Part VI
Case studies: clothing and domestic uses

27

INTRODUCTION

We now turn to the study of materials worn in real-life situations, starting with case studies selected from the traditional uses of textiles in clothing and in household products, such as sheets, towels and carpets.

Although it is sometimes useful to make quick exploratory studies, any proper investigation, unless it is a particular example of an application which has been previously investigated in detail, requires a very thorough study by a variety of techniques, as described in Chapter 2, and takes a long time. Inevitably, therefore, the examples included here cannot be regarded as more than a somewhat arbitrary selection from the vast range of different types of textile fabric used in a vast variety of products and situations. The choice was dictated partly by the availability of interesting and adequately documented samples. No sexist bias was intended, but it turns out that more men's garments than women's were examined.

28

TROUSERS AND JACKETS

Our first example of a case study of textile failure arose from a customer complaint. A pair of men's trousers, made of a blend of wool, polyester and rayon, had worn into a hole, **28A(1)**, after only a few days of use. Examination at higher magnification shows fibres failing by multiple splitting, **28A(2),(3)**, and breaking with bushy ends, **28A(4)**. This is characteristic of failure by bending and twisting, as found in the laboratory biaxial rotation fatigue test. Further wear may cause fibre ends to become rounded off, **28A(5)**. There is also some evidence of central splitting, **28A(6)**, which may be a result of pure flex fatigue by the shear mechanism described in Chapter 12. This example of textile failure was not the subject of major study, and details of fabric construction and conditions of use are not known, but it does demonstrate the typical pattern of wear and the characteristic form of fibre failure.

More detail was available of four pairs of men's trousers subject to a wear trial by IWS. All the trousers, which differed in fibre composition or weave, had worn through in the seat, close to the back seam and in or near the crotch, although the precise pattern of wear did vary. One pair of trousers was made of a grey pin-stripe material blended from a mixture of black and white wool fibres, with the pin-stripe formed by two continuous-filament polyester yarns. There was a hole in the crotch region on one side of the centre seam, with the fabric worn thin on the other side of the seam. The polyester yarns had not broken but continued across the hole, undamaged except for slight peeling on the filament surfaces, even though warp and weft wool yarns had worn completely away. The wool fibres start to break down at several places along their length, **28B(1)**, with the development of multiple splitting, **28B(2)**, leading to break with a bushy end, **28B(3)**, and then to rounding off with more wear, **28B(4)**.

Another pair of trousers was a charcoal-grey blend of wool and polyester staple. This pair had pilled badly on both sides of the centre back seam near the crotch, and this had caused the fabric to wear thin on one side of the seam and into a hole on the other. The fibre damage is the typical multiple splitting at many places. This takes place in both wool and polyester fibres, **28B(5)**, and is followed by rounding off, **28B(6)**.

The other two pairs of trousers from the IWS trial were looser tweeds, made from all wool. There were some differences in the exact location of wear, and another effect observed was the loss of nap from the surface, which made some parts of the fabric appear bald or threadbare, **28C1(b)**, compared with the relatively unworn trouser legs where the surface hairiness is evident, **28C(1a)**. A characteristic feature in these wool tweeds was the loss of yarn in one direction in the crotch region but not in the other direction, **28C(2)**. Nevertheless, the sequence of fibre damage — splitting, bushy ends and rounding off — was similar, but not as severe or widespread as in the wool/polyester trousers.

In all four pairs of trousers similar fibre damage was found, not only extensively in badly worn regions, but also in a few fibres in the trouser legs, where the fabric did not show obvious signs of wear. The fibre breakdown is occurring throughout the material, but is more severe in particular regions.

The remaining examples in this chapter are garments subject to ordinary wear, and not from special wear trials.

The mechanism of fabric wear by pilling is discussed in Chapter 30, but is also illustrated by a woven wool/polyester fabric used in ladies' trousers. The pills, which appear on the fabric surface, are tangled balls of fibres, **28C(3)**. They are surrounded by material which is deficient in fibres. The fibres in the pills show evidence of much multiple splitting, **28C(4)–(6)**. In all wool fabrics the pills easily break off, but the stronger polyester fibres in the blend hold them on the fabric more strongly, so that higher pill densities develop.

The next case study is of a pair of men's trousers from a suit made from an extremely durable worsted material, containing hard twisted wool yarns, tightly woven in the fabric. It proved impossible to wear holes or thin places in the material, but the suit was eventually discarded because the seat of the trousers had become excessively shiny. It is thus a complete contrast to the first case study, in which a hole formed after very little use.

A typical view of fibres in the outer surface of the seat is shown in **28D(1)**. Fibres in the plane of the fabric at the outermost (upper) level have had their surfaces worn away; but this is not so for fibres deeper in the fabric. Fibres which project out at an angle to the plane of the fabric are broken with multiple splits. A clear example of a fibre with a surface worn flat, so that it reflects light and contributes to the shiny appearance, is shown in **28D(2)**. Detail of a broken fibre from this region is shown in **28D(3)**: it has broken by multiple splitting, but is beginning to be rounded off. On the inner seat surface, **28D(4)**, there are broken fibres, some of which have developed rounded ends. On the knee both fibre breakage, **28D(5)**, and surface wear, **28D(6)** can be seen.

The material used in the pockets of this pair of trousers was also examined. This was a durable continuous-filament polyester fabric, but it had formed a hole near the bottom seam, **28E(1)**. Even away from the hole there was damage to the fibres, with many zones of multiple splitting, **28E(2)**. Detail of fibre breakage is shown in **28E(3),(4a,b)**.

The label on the waistband of this pair of trousers was made of viscose rayon, and also showed evidence of wear, with broken fibres projecting from the interstices of the weave, **28E(5)**. These fibre ends had become rounded off by prolonged wear, but the actual breaks of rayon were sharp, **28E(6)**, and resembled tensile breaks. Rayon is exceptional in not showing failure by multiple splitting.

The last example of trousers is of cotton cord jeans. There is a clear contrast between relatively undamaged fabric, **28F(1)**, and fabric from a worn area on the right knee, **28F(2)**. Fibre ends in the little-worn fabric, **28F(3)**, are typical of fibres cut when the cord fabric was made; but in the worn material there is entanglement and fibre splitting, **28F(4)**.

Finally, we give one example of failure in a jacket. This was a wool/polyester school blazer which had become shabby after use. The wool fibres fail by multiple splitting, **28F(5)**, with the ends gradually being rounded off as they suffer further wear, **28F(6)**.

Yokura and Niwa (1990) report changes in mechanical properties, as measured on the KESF system, of 20 men's summer suiting fabrics after laboratory fatigue tests. They also calculated *total hand values* (THV) and *total appearance values* (TAV) from predictive equations proposed by Kawabata and Niwa (1980) and Niwa and Kawabata (1988). Suits were made from two of the fabrics: N36, a 50/50 wool/mohair blend, and N37, a 35/65 wool/polyester blend. These suits were worn at work in a laboratory for 800 hours over six seasons with dry-cleaning after each season. The changes in mechanical properties were measured in samples from different parts of the garments, and they also show photographs of the jackets, before and after wear. The comment on the appearance of the jackets was:

The jacket tailored from fabric N36 showed a beautiful seam line coming from natural overfeeding and a smooth curve at the shoulder before and after the wear test. On the other hand, jacket N37 showed fabric distortion at the shoulder before wear. The puckering and distortion at the shoulder and sleeve head of jacket N37 became severe after 800 hours of wear.

The overall conclusion was:

Shape retention during wear of a suit jacket tailored from fabric with a total appearance value (TAV) of 4.39 was superior to that of a jacket tailored from a fabric with a TAV of 2.15. The decrease in the TAV of fabrics with a high TAV was less than that of fabrics with rather low TAV after the simulation test. These results suggest that the TAV of the fabrics can be used to characterize the appearance of a suit jacket after wear.

The hysteresis properties of fabrics such as bending (2HB) and shearing (2HG, 2HG5) increased markedly with wear, suggesting that fabric fatigue phenomena can be quantified by the increase in mechanical hysteresis properties. For the wool and wool/mohair blend fabrics, there was a linear relationship between the decrease in the total hand value (THV) after the simulation test and the increase in the 2HG measured after the deformation test of 10^4 cycles along the weft direction. Clearly fabrics with good handle durability show a small increase in the 2HG in the deformation test of 10^4 cycles.

In a second paper, Yokura and Niwa (1991) describe the results of wear for 1500 hours in men's summer trousers made from fabrics N36 and N37 and also from NZ100, an all-wool fabric. Changes in properties and structure of the fabrics, yarns and fibres as a result of wear were measured and explanations of the changes in fabric properties were suggested. SEM pictures of the fibres were taken before and after wear. **28G(1),(2)** show kid mohair fibres from the weft of fabric N36. As a result of wear, the fibres have lost their scales and become roughened on the surface. Fabric NZ100 contained a mixture of merino wool (22 micron) and coopworth (35 micron). **28G(3),(4)** displays a clear wearing away of the scales of the fine merino fibres, but there was little obvious change in the coarser fibres. The slightly coarser merino fibres in fabric N37 also show wear of the scales, **28G(5),(6)**, while the polyester fibres are roughened and debris has accumulated between the fibres. Some multiple splitting of wool fibres was found in the warp of N37, but otherwise there were few broken fibres.

The conclusions from this work include the statements;

Crimp in both yarns and fibers decreased due to considerable extension of the fabrics by the mechanical action of wear and abrasion. As crimp decreased, the yarns became flattened and increased the lateral pressure and contact region at yarn crossover points in the fabrics. These increases are considered to produce increased interyarn friction. The shear torque parameter C_l, which represents the effect of interfiber friction, increased with wear. Increasing interyarn and interfiber friction is considered to govern the increased hysteresis properties of fabrics. The removal of fiber scales and the ragged fiber surfaces were apparent in the SEM observations, and we believe this degradation was influenced by the increased interfiber friction.

The yield stress and strain of fibers for tensile and torsional properties decreased with wear. Fibers were fatigued more markedly in the transverse direction along the fiber axis during wear, so torsional properties of fibers are more affected by the degree of fatigue than tensile properties.

. . . results suggest that the performance of coopworth fibers is superior to kid mohair

. . . in fabric N37 . . . we believe that the wool fibers were weakened by the abrasive action of neighbouring PE [polyester] *fibers.*

The experimental work reported in this study provides a basis for engineering improved fabric quality and for developing new kinds of wool fabrics.

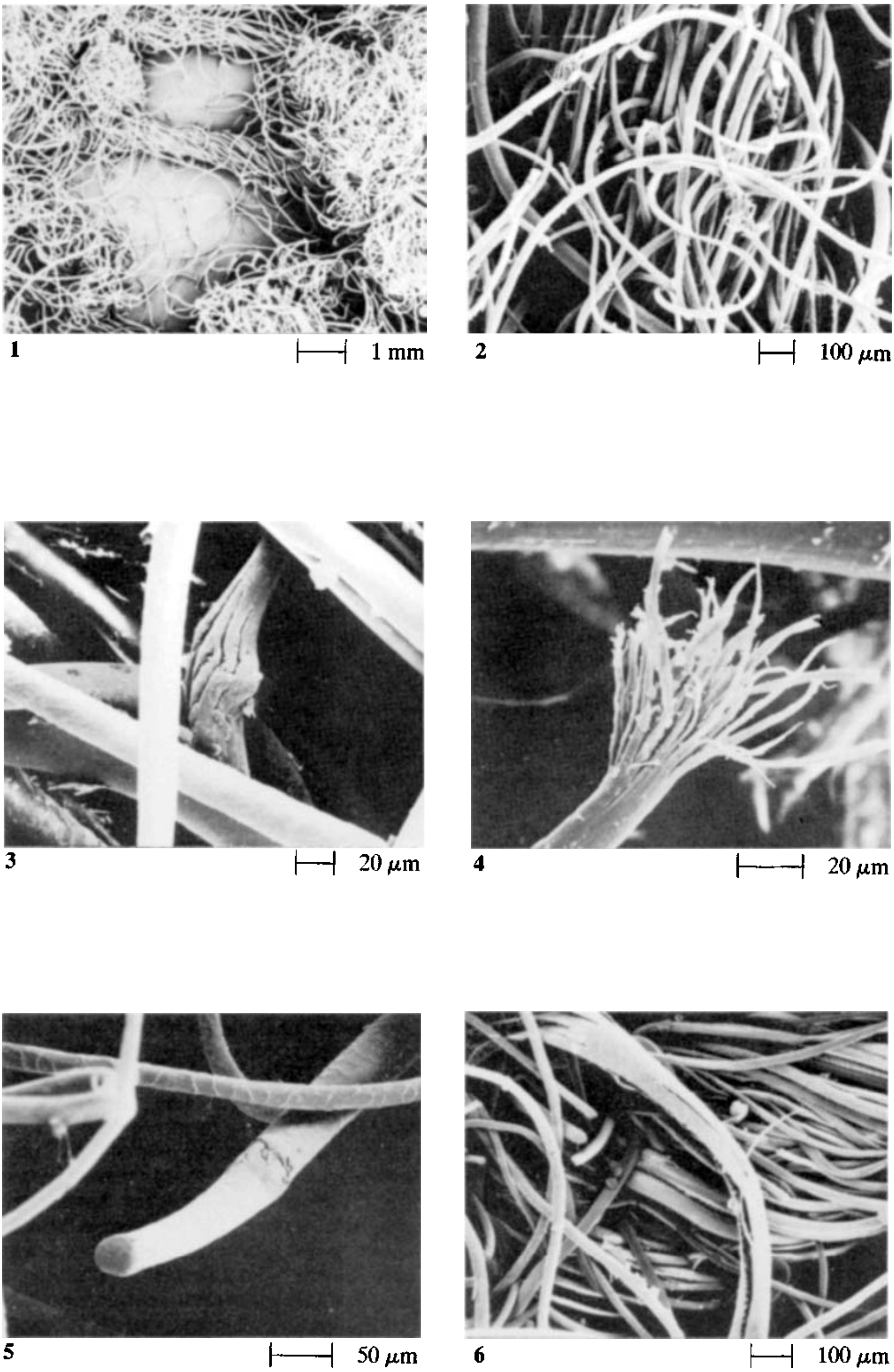
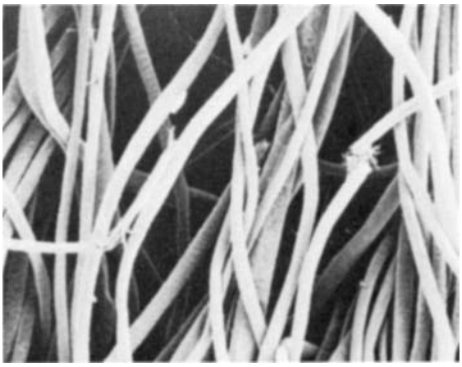
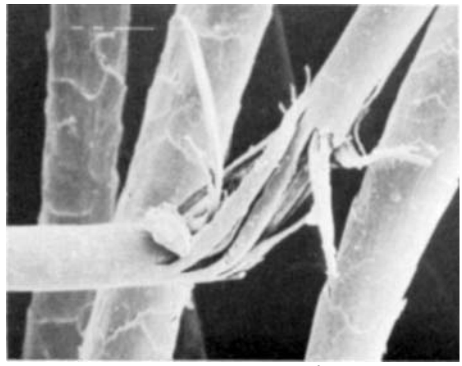


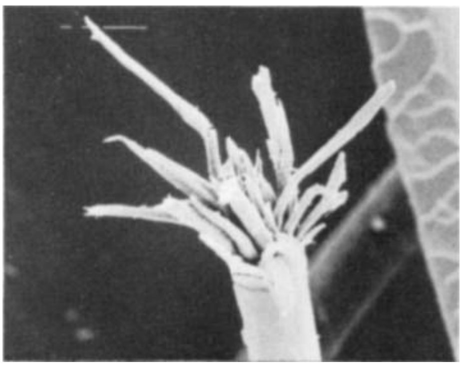
Plate 28A — Unsatisfactory performance of a pair of men's trousers.
(1) Hole formed after very little wear. (2) From region of wear close to the hole. (3)–(6) Details of fibre breakdown.



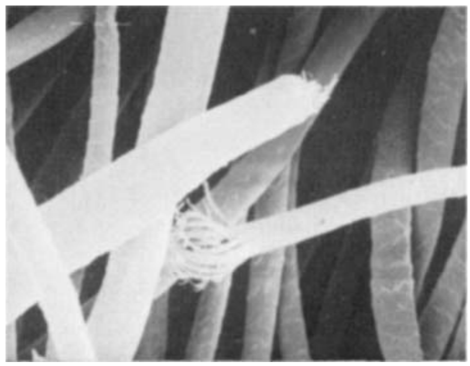
1 100 μm



2 10 μm



3 10 μm



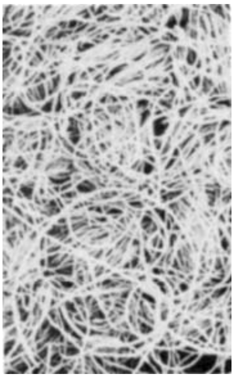
4 50 μm

5 20 μm

6 10 μm

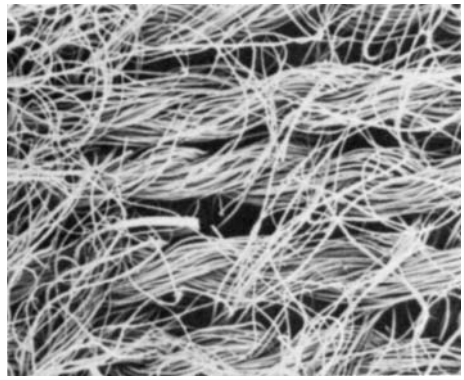
Plate 28B — Study of men's trousers subject to wear trial by IWS.
(a) Grey wool with polyester pin-stripe.
(1) Multiple damage sites. (2) Axial splitting of wool fibres. (3) Bushy end of break. (4) Rounding off with further wear, with another fibre in multiple splitting state.

(b) Charcoal-grey wool/polyester blend.
(5) Multiple splitting in wool and polyester fibres. (6) Rounding off after more wear.

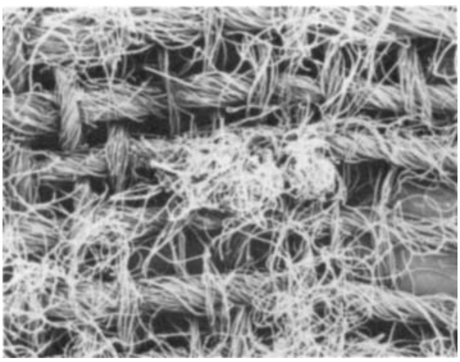


1a 1 mm

1b 1 mm



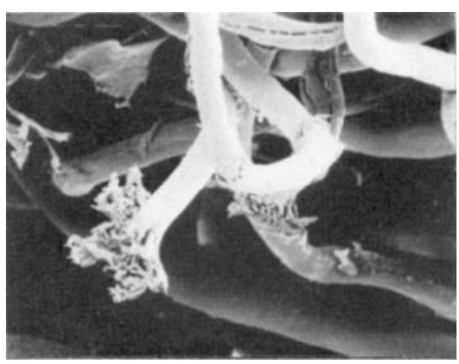
2 1 mm



3 1 mm

4 50 μm

5 100 μm



6 20 μm

Plate 28C — Study of trousers subject to wear trial by IWS (continued).
(c) Fine wool tweed.
(1a) Appearance of relatively unworn fabric. (1b) Surface fibres worn away in seat region.

(d) Coarser wool tweed.
(2) Warp yarns worn away in seat region, leaving weft yarns crossing the gap.

Wear of ladies' wool/polyester trousers.
(3) Pill on fabric surface. (4) Detail of pill. (5), (6) Fibre damage by multiple splitting.

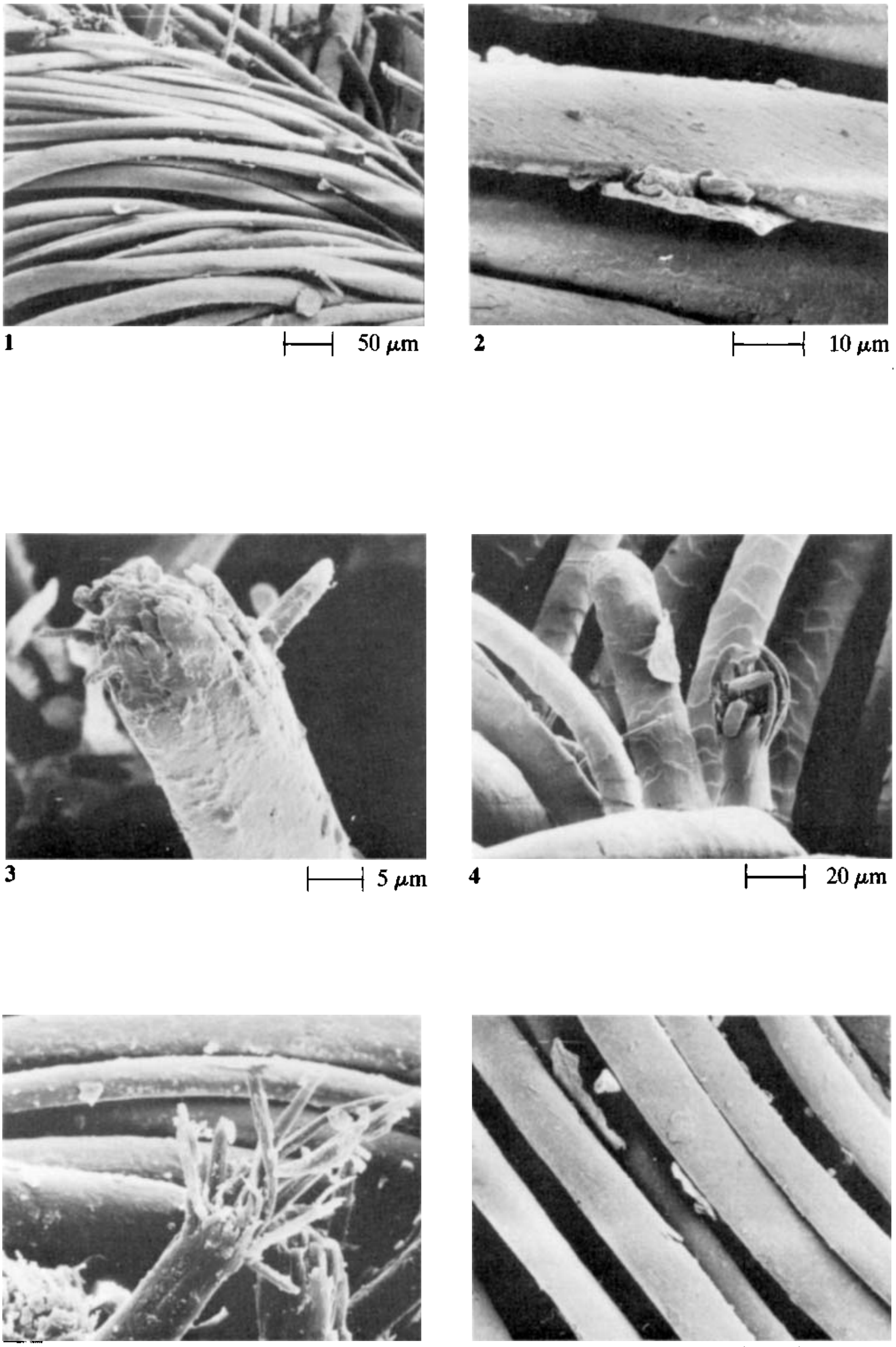


Plate 28D — Examination of worn trousers, made from a durable worsted fabric, after many years of wear. (1)Fibres on outer surface of worn seat. (2) Detail of surface wear of fibres in worn seat. (3) Detail of fibre breakage in worn seat. (4) Fibres on inner surface of worn seat. (5), (6) Fibres in fabric at right knee.

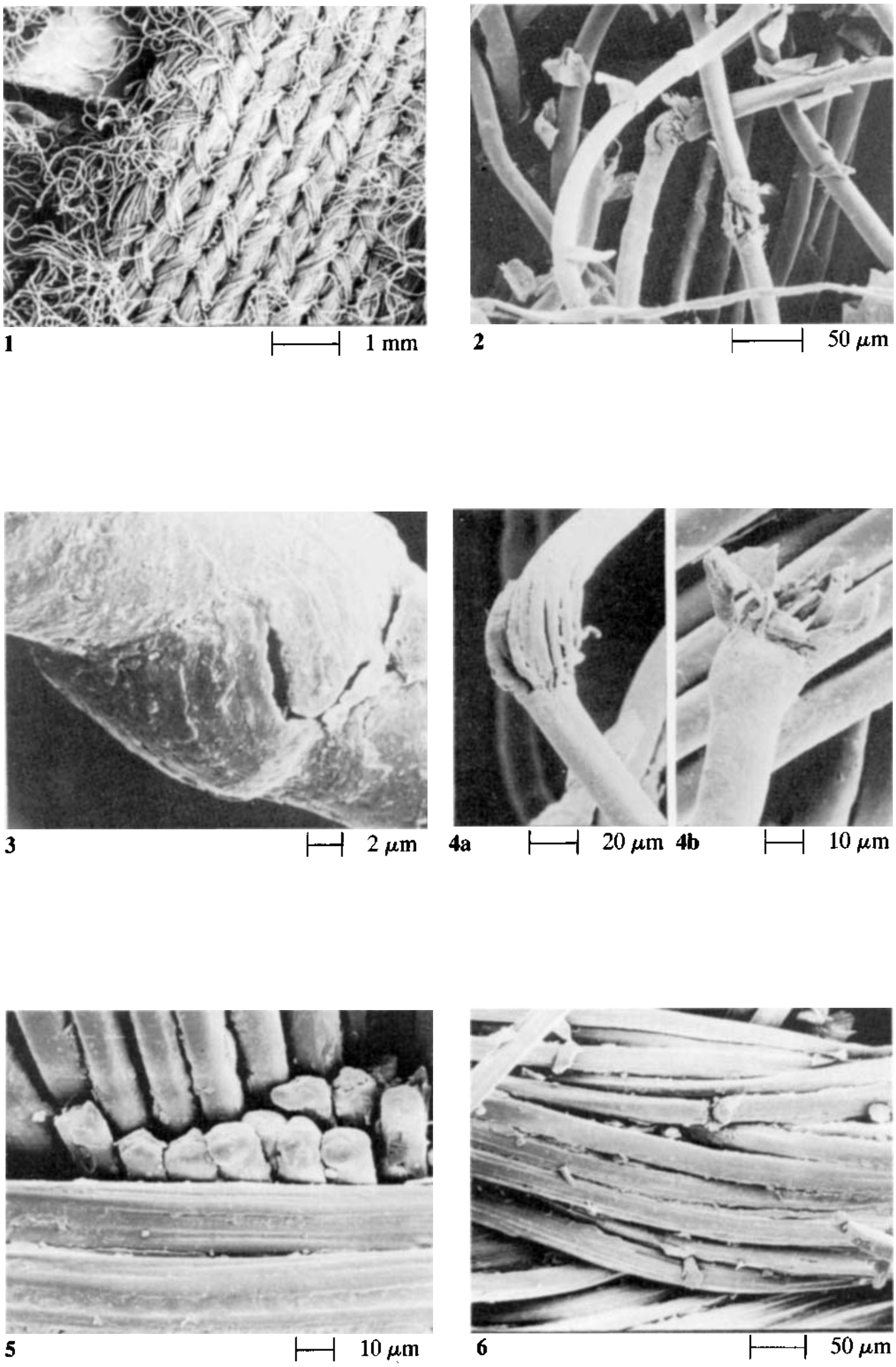
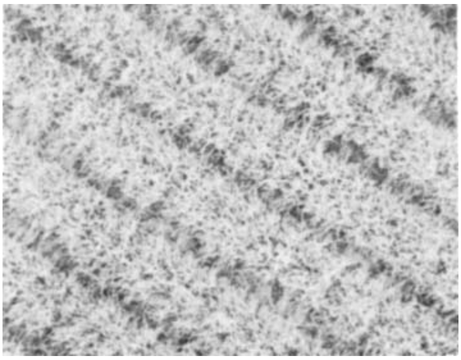
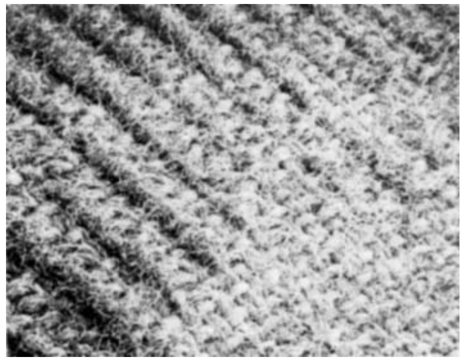


Plate 28E — Examination of pocket from trousers from 28D: continuous-filament polyester fabric.
(1) Edge of hole, near bottom seam. (2) Inner surface of pocket, away from hole. (3) Fibre at broken seam. (4a) Fibre at broken seam. (4b) Fibre at inner surface of pocket.

