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Scanning Electron Microscope Investigation of Morphological Characteristics of Laboratory and Field Wear in Military Fabrics

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ABSTRACT

An investigation has been made with the scanning electron microscope of the morphological characteristics of three selected military fabrics which have undergone abrasive wear on four laboratory instruments (Accelerotor, Schiefer, Stoll Flex, and Taber abraders) and in field wear situations (Ft. Lee Wear Course and/or Viet Nam missions). Cotton broke down by fibrillating, but morphology of the fibrillar bundles varied with the abradant and the application of weight and/or tension. Wear of nylon fibers also caused some breakdown via fibrillation, but morphology seemed less affected by abradants. Morphology of fiber breakdown was influenced by weave type when wear was particularly directional, as in the Stoll Flex abrader. The presence of nylon in a 70/30 nylon/cotton blend had a range of influences upon the morphology and extent of damage to cotton, depending upon the abradant utilized. The analysis of the fabrics studied to date indicates that the Accelerotor best reproduced the morphology of field wear.

Introduction

Because deterioration of military clothing due to wear is an important economic and logistics problem, much attention already has been given to analyzing and characterizing wear of military fabrics. Most of the studies of wear in both civilian and military clothing have been concerned with analyzing the influences of the abradants, the stress-strain characteristics of the fibers, the geometry of the yarns and fabrics, and with making empirical correlations of laboratory wear to field wear.

Several studies have emphasized the importance of the abradant and its influence upon the type of wear action. Some of these studies were based upon theories established for metals. The descriptions of adhesive and abrasive wear action in metals were developed by various researchers, including Archard [1] and Rabinowicz *et al.* [9], respectively. The adhesive wear action characterized by Archard occurs when the abradant is smooth. Molecular junctions form between the two smooth metal surfaces and are sheared by the relative motion of the surfaces to form wear particles. Rabinowicz *et al.* described the abrasive wear action caused by an abradant that is hard and irregular. This type of abradant penetrates the other material and gouges out wear particles. Weiner and his associates [12, 13, 14, 16, 17] have applied these descriptions of wear action for metals to attrition in fabrics and have classified several laboratory instruments according to their dominant wear action. For instance, according to these studies the Stoll Flex abrader is primarily adhesive in its wear action, whereas the Taber abrader is more abrasive.

Backer [2] emphasized that the mechanism of attrition in textile fabrics is complicated in comparison to that in metals and other solid materials due to the combination of so many variables, e.g. fibers that are anisotropic and differ in length and configuration, yarns that vary in hardness, and fabric geometries that differ in spacing and interlacing. He determined that three elements comprise the total mechanism of abrasion in fabrics: friction, surface cutting, and fiber rupture. The element that dominates depends upon such factors as the nature of the abradant, the behavior of the fiber in the structure, and the general conditions of abrasion.

Fibers undergo the frictional action described by Backer when the abradant is quite smooth. Frictional damage includes the concept of molecular adhesion developed for metals. For this type of wear, an increase in normal load generally causes a larger area of damage of the same depth.

The second element of abrasion, a cutting of the surface of the fiber, occurs when the surface irregularities of the abradant are sharp and are small relative to the diameter of the fiber. An increase in normal load on this type of abradant results in damage over the same area but of a greater depth.

The third element occurs when the surface projections are large compared to the fiber diameter, and when the normal load is relatively high. These conditions result in a snagging action that may cause fiber slippage or rupture. In his study of stress-strain properties of fibers, Hamburger [6] described the tensile characteristics which were necessary to gain maximum resistance to abrasion of this type. He determined that materials which give with the passage of an abradant particle and thereby prevent a build-up of local tensile stresses will have greater abrasion resistance than harder materials.

The studies by Backer and other researchers have emphasized the complexity of the interaction of abradant and textile material in the process of wear. However, a review of published research on wear of clothing shows that little attention has been given to microscopic analyses of the actual breakdown processes of fibers which then lead to eventual deterioration of the fabric. There are two notable exceptions to this. In 1949 Gladys Clegg [4] analyzed the fibers from a wide variety of worn cotton garments, both during and at the end of their useful life. She also did a limited examination of wool, silk, linen, and rayon clothing. Examination with an optical microscope of stained wear areas revealed that three types of damage occurred in typical civilian wear. When fibers were held firmly by the fabric structure or by starch, they fibrillated. Those fibers protected from abrasion by weave were bent and compressed and cracked transversely. Most fibers underwent a third type of damage, a gentle bruising and cracking with minor fibrillation.

More recently Goynes and Rollins of the Southern Regional Research Laboratory [5] utilized a scanning electron microscope (SEM) to examine the types of damage in untreated and durable-press-treated cotton fibers after washing and/or drying. They wanted to determine the degree of correlation of washer and dryer damage to laboratory wet and dry abrasion patterns, respectively. In the washing process the untreated fibers deteriorated into stringy bundles of fibrils. The durable-press-treated fibers also fibrillated but wore at a faster rate than the untreated ones and peeled more into sheets. In dryer abrasion the fibers cracked diagonally and horizontally and fiber ends were smoothed, but there was little evidence of fibrillar breakdown. In the fibers subjected to both washer and dryer abrasion, both types of damage were present. It was concluded that these abrasion patterns were similar to those present with any wet or dry abrasion of cotton.

Little or no study has been apparent in the following areas: the physical morphology of abrasive breakdown of man-made fibers; the surface characteristics of abrasive breakdown of fibers under severe conditions such as in military service; the morphology of damage in military field wear as compared to that in laboratory wear; the interaction of fibers in blends; and the influence of weave on the topography of fiber breakdown. This is not meant to imply that past research has ignored the process of fiber breakdown. However, before the development of the SEM, the study of the topography of surfaces was a tedious process which was greatly limited by the small depth of field of the optical microscope. With the three-dimensional rendering of surface characteristics now possible in the SEM, there is the opportunity to see what is happening to the topography of fibers and fabrics subjected to various degradative processes.

