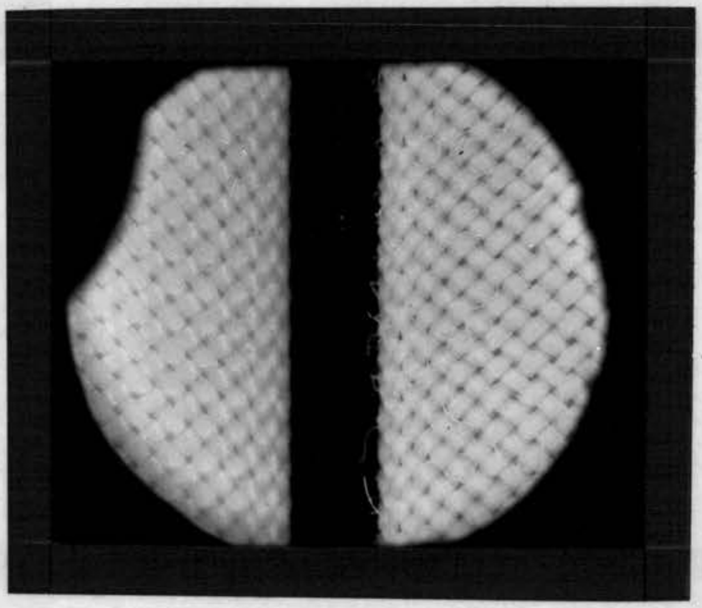


Wool

Plate VI. Photomicrographs of unabraded and abraded yarns. Order for each photomicrograph from left to right, warp unabraded and abraded, filling unabraded and abraded. Magnification 10x.