Label at waistband of the same trousers.
(5) Broken rayon fibres at fabric interstices. (6) Form of breakage of rayon fibres.

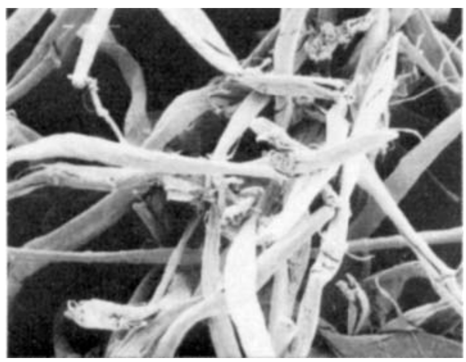


1 2 μm

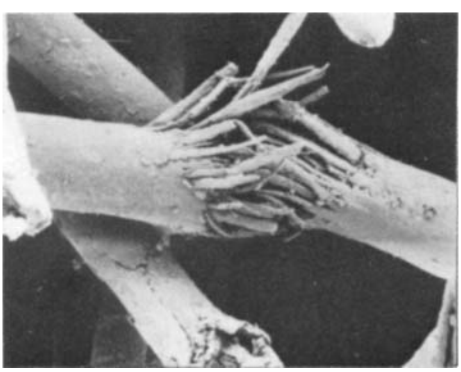


2 2 μm

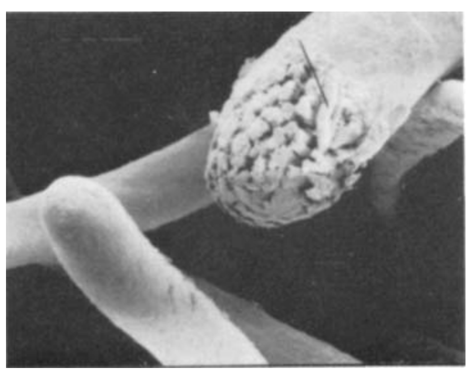
3 50 μm



4 50 μm



5 20 μm



6 10 μm

Plate 28F — Worn cotton cord jeans.
(1) Relatively unworn fabric from pocket. (2) Fabric in well-worn area of right knee. (3) Cut fibres in little-worn fabric. (4) Fibres in worn area of right knee.

Worn wool/polyester school blazer.
(5) Wool fibre broken by multiple splitting. (6) Partial and complete rounding off of broken fibre ends.

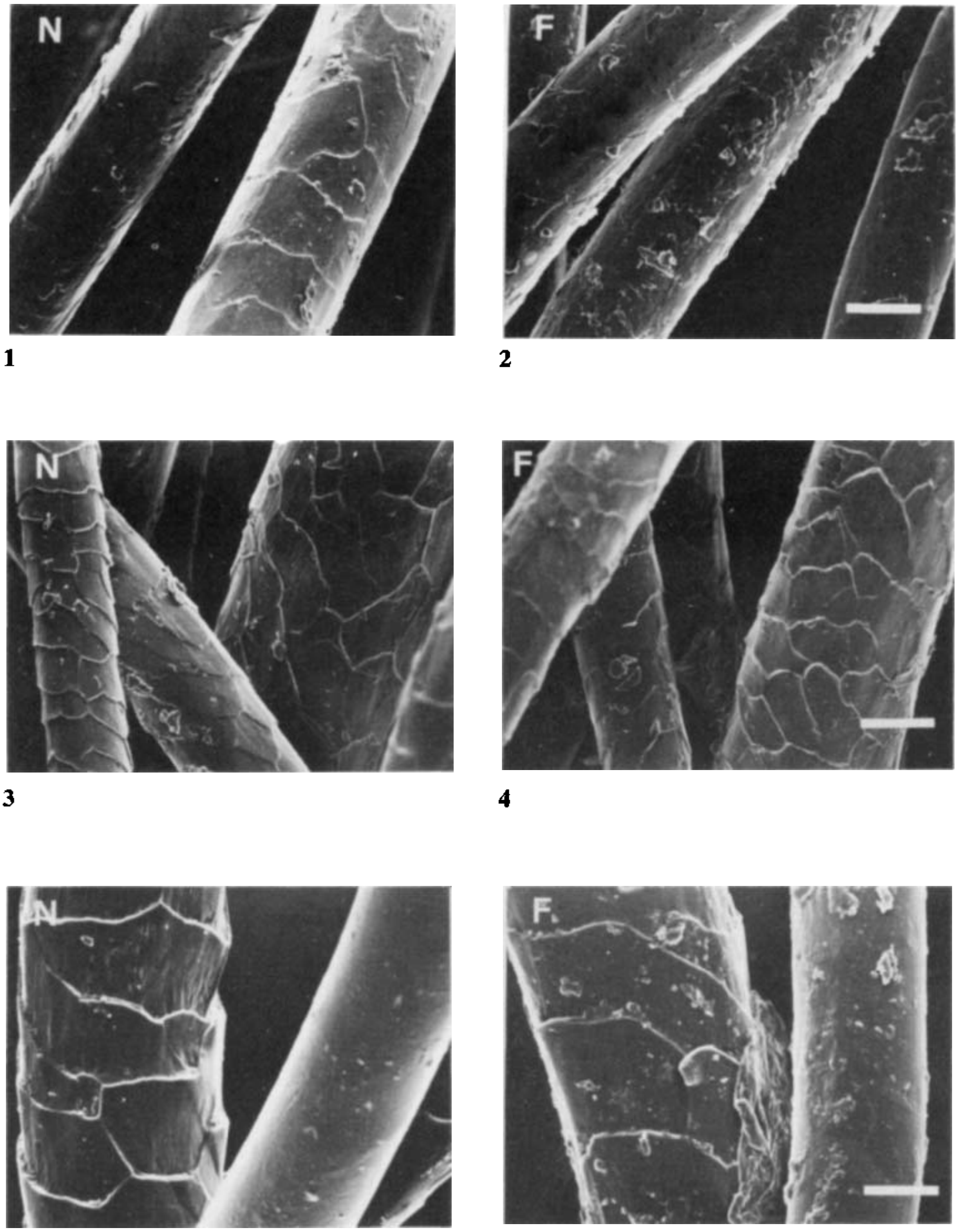


Plate 28G — Wear in men's summer trousers, from Yokura and Niwa (1990).
(1) Mohair fibres in fabric N36 before wear. (2) After wear. (3) Coopworth and merino fibres in fabric NZ100 before wear. (4) After wear. (5) Polyester and merino fibres in fabric N37 before wear. (6) After wear. [Bars are $10\,\mu m$.]

29

SHIRTS

Wear in shirts is influenced both by the material, design and make-up of the garment, and by the habits of the wearer. The worst wear commonly occurs along the collar fold, and in long-sleeved shirts, at the edges of the cuffs. In both these places it is associated with sharp folds, supported by interlinings, which are usually bonded to the fabric, and also in collars by point stiffeners. Wear of collars and cuffs spoils the appearance of shirts, so that they are often rejected, at least for fashionable wear, long before the rest of the garment has sustained much damage. Sometimes, presumably after a lot of desk-work, there is severe wear at the elbows. Wear can also occur at shirt front-openings, and there may be accidental tearing, either during wear or laundering.

A popular modern shirting fabric is woven from 65% polyester/ 35% cotton yarns, as illustrated in **29A(1)**. Note the bulbous ends of polyester fibres, which indicate that the fabric has been singed. The front of the shirt, as shown in **29A(1)**, has suffered little wear and hardly any fibre damage is apparent; but there is severe wear at collars and cuffs, both elbows have worn right through in places and there has been wear elsewhere.

The loss of yarn at the collar fold is shown in **29A(2)**, and in cuff edges in **29A(3)**, where the interlining adhesive and ground-in debris can be seen between the remaining weft yarns. The rigidity given to the fabric, as a result of being stuck to the interlining, is apparent from a section through a cuff, **29A(4)**. This rigidity intensifies the forces on the fabric, since they cannot be relieved by buckling of the fabric; and the adhesion concentrates the forces on individual fibres, which are not free to move out of the way of external pressure. These constructional features of the garment are an important factor in wear at collars and cuffs.

Elsewhere in the shirt the degree of damage depends more on the level and frequency of forces applied, either during use or in laundering. In the front the forces are small, and the damage, as seen in **29A(1)** is negligible. At the inside shoulder there is a little more damage. The polyester fibre breakdown is by multiple splitting, **29A(5a)**,**(5b)**. This may be associated with pilling, as discussed in Chapter 30, and occurs at anchor points in the yarn, **29A(6)**.

The severe wear at the elbow is shown in **29B(1)**, and is a result of the rubbing of the fabric on solid surfaces during use. The warp yarns are wearing away, and piles of fibre lie on the surface. The most common form of fibre damage to be seen is localized multiple splitting, **29B(2)**,**(3)**, similar to that found in laboratory biaxial rotation fatigue (Chapter 13), although there is some more extensive splitting and fibrillation, **29B(4)**, which may be due to peeling from the surface. Because most of the cotton has worn away in this region, the observed effects are mostly in polyester fibres.

The effects of wear at the elbow can also be illustrated by another polyester/cotton shirt. The relatively undamaged fabric from the front facing is shown in **29B(5)**, and contrasts with the worn fabric from the elbow, **29B(6)**, where some of the cotton has been lost and the material has stretched, leaving a more widely spaced scaffolding of threads.

Another example of severe wear on the edge of a cuff is illustrated in a 100% cotton shirt in **29C(1)**. The warp threads running along the edges have worn completely away, and some weft threads have broken. The fibre damage consists of fibrillation, **29C(2)**, and splitting, **29C(3)**, which is typical of cotton. Severe wear is also seen on the collar, **29C(4)**, particularly near the point. Wear has continued through to the interlining surface, where the yarns have partly worn through, **29C(5)**, leaving tufts of fibre ends at the interstices of the weave. Typical fibre damage in this region is shown in **29C(6)**.

Examination of one set of experimental cotton shirts with an easy-care finish from a wear trial directed by the late Mrs J. Lord, at the Shirley Institute, frequently showed not only some wear on the fabric surface but also failure by tears parallel to the warp and weft on either side of the front opening just below the collar, **29D(1)**. The general nature of the fibre damage on the surface is fibrillation and splitting, **29D(2)**. The edge of the tear is shown in **29D(3)**, where the cotton fibres may break by splitting along the lines of the spiral structure, **29D(4)**, but often show much sharper angular breaks and cracks, **29D(5),(6)**. The latter are characteristics of resin-treated cotton, which can be unduly weakened and embrittled by the chemical cross-linking.

An example of more severe wear of the collar of a cotton/polyester shirt is shown in **29E(1)**. In addition to the wearing away of yarns, the appearance of the material is spoilt by the development of pills, which are tangles of polyester and cotton attached to the fabric by a few anchor fibres. In the severely worn region the cotton has disapppeared, so that the visible fibre damage is in the polyester fibres, **29E(2),(3)**. These pictures show the complete sequence: first in **29E(3)** from undamaged fibre, through multiple splitting, to break with a bush end; and then in **29E(2)** to a rounding of the broken end with further wear.

Fibre damage in a warp-knitted, continuous-filament nylon shirt shows a similar pattern, **29E(4)–(6)**.

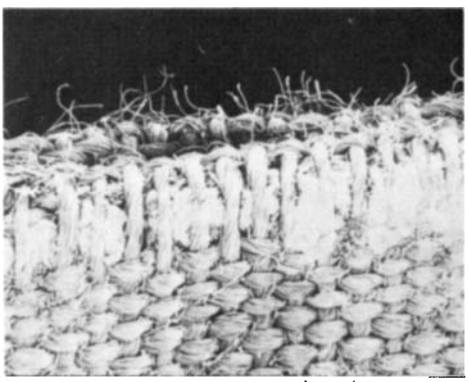
A relatively undamaged region of another warp-knit nylon shirt is shown in **29F(1)**. However, even in this region, fibres are beginning to break, and show the typical bushy and rounded ends, **29F(2),(3)**. There is also evidence of peeling, **29F(4)**, which may be a consequence of shear on the surface of the fibres at the yarn crowns. More severe wear, with many broken fibres in the yarn, is shown in **29F(5)**, but the fibre breakdown is similar, **29F(6)**.

It is stated at the beginning of this chapter that wear is in part influenced by the material used. Most of the shirts examined have been made from a poplin weave fabric, a weave which has been most frequently used in shirtings for many years. In this weave, warp and weft yarns interlace alternately in both yarn directions as shown in **29A(1),(3)** and **29D(3)**. There are approximately twice as many warp as weft yarns and in consequence the fabric can be said to be warp faced. Weft yarns are more deeply seated within the fabric and only when the warp has been seriously eroded are weft yarns susceptible to wear.

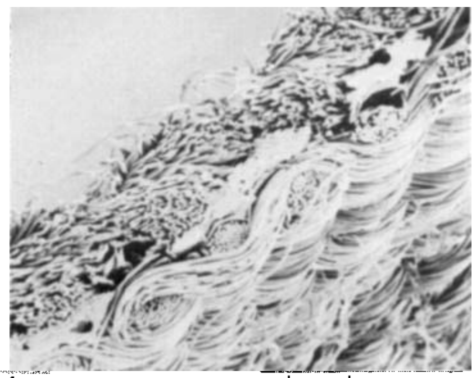
The design of a shirt demands that collars and cuffs are cut along the warp direction; for example in a striped shirt the stripes run the length of the collar and around cuffs. Thus warp yarns at the parallel to a collar fold and cuff edge receive the brunt of the wear and only when they are virtually worn away do weft yarns begin to suffer serious damage and fail, **29C(1)**.

1 $100\ \mu m$

2 $200\ \mu m$



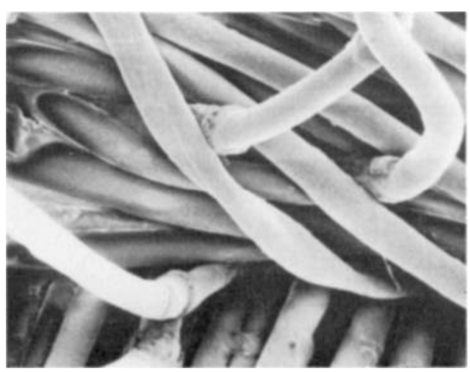
3 $500\ \mu m$



4 $200\ \mu m$

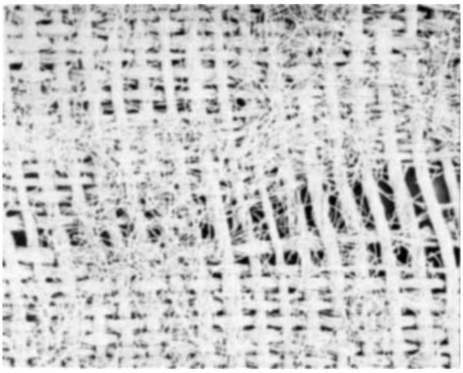
5a $10\ \mu m$

5b $10\ \mu m$



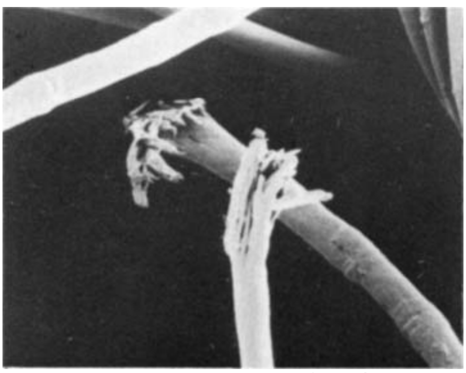
6 $20\ \mu m$

Plate 29A — Wear of 65% polyester/ 35% cotton blend shirt.
(1) Fabric from front of shirt, with little wear. (2) Worn collar fold. (3) Worn cuff edge. (4) Section through cuff, showing bonded interlining. (5a,b) Fibre damage from inside shoulder. (6) Anchor fibres in a pill on inside shoulder.



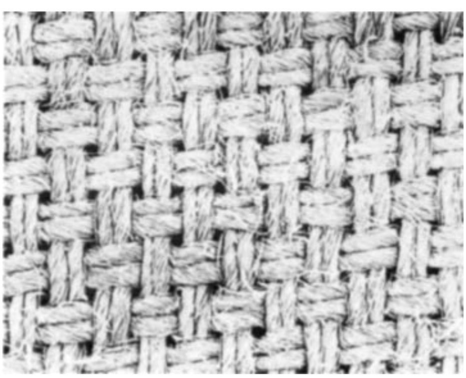
1 1 mm

2 10 μm

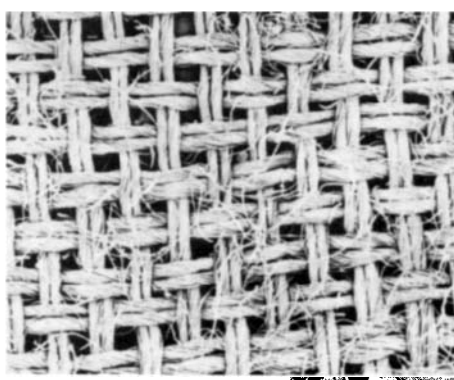


3 20 μm

4 10 μm



5 1 mm



6 1 mm

Plate 29B — Wear of 65% polyester/ 35% cotton blend shirt (continued).
(1) Badly worn material at the elbow. (2)–(4) Details of fibre damage at elbow.
Wear in another polyester/cotton shirt.
(5) Front facing, with little sign of wear. (6) From elbow.

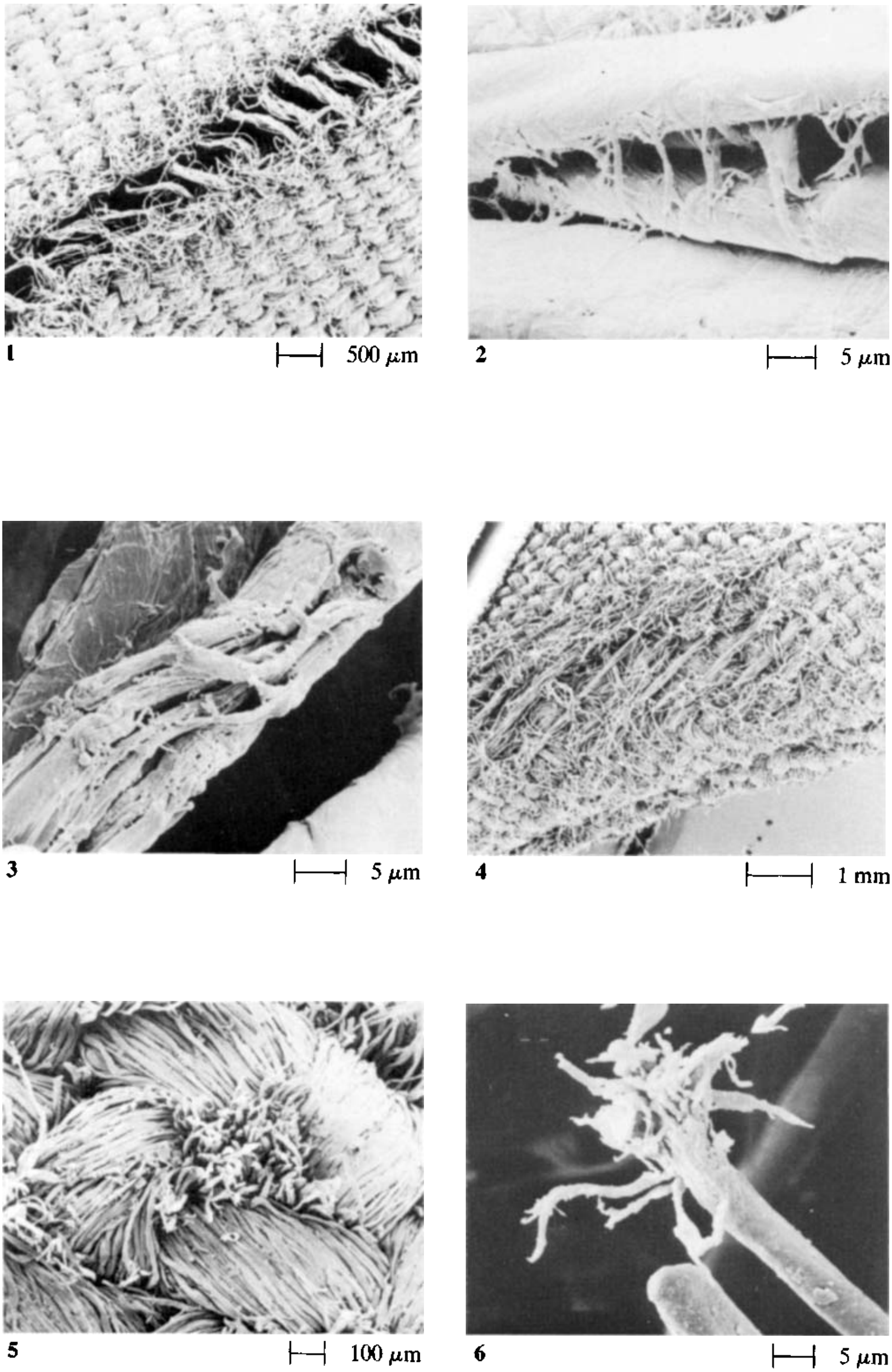
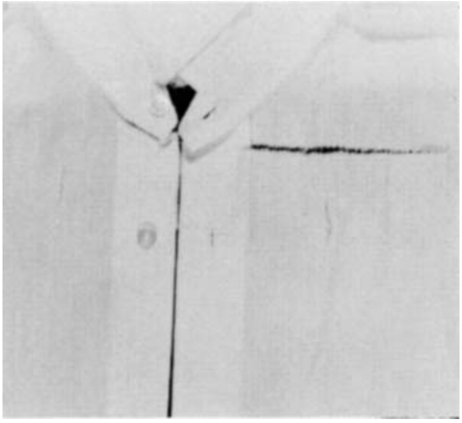
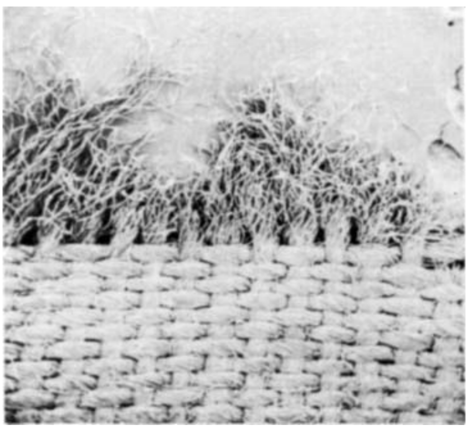


Plate 29C — Wear of cotton shirt.
(1) Edge of cuff. (2), (3) Fibre damage in cuff. (4) Damage at point of collar. (5) Partial breakage of yarn in collar interlining. (6) Fibre break in collar.



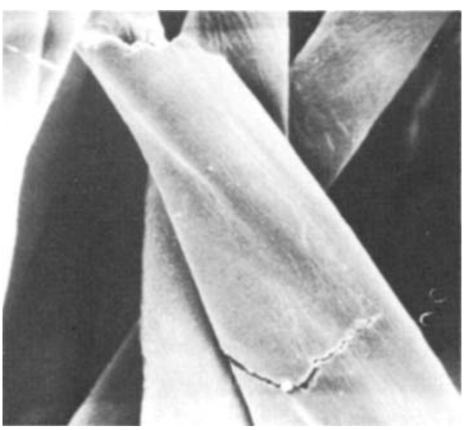
1

2 20 μm

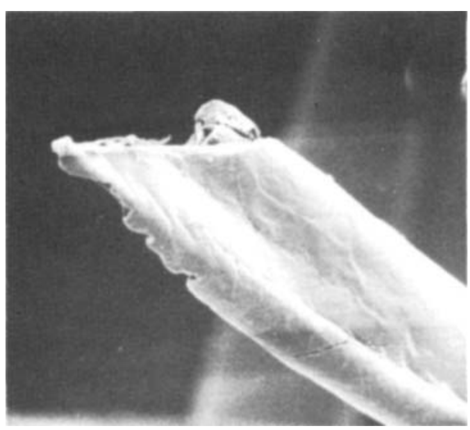


3 500 μm

4 10 μm

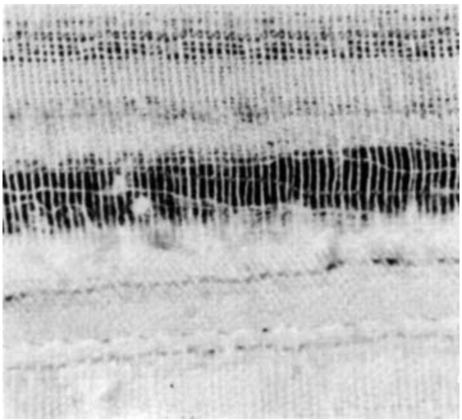


5 5 μm



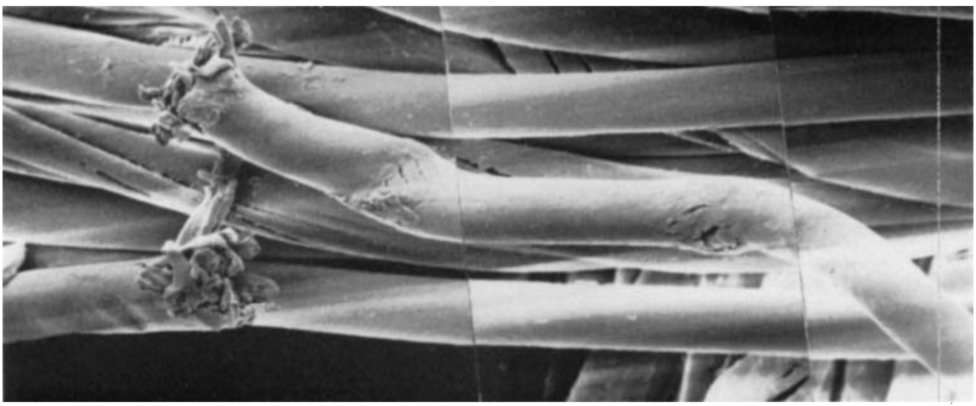
6 5 μm

Plate 29D — Experimental resin-treated cotton shirt from a wear trial.
(1) Tears in fabric. (2) Fibre damage on fabric surface. (3) Edge of tear. (4)–(6) Detail of fibre breakage.

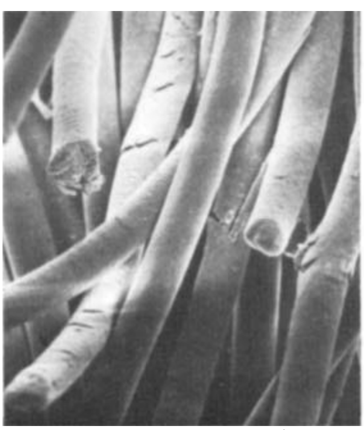


1

2 5 μm



3 10 μm

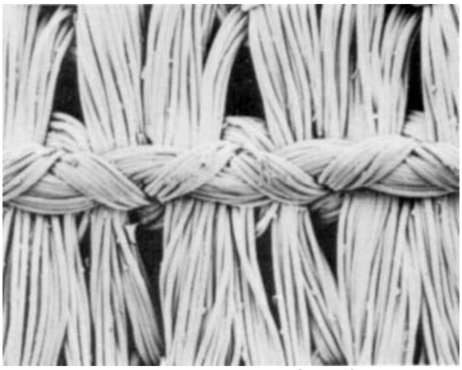


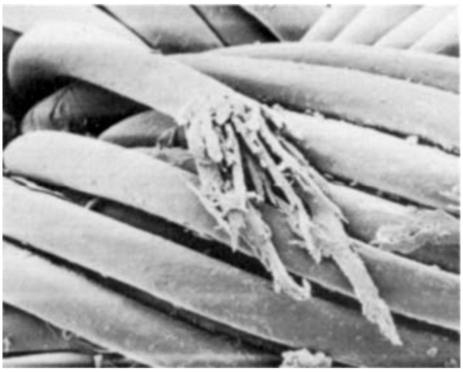
4 20 μm

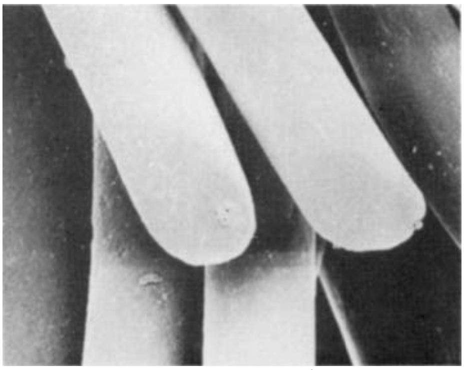
5 10 μm

6 5 μm

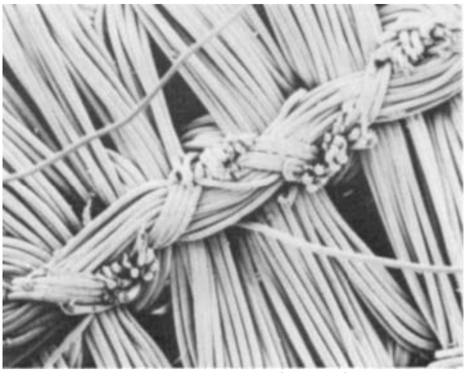
Plate 29E — Worn collar of 65% polyester/ 35% cotton blend shirt.
(1) Collar fold region, showing loss of yarn and pills. (2), (3) Polyester fibre breakdown.
Worn collar of warp-knitted nylon shirt.
(4)–(6) Fibre breakdown.