Experimental

In this study nine fabrics were abraded on four laboratory instruments and, when possible, corresponding samples also were obtained from the Ft. Lee Wear Course and/or Viet Nam. To date, the morphological features of three of the sets of fabrics have been examined in the SEM.

FABRICS. These three fabrics are: a 100% cotton poplin weighing 6.0 oz/sq yd; a 10.0-oz/sq yd herringbone twill of 100% cotton; and a poplin weave in an intimate blend of 70% nylon Type 420 and 30% cotton which weighed 6.4 oz/sq yd.

ABRADERS. Four laboratory abraders were utilized in order to determine the influence of various types of abrasion devices and to ascertain the best laboratory reproduction of field wear. These were the Accelerotor, Schiefer, Stoll Flex, and Taber abraders.

The rotor blade of the Accelerotor travelled at 3000 rpm and drove a loose sample against the abrasive paper liner of the circular chamber. The medium-coarse paper liner, number 250, gave a multidirectional wear action classified as abrasive according to studies by Weiner *et al.* [12, 13, 14, 16, 17]. However, the fabric was subjected to a variety of actions, e.g., compression, flexing, and stretching, in addition to rubbing.

The spring steel blade was utilized with the Schiefer abrader and produced wear that was primarily adhesive in nature. A load of 4 kg (9 lb) was used on top of the abradant. The wear action was multidirectional, and the offset and small difference in speed of rotation of abradant and specimen allowed each part of the specimen to contact a different part of the abradant at each rotation.

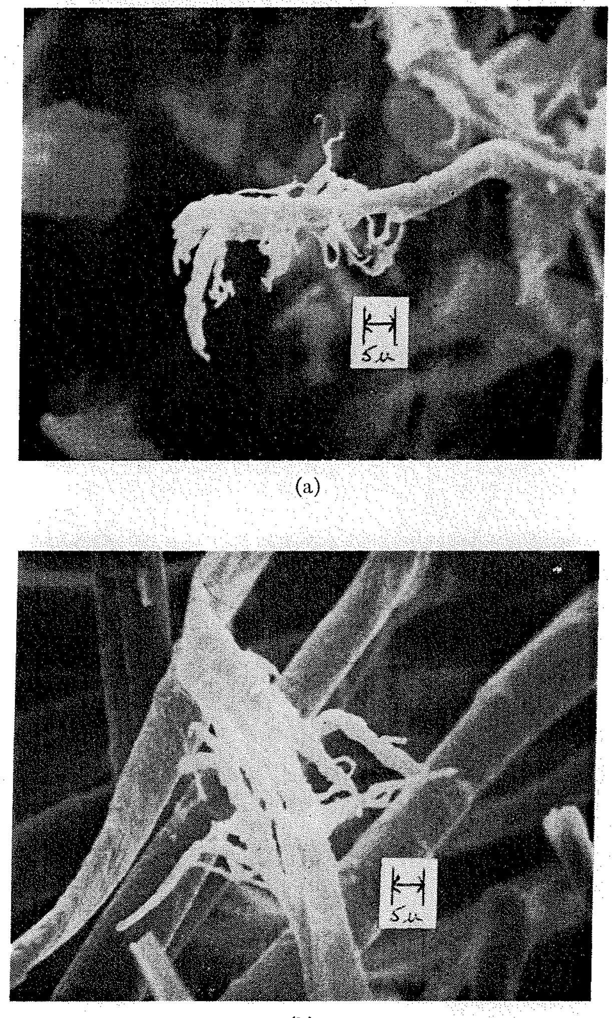
In the Stoll Flex abrader the specimen was folded over the steel bar under a controlled tension of 1.8 kg (4 lb), and a load of 0.9 kg (2 lb) was used as pressure. The dominant wear action has been classified by Weiner *et al.* as adhesive [12, 13, 14, 16, 17]. Because the wear action was directional, both warp and filling samples were tested.

The rubber base CS-17 abrasive wheels were used on the Taber abrader and each was weighted with 500 g. The wear action was multidirectional and abrasive in nature.

The morphological characteristics of damage from these four laboratory abraders were compared to the effects of field wear. The field wear samples were taken from uniforms tested on the Ft. Lee Wear Course and/or uniforms worn in service in Viet Nam. The Wear Course consists of an irregular track, approximately one-quarter mile in length, along which 30 different obstacles are arranged. These obstacles simulate most of the physical situations which might be encountered by the combat soldier, e.g., a stone embankment, a section of railroad track, a single log bridge, cinders, sand, gravel, boulders, and concrete culverts. Little is known about the particular history of the samples from Viet Nam except that they were typical of garments observed in a salvage study.

Scanning Electron Microscope. The morphological characteristics of the fabrics worn in the laboratory and field were determined by examination utilizing an AMR Model 900 SEM. The samples were taken from wear areas in which at least a few yarns were broken. The exception was the set of samples taken from Accelerotor tests, in which heavy abrasion was produced without the formation of localized breaks. The samples were mounted on studs with silver paint and single-sided, conductive, adhesive tape and then coated with a thin layer of carbon followed by gold-palladium.

The secondary electrons emitted by the samples were collected to obtain pictures of the topography of the fibers. Fibers both in the areas of hole formation and in abraded locations away from the broken yarns were examined. Four aspects of abrasive wear were evaluated from a number of pictures taken of each sample: 1) the general physical morphology of abrasive damage to cotton and nylon fibers, 2) the best laboratory reproduction of the morphology of field wear, 3) the influence of weave on the topography of wear of cotton, comparing the 100% cotton poplin and herringbone twill samples, and 4) the influence of a blend with nylon upon the damage to cotton (this compared the damage in the 100% cotton poplin to the cotton damage in the 70/30 nylon/cotton poplin).



(a)

(b)

Fig. 1. Cotton fibers away from hole formation; fibrillation from field wear.