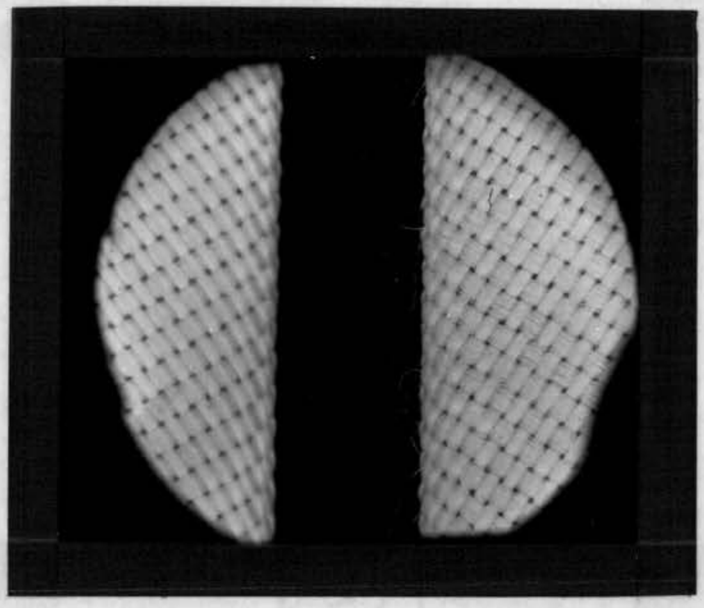


Nylon

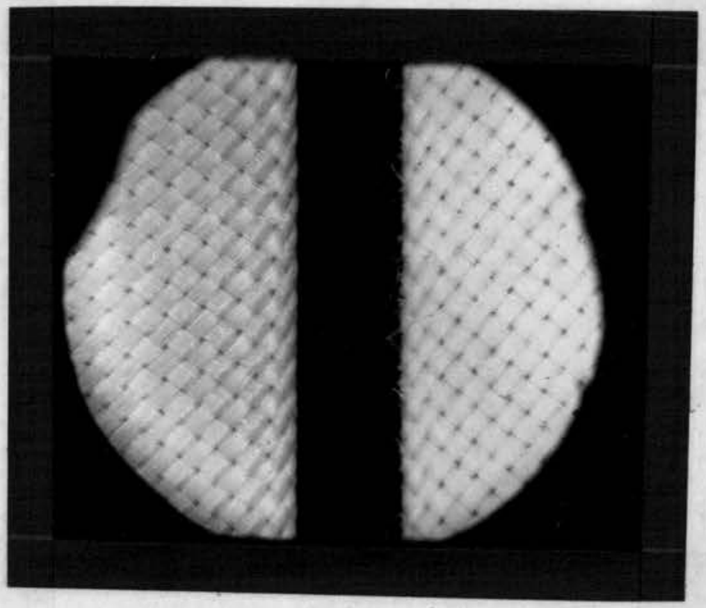


Dacron

Plate VII. Photomicrographs of fabrics folded on the bias. Unabraded on left and abraded on right. Magnification 10x.

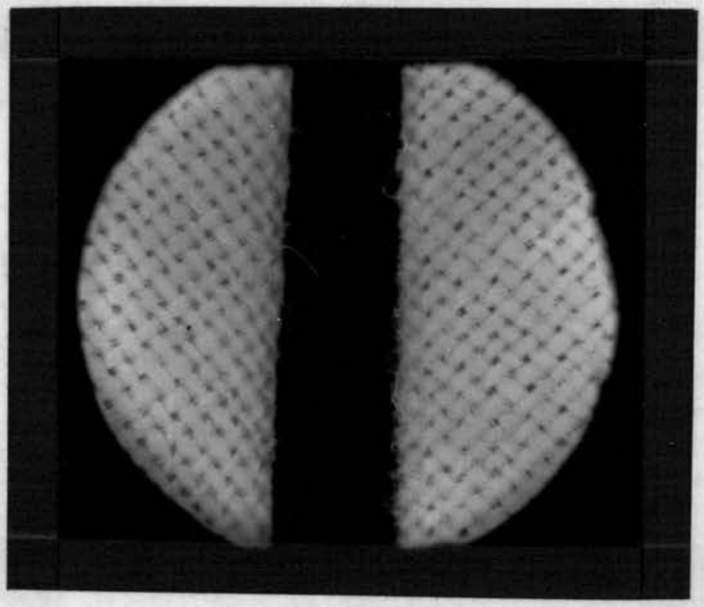


Viscose Rayon

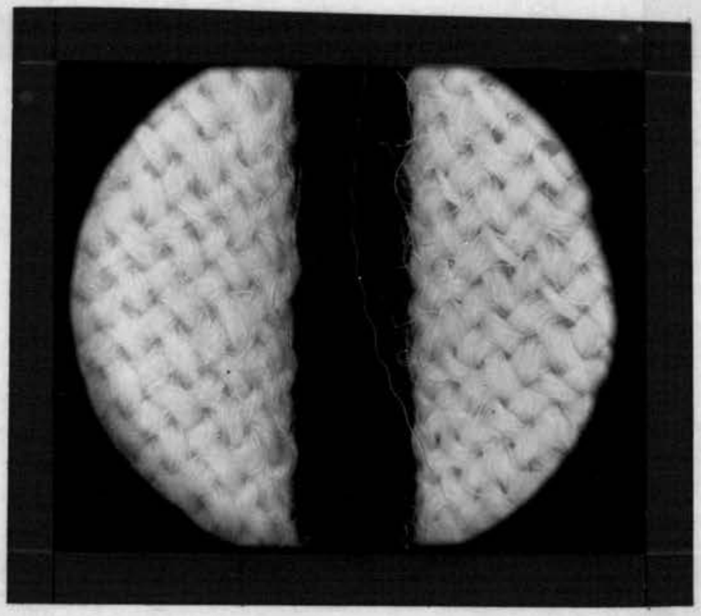


Orlon

Plate VIII. Photomicrographs of fabrics folded on the bias. Unabraded on left and abraded on right. Magnification 10x.