1 200 μm


2 20 μm


3 10 μm


4 20 μm


5 200 μm


6 10 μm

Plate 29F — Worn collar of another warp-knitted nylon shirt.
(1) Relatively undamaged fabric. (2) Fibre break by multiple splitting. (3) Rounding of end after further wear. (4) Peeling on fibre surface. (5) Region of greater wear. (6) Fibre breakdown.

Previous Page

30

WEAR AND PILLING IN KNITTED AND WOVEN FABRICS

Pilling is a form of change of fabric appearance, in which small tangled balls of fibre are distributed over the surface of the material. It is most prevalent in loosely constructed knitted or woven fabrics made of staple fibres, but can occur in other circumstances. The density of pills results from a balance between the rate of pill formation and the rate of loss of pills by their breaking off; and it can thus be minimized either by preventing pills forming, as a result of holding fibres more firmly in the fabric, or by allowing them to break off more easily, as a result of weakening the fibre.

Wear is associated with pilling in several ways. Firstly, the pilling itself is a form of deterioration of appearance brought on by use, and thus is 'wear' in the broad sense of the term. Secondly, as shown by the work of W. D. Cooke (1981, 1982, 1983, 1984, 1985), pilling can be a major source of fabric attrition, with the material becoming thinner, as pills form and break off, and may eventually lead to the formation of a hole. Thirdly, again from the work of Cooke, the mechanism of pill formation and loss is closely linked with the development of multiple splitting, as found in biaxial rotation fatigue (Chapter 13).

A general view of extensive pilling on a merino wool worsted-spun ladies' jumper is shown in **30A(1)**; and a microscopical view of the characteristic fatigue of wool fibres in pills is shown in **30A(2)**. These pictures are of samples from a large wear trial by IWS, but unfortunately a detailed SEM study was not made. Light wear on the back of a discarded wool jersey is shown in **30A(3)**, together with detail of the multiple splitting, **30A(4)**, which leads to breakage, **30A(5)**, and later rounding of the fibre end, **30A(6)**.

A much more detailed and carefully monitored study was made of the development of pilling in men's knitted underwear, made of cotton and various man-made fibres. A typical pill is shown in **30B(1)**, and the type of entanglement which occurs is seen in **30B(2)**. If a length of fibre is removed from a pill, it is found to contain a sequence of zones of multiple splitting, and a bushy broken end, **30B(3)**. This led Cooke to describe the mechanism of pilling as intermittent pull-out and roll-up. A schematic view of a pill is shown in Fig. 30.1, with the tangled ball connected to the fabric by anchor fibres. Bending and twisting at the anchor point cause multiple splitting fatigue, and the increased flexibility of the fibre then allows tension to be transmitted more effectively, so that another length of fibre is pulled out of the fabric. The excess length then gets rolled up into the pill. As the pill gets larger, the greater forces developed will cause zones with multiple splits to break; and when all the anchors have

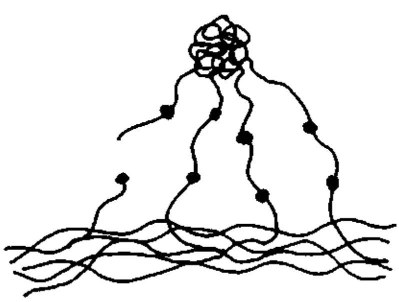


Fig. 30.1 — Pill near the end of its life, based on a schematic sequence drawn by W. D. Cooke.

ruptured, the pill will fall off. Other examples of the multiple splitting fatigue are shown in **30B(4)(5)**.

The last set of illustrations comes from a laboratory pilling test of woven overall fabrics. An early stage of pill development in a polyester/cotton fabric is shown in **30C(1)**, and a fully developed pill in **30C(2)**. Although some cotton fibres can be observed in the pills, the main component is polyester, in which multiple splitting fatigue can be seen, **30C(3)**.

A badly pilled polyester/modal (rayon) fabric showed considerable multiple splitting of polyester, **30C(4)**, together with broken fragments of the modal, **30C(5)**. The initial twisting and splitting of the polyester, which leads to pills, can also be seen in **30C(5)**. Little modal debris is found in the pills, but fragments are easily transferred to other fabric samples, **30C(6)**.

Wear in a wool cardigan shows characteristic wear and lifting of scales on the surface of the fibres, **30D(1),(2)**. Fibre breaks have been worn into the typical rounded end, **30D(3)**.

A hole in a cotton knit garment, **30D(4)**, illustrates the way in which fibres break up by multiple splitting into coarse fibrils. In contrast to this, a cotton T-shirt, in which wear will be due mainly to washing, shows the peeling away of fine fibrillar sheets, **30D(5),(6)**. This is similar to the wear in bed-sheets and towels, shown in **32A–D**. In some of the fibres, **30E(1),(2)**, larger chunks split off.

There are a few examples of the wear of silk in Chapter 31, but the break-up by peeling away of fibrillar layers is more clearly shown in **30E(3)–(6)**. The damage is most severe on the crowns of the yarns in the woven fabric.

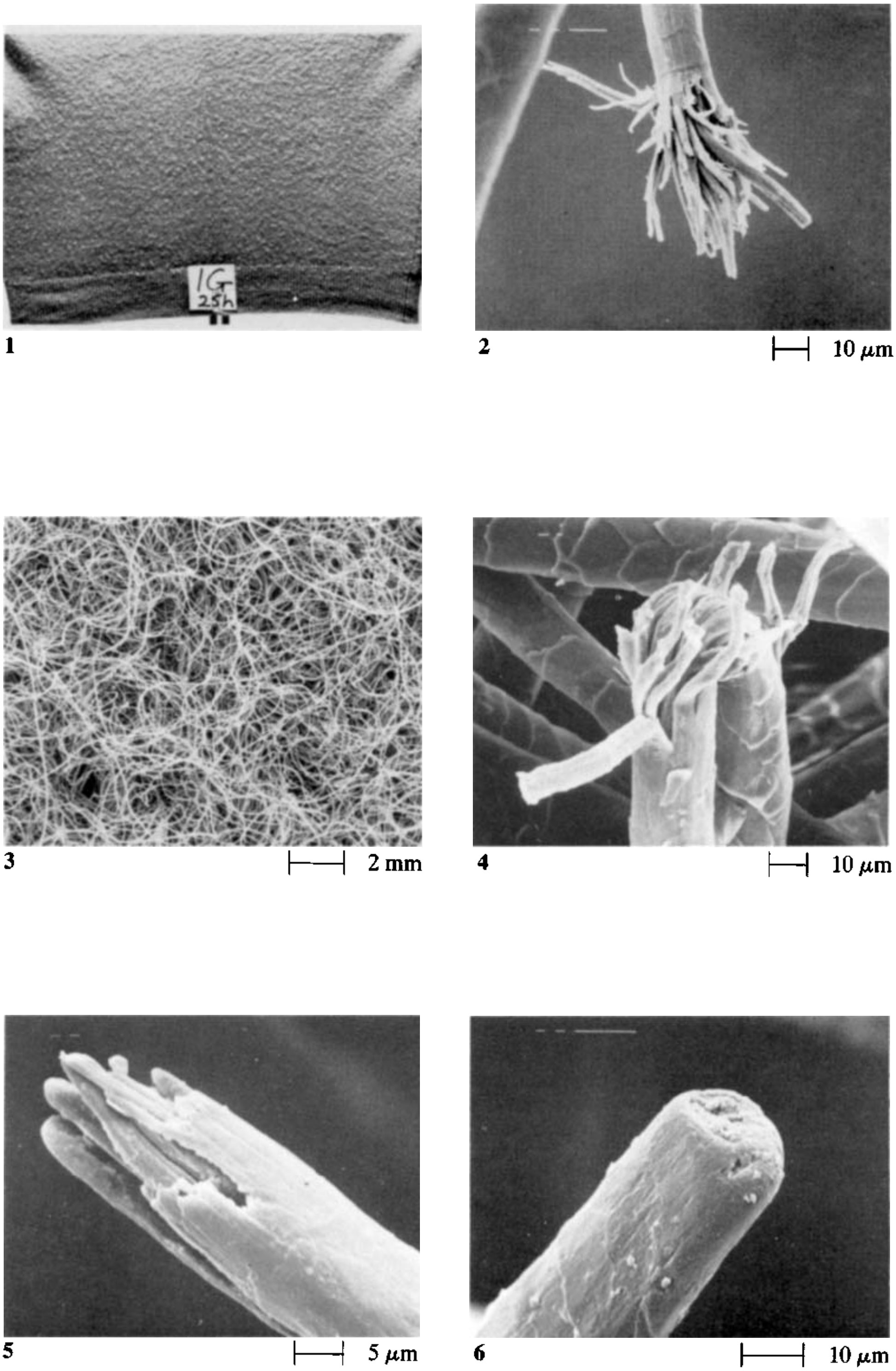


Plate 30A — Wear in wool sweaters.
(1) Ladies' merino worsted jumper, after being worn for 50 hours, with a wash at 25 hours. (2) Wool fibre in such a worn jumper. (3) Least-worn area on the back of a discarded man's jersey. (4)–(6) Detail of fibre failure.

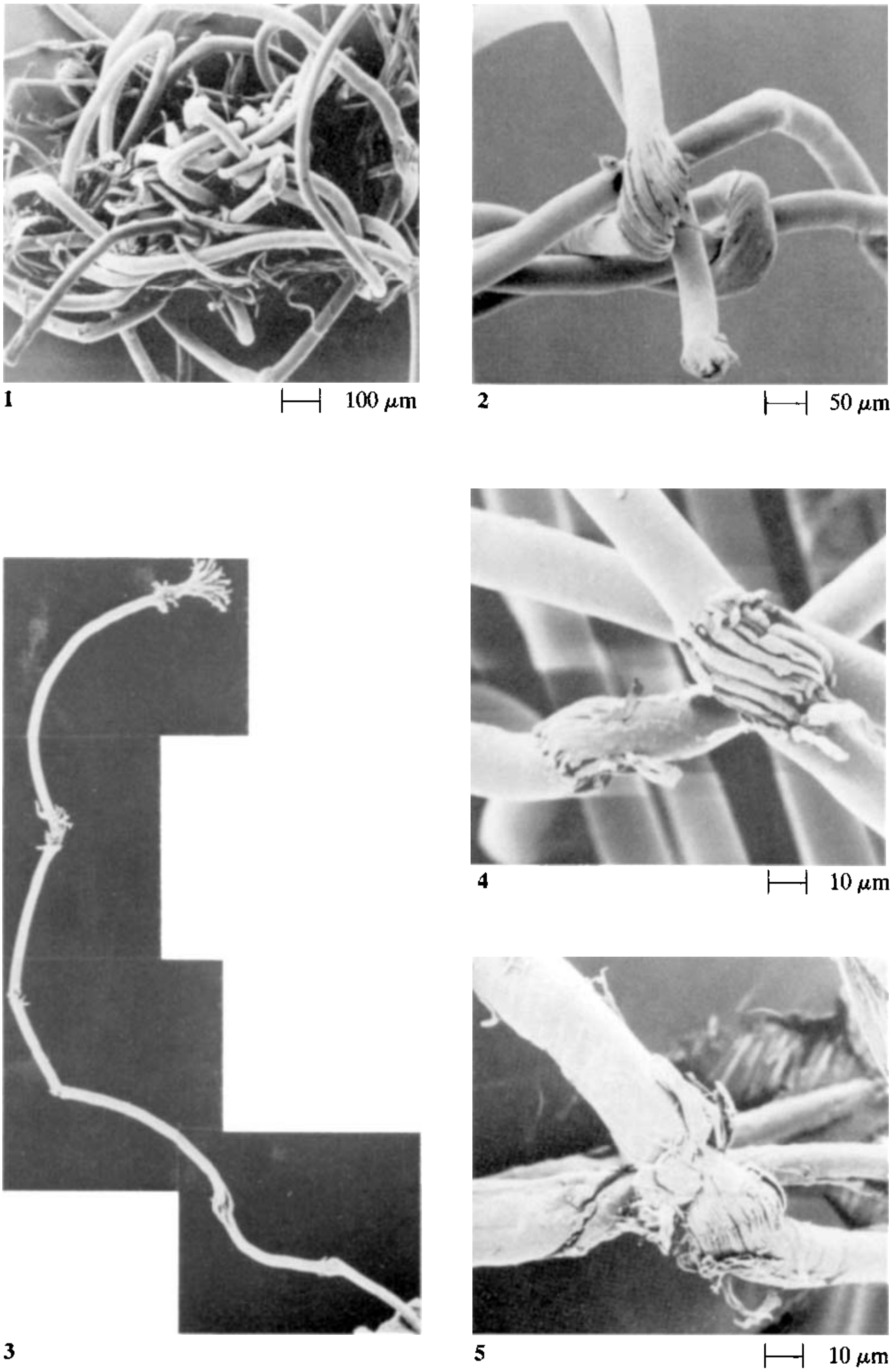
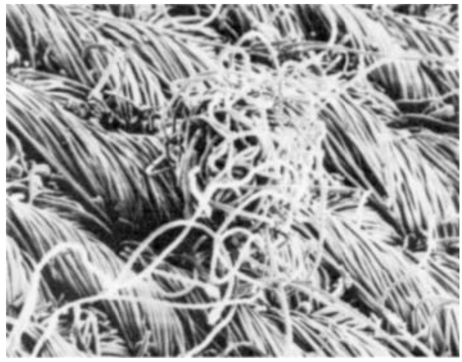


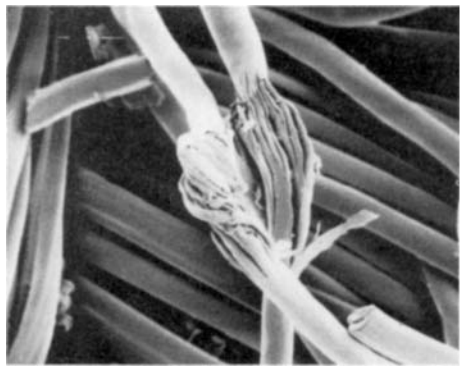
Plate 30B — Pilling in underwear.
(1) A typical pill. (2) Fibre entanglement. (3) A fibre from a pill. (4) Multiple splitting in polyester, (5) Multiple splitting in cotton.

1 $200\ \mu m$



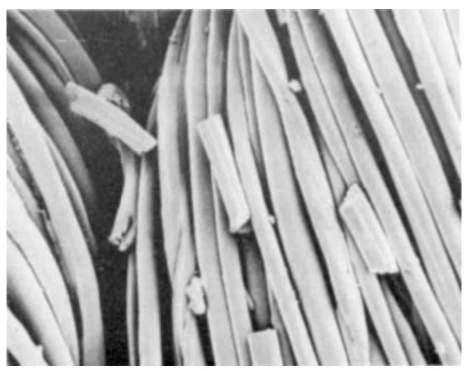
2 $200\ \mu m$

3 $10\ \mu m$



4 $20\ \mu m$

5 $100\ \mu m$



6 $50\ \mu m$

Plate 30C — Pill-testing of woven overall fabrics.
(1) Early stage of pill development in polyester/cotton fabric. (2) Well-developed pill in same fabric. (3) Detail of fibre splitting in another polyester/cotton fabric. (4) Polyester splitting in polyester/modal fabric. (5) Broken modal fragments, and initial twisting and splitting of polyester. (6) Modal fragment present on the surface of a polyester/cotton fabric.

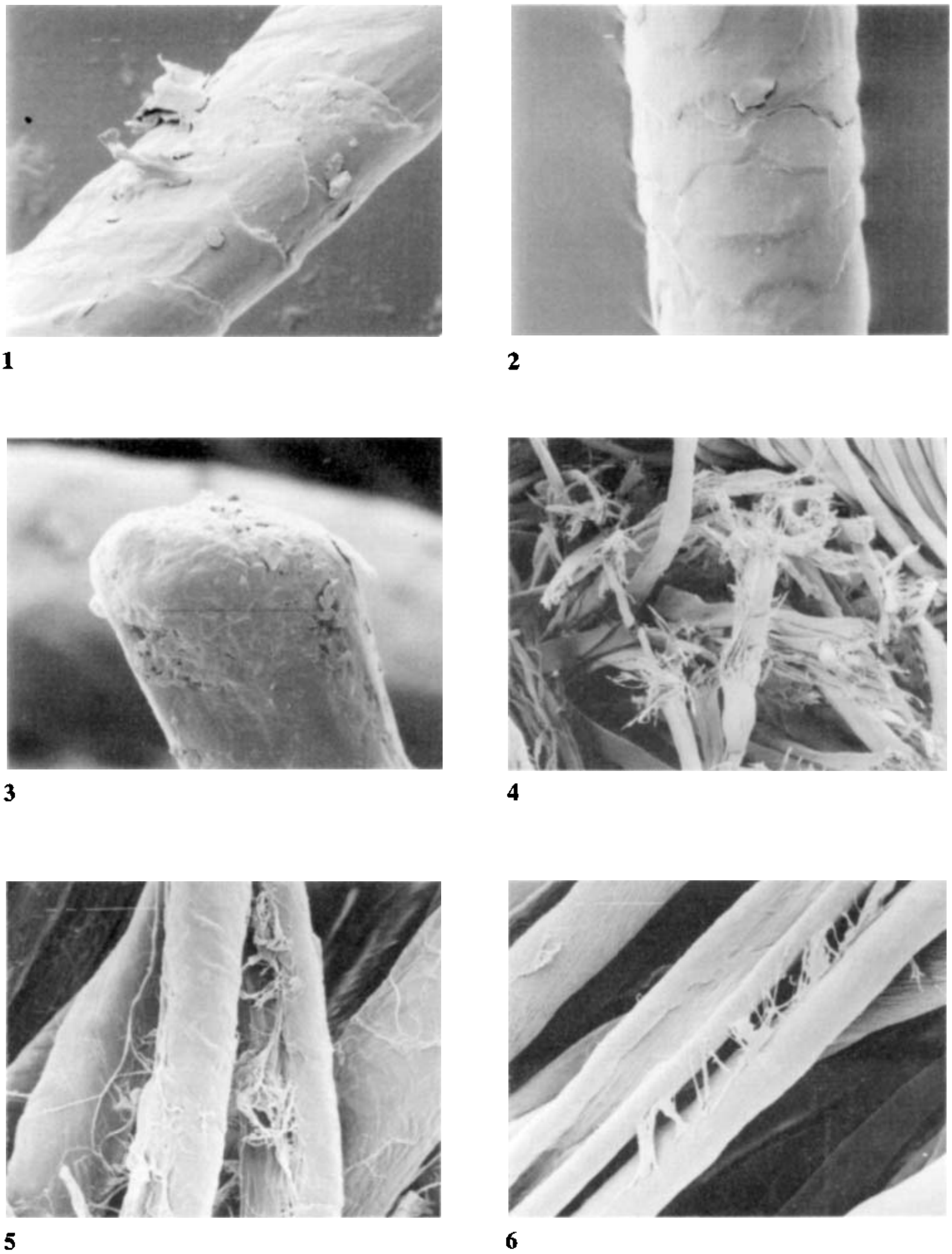
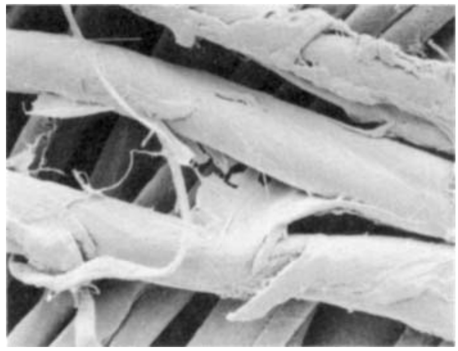
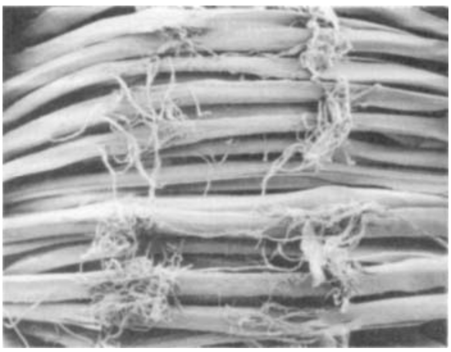


Plate 30D — Wear in a wool cardigan.
(1),(2) Surface wear and lifting of scales. (3) Rounded end of broken fibre.
Hole in a cotton knit.
(4) Fibre failure by multiple splitting.
Worn cotton T-shirt.
(5),(6) Peeling of fibrillar layers.

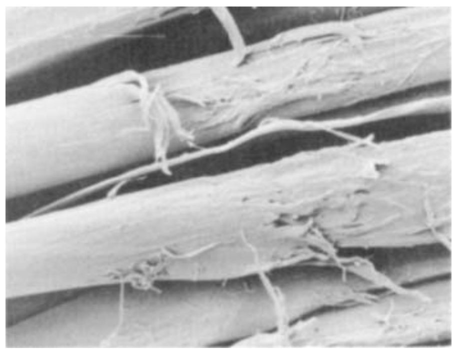
1



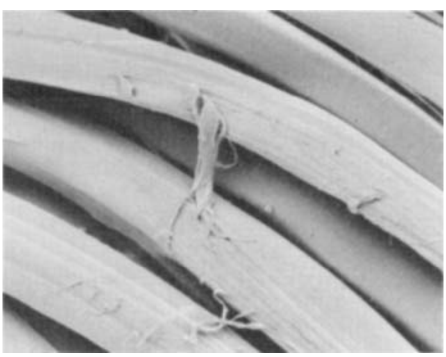
2



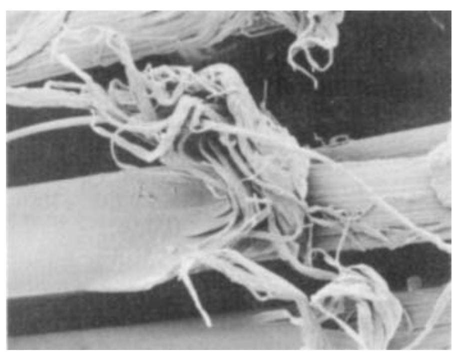
3



4



5



6

Plate 30E — Worn cotton T-shirt (continued).

(1),(2) Splitting away of larger pieces.

Worn silk fabric.

(3) Damage concentrated on yarn crowns. (4)–(6) Detail of fibre peeling.

31

SOCKS, UNDERWEAR AND OTHER ITEMS

Although knitted nylon socks are extremely durable, in contrast to wool socks, which once made darning a weekly household chore, they do eventually wear into holes, **31A(1)**, through extensive fibre breakdown by multiple splitting, **31A(2)**. The nylon fibres break by developing long axial splits, **31A(3)**, which may be due either to repeated bending (Chapter 12) or bending and twisting (Chapter 13). The individual portions of the split then break to give an end with many splits, **31A(4),(5)**. In a little-worn area on top of the foot of another nylon sock, there is evidence of an axial split, **31A(6)**, which might be due either to tensile fatigue (Chapter 11) or to peeling by surface shear (Chapter 14).

Thicker, absorbent sports socks are differently constructed. Traditionally, they would have been knitted in thick cotton or wool yarns, but a common modern method is to use a combination of continuous-filament nylon yarns, to give durability, and acrylic yarn, to give bulk, in a knitted pile construction. An example of a black nylon/red Orlon sock, which has worn away at the ball of the foot, is shown in **31B(1)** and illustrates the various stage of wear. Away from the hole, the material is only moderately worn and the loops of the pile yarn can be seen. Coming in towards the centre of wear, there is increasing wear of the pile and then a region where only the nylon yarns remain. There is an actual hole just outside the worn region, probably due to snagging on a projection. There was another hole in the heel of this sock. The breakdown of the acrylic fibres is by multiple splitting, **31B(2)**.

A moderately worn region in a white nylon/Acrilan sock is shown in **31B(3)**, and demonstrates that the loss of the acrylic fibres is associated with the formation of pills, which is the attrition mechanism discussed in Chapter 30. Examination of a region where the Acrilan has been completely lost shows no damage to the nylon fibres, **31B(4)**. The fibre breakage is frequently by the multiple splitting, **31B(5),(6)**, which is characteristic of combined bending and twisting. However, it can also occur with a central split, **31B(7),(8)**, which was found in simple flexing, as discussed in Chapter 8. Sometimes there appears to be a combination of both effects, **31B(9)**.

Knitted nylon tights can suffer damage by snagging. Any broken fibres may slip back into the knitted structure, or become tangled up in pills, **31C(1)**. The individual fibre breaks are a rare example in actual use in clothing of failure in the high-speed tensile break mode with mushroom ends, **31C(2),(3)**. The reason is that this is a situation in which a filament is caused to break rapidly by a sudden pull, when it catches and snags.

A silk vest which had been used for many years finally deteriorated to the point where the knitted structure became thin, **31C(4)**, from loss of fibre. The silk fibres show evidence of surface peeling, **31C(5)**, and some fibres had broken from tensile loading of the weakened structure, **31C(6)**.

In woven cotton/polyester underpants, the fabric in relatively undamaged regions is compact, **31D(1a)**; but in regions of high wear, the cotton has mostly been lost from the yarns, leaving a thin open weave of residual polyester, **31D(1b)**, with some tangled cotton fibres on the surface. In regions of intermediate damage, the cotton fibre is seen to break down by multiple splitting, **31D(2)**. Eventually, even the polyester goes from one yarn direction, **31D(3)**. The early stages of damage are shown in **31D(4)**, with fibre details in **31D(5)(6)**.

A similar loss of cotton, which is present in the little-worn regions, **31E(1a,b)**, is found in knitted cotton underpants, where the fabric is strengthened by knitting a fine continuous-filament nylon yarn in together with the cotton yarn. In worn regions, **31E(2a,b)**, only the filament yarns remain in the knit structure, with some tangles of cotton fibre attached. The cotton fibre breaks down, probably to a considerable extent in washing, by peeling off of fibrillar layers, **31E(3)**. However, it is also interesting to see that the nylon suffers damage by surface peeling, **31E(4)–(6)**.

As a conclusion to the chapters on ordinary clothing, and before going on to household products and industrial workwear, we give two examples of wear in accessories.

A tie made from the expensive high-fashion continuous-filament yarn, Qiana, which is now no longer made, developed excessive pilling in use. Little-worn fabric, from under the label, is shown in **31F(1)**. On the front of the tie, the appearance had deteriorated, **31F(2)**, due to the pills, **31F(3)**. Detailed examination shows some fibre breaks, **31F(4)**, with bulbous ends similar to high-speed tensile breaks, perhaps due to pulling of the pills, but none of the multiple splitting of anchor fibres, which is reported for other types of fibre in Chapter 30. The strength of Qiana prevents the pills breaking off, and so leads to the large unsightly accumulation of pills on the surface.

A worn silk tie is damaged by multiple splitting of the fibres, **31F(5)**, followed by break to give a bushy end, **31F(6)**, in the common pattern of wear.

Cotton handkerchiefs usually become thin and tear with continual use and laundering. This can be accentuated along creases, which are pressed during ironing, as illustrated in **31G(1)**. Detail of the way in which the yarn has worn thin is shown in **31G(2)**. The breakdown of the cotton fibres starts by splitting along the helical lines between fibrils, **31G(3)**, which will be in both Z and S senses in different parts of the fibres, **31G(4)**. A pronounced split is shown in **31E(5)**, and an almost broken fibre in **31E(6)**. Although handkerchiefs are frequently used surface attrition of fibres is slight, the main causes of damage being laundering and ironing.