Results and Discussion

Physical Morphology of Abrasive Damage to Cotton and Nylon Type 420 Fibers. Regardless of the method of abrasion, the cotton fibers deteriorated by fibrillating, and then as wear progressed to hole formation, the fibrillar bundles generally were smoothed off. However, the surface characteristics of the bundles of fibrils and smoothed fiber ends varied with the abradant.

Figures 1–3 illustrate the deterioration of cotton fibers in areas of lesser abrasion away from hole formation. Field wear damage ranged in dimension from stringy fine fibrillation (Fig. 1a) to somewhat more coarse fibrillar components. However, the rounded conformation of the bundles of fibrils was characteristic of all field wear cotton samples examined. A few fibers were viewed in which fiber deterioration via fibrillation was in progress before separation of the fiber was complete (Fig. 1b).

Fibrillation also occurred when cotton was abraded in the Accelerotor. Although none of the fine stringy fibrillation of field wear was present, the bundles of fibrils were quite round (Fig. 2) as in field wear. This

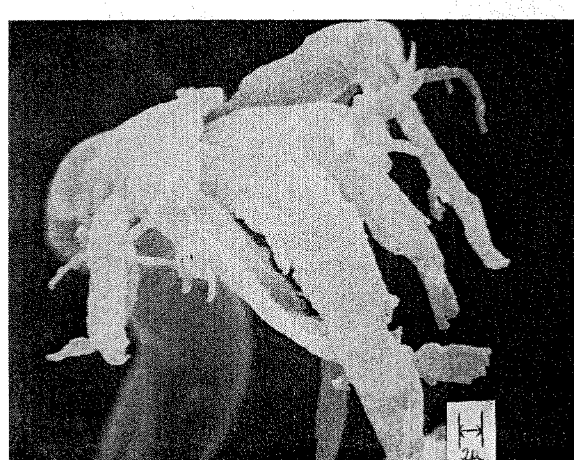


Fig. 2. Cotton fiber; fibrillation from Accelerotor abrasion.

conformation can be attributed to the design of the abrader, which allows the sample to abrade freely with no application of weight or tension other than the centrifugal force created in rotation.

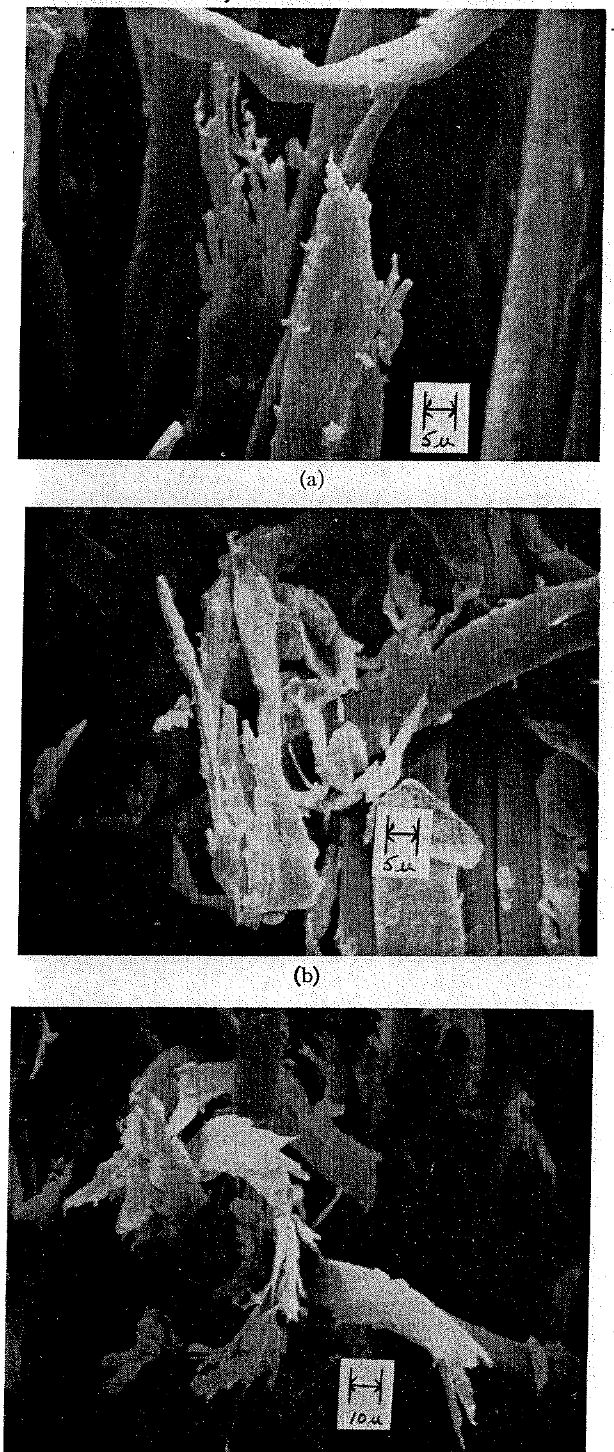


FIG. 3. Cotton fibers away from hole formation; fibrillation from abraders applying weight and/or tension: a—Schiefer; b—Stoll Flex; c—Taber.

In contrast, the bundles of fibrils in cotton fibers abraded by the Schiefer (Fig. 3a), Stoll Flex (Fig. 3b), and Taber (Fig. 3c) abraders became flattened and angular because of the weight and/or tension used to accelerate wear. Because the Stoll Flex instrument abrades in a directional manner, the bundles of fibrils also became somewhat oriented to the direction of abrasion.

In general the presence or absence of weight and/or tension seemed to cause more difference in the physical morphology of wear damage than did the degree of roughness of the abradant and whether it caused adhesive or abrasive wear.