Cotton

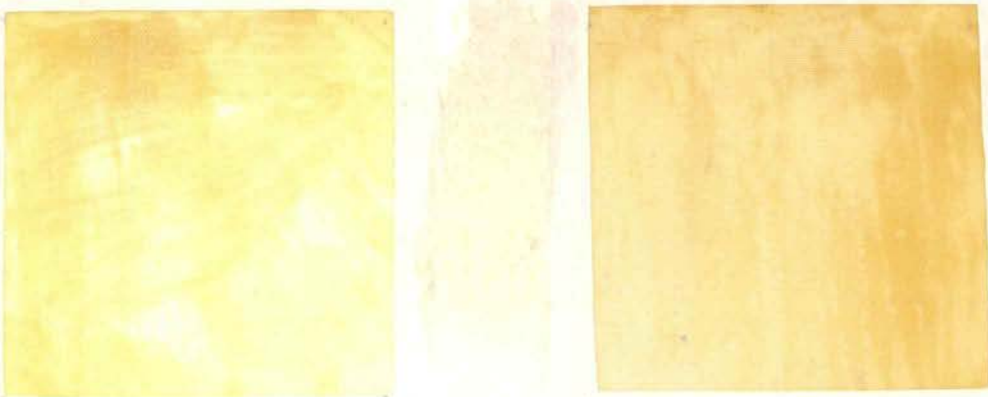


Wool

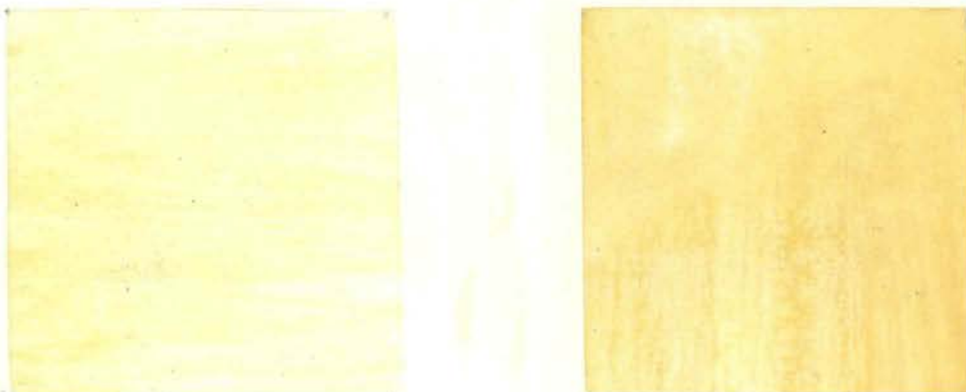
Plate IX. Photomicrographs of fabrics folded on the bias. Unabraded on left and abraded on right. Magnification 10x.