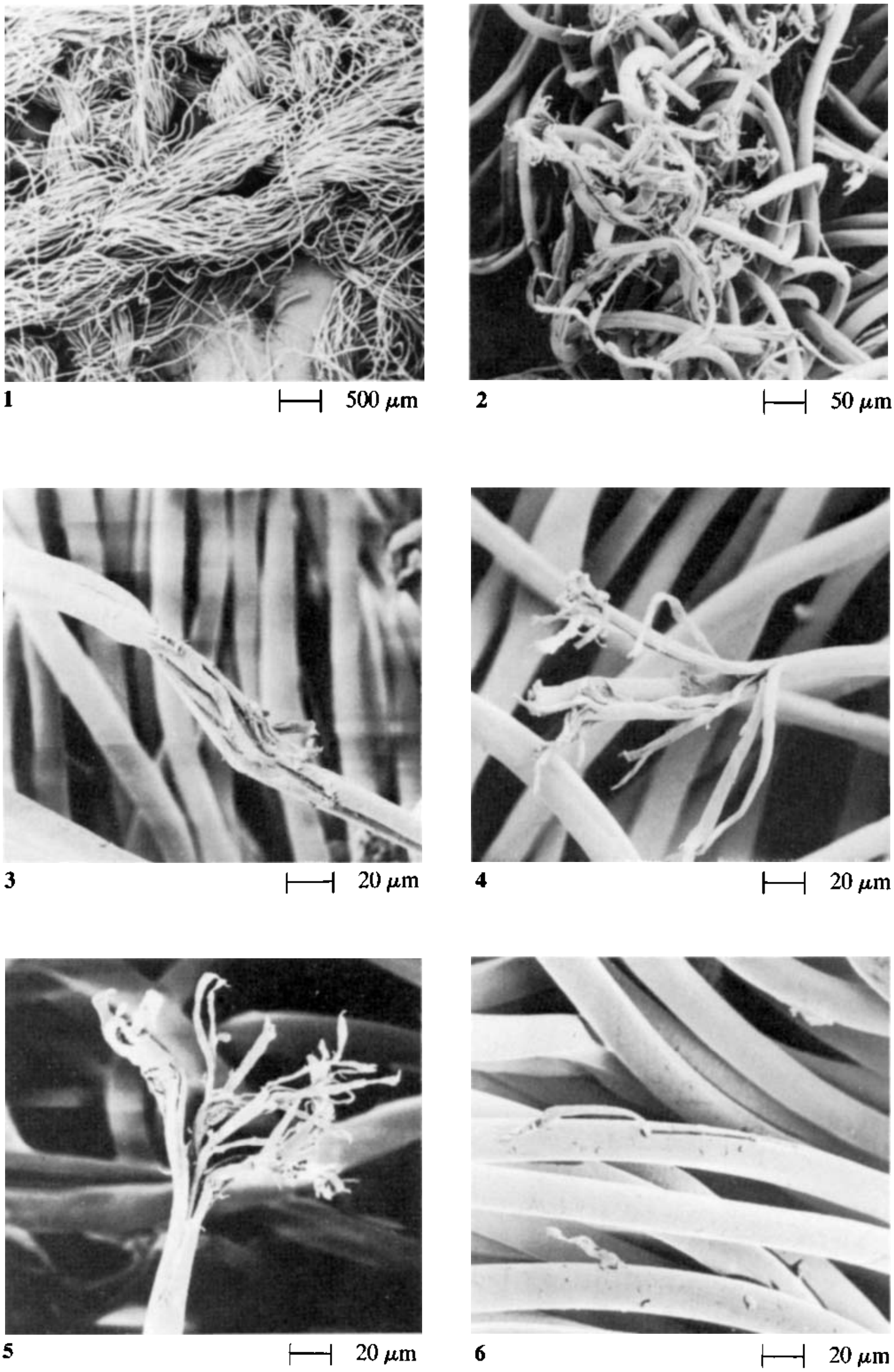


Plate 31A — Worn knitted nylon socks.
(1) Hole in heel. (2) Fibre splitting near hole. (3)–(5) Detail of fibre break. (6) From region of little wear on top of foot of another sock.

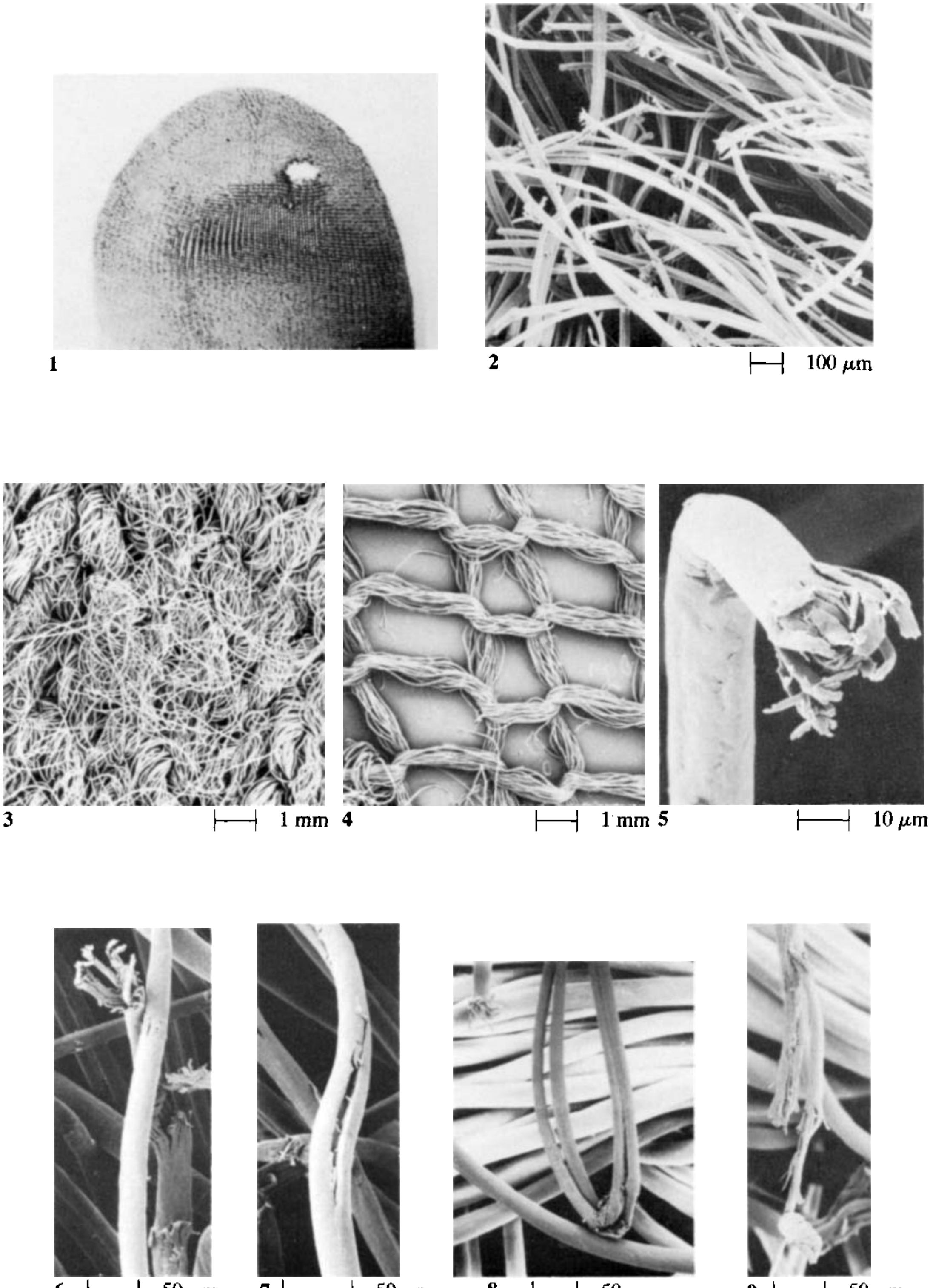


Plate 31B — Wear in nylon/Orlon sports sock.
(1) Macrophotograph showing worn area at ball of foot. (2) Orlon fibre breakage.
Wear in nylon/Acrilan sports sock.
(3) Pill in region of moderate wear. (4) Nylon yarns in severely worn region. (5)–(9) Details of Acrilan fibre breakage.

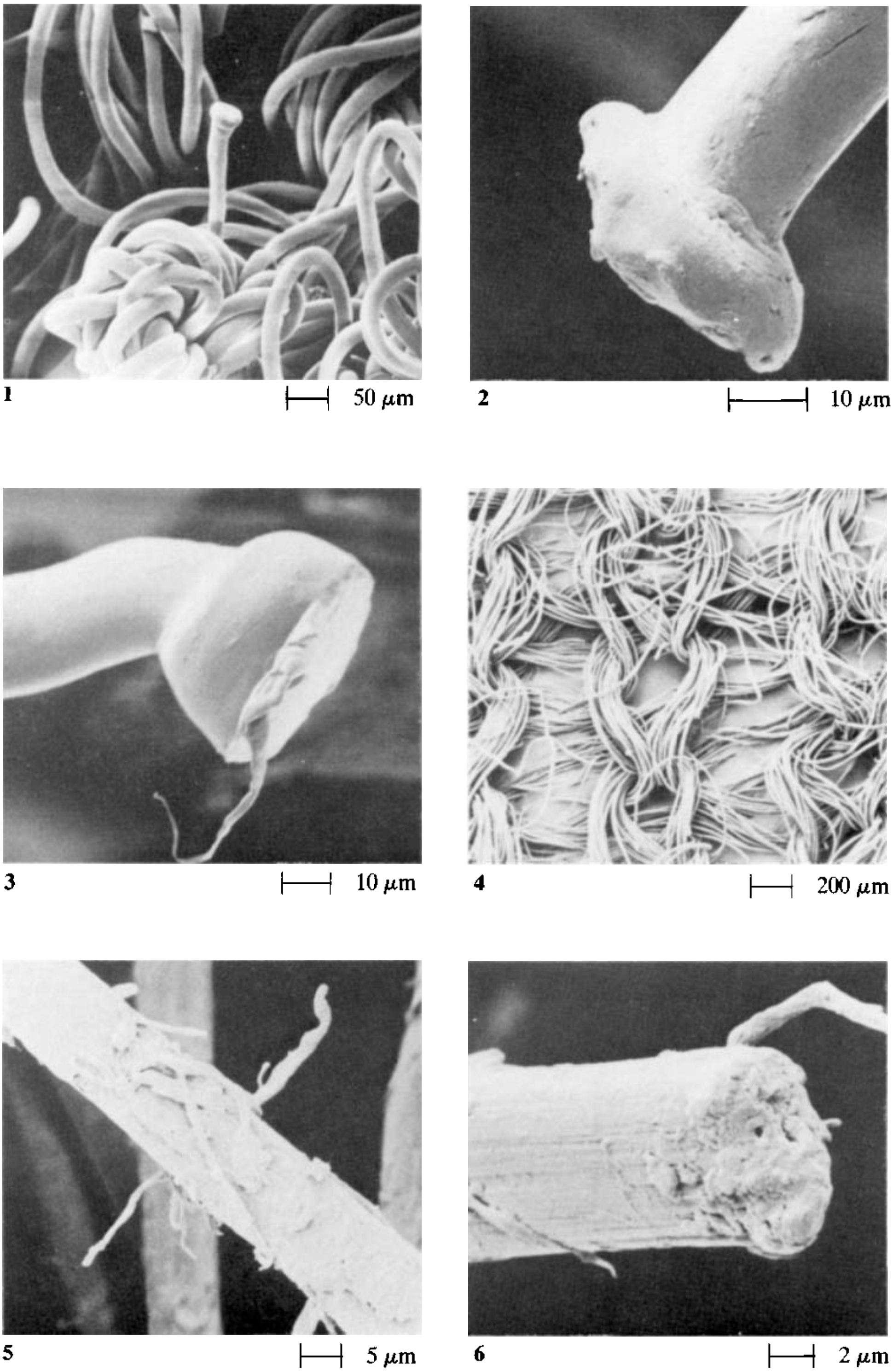


Plate 31C — Ladies' nylon tights.
(1) Pill formed after snagging. (2), (3) Details of fibre break.
Worn silk vest.
(4) General appearance. (5) Surface peeling. (6) Fibre break.

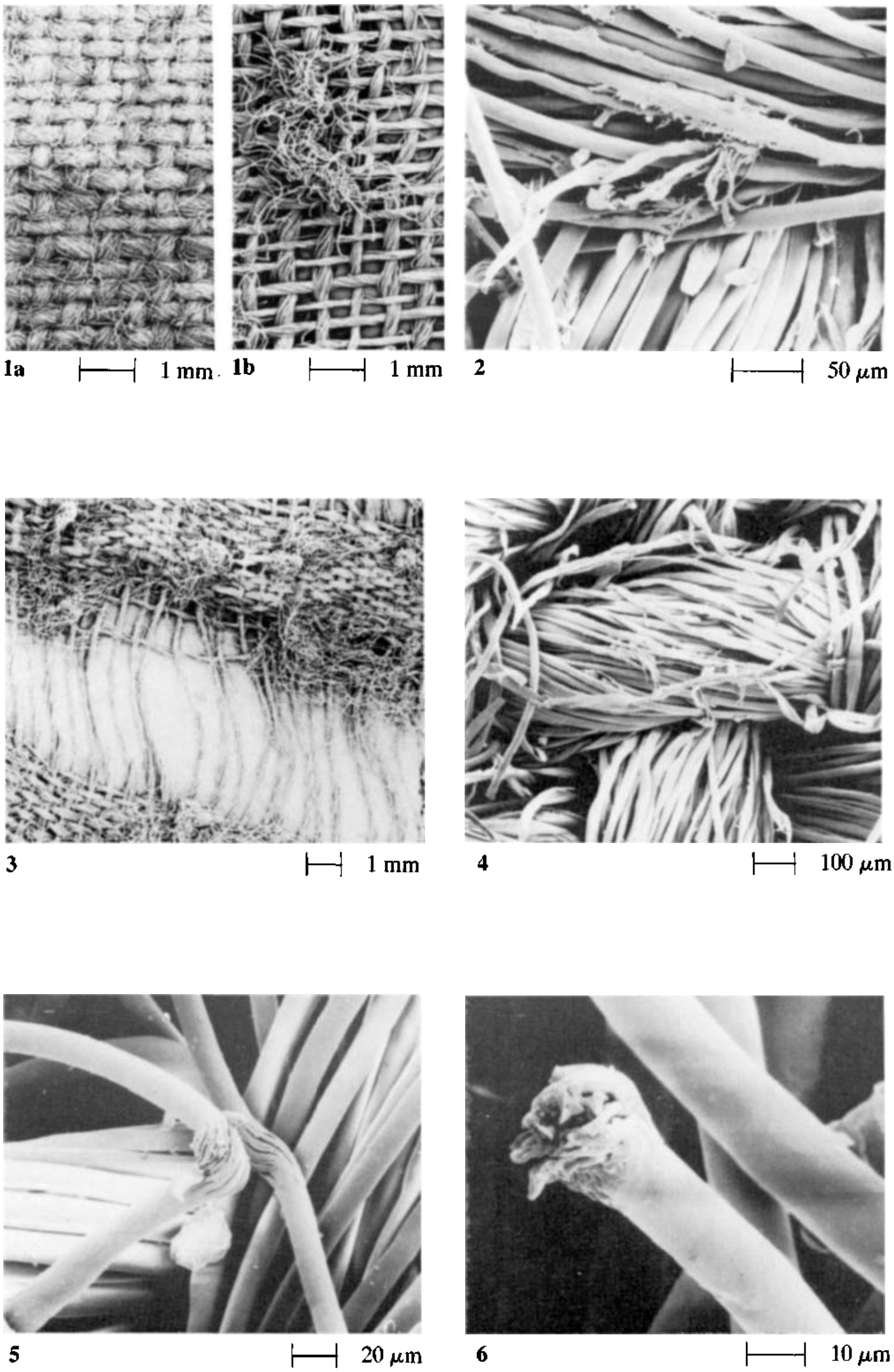
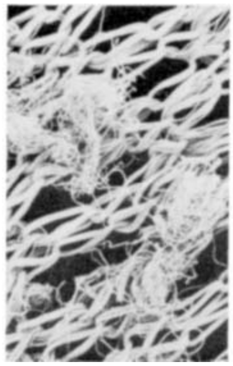


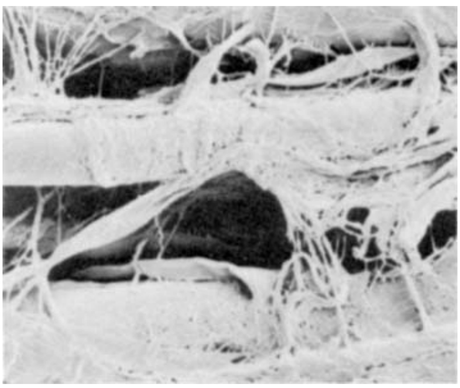
Plate 31D — Worn woven cotton/polyester underpants.
(1a) Relatively undamaged region. (1b) Region of severe wear. (2) Form of fibre breakdown. (3) Region of very severe wear. (4) Region of intermediate wear. (5) Multiple splitting of fibres. (6) After breakage, partial rounding of bushy end.

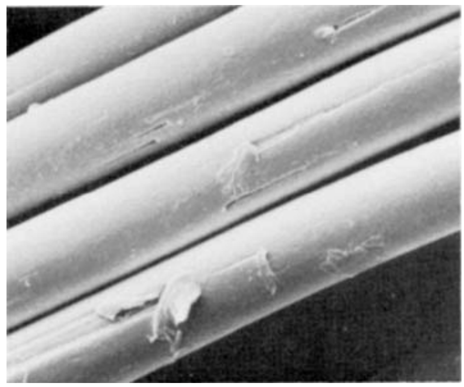

1a 1 mm

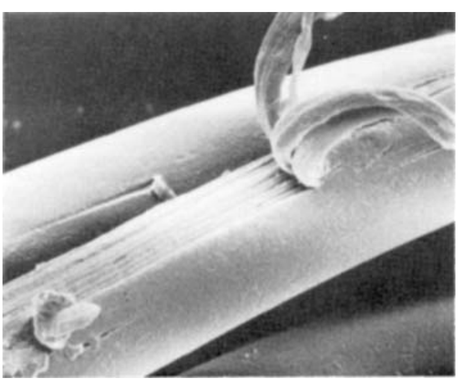

1b 200 μm


2a 1 mm


2b 200 μm


3 50 μm


4 10 μm


5 10 μm

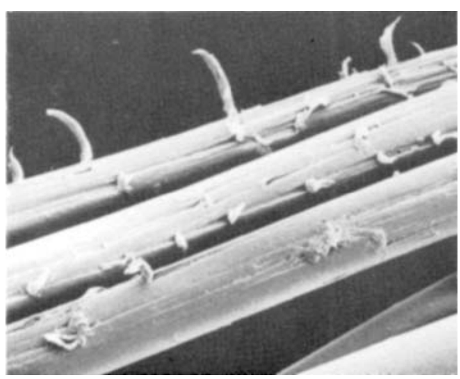
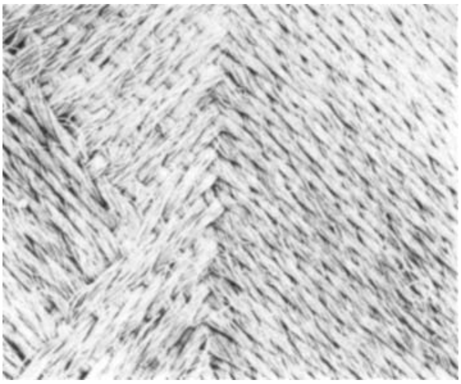
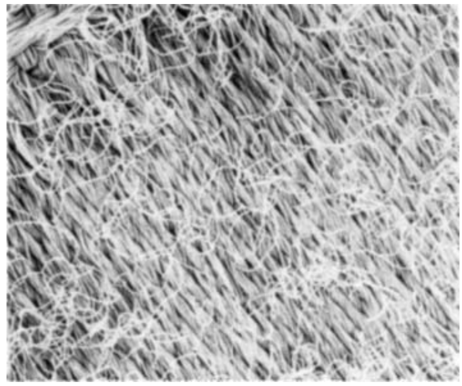

6 20 μm

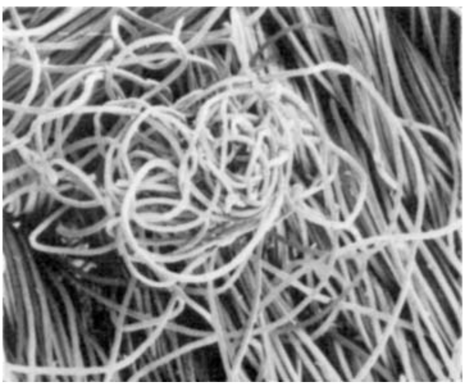
Plate 31E — Worn knitted cotton/nylon underpants.
(1a,b) Little-damaged fibre. Note nylon reinforcing yarn. (2a,b) Badly worn fabric. (3) Cotton fibre breakdown. (4)–(6) Surface peeling of nylon.



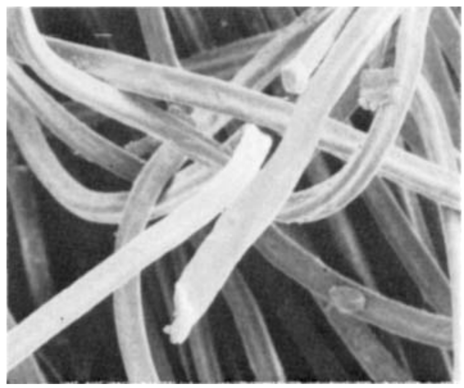
1 1 mm



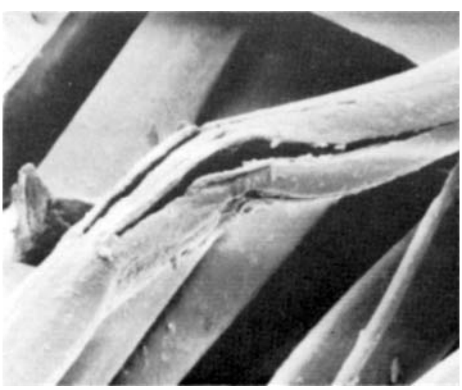
2 1 mm



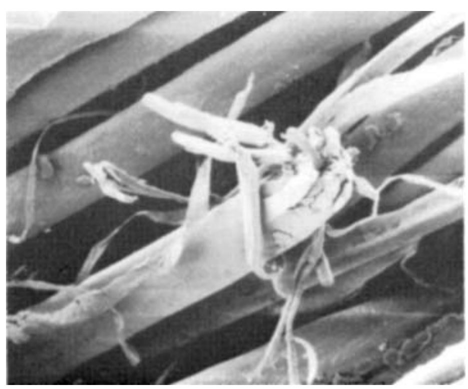
3 200 μm



4 50 μm



5 10 μm



6 10 μm

Plate 31F — Worn Qiana tie.
(1) Little-worn material, under the label on the back of the tie. (2) Material on front of tie. (3) Detailed view of a pill. (4) Detail of fibres.

Worn silk tie.
(5) Multiple splitting of fibre. (6) Fibre break.

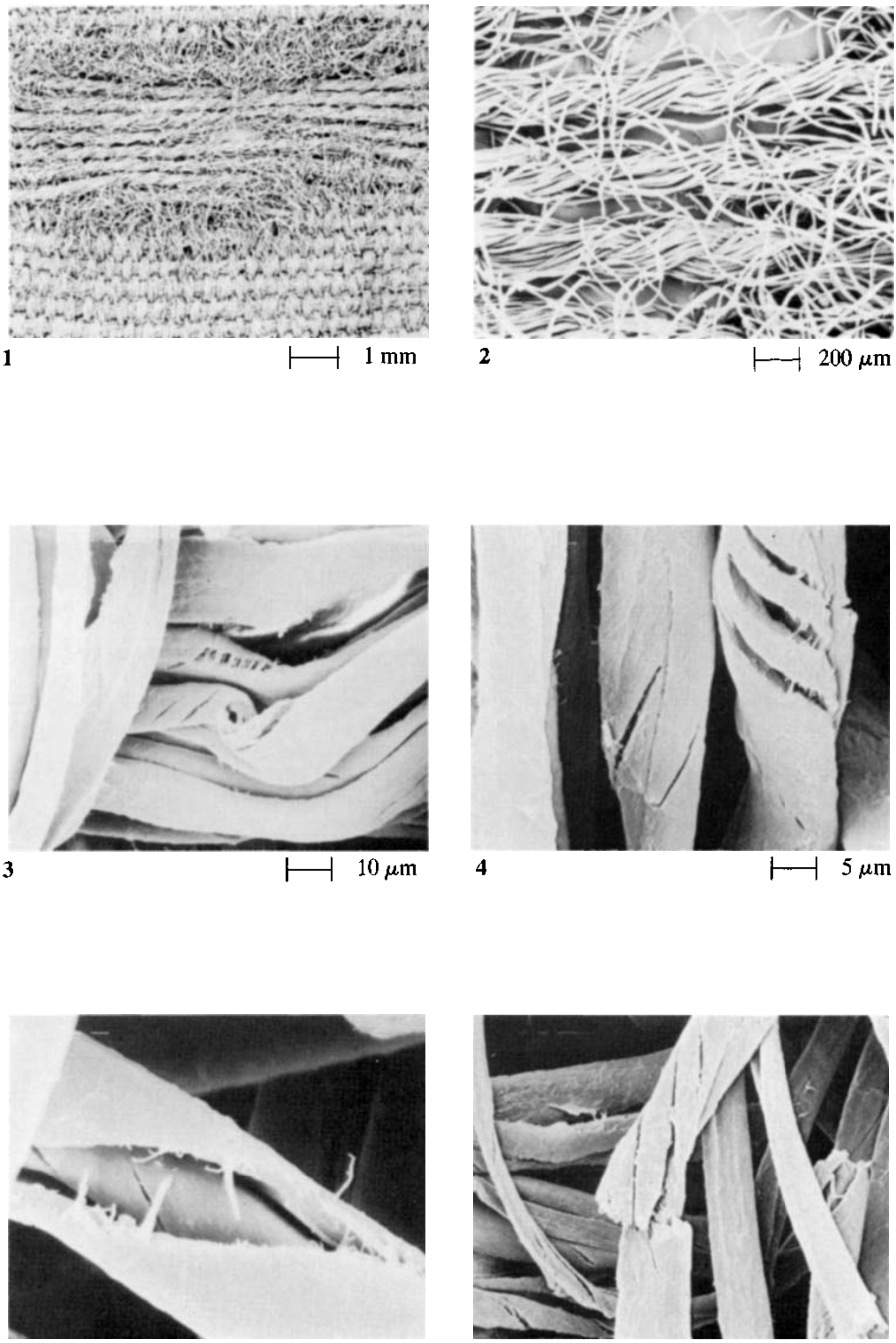


Plate 31G — Worn cotton handkerchief.
(1) Worn area near crease put in by ironing. (2) Detail of fabric wear. (3)–(6) Breakdown of cotton fibres.

32

HOUSEHOLD TEXTILES

Textiles are used in many places in the home. Articles collected after severe wear, which is common before they are discarded, can be examined to show forms of breakdown; but the detailed investigation of comparative wear requires well-designed trials.

An extensive and carefully monitored study of five types of bed-sheets was carried out at the Shirley Institute, and some samples were made available for SEM examination. Four different organizations and types of laundries were used in the trial, which lasted for six years. One feature of the study was to see how much loss of strength could be attributed to laundering alone, compared with use plus laundering, and tests were also made to separate the incidence of chemical and mechanical damage. Reference should be made to the paper by Lord (1971), for the details of this study; but Table 32.1 shows that large differences result from fabric type and laundering conditions.

A laundered-only cotton/nylon blend sheet after 30 cycles of laundering is shown in **32A(1)**: there is some peeling away of layers of fibrils in the cotton, but not the sort of damage which would cause much loss in strength. In contrast to this, the use and laundering of an all-cotton sheet after the same number of cycles does show appreciable splitting of cotton fibres, **32A(2)**. More extensive separation of lamellar layers in cotton fibres is shown after more use and laundering in **32A(3)**. Splitting of cotton can be seen in the nylon/cotton sheet after use, **32A(4)**, but the nylon is undamaged. Rayon fibres in a blend show peeling of strips of material, **32A(5)**, and this is marked even after rather little use, **32A(6)**.

There is an interesting difference between the apparent extent of damage as revealed by different types of examination of the sheets. More damage is visible in SEM pictures of the sheets after use at the men's hostel, and this is caused by severe mechanical wear, although the splitting does not necessarily weaken the fibres unduly. But the sheets after use at the school are actually weaker, as shown by their lower tear strength: in these sheets the damage is chemical, and the material gives higher values in a cotton fluidity test, which is an inverse measure of degree of polymerization. The greater chemical damage was due to the use of more bleach in order to get the schoolboys' sheets clean. The internal chemical damage is not shown up in the SEM pictures.