In the areas of hole formation the fibrillar bundles of cotton generally wore off, leaving smoothed or partially smoothed fiber ends. However, there was the same influence of weight and tension as was found in the areas of lesser abrasion. A rounded fiber end with shortened fibrillation characteristic of field wear is illustrated in Figure 4a. In contrast, the fiber ends

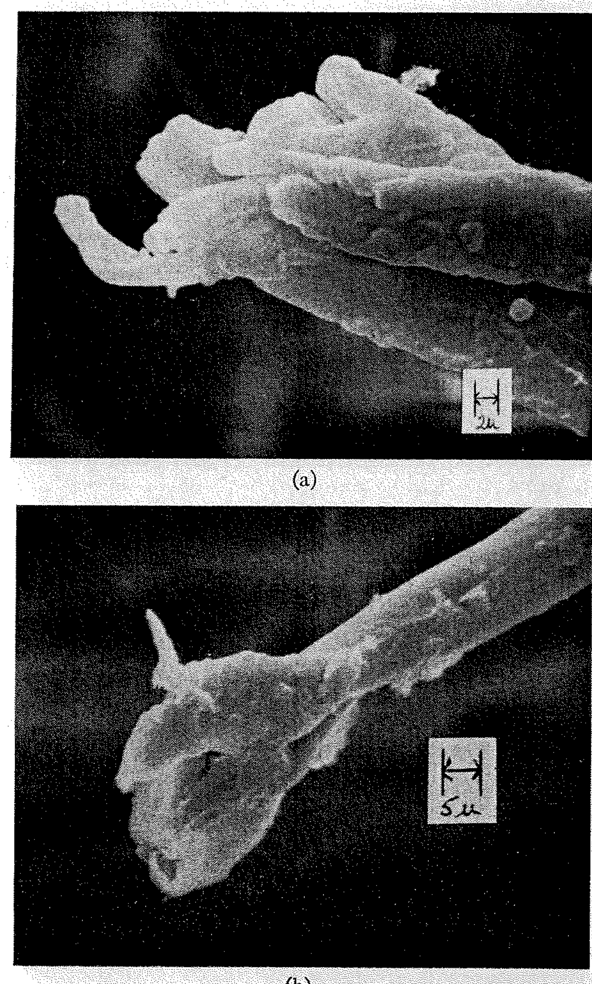
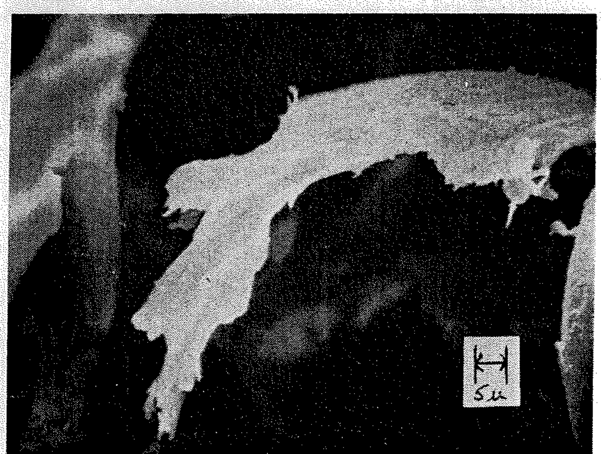


FIG. 4a and b. Smoothed ends of cotton fibers in the hole area: a—Field wear; b—Schiefer.

were flattened and sometimes sliced in appearance when abraded to hole formation in the Schiefer (Fig. 4b), Stoll Flex (Fig. 4c), and Taber (Fig. 4d) abraders. Under the test conditions used in this study, the Accelerotor did not create holes in the samples. It is possible to create holes with the use of folded samples.

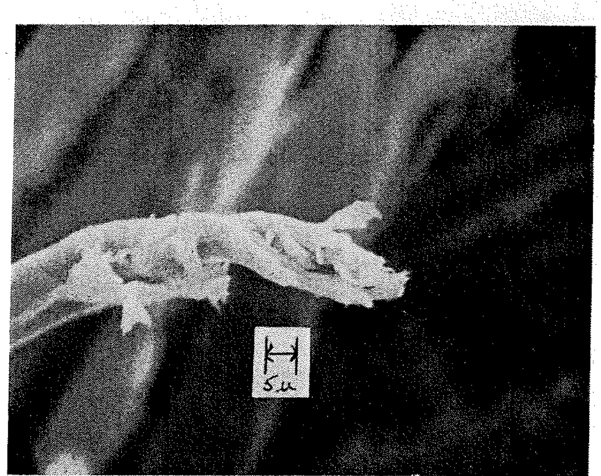
(c)



(d)

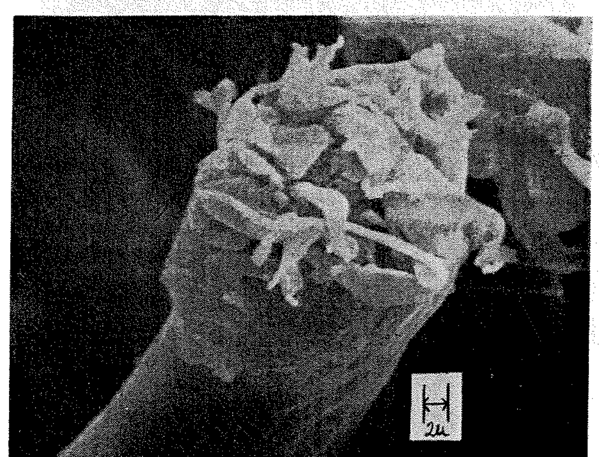
FIG. 4c and d. Smoothed ends of cotton fibers in the hole area: c—Stoll Flex; d—Taber.