A P P E N D I X B

Fabric Samples



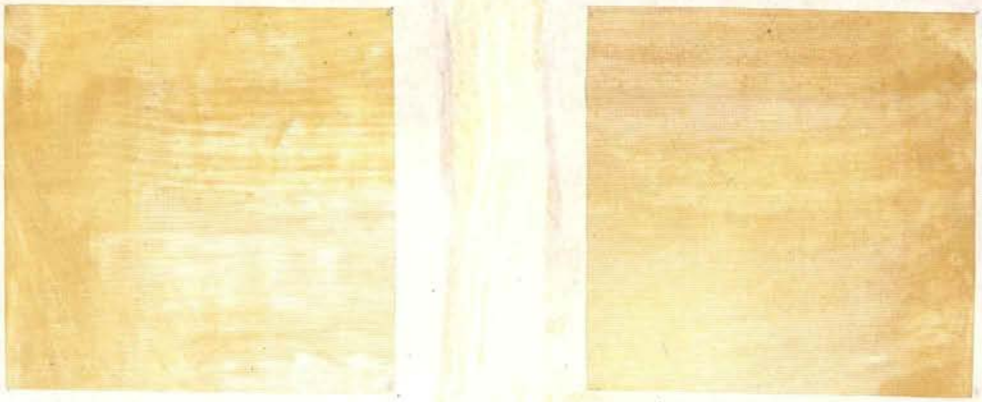
Nylon



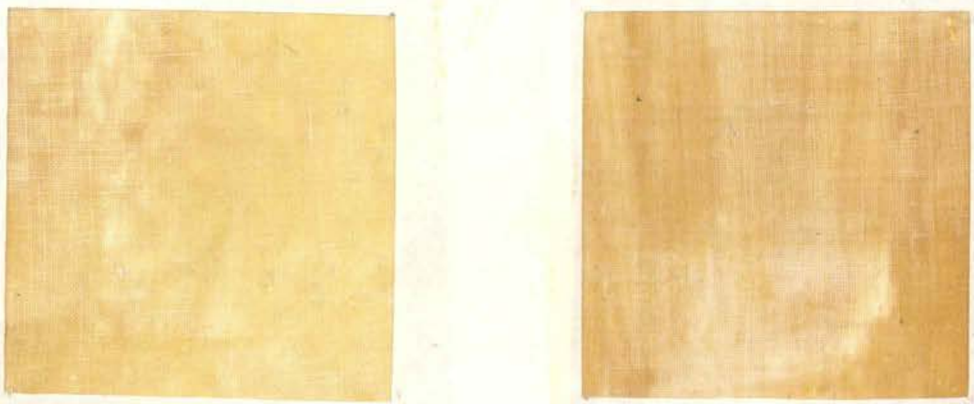
Dacron

Orlon

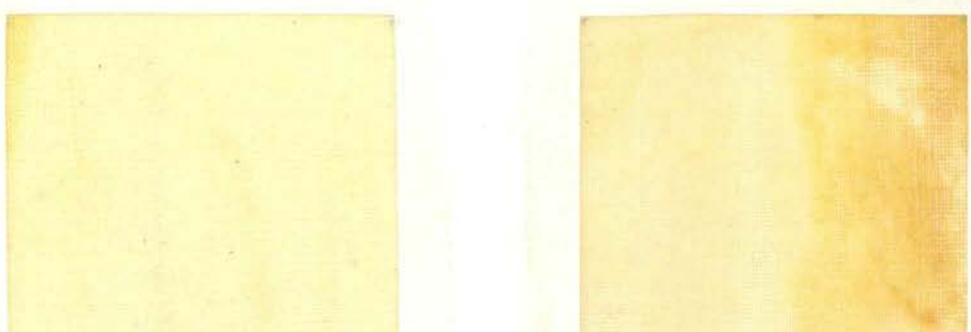
Specimens before and after abrasion. Unabraded on left and abraded on right.



Viscose Rayon



Cotton



Wool

Specimens before and after abrasion. Unabraded on left and abraded on right.

APPENDIX C

Statistical Calculations

Table VII

SIGNIFICANT DIFFERENCE BETWEEN CONTROL AND ABRADED FABRICS AS INDICATED BY t

Fiber Composition	Warp Breaking Strength (t value)	Filling Breaking Strength (t value)	Bursting Strength (t value)	Hemmed Weight (t value)	Adhesive Weight (t value)
Nylon	12.70**	12.46**	35.45**	12.76**	5.36**
Dacron Polyester	31.54**	30.54**	51.46**	10.39**	6.24**
Cotton	11.30**	8.21**	.62n.s.	3.01**	3.23**
Wool	26.93**	23.37**	19.48**	9.04**	15.11**
Viscose Rayon	16.73**	45.56**	26.85**	.18n.s.	.42n.s.
Orlon Acrylic	31.79**	54.06**	45.04**	.72n.s.	1.64n.s.

n.s. - not significant
* - 5% level of significance
** - 1% level of significance

Table VIII

STANDARD DEVIATION

Fiber Composition	Warp Breaking Strength	Filling Breaking Strength	Bursting Strength	Hemmed Weight	Adhesive Weight
Nylon	8.30	6.05	6.59	.0010	.0027
Dacron	5.81	5.03	7.96	.0096	.0010
Cotton	2.78	3.16	5.06	.0056	.0031
Wool	.57	.61	1.85	.0054	.0045
Viscose Rayon	3.07	1.03	3.20	.0037	.0040
Orlon	2.85	1.61	4.64	.0011	.0017