Wear in ordinary use of a patterned domestic towel, made of cotton in the usual loop-pile woven terry fabric, is illustrated in **32B**. There was an expected variation of wear in different parts of the towel, but, in addition, the severity of wear in any location varied with the colour of the yarn. In a region of least wear the loops are clearly visible on the fabric surface, **32B(1)**, but some fibrillation of the cotton fibres is apparent, **32B(2)**, as would be expected from repeated washing, even without the effects of use. In regions of severe wear, top left of **32B(3)**, the loops have almost disappeared, leaving the base weave clearly visible. An interesting feature of **32B(3)** is that it shows the boundary between two differently coloured areas of the pattern: the bottom right still shows the relatively undamaged loops. In the severely worn region there is considerable damage to the cotton fibres, **32B(4)**, with pronounced splitting, **32B(5)**, and fibrillation, **32B(6)**.

The monitored use of towels was only available for cabinet towels supplied by a rental company. One sample was a smooth woven cotton fabric, shown as a control after one washing, in **32C(1)**. The initial processing in preparation for use has already led to the peeling away of some layers from the cotton fibres, **32C(2)**. After being washed 50 times (without use), the peeling is more extensive, **32C(3)**. A cotton/Vincel (rayon) blend after 100 washings shows considerable smearing of layers from the cotton, **32C(4)**. The effect of 200 washing cycles on all-cotton fabric is shown in **32C(5),(6)**.

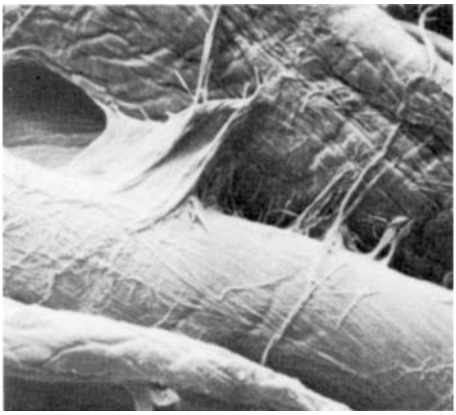
After 100 washes the cotton/rayon blend shows some peeling of cotton and the first signs of damage in the rayon, **32D(1)**, but after 200 washes the Vincel (rayon) is showing massive

Table 32.1 — Comparative life expectancy of sheets
Number of wash cycles giving a reduction of strength to 100 gf/thread, which is about 25% of original value. UL = used and laundered; LO = laundered only.
The lowest and highest values, UL and LO, are shown in bold type.

Organization		Sheet type				
		100% cotton	65% cotton/ 35% rayon	48% cotton/ 52% rayon	89% cotton/ 11% nylon	80% cotton/ 20% nylon
School/ private laundry	UL	**53**	56	62	55	60
	LO	236	194	**182**	214	220
College/ local authority laundry	UL	105	100	119	108	**132**
	LO	216	196	198	264	310
Hostel/ commercial laundry	UL	101	105	114	104	126
	LO	295	200	207	332	**1021**
Nurses' home/ hospital laundry	UL	88	77	91	80	105
	LO	280	217	197	296	450

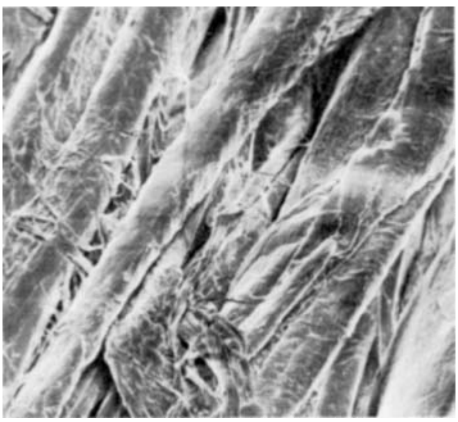
splitting, **32D(2)**. After the same number of washes polyester fibres in a blend with cotton have no signs of damage, **32D(3)**.

The final illustrations in this chapter are an example of uncontrolled wear: a cotton curtain, used for about six years in a men's cloakroom, in conditions of considerable exposure to light. A general view of a tear is shown in **32D(4)**, with details of fibre breakage in **32D(5)(6)**. The chemical changes, associated with tendering by light, have led to sharp breaks at an angle to the fibre axis.

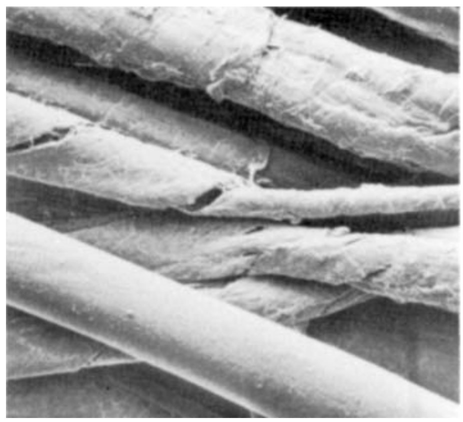


1 5 μm

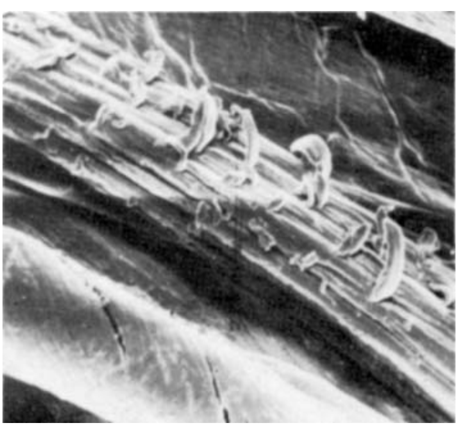
2 5 μm



3 10 μm



4 10 μm

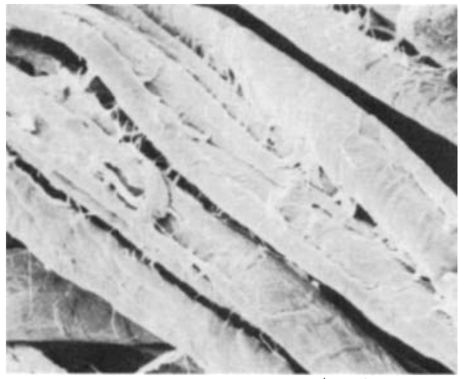


5 5 μm

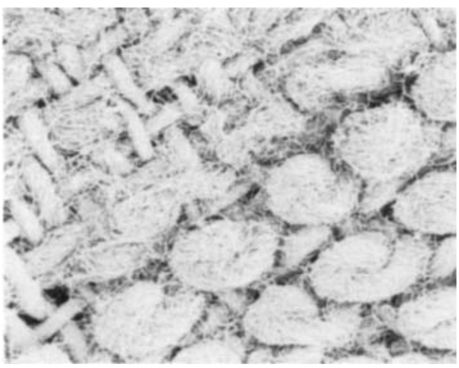
6 10 μm

Plate 32A — Wear in bed-sheets.
(1) 80% cotton/20% nylon sheet, 30 cycles commercial laundering only. (2) 100% cotton sheet, 30 cycles, used in hostel, commercial laundering. (3) as (2), 50 cycles. (4) 80% cotton/20% nylon sheet, 30 cycles, used in hostel, commercial laundering. (5) 48% cotton/52% rayon sheet, 50 cycles, used in school, private laundry. (6) as (5), 10 cycles, used in hostel, commercial laundering.

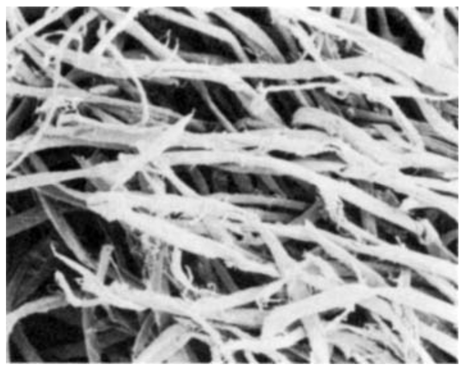
1 2 mm



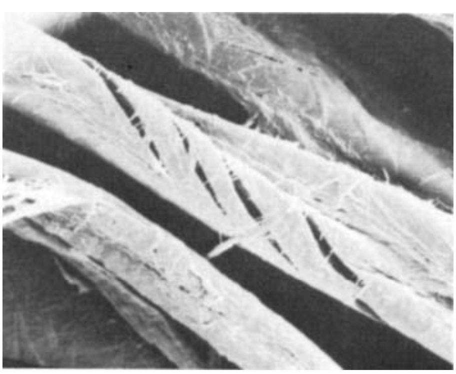
2 10 μm



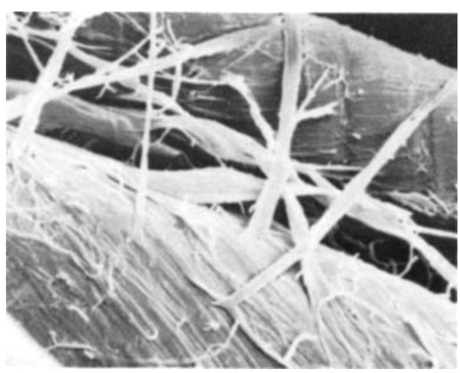
3 2 mm



4 50 μm



5 10 μm



6 5 μm

Plate 32B — Uncontrolled wear of a domestic bath towel.

(1) Area of least wear (pink). (2) Detail of peeling of cotton fibres in this area. (3) Boundary of colour difference in towel, with severely worn area in top left, and less worn in bottom right. (4)–(6) Detail of damage in badly worn area.

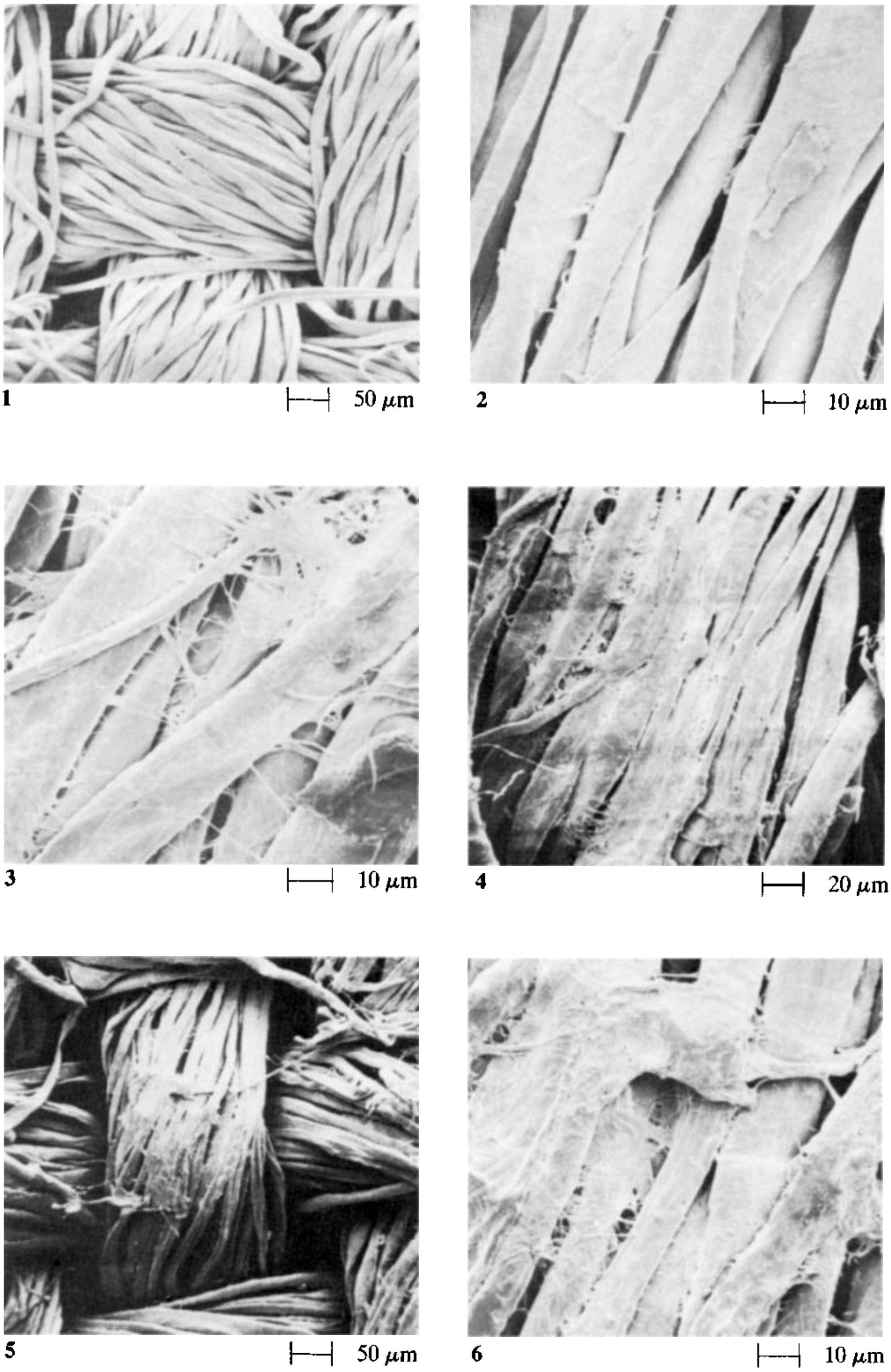


Plate 32C — Washing-only trials of cabinet towels.
(1),(2) 100% cotton, after one wash. (3) 100% cotton, after 50 washes. (4) 50% cotton/50% Vincel (rayon), after 100 washes. (5),(6) 100% cotton, after 200 washes.

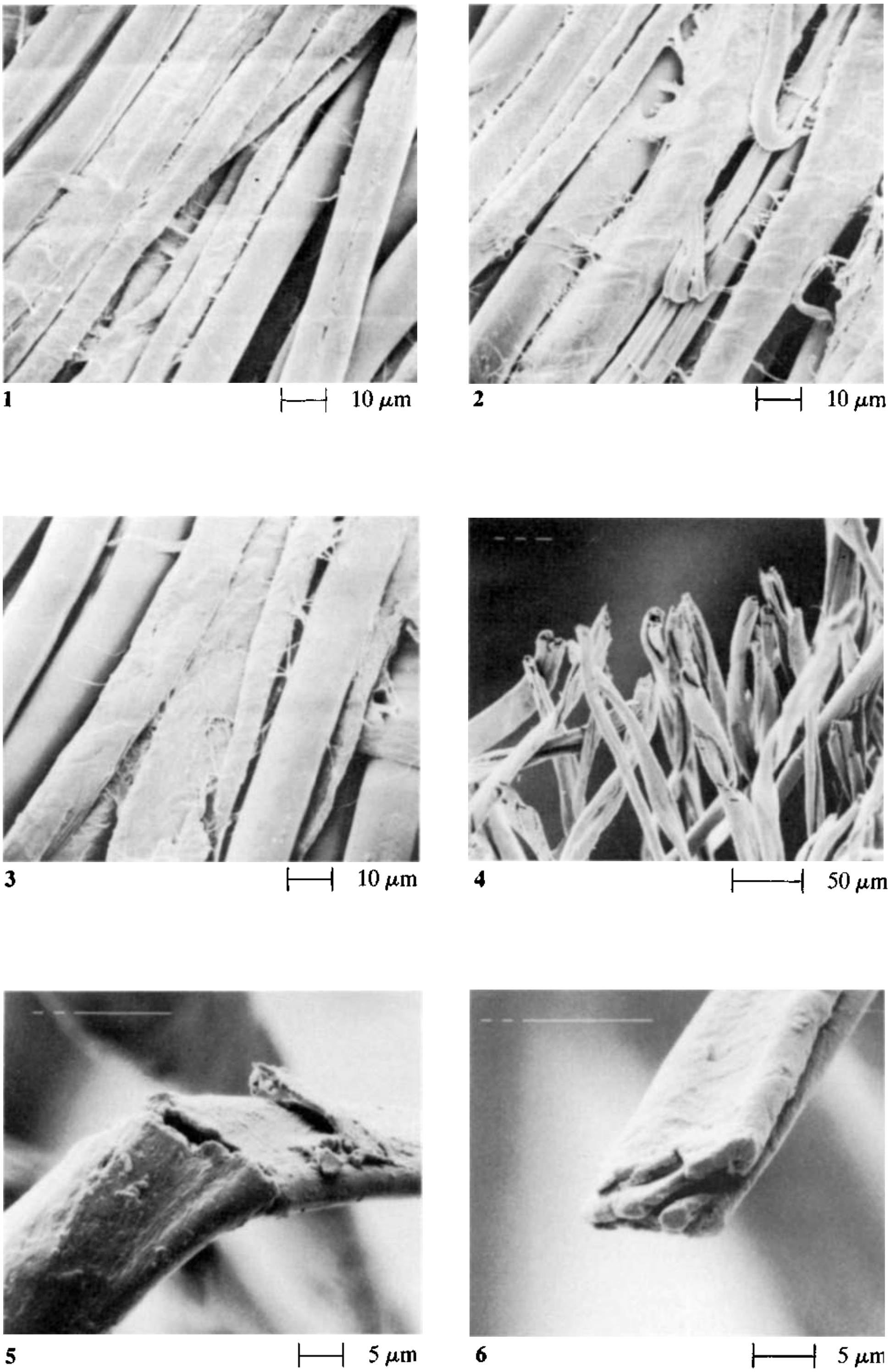


Plate 32D — Trials of cabinet towels (continued).
(1) 50% cotton/50% Vincel (rayon), after 100 washes. (2) As (1), after 200 washes. (3) 50% cotton/50% polyester, after 200 washes.
Light-tendered cotton curtain after six years' use.
(4) Edge of tear. (5),(6) Detail of fibre breakage.

Previous Page

33

CARPETS

Like most modern textiles, carpets are now made from a wide range of fibres in a variety of constructions. They are used in a great diversity of circumstances, ranging from the protected environment of a bedroom to the demanding requirements of an airport departure hall. There will thus be diverse patterns of wear; and the studies of failure mechanisms, which have been made since the SEM became available, have only touched on part of the subject.

Because of the interactions of art and function, visual and tactile aesthetics, cost and useful life, together with differences in fibre properties and structural arrangements, carpets illustrate very clearly the complexity of the appreciation of wear, which is found in some degree in all consumer textiles. Wear may be manifested in the simplest way as a loss of fibre from the pile, which eventually reveals bare patches of the carpet backing. But the carpet can also change appreciably owing to permanent deformation of fibres without any fibre breakage. The simplest example of this is a flattening of the pile, which may or may not recover in time, but other examples are shading, where pile angle changes direction in large areas of the carpet, often beginning when tuft tips bend backwards and change of appearance due to uncrimping of fibres. Other changes, such as loss of sharp tuft definition, may be due to shifts in the packing of fibres and the formation of entanglements, which can appear as pills on the surface. Even more remote from the theme of this book, deterioration due to such effects as soiling by dirt or spillage and fading of areas exposed to sunlight. Many of these changes, whether caused mechanically or chemically, may be very small in themselves and would hardly be detectable if they occurred over the whole carpet, but become dramatically apparent when they occur on selected patches or tracks.

The impact of changes on the observer is most serious in modern plain carpets in clear, bright colours with tightly defined tufts, and is much reduced by patterning, muted colours and shaggy pile. Finally, it must be noted that the life of a carpet may be ended — or pass into a poorer situation — for reasons unconnected with even the broadest definition of wear, but rather because of a mere desire for change, a new fashion or the termination of a contract.

In former times, it was difficult to take an engineering approach to carpet wear, because the evolution of technology was very slow and carpets lasted for a lifetime, but now that there are rapid changes in technology, and the planned life of a carpet may be as short as five years, it has become necessary to develop effective ways of testing and monitoring carpet wear. In this chapter we shall concentrate on inputs to these studies which are particularly associated with fibre failure. All the observations are on carpet samples provided by the International Wool Secretariat (IWS) or the Wool Research Organization of New Zealand (WRONZ), but they include man-made fibre carpets for comparative purposes.

The main study covered a variety of carpets which had been subject to exposure to wear as follows:

(a) unworn;
(b) a floor trial in a straight-walk situation;
(c) a floor trial at a location of turning-walk;
(d) on WRONZ 6S (W6S) laboratory tester in turning mode.

It must be emphasized that these were exploratory studies of 2-inch square samples from much larger test pieces, and were intended only to show the forms of damage occurring. A proper comparison of quantitative effects would require more controlled sampling.

Severe wear, with exposure of carpet backing, is shown in 100% wool cut-pile carpet from the turning trial, **33A(1)**; and the dominant cause, namely breakage of fibres following multiple splitting, is shown by the detail in **33A(2)**. An overall comparison of the effect of the wear test is given by the appearance of complete tufts, **33A(3)–(6)**. The W6S test, **33A(4)**,

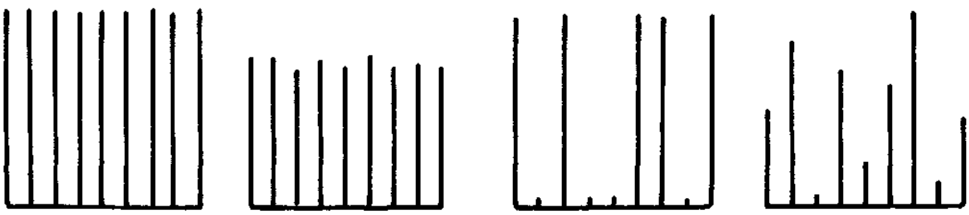


Fig. 33.1 — Schematic indications of possible patterns of loss of pile. (a) Original tuft. (b) Hypothetical: wear from tip of tuft, almost uniformly on all fibres. (c) Hypothetical: break from base of tuft. (d) Closer to reality: breaks randomly distributed through pile.

shows only a minor degree of wear, in comparison with the unworn tuft, **33A(3)**; and the straight walk, **33A(5)**, gives a similar low level of wear, although there appears to be more compacting of the tuft, and an interesting change of twist level, tighter on one side and looser on the other.

The turning trial, **33A(6)**, gives much more severe wear and provides an important indication of the manner of loss of fibre from the pile. A few fibres remain at, or very close to, their original full length, and the fibre density then increases down the tuft. This suggests that individual fibres break at different depths within the pile, either owing to points of weakness or to random mechanical stressing within the fibre bundle, and varied lengths are lost, so that there is a gradual thinning from base to tip of the tuft. The pattern is illustrated schematically in Fig. 33.1. The mass of pile, unworn in Fig. 33.1(a), is not reduced either by wearing away of fibre ends, Fig. 33.1(b), or by breaking of whole fibres from the base, Fig. 33.1(c),but the wear is closer to a random distribution of breaks, Fig. 33.1(d), although there may be some bias with position in the pile, and repeated breaks in the residual fibre will give an evolving pattern of loss of fibre.

Examples of various stages of the breakdown of wool fibres in carpets are shown in **33B**. Even though the general wear is not severe, the SEM pictures show that there is fibre damage in the W6S test, **33B(1)**, and the straight walk, **33B(2)–(5)**. The breakage follows multiple splitting, and is similar to that caused by the laboratory biaxial rotation test, **19D(6)**, which involves bending and twisting, but might also be caused by flexing without twisting. Both intermediate stages and final rupture are seen in **33B(1)**.

Possible causes of failure are suggested by **33B(2)**, where the splitting has developed at a location where one fibre is bent round another. If the bent portion rolls along the fibre, it will suffer the same type of deformation as in biaxial rotation over a pin (Chapter 13), with opposite sides of the fibre going alternately into tension and compression and torque developing owing to friction and hysteresis. Alternatively, if the fibre is pulled backwards and forwards, the effect will be similar to simple flex fatigue without twisting (Chapter 12), which can also cause splitting.

The sequence of damage is illustrated in **33B(3)–(5)**. First there is multiple splitting, **33B(3)**, then some splits break, **33B(4)**, until finally they have all broken to give the characteristic bushy ends, **33B(5)**. The scales on the surface of the wool fibre do not split in the same way, but do get broken off in the damaged zone and worn away beyond. The final appearance resembles the damage that occurs in a rope made from yarns in a plastic sheath.

Although SEM examination is needed in order to show the detailed form of fibre damage, the regions of splitting or rupture can be identified in the light microscope, **33B(6)**, and this is an easier way of studying the extent of damage in a larger amount of material. These pictures also show that splitting can occur at several places along the same fibre, usually at bends or points of inter-fibre contact, with the most severe causing breakage.

The relative durability of nylon and wool is shown up by examination of an 80% wool/20% nylon cut pile carpet. Compared with an unworn tuft, **33C(1)**, a tuft from the severe turning-walk trial, **33C(2)**, shows the nylon fibres projecting as a fringe at their original length, but the wool fibres broken off at various depths within the tuft. This is even more clearly seen in a view of a more badly worn tuft, **33C(3)**. In the light microscope, **33C(4)**, it is possible to distinguish the bushy ends of the shortened wool fibres from the smeared or bulbous ends of the nylon fibres, as formed by the cutting of the pile. The only visible damage to the nylon is some formation of kinkbands, **33C(5)**, whereas the wool fibres have the usual multiple split break, **33C(6)**.

Similar differential wear is found in an acrylic/nylon blend, **33D(1)**. In the turning trial the acrylic fibre has been lost almost to the base of the tuft, but the nylon fibres appear to be intact. Detail of the fibre damage is shown in **33D(2)**, and is similar to failure mechanisms in wool. This form of fibre damage is also seen in the much less severely worn straight-walk and W6S samples, **33D(3)–(5)**. After the turning trial the wear of some fibres has passed to the third stage, in which the bushy end becomes rounded, **33D(6)**.

In 100% nylon carpets there is almost no loss of material through fibre breakage, although there are changes of appearance due to fibre deformation, rearrangement, and entanglement, associated with considerable flattening of the pile, distortion of tufts, and loss of tuft and pattern definition on the surface. Examples of damage in trilobal nylon fibres after the severe turning trial are some mangling of fibre ends, **33E(1)**, acute bending, **33E(2)**, and the formation of pits and cracks in the fibre surface, **33E(3)**.

The observations on an 80% polyester/20% nylon carpet with round fibres showed a similar response, but there was some cracking, **33E(4)**, and wrinkling of skin in the fibres, probably through snagging at pilling on the surface of the carpet.

In a polypropylene carpet the fibre damage has a different form, and is predominantly peeling from the fibre surface, **33E(5),(6)**. This is similar to that found in surface shear (Chapter 14), and must reflect great sensitivity to this mode of breakdown in polypropylene.

Rayon shows yet another form of fibre damage. The carpet examined was of Evlan carpet rayon, with a small amount of trilobal nylon, which remained unbroken. Cut fibres in the unworn carpet have the form shown in **33F(1)**, although some have not been completely severed, **33F(2)**. Fibre breaks are shown in **33F(3)**, and come from transverse cracks, **33F(4),(5)**, leading to fractured ends perpendicular to the fibre axis, **33F(6)**.

One situation leading to localized wear of carpets is rubbing under chair castors, and a particularly severe example occurs with office chairs. We have examined samples provided by WRONZ from both actual wear in a newspaper office after 13 months trial and a test-method (not developed by WRONZ) called the 'Bamburg castor-chair' test.

In the office test of 100% wool cut-pile carpet, there was a moderate, but not an excessive, amount of fibre damage by the usual mode of multiple splitting, **33G(1),(2)**. In 100% nylon loop pile there is some flattening of pile, but no damage to the trilobal fibres, except for an occasional squashed or split filament, **33G(3)**. In contrast to this the Bamburg test after 25,000 cycles causes much more damage in wool carpets than is seen in use, **33G(4)**, and appreciable damage, by squashing and flattening plus some splitting, in nylon, **33G(5)**. Another feature of the test, which is not found in use, is the accumulation of a considerable amount of debris, packed deep into the pile of the wool carpets. Debris can be removed from the surface of the sample by dabbing with an adhesive surface: an example from a blend carpet is shown in **33G(6)**, where the long lengths are nylon and the short ones are wool. These observations indicate that the Bamburg test is not well related to wear in use, and misrepresents the wear of wool and wool-rich carpets in comparison with nylon carpets.

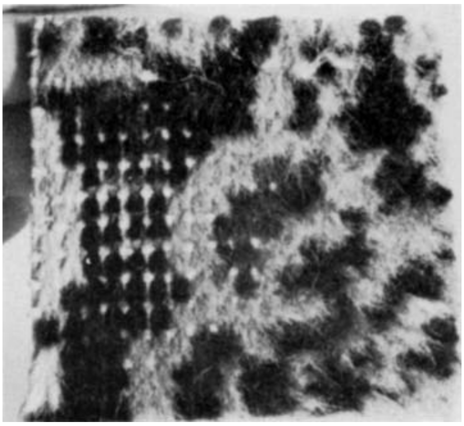
At the time of our first studies of carpet wear, reported earlier in this Chapter, we were impressed by the multiple splitting failures, which were similar to those found in our concurrent studies of biaxial rotation fatigue, which combine bending and twisting. In particular, **33B(2)** seemed to be explained by a similar mechanism. However, it was recognised that bending alone also leads to multiple splitting where there is variable curvature; **33B(1)** could be interpreted in this way. However, a closer examination of all the data, including more recent studies, suggests that, in most cases, the splitting is a secondary feature and not the initial form of damage.