The wear morphology of nylon Type 420 exhibited some similarities and some differences to that of cotton. The nylon also deteriorated by fibrillation, but the fibrillar bundles generally were shorter and sometimes thicker than those of cotton (Fig. 5). Another difference was the lack of influence of the weight and tension of abraders in the areas of lesser abrasion damage. In the Taber and Stoll Flex abraders the chunks of nylon fibrils remained quite round (Fig. 5a), rather than becoming flat and angular as in the breakdown of cotton. The Schiefer abrader caused so little damage to nylon fibers that its effects cannot be compared. As would be expected, the conformation of the nylon fibrillation was also round in field wear (Fig. 5b) and in abrasion from the Accelerotor (Fig. 5c). The



(a)

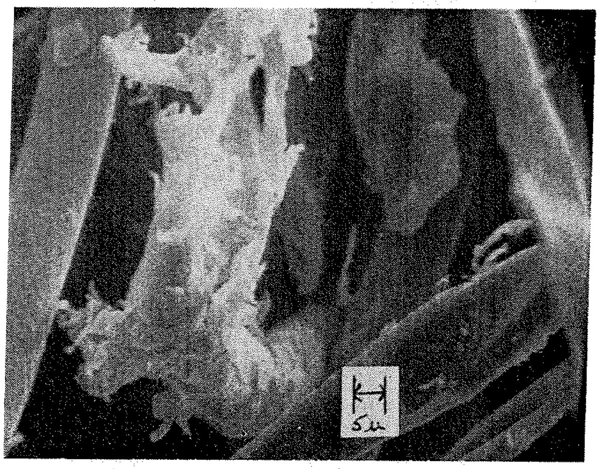
(b)



(c)

FIG. 5a, b, and c. Fibrillation of nylon Type 420 fibers away from hole formation: a—Taber; b—Field wear; c—Accelerotor.

fibrillar breakdown of a nylon fiber in the Accelerotor before complete severance of the fiber is illustrated in Figure 5d.

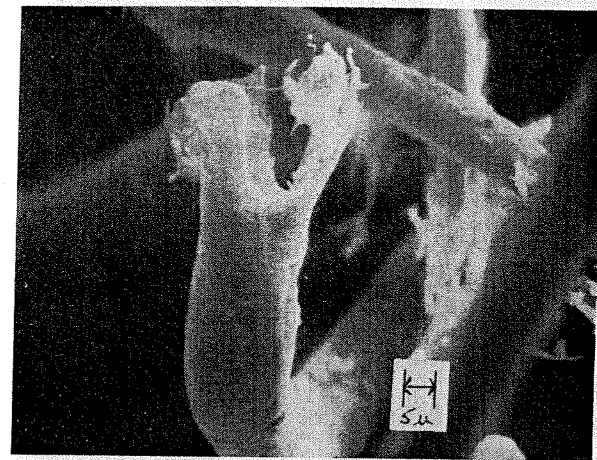


(d)

FIG. 5d. Fibrillation of nylon Type 420 fibers away from hole formation: d—Accelerotor, fibrillation in progress.

Although the type of abrader seemed to have little influence on the morphology of nylon in its earlier stages of wear, the abrader did affect the topography of abrasion of nylon by the time damage had progressed to formation of holes. In field wear the smoothed ends of nylon still remained round (Fig. 6a) but the weight and tension of the Stoll Flex and Taber abraders caused the fiber ends to become flattened (Fig. 6b).

The morphology of abrasive wear of nylon has not been examined previously. However, a study at the U. S. Army Natick Laboratories of fracture morphology of several high performance fibers revealed that nylon Type 728 did not show a tendency to fibrillate when broken on the Instron but instead exhibited a vertical break with curled edges (Fig. 7). In their study of the fractography of fibers, Hearle *et al.* [7] found that the ends of nylon 6 and 66 fibers, broken by the Instron, were blunt and irregular over most of their surface with an angular area where the break initiated. No fibrillation was evident. However, cognizance must be taken of the many types of nylon developed for specific end uses. Type 420 is a high tenacity nylon designed for blending with cotton. Its elongation is lower than that of a regular nylon and its initial modulus has been increased to be similar to that of cotton. Consequently, the fibrillation exhibited by abraded nylon Type 420 may not be characteristic of abrasion damage of other types of nylon, and further study needs to be made of abrasive wear of nylon fibers of several types.



(a)

(b)

FIG. 6. Ends of nylon Type 420 fibers in the hole area: a—Field wear; b—Taber.

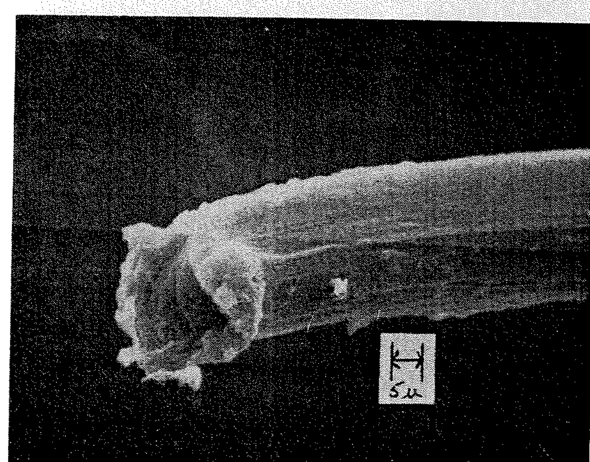
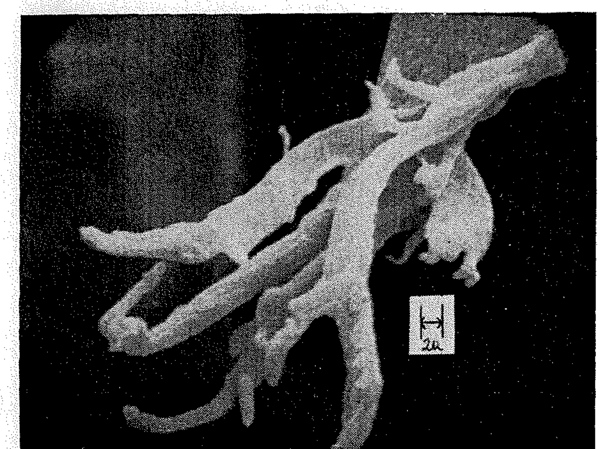


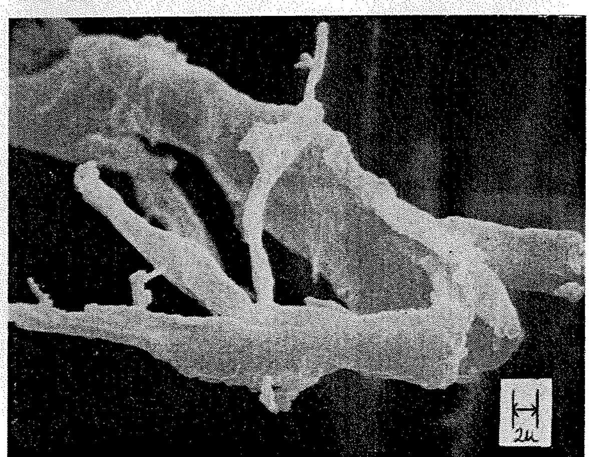
FIG. 7. Nylon Type 728 fractured on the Instron.