Carnaby (1981,1984,1985) and Tandon *et al* (1990) have proposed a model in which carpet wear is attributed to the breakage of fibres at random heights in the pile, with a subsequent loss of broken pieces. Quantitative studies have been carried out at UMIST by A. Sengonul and P. Noone in order to test this hypothesis. Optical microscopy combined with image analysis enabled a large number of fibres to be studied. Tufts were taken from more and less worn parts of the carpet sample, and then, in order to avoid bias, a procedure for the random choice of fibre from the tufts was used.

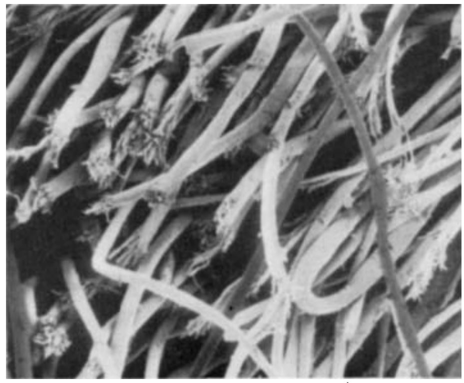
The first study was of a piece of all-wool tufted carpet from a straight-walk trial. As shown in **33H(1)**, the wear is not severe. The purpose of the investigation was to determine the type and location of damage in each of the selected fibres. Preliminary studies enabled the damage to be divided into eight types. Type A, **33H(2),(3)**, was the mildest form and appears as a slight bending with some flattening. Type B, **33H(4),(5)**, consists of a bulbous distortion, which is accompanied by kink bands and cracks; a variant called type I has just the bulbous form. Type C, **33H(6),(7)**, has a deep gash in the side of the fibre, often half the width of the fibre, with little fibrillation. Type D, **33I(1),(2)**, has a high degree of splitting. Type E, **33I(3),(4)**, starts as a deep kink-band crack on one side of the fibre, from which an axial slit may develop. Type F, **33I(5),(6)**, is a less severe form, which may also be found in unworn carpet fibres, and consists of very clear kink bands. Finally there are a variety of forms of broken ends, listed as type G and shown in **33J**. These range from simple forms, **33J(1)–(3)**, to varying degrees of axial splitting, **33J(4)–(7)**. The optical micrographs do not show the details of damage as clearly as the SEM pictures, but they are adequate to identify the type of damage. Having noted the type, its position is recorded by an image analysis system. The results can then be displayed and used to check the theory.

For the second study, the carpet had been subject to a turning-walk trial and, as shown in **33K(1)**, the damage was more severe and was comparable to that in **33A(1)**. A detailed quantitative investigation was carried out as before. In addition, a few tufts, such as the one in **33K(2)**, were examined in the SEM. The major source of damage appeared to be a sharp kinking, which yields effects similar to those found in the buckling test of wool yarns as shown in **12J,K**. An example of such a sharp bend is shown in **33K(3)**, with a crack developing on the inside of the bend. A small crack is seen in **33K(4)**. A larger crack in the 45° direction expected for a kink band is shown in **33K(5)**, which also has indications of another crack in the same direction and one in the other 45° direction. Substantial cracks on the inside of bends are apparent in **33K(6)** and **33L(1)**. In **33L(2)**, the crack is on the outside of a bend, but this has probably been bent back in the reverse direction. A clean fibre end is shown in **33L(3)**; this might be break along a kink band, but is more likely to be a fibre that has been cut on the face of the pile. Break usually proceeds from the kink-band crack to develop axial splitting, as seen in **33L(4)–(6)**. Broken ends with multiple splitting are shown in **33M(1)–(4)**. Further wear leads to rounding of the end, starting in **33M(5)** and well developed in **33L(6)**.

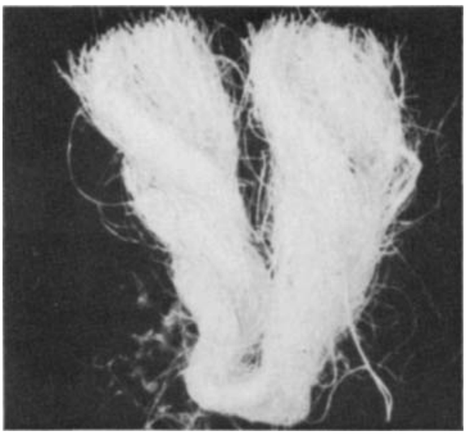
The overall conclusion from the quantitative studies is that the location of damage and the change in length of the fibres, which in the turning trial comes down from a modal length of 12 mm to 4 mm in a highly worn tuft, is compatible with fatigue and loss of fibre occurring at random locations. The common sequence of damage is formation of kink-bands, which turn into cracks and then develop axial splitting before rupture occurs.



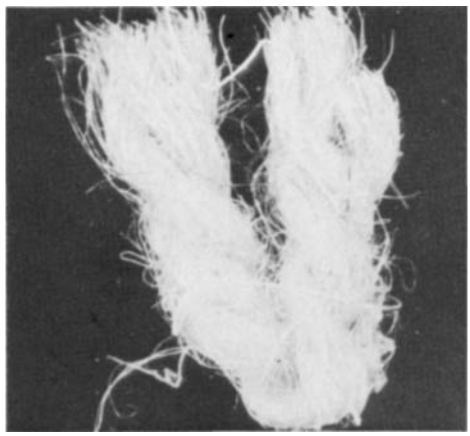
1



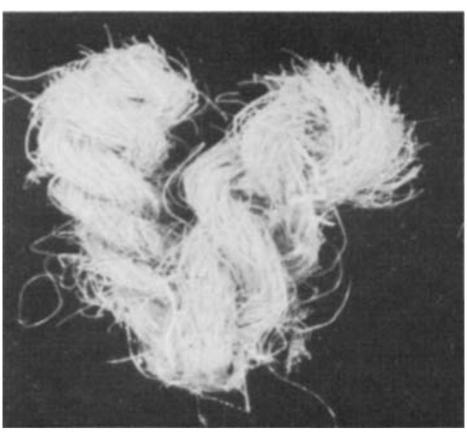
2 100 μm



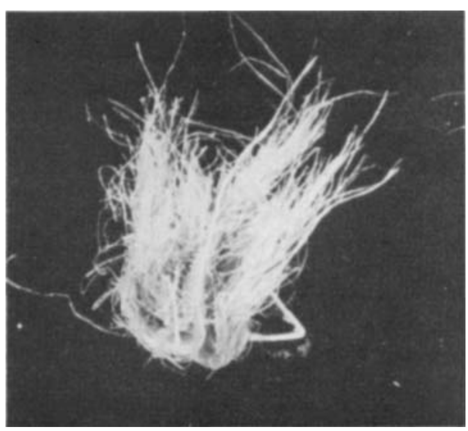
3



4



5

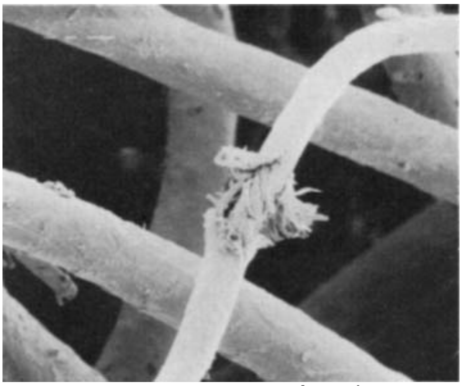


6

Plate 33A — 100% wool cut-pile carpet.
(1) Appearance of 2-inch square piece after turning walk trial, at edge of the region of severe wear, which exposes carpet backing (photograph). (2) Detail of fibre damage after turning trial.
Tufts removed from carpet sample (macrophotography).
(3) Unworn. (4) After WRONZ 6S laboratory test. (5) After straight-walk trial. (6) After turning-walk trial.

1 100 μm

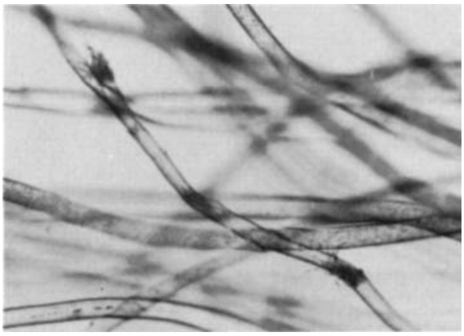
2 20 μm



3 20 μm

4 10 μm

5 10 μm



6

Plate 33B — Wool fibres in worn carpets.
(1) 100% wool, cut pile, WRONZ 6S test. (2) 80% wool/20% nylon, cut pile, straight walk. (3)–(5) 100% wool, loop pile, straight walk.

Optical micrograph.

(6) 80% wool/20% nylon, cut pile, turning trial.

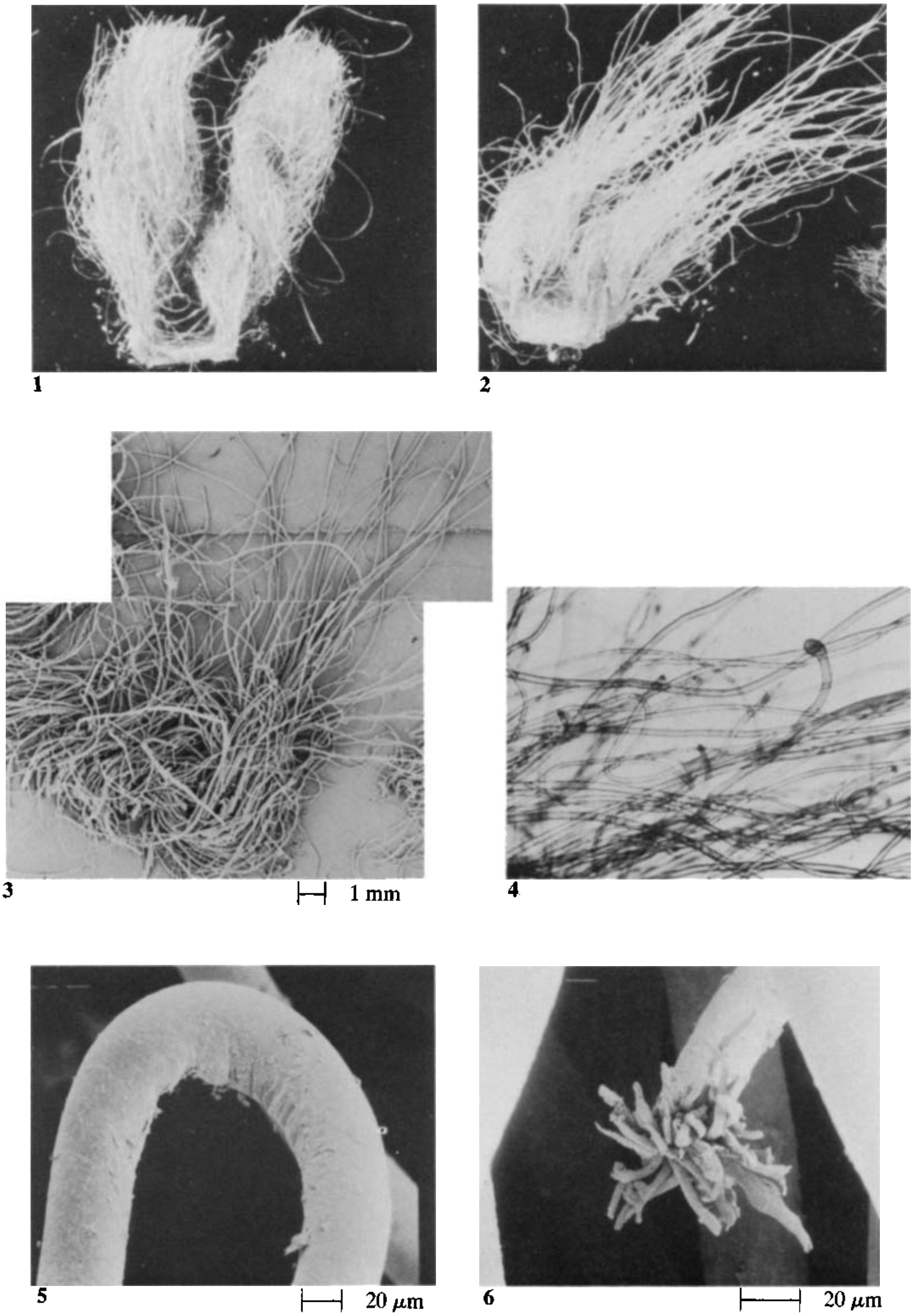
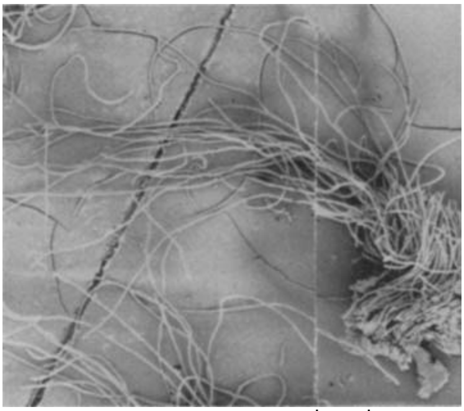
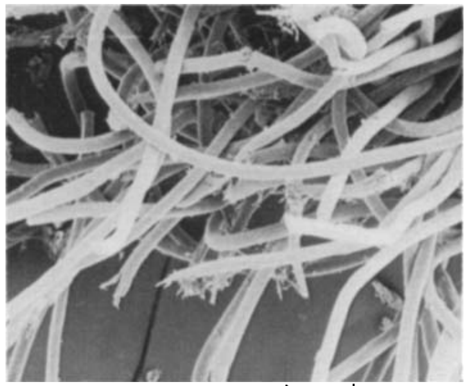


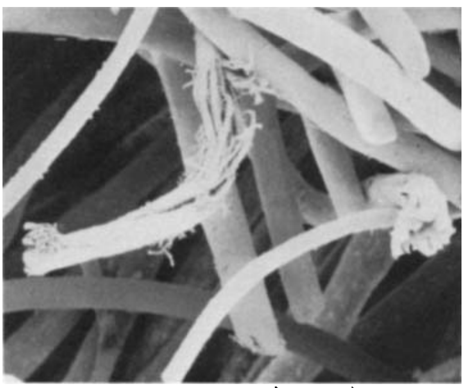
Plate 33C — 80% wool/20% nylon, cut pile carpet.
(1) Tuft from unworn carpet (macrophotograph). (2) Tuft after turning trial (macrophotograph). (3) Another tuft after turning trial. (4) Fibres after turning trial (optical micrograph). (5) Nylon fibre, after turning trial. (6) Wool fibre, after turning trial.



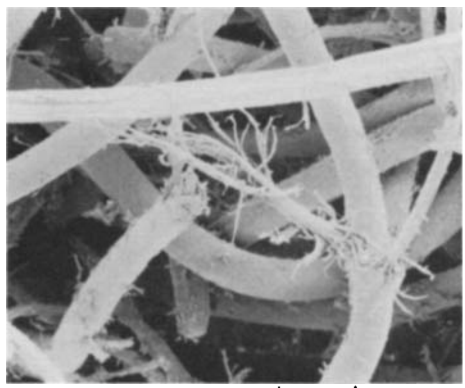
1 2 mm



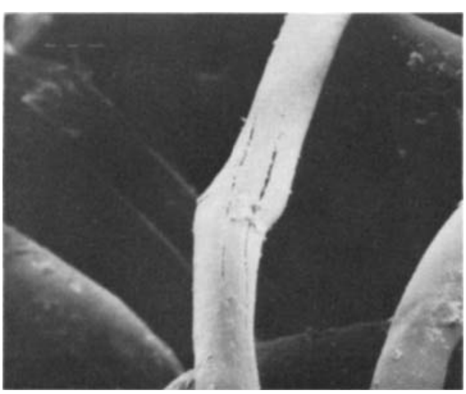
2 200 μm



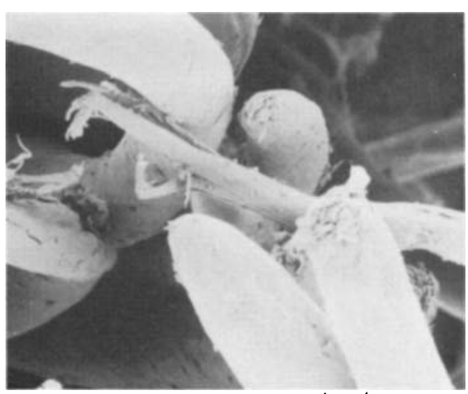
3 100 μm



4 100 μm



5 50 μm



6 20 μm

Plate 33D — 80% acrylic/20% nylon, cut-pile carpet.
(1) Tuft after turning trial. (2) Fibres after turning trial. (3) Fibres after straight walk. (4) Fibres after W6S test. (5) Early stage of splitting of acrylic fibre, after straight walk. (6) Fibre ends subject to further wear after rupture, from turning trial.

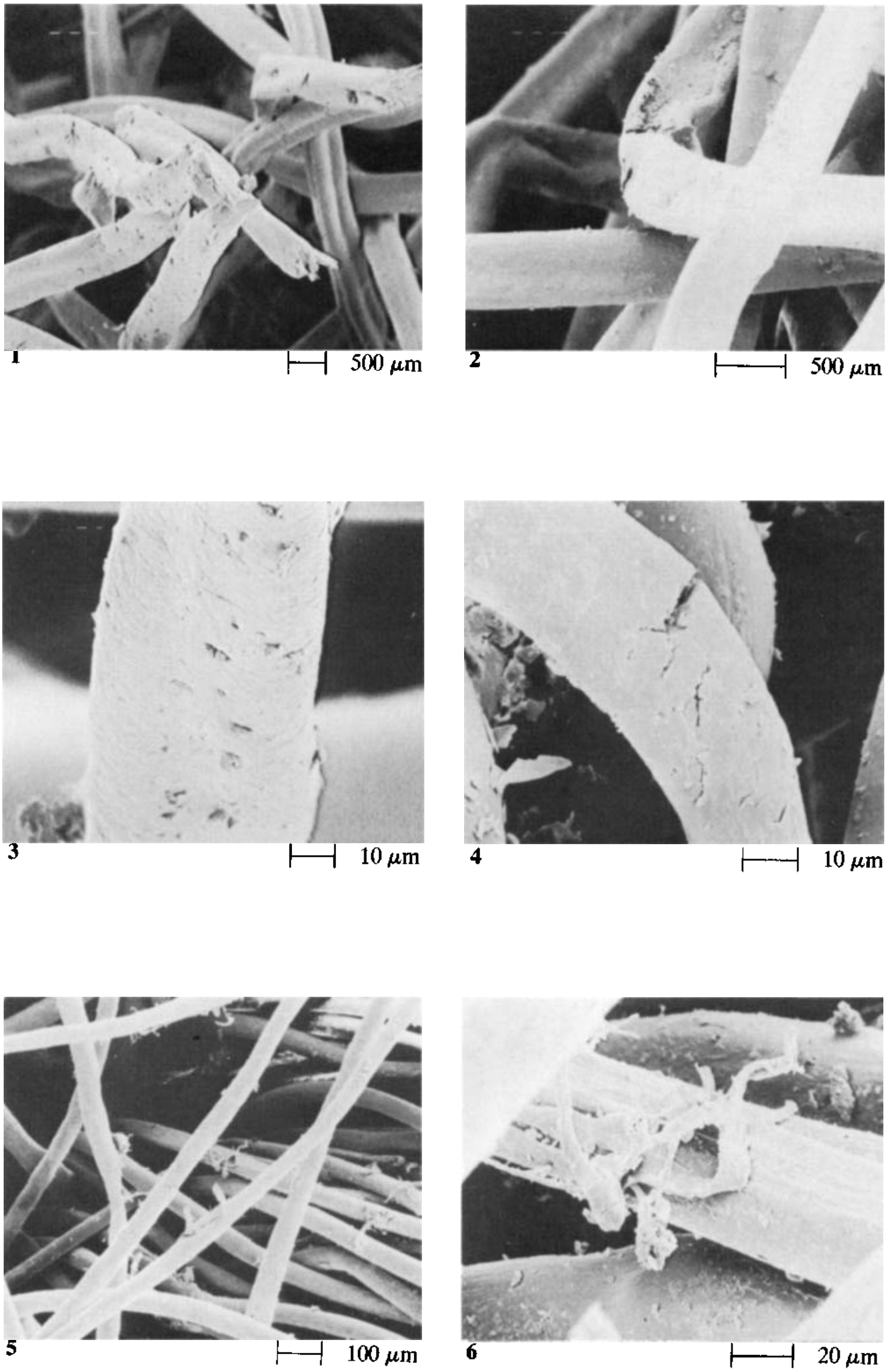


Plate 33E — 100% trilobal nylon, cut pile.
(1) Fibre ends, after turning trial. (2) Sharp bend, after turning trial. (3) Fibre surface, after turning trial.
80% polyester/20% nylon, cut-pile carpet.
(4) Fibre cracking, probably polyester, after turning trial.
100% polypropylene, loop pile.
(5),(6) Surface peeling, after straight walk.

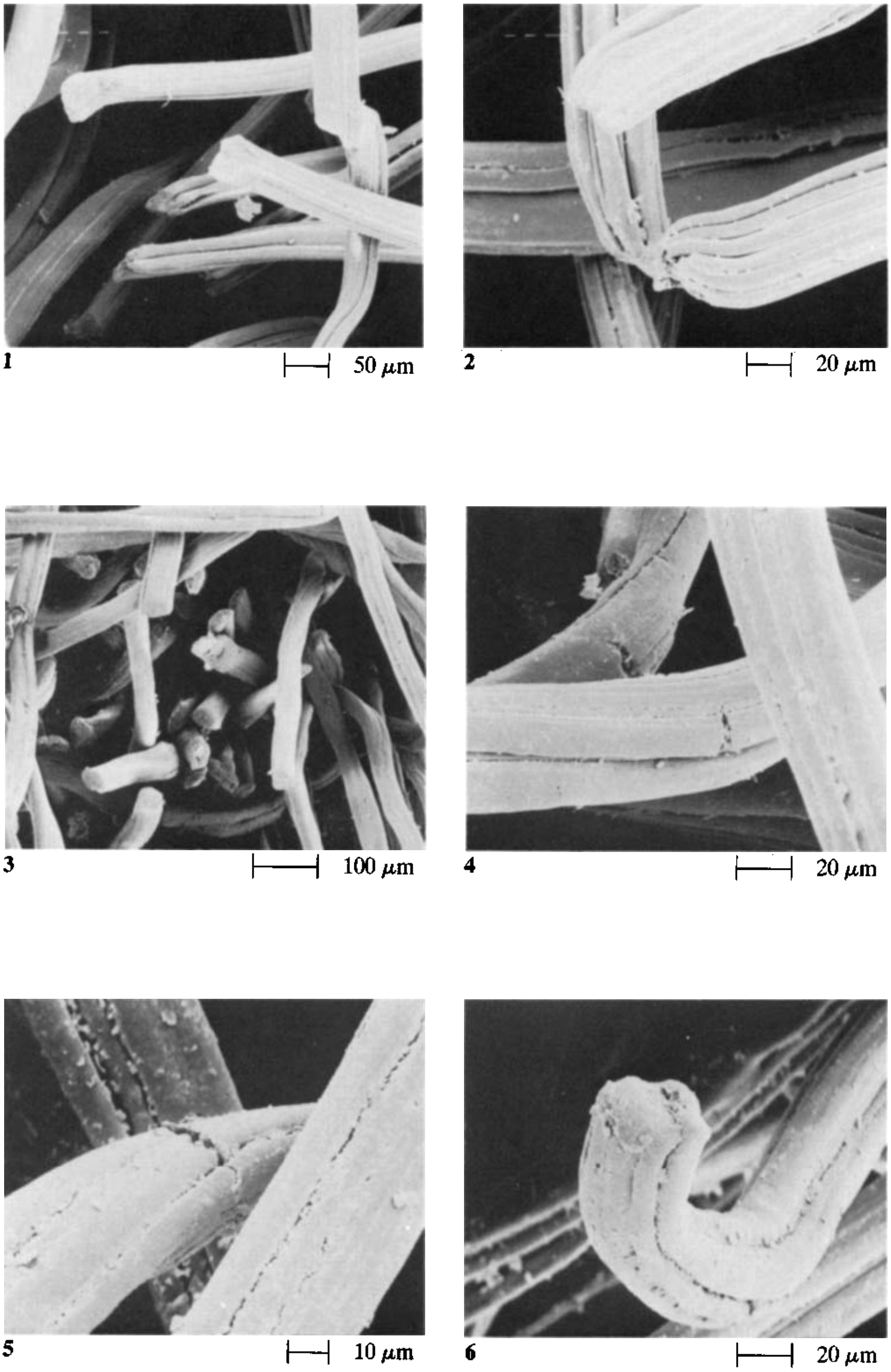


Plate 33F — Evlan (rayon) with some nylon, cut-pile carpet.
(1) Fibre ends in unworn carpet. (2) Incompletely severed end in unworn carpet. (3),(4) After turning trial. (5),(6) After straight walk.

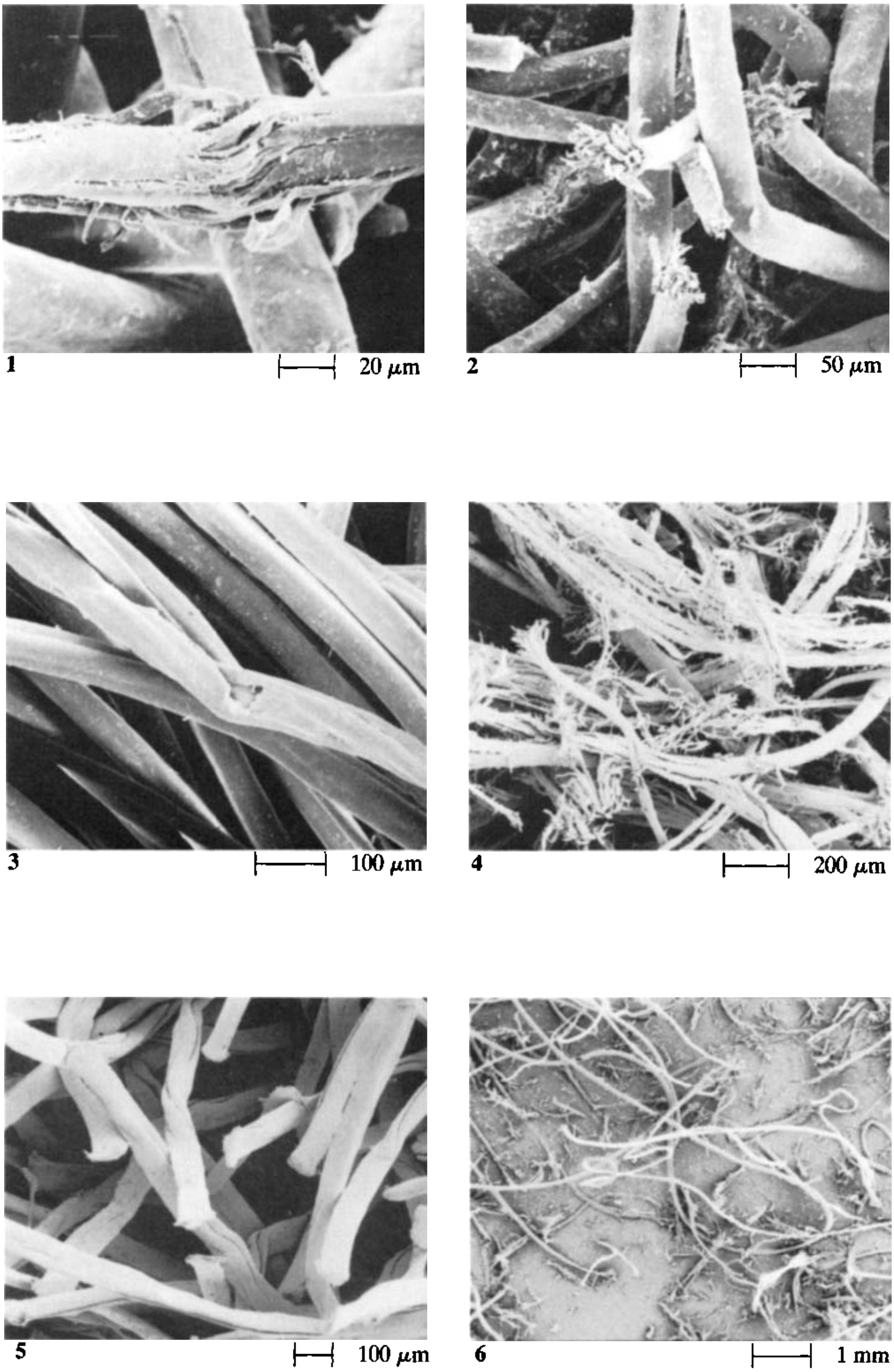


Plate 33G — Office trial at a desk with castor chairs.
(1),(2) 100% wool, cut pile. (3) 100% nylon, loop pile.
Bamburg test.
(4) 100% wool, cut pile, 25 000 cycles. (5) 100% nylon, cut pile, 25 000 cycles. (6) Debris from carpet surface, 80% wool/20% nylon, cut pile, 25 000 cycles.

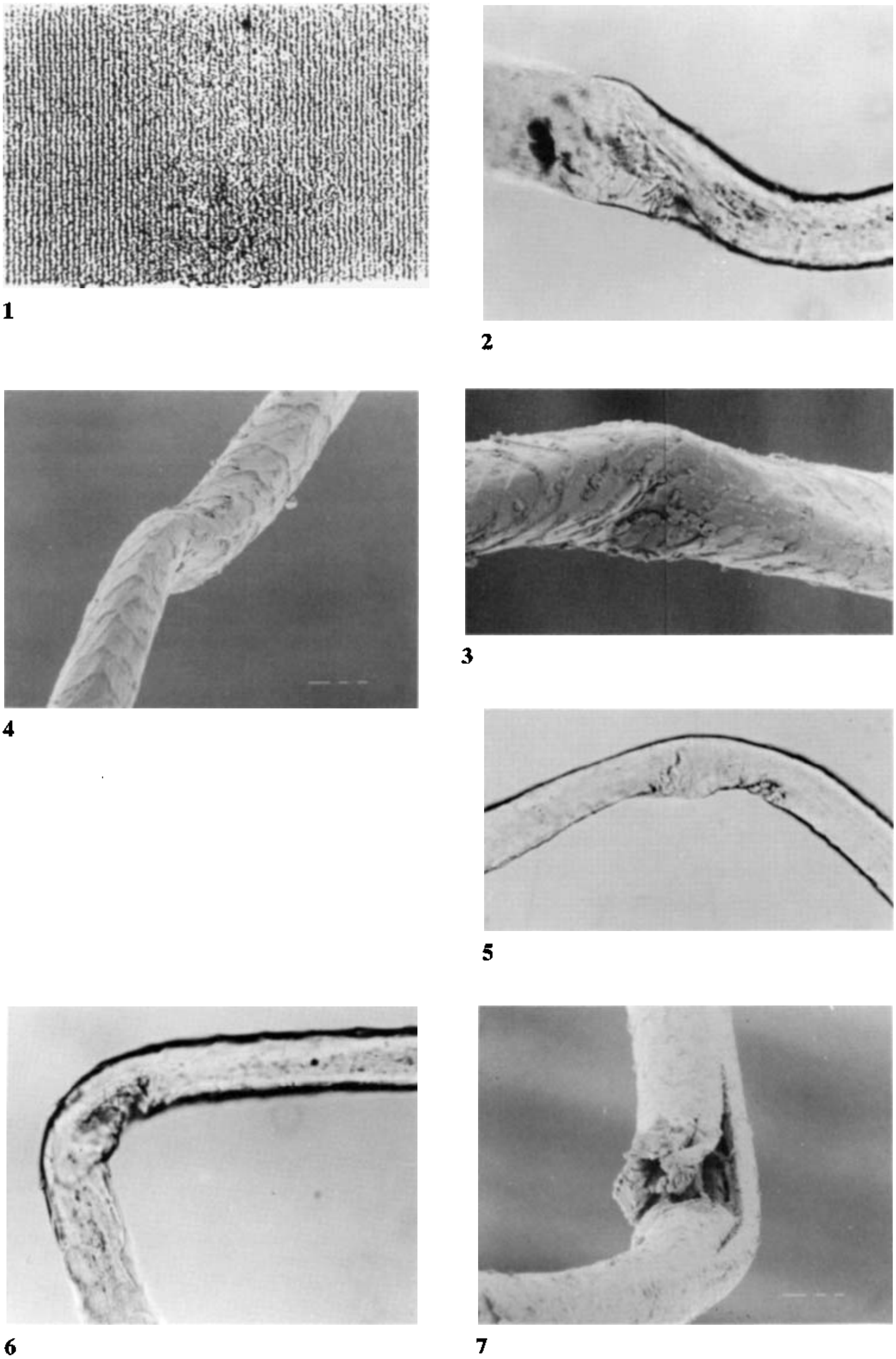
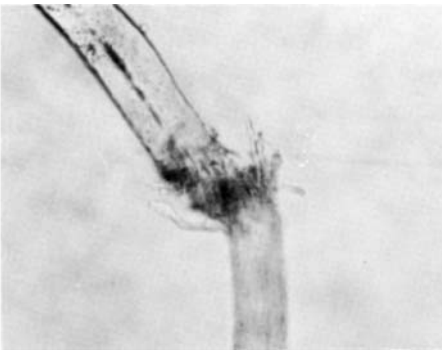
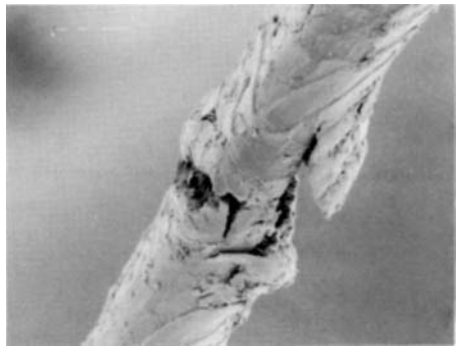


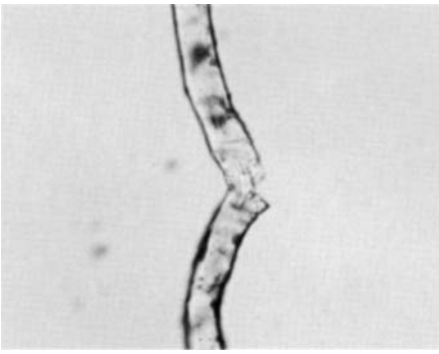
Plate 33H — Straight-walk wool carpet trial.
(1) Central worn part of carpet. (2),(3) Type A damage. (4),(5) Type B. (6),(7) Type C.



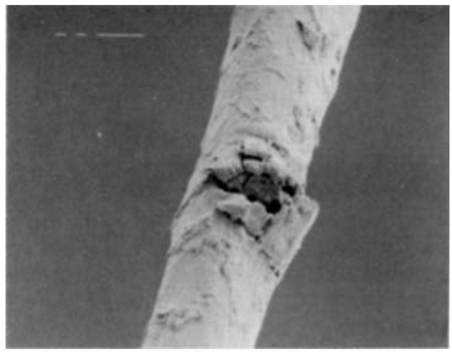
1



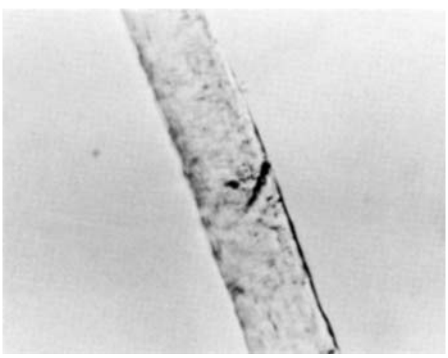
2



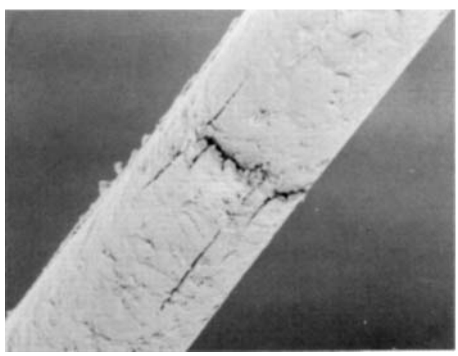
3



4



5



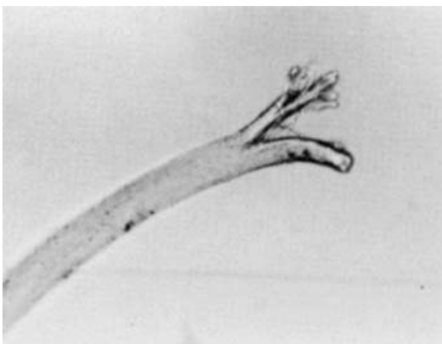
6

Plate 33I — Straight-walk wool carpet trial (continued).
(1),(2) Type D damage. (3),(4) Type E. (5),(6) Type F.

1

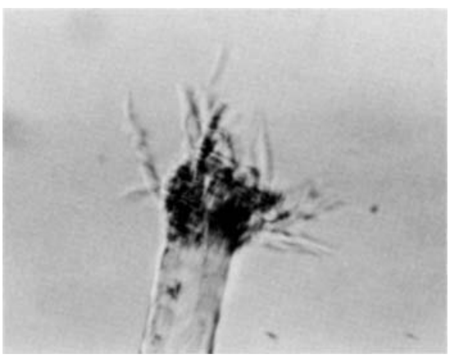
2

3

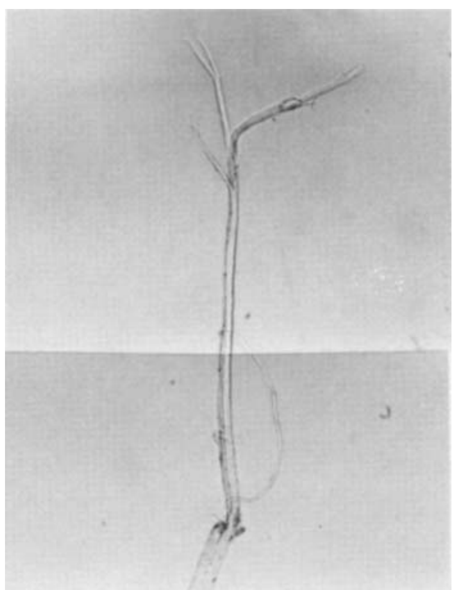


4

5

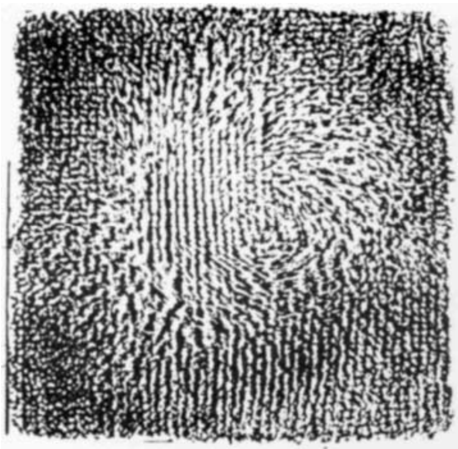


6

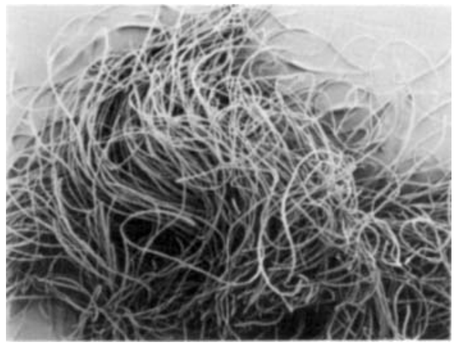


7

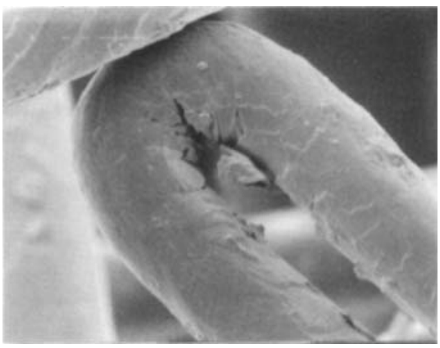
Plate 33J — Straight-walk wool carpet trial (continued).
(1)–(3) Simple breaks. (4)–(7) Breaks with axial splitting.



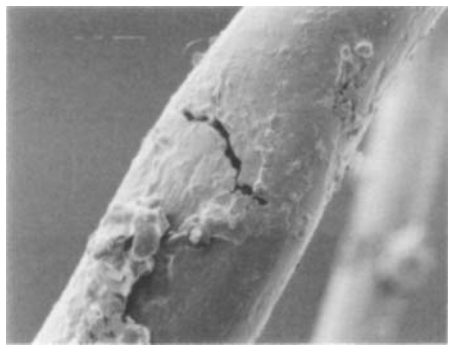
1



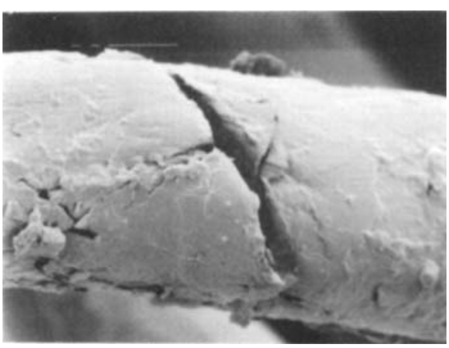
2



3



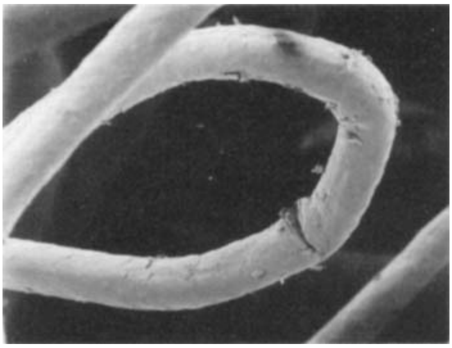
4



5

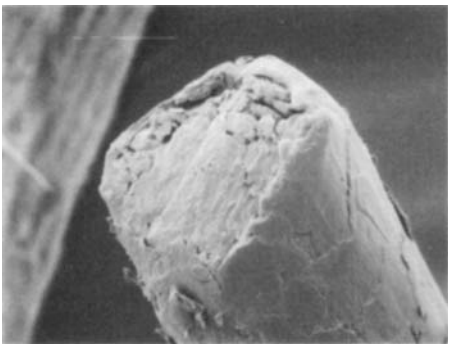
6

Plate 33K — Turning-walk wool carpet trial (continued).
(1) Worn sample of carpet. (2) Tuft from which selected fibres were observed in detail. (3) Sharp bend. (4)–(6) Cracks in fibres.



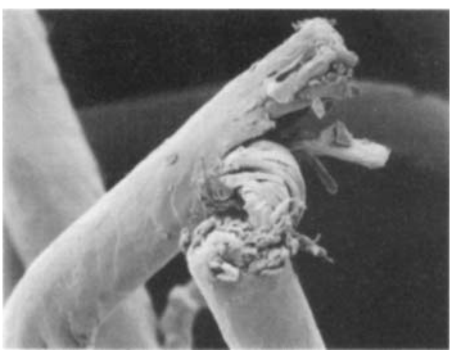
1

2



3

4

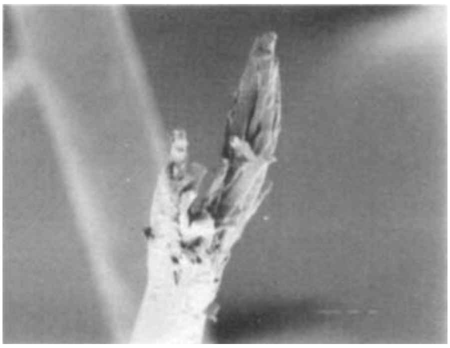


5

6

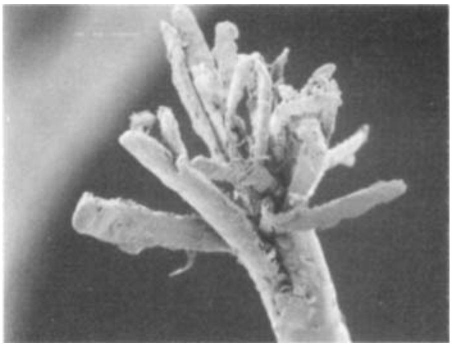
Plate 33L — Turning-walk wool carpet trial (continued).
(1) Crack on inside of bend. (2) Crack appearing on outside of bend. (3) Probably a cut end. (4)–(6) Development of axial splitting.

 Next Page



1

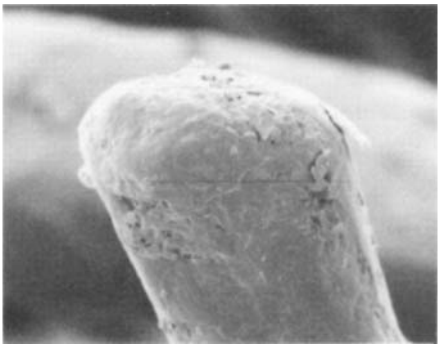
2



3

4

5



6

Plate 33M — Turning-walk wool carpet trial (continued).
(1)–(4) Breaks with axial splitting. (5) Beginning of rounding of end. (6) Rounded end.

34

INDUSTRIAL WORKWEAR

Industrial clothing provides a productive means of studying wear in textile materials for two particular reasons. Firstly, the forms of product and of wear are varied, with uses ranging from the delicate environment of a clean room to the rigours of a coal-mine, but are usually well defined. Secondly, when the employer provides and launders the garments, their life-usage is known: the monitoring and recording is particularly detailed when the garments are supplied under contract by a rental company. Furthermore, rental companies need to build up a body of knowledge and test procedures, so that they can select fabrics and garment designs which will last for the period of a contract, but no longer, except for a certain safety margin. If the garments, or at least any appreciable fraction of them, become unacceptably worn before the contract finishes, typically after two years, then replacement is a high cost. If the garments last too long, then they are over-designed and thus would normally be more expensive.

Where the working environment is not severe, laundering may be the major cause of wear. A washing machine is a good laboratory wear tester; and repeated laundering of garments is a rapid means of evaluation, as illustrated by the overalls from which the fabric specimens shown in **34A** were taken. After 250 launderings of a 100% cotton overall under standard conditions, there is appreciable disturbance of the fabric, **34A(1)**, and sheets of fibrils are peeling away from the cotton fibres, **34A(2)**, which, in some places, are badly disintegrated, **34A(3)**. In a comparable 50% cotton/50% modal rayon (Vincel) overall, similar fabric disturbance and damage to the cotton fibres is apparent, **34A(4),(6)**, but the rayon fibres have suffered little in comparison with the cotton, **34A(5)**. This does not imply that 100% rayon would be more durable, since the cotton fibres in the blend may well be taking most of the load, and protecting the rayon. In addition, some fibrillation, as seen in **34A(5)**, still leaves much of the cotton fibre intact, whereas any breakdown of rayon is usually more severe. In the language of fracture mechanics, the peeling apart of the cotton fibres is a way of absorbing a lot of energy before ultimate failure.

Actual wear in use is illustrated in **34B**, which shows the appearance of material in a navy-blue twill weave 100% cotton coverall after more than six years use in a dirty industrial environment. Damage and loss of colour was most severe in regions below the waist, particularly in the seat, thigh, knee and shin areas, and was markedly absent on the chest, back and collar. In any part of the garment there was preferentially severe abrasion on the raised surfaces of the seams, accentuated on the front seam by the rubbing of metal buttons.

The material had been repaired with a patch below the pocket on the right thigh, and by darning at the corresponding place on the left thigh. There was also mending by darning of splits at the crotch seams, and in a few other places. The fabric is severely abraded at the bottom of the legs, and has been patched on the left side. Some holes in the trouser seat can be attributed to general wear, but other small holes in the back, with no associated loss of colour, are probably due to some specific localized cause. The sleeve cuffs had been folded back, so that wear occurred on the inner fabric surface, especially at folds and seams. There was little wear at the elbows, but rather badly abraded seams under the arms, presumably due to fabric surfaces rubbing together.

The moderately severe wear on the seat of the coverall shows fibre breakage on the crowns of the warp yarns causing the development of a fuzzy line of fibre ends along the crevices of the weave, **34B(1)**, in a manner typical of cotton fabrics. The breakage of the cotton fibres is by multiple splitting, **34B(2)**, similar to that shown by many types of fibre in bending and twisting fatigue (Chapter 13). The splits start along the helical lines of the cotton fibre structure, and continue to have this bias, but are less influenced by the fibrillar structure of cotton than is found with the milder laundering treatments. There is no peeling away of sheets of fibrils, as seen in **34A(3),(5)**.

The wear on the underarm seam is different, and shows abrasive flattening and compacting of the yarns, **34B(3)**. At a higher magnification, **34B(4)**, it can be seen that the individual fibre identity has been completely lost by smearing out of material on the yarn crowns, and is partly lost in the crevices between yarns, although fibre ends with multiple splits can still be discerned. This form of damage results from shear between two fabric surfaces, rubbing against one another, probably aided by the effects of perspiration, and without any opening up of the yarn and fabric structure by bending.

The seam at the centre back is less severely worn, and does not show either broken fibres in the crevices or the surface smearing. However, a few places on the cotton fibres show the start of multiple splitting breakdown, **34B(5)**, leading to break with a bushy end, **34B(6)**.

Localized damage is shown by a hole in the back of the coverall. There is severe disturbance over a small region, but the surrounding fabric is intact, **34C(1)**. There are many rounded fibre ends, **34C(2)**, and some split ends, but little evidence of fibre fatigue. Most probably, the hole was made by catching on a pointed projection: this would break fibres, and the ends would become rounded by subsequent wear and laundering.

The badly worn area at the knee shows the usual features of hard wear, **34C(3)**, with the many broken fibres between the yarns having bushy ends following multiple splitting, and with some smearing on the yarn surfaces. However, there is also much more extraneous matter adhering to the yarns, **34C(4)**: this is probably a mixture of grease, dirt and fibre particles.

The fraying of the hem fold at the bottom of the trouser leg is shown in **34C(5)**, with detail of fibre damage in **34C(6)**. The damage is similar to that found elsewhere, but very severe, with the splitting leading to fibrillation.

The information from examination of this old coverall helps to answer the two important questions: how does damage develop? what can be done to improve the product? Wear in cotton fabrics in severe environments is clearly a result of rubbing and abrasion, intensified by the loosening effect of water on the internal structure of the fibre. Where the fabric remains flat smearing predominates, but where it is repeatedly bent the fibres remain separate as they split and break. The twill weave puts durable hard-twisted warp yarns on the fabric surface, with the softer weft yarns inside. The route to greater durability is to have even harder-wearing yarns on the surface, such as blends with nylon or polyester, and to minimize freedom for fibre bending.

Blue cotton/polyester coverall, supplied under contract for an industrial location by a rental company, had the fabric appearance shown in **34D(1)** in a region of negligible wear. The singed ends of the round polyester fibres and the convoluted cotton fibres can be seen. In contrast to this view, fabric from moderately worn material in the middle of the back is more hairy and shows broken fibre ends at the yarn interlacing points, **34D(2)**. A higher-magnification picture, **34D(3)**, shows the usual multiple-splitting damage in the polyester fibres and the rounded ends which result from wear after the breakage. The splitting of the cotton fibres is more influenced by their characteristic structure. Much more severe damage, but of the same general type, is shown along the edge of the trouser hem, **34D(4)**.

A small hole in the right trouser knee, **34D(5)**, was evidently accidental damage which resulted in fusing of the polyester fibres. The exposed cotton fibre surfaces show no influence of the heat, although the fibres have been trapped by the molten polyester. The fusing was limited to an area close to the edge of the hole, indicating that the cause of damage was very localized. There were also two small holes in the seat, near which the polyester fibres had formed bulbous ends, **34D(6)**, which suggests damage by heat or perhaps a chemical agent.

The pictures shown in **34E** and **34F** are taken from a study of a coal-miner's coverall, which had been withdrawn from service because the rental company considered it to be no longer of the standard required. The fabric was a polyester/modal (rayon) twill weave. The material had been given an easy-care finish, which cross-linked the cellulose and changed its mechanical properties. The material had been dyed orange, but had faded considerably on exposed surfaces and was stained in heavily worn areas. There were many holes, some of which had been repaired. The damage was located where expected from the nature of the work, but details, as given for the first blue coverall, will not be repeated here. The largest hole on the knee appeared to be due to a cut.

Fabric from the reverse face of the collar, **34E(1)**, is almost indistinguishable from samples of original fabric, which had been examined previously. This illustrates how control material can be found within a used garment, where it is protected from damage. The fabric has been singed to give a smooth surface, which is not hairy, and the bulbous ends of the polyester fibres can be seen. In contrast to this, the rayon fibres have square ends, although most of these will be due to breakage and only a few from cutting in manufacture.

Examination of the back of the fabric at low magnification shows little appearance of wear, but a closer look indicates that there are some broken fibre ends between the yarns, **34E(2),(3)**. The two polyester fibres in **34E(3)** have failed in the usual way by multiple splitting to give a ragged end; but the modal rayon fibres have broken cleanly, as if they had been snapped by a brittle break. Similar effects can be seen in **34E(4a)**, where the polyester fibres have suffered splitting, but the modal fibres appear undamaged except where they are broken, or where a crack has gone part way across the fibre, **34E(4b)**. This form of breakage of modal, rather than the peeling which often occurs in rayon, probably results from the application of an easy-care finish, which embrittles the cellulose and makes it easy to break. This was confirmed by the presence of much orange-coloured dust, consisting of small fragments of broken modal fibres, in the laundry.

Severe damage at the edge of a hem is shown in **34E(5),(6)**. Close investigation shows that the modal rayon fibres have almost completely disappeared from the yarn crowns in such badly worn areas, as pieces have broken off and left the fibre ends projecting from between the yarns, together with the bushy broken polyester fibres. At the heel, wear at the edge of the hem had destroyed the fabric integrity.

Another region of severe wear is on the knee, where the fabric has become very hairy, especially around holes, **34F(1)**. The polyester fibres break down owing to bending and twisting, with many bushy ends, **34F(2)**, which develop from multiple splits, **34F(3)**, very similar to a laboratory failure in a biaxial rotation fatigue test (Chapter 13).

Apart from general wear, there may be other forms of accidental damage. Two small holes, darkened round the edges, were found in the front of the left trouser leg. The damage is very localized, **34F(4)**, and shows much fibre fusion, **34F(5)**. The fibres in one yarn end, which would have passed through the middle of the hole, are completely melted together. The melting is not confined to the holes, but is also found to a lesser extent in nearby regions, **34F(6)**. This damage is clearly caused by very localized heat, and a likely cause is the impact of sparks generated in welding.

Workwear may also be worn in situations where they are subject to chemical attack. This can lead to unusual forms of damage, as we found in a blue polyester overall used in a virology laboratory. The fabric will have experienced chemical and biological contamination, but the most serious factor was that the garments were sterilized in an autoclave both before and after each period of use, with cleaning between the two autoclave treatments. The presence of wet steam seems to have been particularly damaging. The back of the garment retained only 40% of its original strength; and the worst affected part of the front had lost over 90% of its strength! There were splits at creases and folds, and also considerable discoloration. The sleeves were easily torn.

Fabric from the overall back seems undamaged at low magnification, **34G(1a)**, but higher magnification reveals transverse cracking of filaments at yarn interstices, **34G(1b)**. Surface cracks are seen in **34G(2)** as is a filament broken by axial splitting: this suggests that the interior of the fibre was less damaged, and could break in the usual way. However, along a warp-way split in the fabric over the zip fastener, **34G(3)**, the breaks were of a different form, **34G(4)–(6)**. They were stake-and-socket failures, as found by Ansell, and shown in **16D(1),(2)** and **26B(5),(6)**, and result once again from exposure to hot, wet conditions with chemical present. It was commercially valuable to the supplier of the garments to establish that the cause of failure was the form of use, and not any fault in the product. Changes in the autoclave procedure led to less damage.

Very strict requirements are put on fabrics for garments used in clean room, whether in the micro-electronics industry or in medicine. The fabric is intended more to protect the environment from the wearer, than vice versa. The user, with some lower layers of regular clothing, is enclosed so that no contaminating particles can escape. This means that dense weaves of closely packed continuous-filament yarns, as in **34H(1)**, must be used. However, it is also vital that the fabric material itself should not shed particles: once again, the important feature is whether fibre damage harms the environment, and not whether it causes any significant deterioration in the fabric, which is the usual concern in wear studies.