MORPHOLOGY OF LABORATORY ABRASION COMPARED TO FIELD ABRASION. Duplication of wear in "real-life" situations by means of laboratory instruments has been a testing problem for many years. Studies by Weiner and his associates [13, 14, 15, 17] have shown that instruments which produce a similar type of wear action correlate well to each other when relative rankings of fabrics are the basis of comparison. This study has analyzed the reproduction of the morphology of military field wear by four laboratory abraders. It should be determined in further study if production of the same type of fiber breakdown also produces the same relative rates of wear.

The Accelerotor best reproduced the surface characteristics of field wear in the three fabrics analyzed to date. This trend could be observed in the previous discussion of the general pattern of breakdown in the fibers. The Accelerotor allows the fabric to abrade freely. There is no application of pressure or tension other than centrifugal force, and consequently, the rounded fibrillation of field wear was reproduced. Further examples of this similarity of field and Accelerotor wear are shown in Figures 8a and 8b. In contrast, the fibrillation was flatter and more angular when produced by the Schiefer (Fig. 8c), Stoll Flex (Fig. 8d), and Taber (Fig. 8e) abraders because of the weight and/or tension utilized to accelerate the abrasion process in these instruments.



(a)



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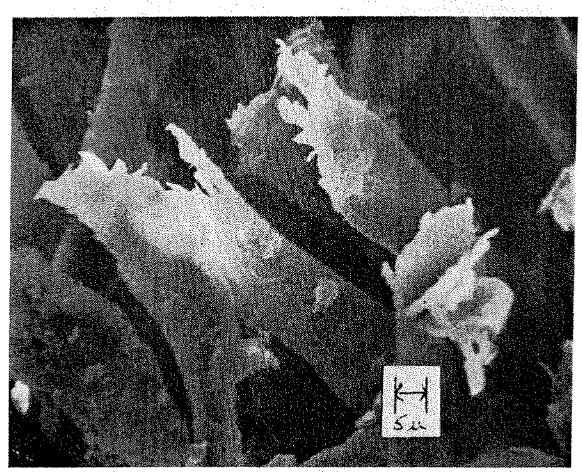

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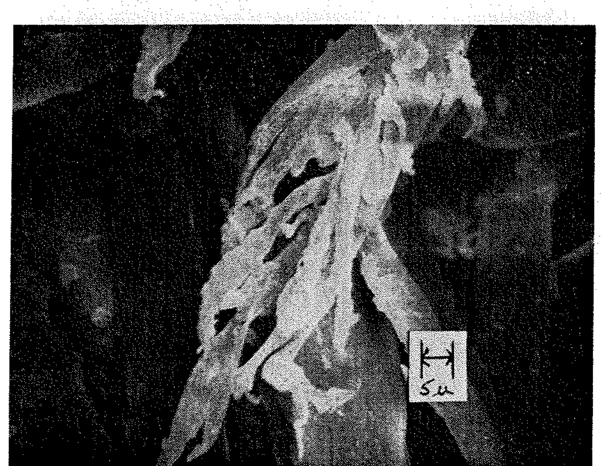

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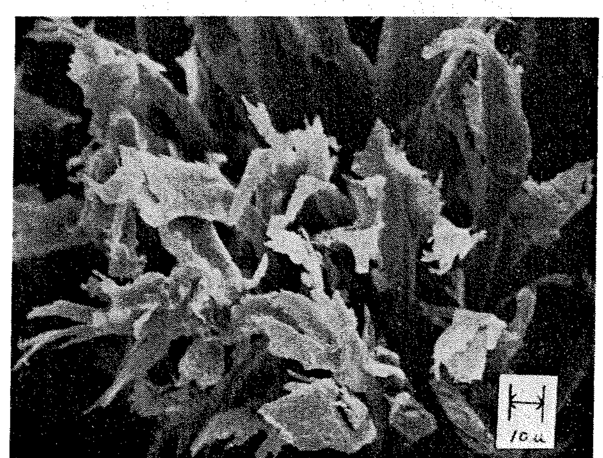
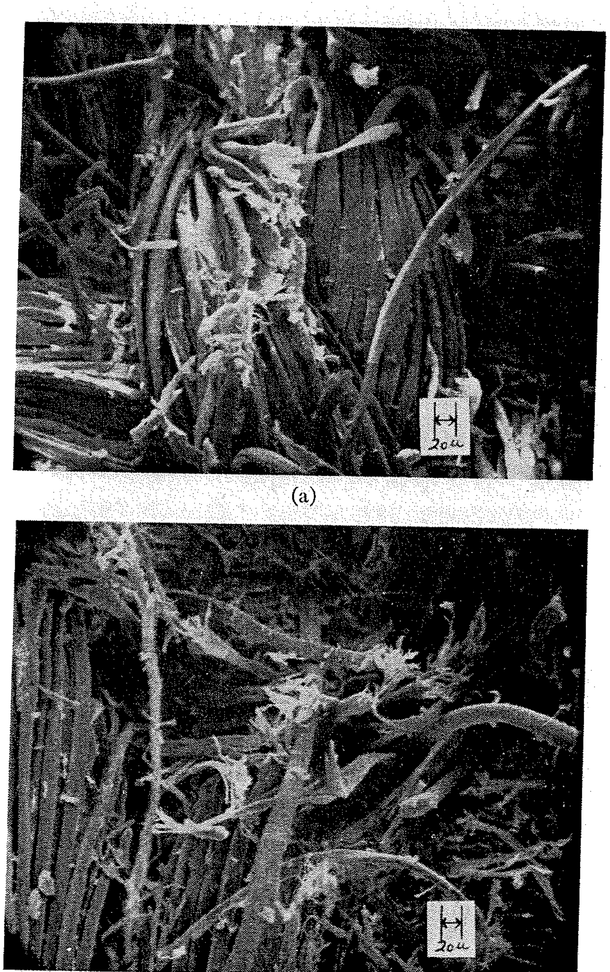


(e)

FIG. 8. Comparison of field to laboratory abrasion of cotton fibers: a—Field wear; b—Accelerotor; c—Schiefer; d—Stoll Flex; e—Taber.

INFLUENCE OF FABRIC GEOMETRY UPON WEAR MORPHOLOGY. The third factor that was analyzed was the influence of weave geometry upon the morphology of wear. To date this has been limited to a comparison of the poplin and herringbone twill weaves for the cotton fiber. Some differences in morphology were found between these two structures. A particularly interesting effect occurred in the interaction of the weave with the wear action of the Stoll Flex abrader when the filling direction of the fabrics was tested. Because the warp yarns completely cover the surface of the poplin, the brunt of the initial wear action was on them even though the samples were tested in the filling direction. This meant that the abrasion was across the fibers rather than along their major axes. This action caused them to peel and slice off in wearing (Fig. 9a). In the twill weave the distribution of yarns on the surface was still unbalanced but wear was more evenly distributed than in the poplin fabric. Thus, the filling yarns were able to absorb some of the wear. As a result there was more fibrillation in the twill fabric (Fig. 9b).



(b)

FIG. 9. Influence of fabric geometry upon abrasion: a—Cotton poplin; b—Cotton herringbone twill.

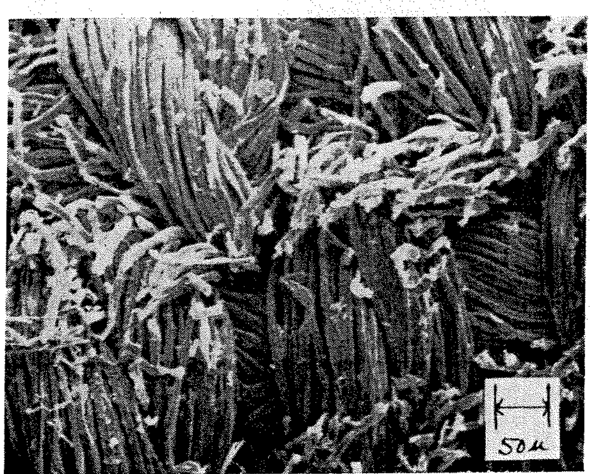
The influence of fabric geometry upon abrasion resistance, based upon degree of wear, has been analyzed by Backer and Tanenhaus [3]. One conclusion was that an increase in geometric area of contact between fabric and abradant will lead to an increase in abrasion resistance. Such factors as lower twists, increased yarn diameter, and more yarns per inch will increase the area of contact. Another effective means of increasing the abrasion resistance through textile geometry is to protect the stress bearing yarns in a fabric with surface floats of the other set of yarns and to orient these floats in the direction of abrasion. The sateen weave in various orientations is particularly illustrative of this latter concept. Evaluation of the morphology of wear in sateen structures and other weave configurations should add to the body of knowledge of the influence of fabric geometry upon abrasion.

INFLUENCE OF THE PRESENCE OF NYLON UPON DAMAGE TO COTTON. Studies have shown that the addition of high-energy-absorbing fibers such as nylon usually increases the wear life of a fabric [6]. The final factor analyzed was the influence of a blend of nylon with cotton upon the damage to cotton, comparing the extent and morphology of damage to cotton in the 100% cotton poplin to that in the 70% nylon/30% cotton poplin. The influence of nylon upon cotton varied with the abradant involved, and ranged from the circumstance in which cotton was highly protected by nylon to the condition in which little or no protection was afforded to cotton by the presence of nylon.

The nylon/cotton poplin did not reach an end-point of test in the Schiefer abrader after 50,000 cycles of testing. There was very little damage to the fabric

(a)

FIG. 10a. Influence of blending nylon with cotton upon abrasion from the Schiefer abrader: a—70/30 nylon/cotton poplin.

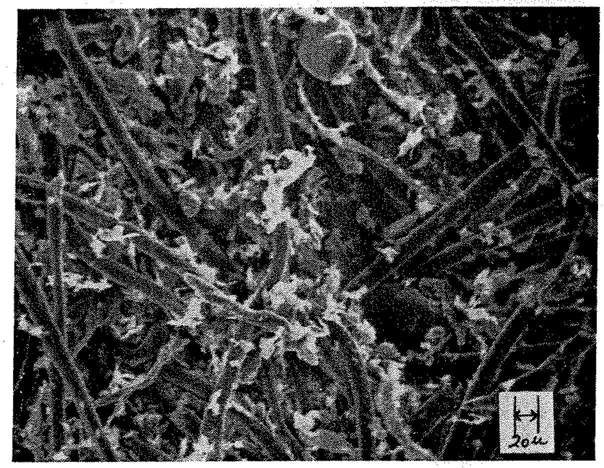


(b)

FIG. 10b. Influence of blending nylon with cotton upon abrasion from the Schiefer abrader: b—100% cotton poplin.

(Fig. 10a), and the nylon seemed to resist wear and to give protection to the cotton so that it, too, did not wear. There was more damage apparent in the 100% cotton poplin (Fig. 10b), and an end-point of 5000 cycles of test was attained.

The samples from the Stoll Flex abrader provided a distinct contrast to the other samples, especially those from the Schiefer abrader. In the *nylon/cotton poplin*, the cotton was severely damaged. Very fine fibrillation was apparent (Fig. 11a) and debris from damaged cotton fibers was scattered all over the fabric (Fig. 11b). It appeared that the cotton wore away before the nylon was affected by abrasion and that the nylon did not afford protection to cotton, nor did it share the load of attrition. The number of flex cycles to cause hole formation was several times higher in the blended poplin than in the all-cotton poplin, but 30% of the fiber content of the former took the load of abrasion and wore away before the nylon began to interact. In



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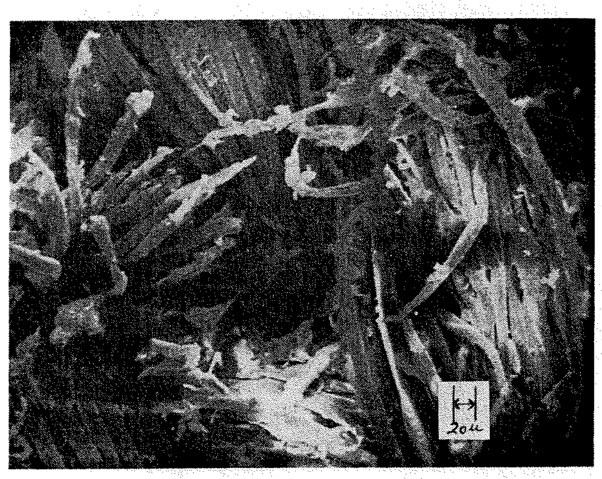

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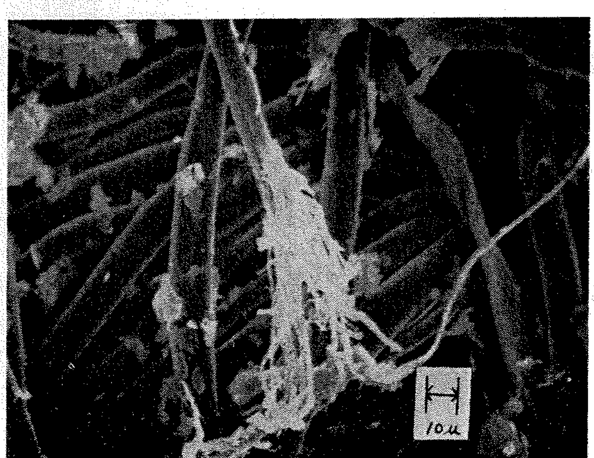

(a)

(d)

FIG. 11. Influence of blending nylon with cotton upon abrasion from the Stoll Flex abrader: a—Cotton fiber from the blended poplin; b—70/30 nylon/cotton poplin; c—100% cotton poplin; d—Fibers from the all-cotton poplin.

contrast there appeared to be less wear in the all-cotton poplin (Fig. 11c), even though it took fewer cycles to reach an end-point of test, because the wear was more evenly distributed. Fibrillation occurred (Fig. 11d) but was not as finely divided as in the blended poplin.

The following hypothesis is proposed to explain the contrast in wear resistance of the blended fabric in the Schiefer and Stoll Flex abraders. In the Stoll Flex abrader, the sample is subjected to a flexing action as well as a rubbing motion. The nylon fibers cannot protect the cotton fibers from this flexing motion, and thus the cotton fibers in the blended fabric deteriorated in this abrader. In those abraders such as the Schiefer where the abrasion is totally a rubbing action, the cotton in the blend can be protected by the nylon and will not interact with the abradant. Fabrics tested in the Accelerotor also undergo some flexing. This may explain the similarity of damage in the all-cotton and blended poplins abraded in the Accelerotor.

In the Taber abrasion and field wear the extent of damage was less in the blended poplin than in the all-cotton fabric. The nylon seemed to give some protection to the cotton fibers but not as much as in the samples from the Schiefer abrader.

The presence of nylon caused little change in the amount of damage to cotton in the poplins abraded by the Accelerotor. The lack of influence of the nylon is confirmed by a comparison of average percent weight loss of the two fabrics after five minutes of Accelerotor abrasion. The blended poplin lost 11.5% weight, whereas the all-cotton poplin lost 12.0%. It is interesting to note that the similarity in degree of wear in the two poplins in Accelerotor abrasion does not correlate with the results of field wear, even though the Accelerotor best reproduced the morphology of field wear. It was the Taber abrader that best reproduced the difference in amount of wear in the two poplins in field wear. Possibly a longer time of abrasion in the Accelerotor would develop differences in degree of wear in the two fabrics.

Summary

The results of this first phase of a SEM analysis of laboratory and field wear in various military fabrics can be summarized as follows:

The major process of deterioration of cotton in laboratory abrasion and military field wear of the fabrics examined to date is by breakdown into fibrillar components which are smoothed off as wear progresses. Those abrasion environments which allow the fabric to abrade or wear freely with little or no application of weight or tension—i.e., field wear and the Accelerotor—give a round morphology. The abraders which use weight and/or tension to accelerate wear—i.e., the Schiefer, Stoll Flex, and Taber Abraders—cause the bundles of fibrils and smoothed fiber ends to become flattened and angular. Nylon Type 420 also fibrillates, but the fibrils are shorter and thicker than those of cotton and they do not seem to be as affected by weight and tension of abradants. When the wear progresses to hole formation, the influence of weight and tension becomes noticeable.

Because of its lack of weight and tension in testing, the Accelerotor best reproduces the rounded fibrillation that is characteristic of field wear in the three fabrics studied to date. The presence of weight and tension caused more difference in the physical morphology of abrasion damage than did the degree of roughness of the abradant.

There are some differences in the morphology of abrasion damage in the herringbone and poplin geometries when the abrasion is particularly directional, as in the Stoll Flex abrader.

The analysis of the blended poplin showed that the presence of nylon has very different influences upon the extent and morphology of damage to cotton, depending upon the type of motion involved in abrasion and wear.

The investigation will continue with examinations of the morphology of abrasive deterioration of a variety of man-made fibers, including other types of nylon, of the effects of different types of blends, of the influence on morphology of wear of other fabric geometries, and of the effect of various additive finishes.

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