As with the first case dealt with in this chapter, the actual wear in use is not severe, and more damage comes from servicing the garments, in this case by dry-cleaning. Such tightly woven fabrics are uncomfortable to wear and cause perspiration, and so must be changed and cleaned frequently. Samples of fabric from garments made from five different continuous-filament polyester fabric constructions were examined after the garments had been subjected to 50 and 300 dry-cleaning cycles, without use. Detailed analysis of the results enabled the fabrics to be ranked in order of merit, from slight peeling in fabric D after 300 cycles to severe peeling on every yarn crown, with long ragged pieces being stripped off, in fabric A.

General damage to the fabric was limited to surface peeling of filaments on the top of yarn crowns, as seen in a fairly severe form on fabric A after 300 cycles in **34H(1),(2)**, and at an early stage after 50 cycles in **34H(3)**. In contrast to this, the damage is slight in fabric D after 300 cycles, **34H(4)**. There is more severe damage at hems and seams, which is at its worst where a hem meets a seam, as in **34H(5)**. The large concentration of multiple splitting failure of fibres can cause complete breakage of yarns. Material may also be damaged by sewing, and **34H(6)** shows a position where a sewing needle has exited: fibres have been broken by the sewing action. The breakage which occurs in these regions of severe wear is an unwanted source of fibrous contamination of the atmosphere.

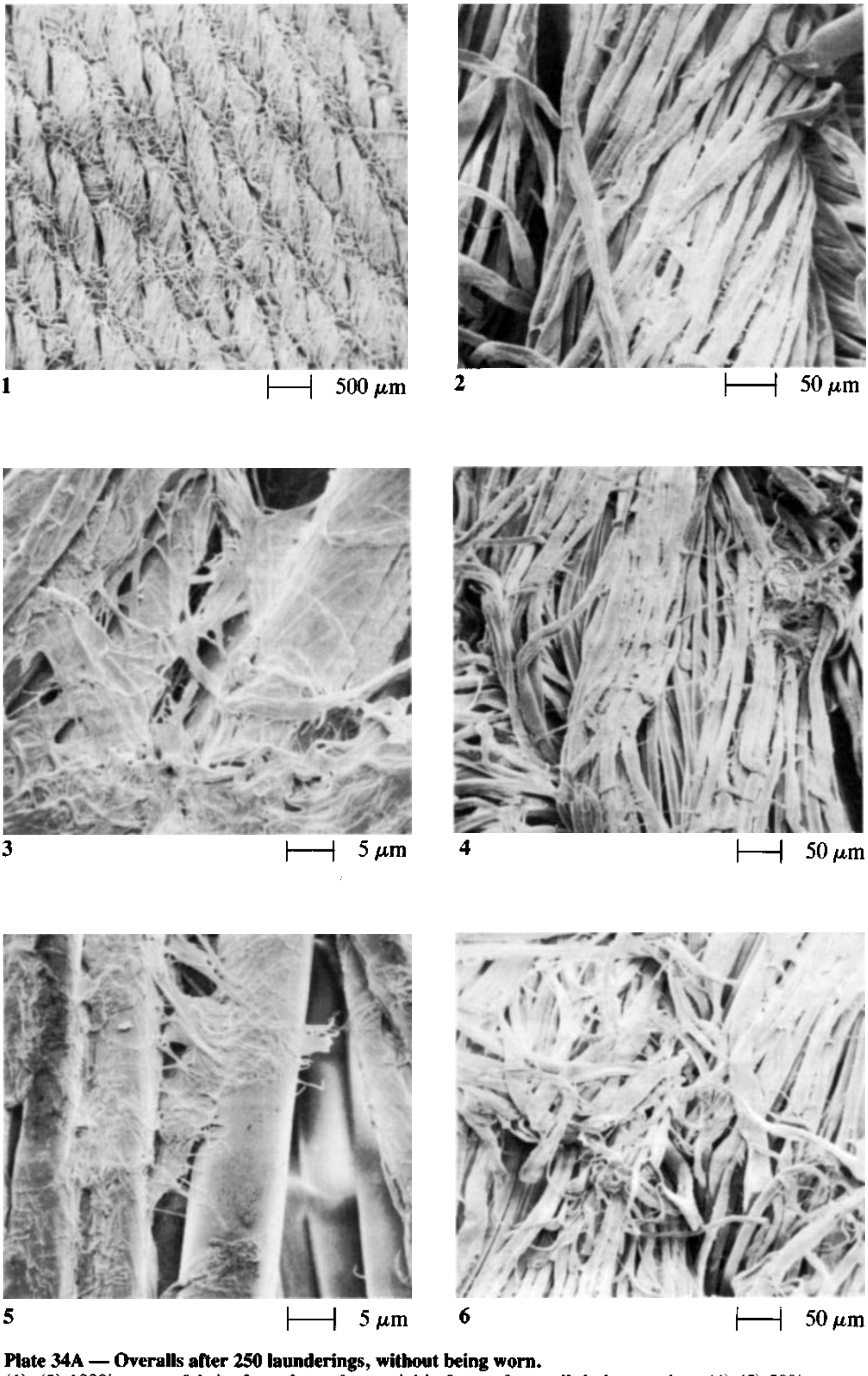
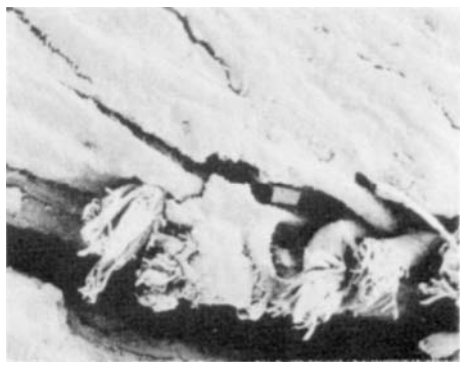


Plate 34A — Overalls after 250 launderings, without being worn.
(1)–(3) 100% cotton fabric, from face of material in front of overall, below pocket. (4),(5) 50% cotton/ 50% modal rayon (Vincel fabric), from face of material in front of overall, below pocket. (6) ditto, but from reverse side of material.

1 500 μm

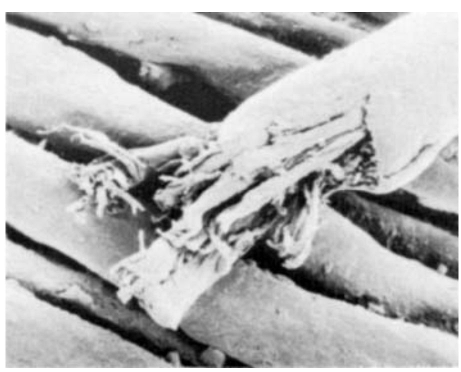
2 50 μm

3 1 mm



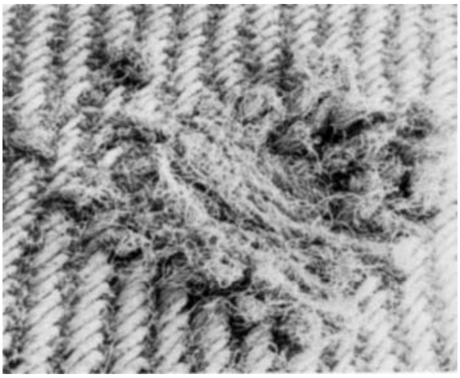
4 20 μm

5 10 μm



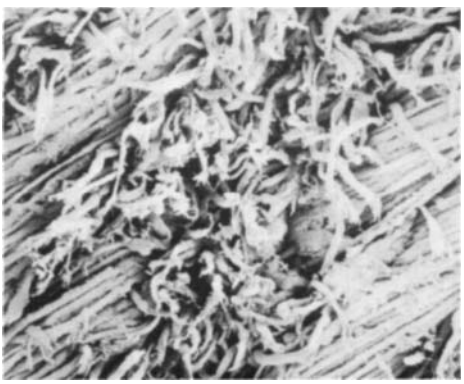
6 10 μm

Plate 34B — Blue cotton twill coverall after industrial use for six years.
(1),(2) From worn area in seat. (3),(4) From underarm area. (5),(6) From seam at centre back.

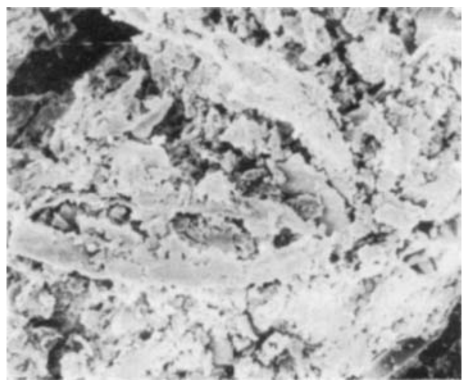


1 1 mm

2 20 μm



3 100 μm



4 10 μm

5 500 μm

6 50 μm

Plate 34C — Cotton coverall (continued).
(1),(2) Hole in back of garment. (3),(4) From badly worn area on knee. (5),(6) Frayed edge at bottom of trouser leg.

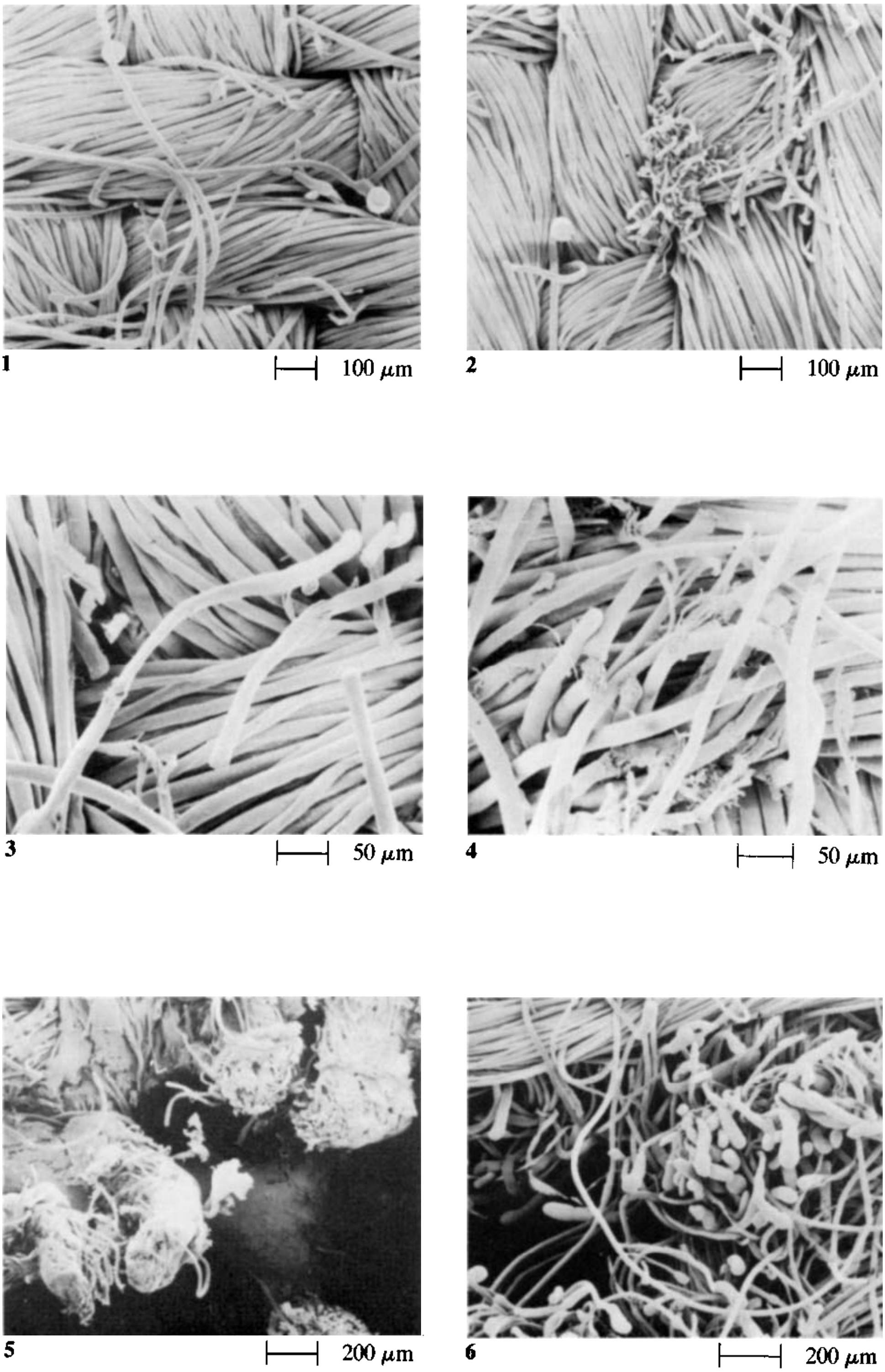


Plate 34D — A cotton/polyester coverall after industrial use.
(1) Fabric from inside breast pocket showing negligible wear. (2),(3) Fabric from centre of the back. (4) Edge of trouser hem. (5) Edge of hole in knee. (6) Small hole in seat.

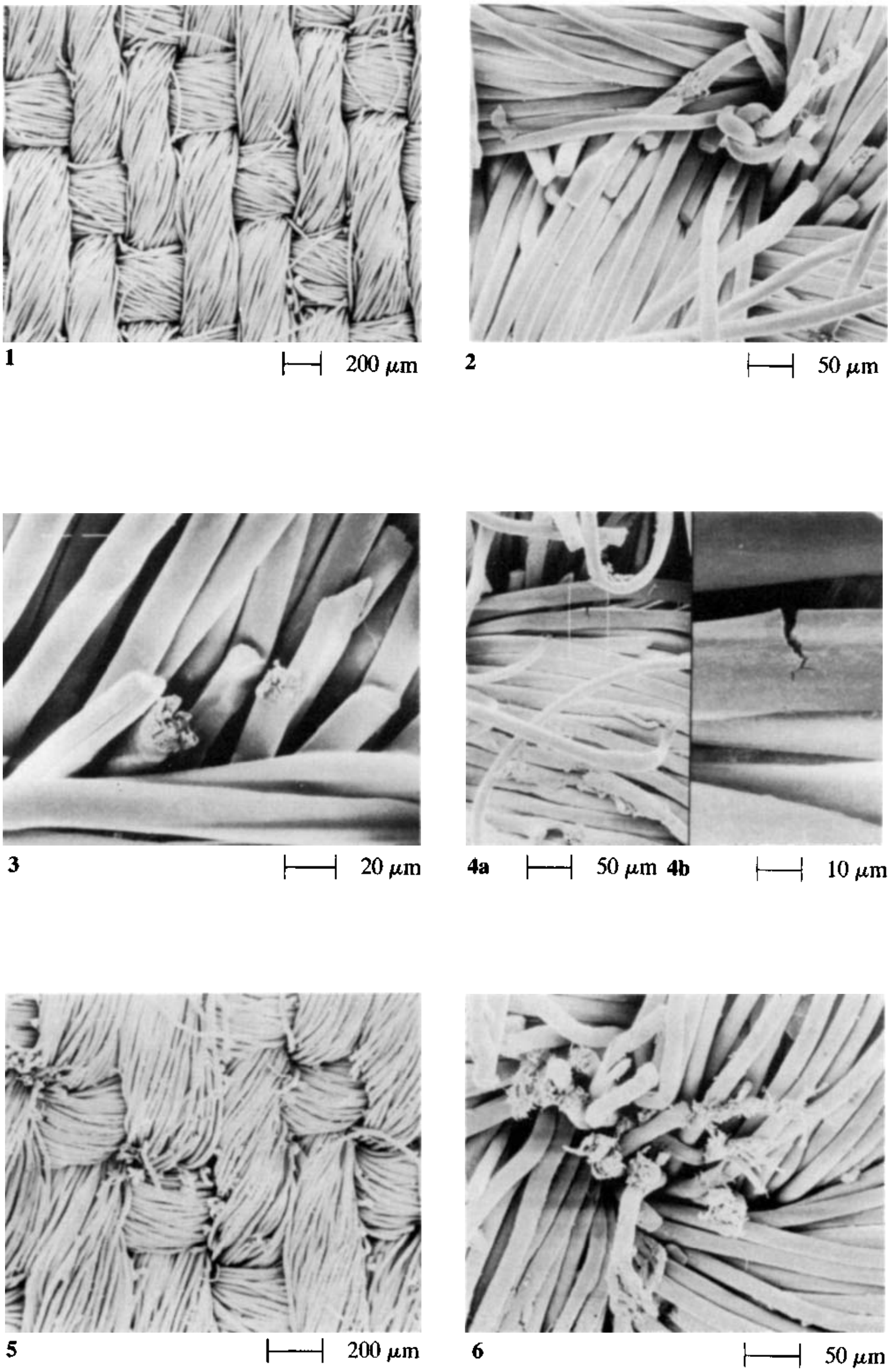
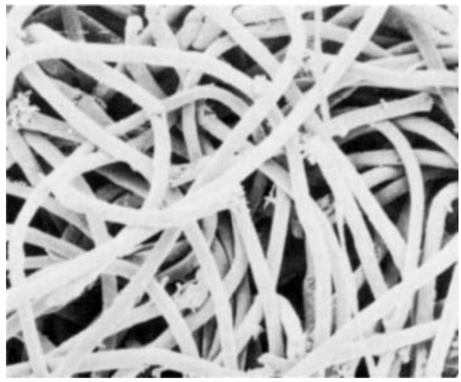


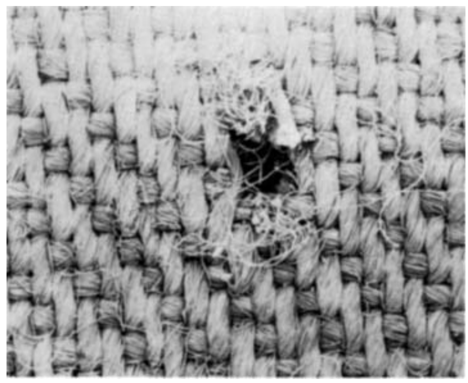
Plate 34E — Coal-miner's polyester/modal (rayon) coverall withdrawn from use because of poor appearance.
(1) Almost undamaged fabric from reverse side of collar. (2),(3) Slightly damaged fabric from centre back region. (4a) Fibre damage from centre back region. (4b) Enlarged view of part of (4a). (5), (6) Badly damaged fabric at edge of hem.

1 1 mm

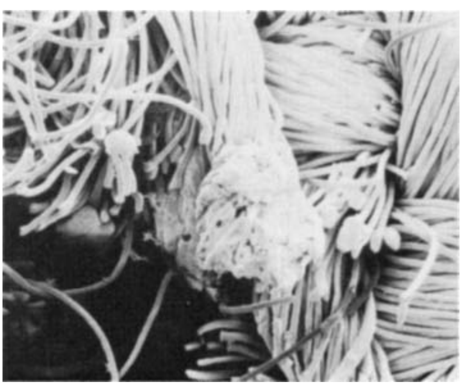


2 50 μm

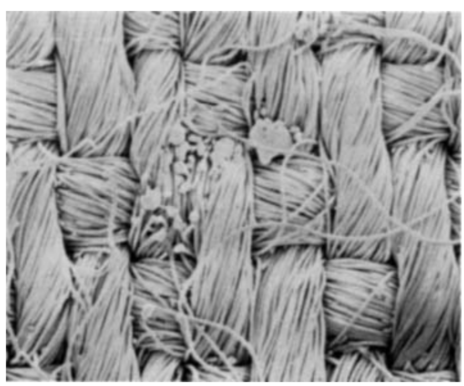
3 10 μm



4 1 mm



5 100 μm



6 200 μm

Plate 34F — Coal miner's polyester/modal coverall (continued).
(1) Hole in knee. (2),(3) Detail of fibre damage in the badly worn knee region. (4) One of two small holes in trouser leg. (5) Fibre fusion around the hole. (6) Fibre fusion in fabric near the small holes.

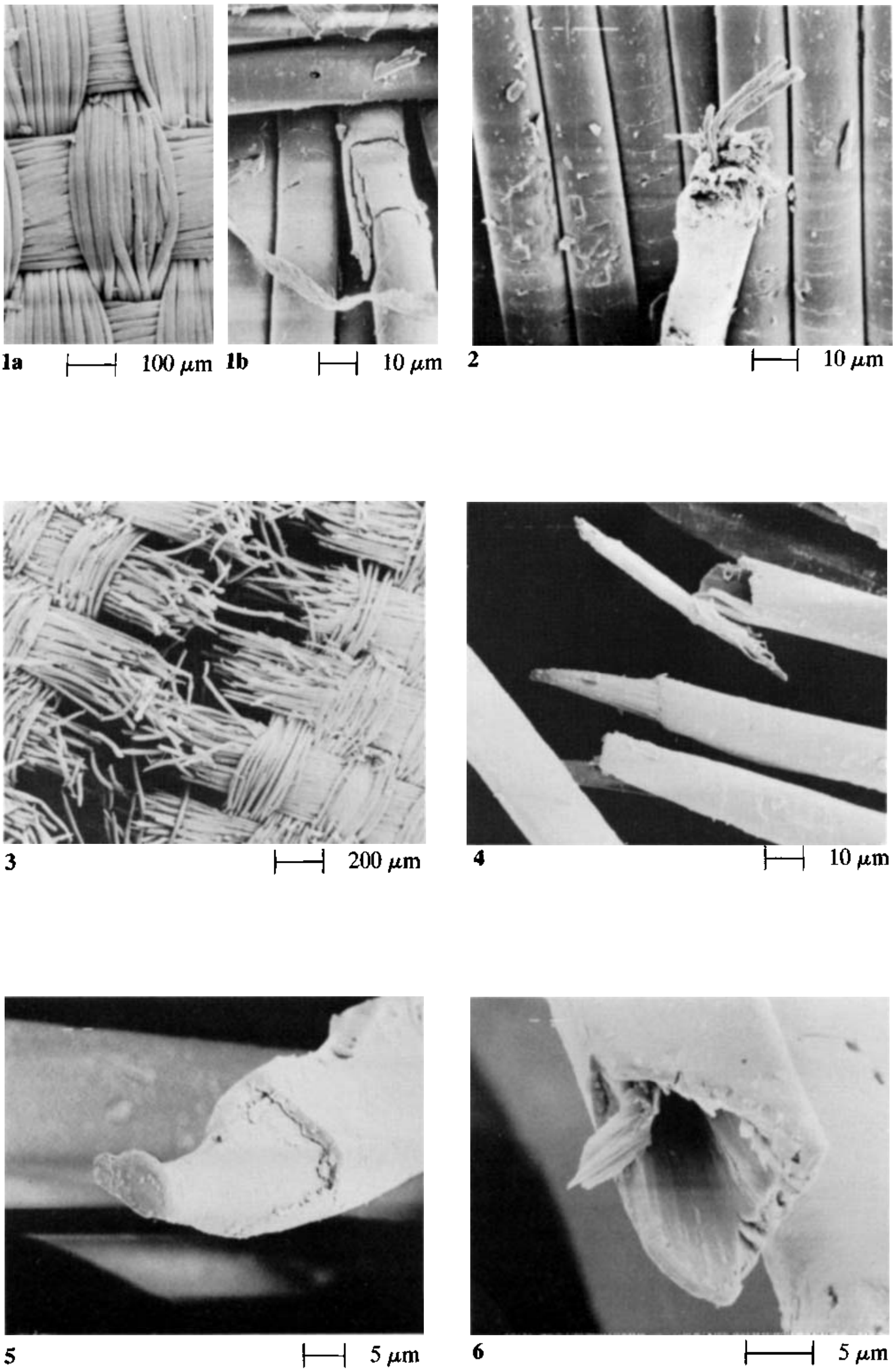
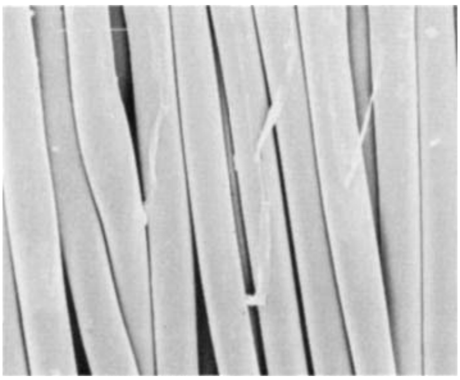


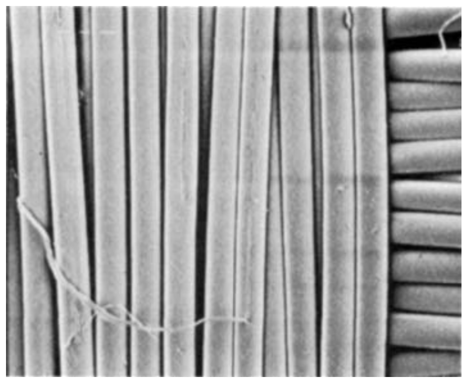
Plate 34G — Polyester overall worn in a virology laboratory, and autoclaved between each period of use. (1a) Fabric from back of overall. (1b) Enlarged view of part of (1a) showing transverse cracking. (2) Fibre broken with multiple splitting. (3) Tear in fabric over zip fastener. (4) Stake-and-socket breaks from the tear. (5) Detail of stake. (6) Detail of socket.

1 100 μm

2 20 μm

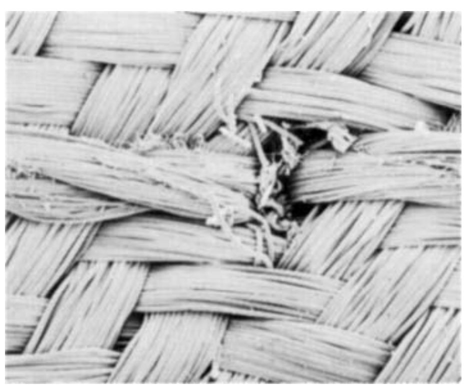


3 20 μm



4 50 μm

5 50 μm



6 100 μm

Plate 34H — Clean-room garments of continuous-filament polyester fabric after being dry-cleaned for 50 or 300 times.

(1),(2) Fabric A after 300 cycles. (3) Detail of fabric A after 50 cycles. (4) Fabric D after 300 cycles. (5) Fabric B after 300 cycles, near junction of hem and seam. (6) Fabric C after 300 cycles, at point of exit of sewing needle.

Previous Page

35

ARMY COVERALLS

Military clothing provides interesting case studies of garments subject to very severe wear, and also, because of a frequent need for thermal protection, includes the use of special treatments and fibres.

The first group of coveralls examined had been subject to normal army usage for a time in which major damage had been incurred. The pictures in **35A** and **35B** are of 100% cotton woven coveralls. In **35A(1)** the lower part of one garment is shown, which has worn into holes at each knee; there is another hole midway down the right shin, which has been patched. Parts of the garment which have suffered general wear, such as the shoulders, below the waist, seat and thighs have a rubbed and faded appearance. Throughout the garments, seams and raised edges are abraded and have lost colour. There is another hole near the front opening at the waist, and there are slit-like holes along the hem at the bottom of the trousers. The inner surface of the garment also shows rubbing along the seams and some pilling on the seat. Another coverall worn by the same corporal shows wear in the same places, but this is even more severe, with holes on both shins, at the ankles and on the trouser leg pocket. Some of these holes have been patched, and even the patches have been patched.

In **35A(2)** the break-up of the cotton fibres in a region of severe damage is shown. At lower magnification, **35A(3)**, it can be seen that there are many broken fibre ends, concentrated at the junctions of yarn cross-overs, while from higher magnification, **35A(4)**, it is clear that extensive splitting is the mode of breakdown of individual fibres.

Even on the inside surface of the fabric, **35A(5)**, there is some wear which shows up as peeling away of layers of the fibre surface, **35A(6)**. This type of damage may result from laundering, as illustrated in Chapter 34.

Successive stages of development of the splitting of the cotton fibres in regions of wear at creases in the fabric are shown in **35B(1),(2)**.

Two coveralls used by another corporal show less severe damage. The only holes are on the left knee of one garment, and towards the inside of the left thigh on the other. The two holes on the thigh, which have been patched, follow the lines of creases or folds formed during use. These two coveralls also showed many lighter coloured lines of damage, which looked like scratch marks. Generally it is easier to observe the course of damage in these less-worn garments.

In **35B(3)** considerable peeling off of fibre layers is shown, in an area between two small holes in the knee. Probably, rubbing action on the knee has led to a scraping of the yarn crowns with fibre layers being pulled away, intensifying any effect caused by laundering. The damage eventually leads to breakage of yarns, and then this loosens the fabric, allowing considerable disturbance and formation of a hole. In other parts of the garment, **35B(4),(5)**, multiple splitting occurs, and this is probably a consequence of bending and twisting of fibres. Even on the inner surface of the fabric, **35B(6)**, fibre ends broken by splitting can be found, although these have probably migrated from the outer surface.

Thus the general mode of failure of these cotton coveralls subject to very extensive use is the multiple splitting found in the laboratory in biaxial rotation fatigue tests (Chapter 13), together with some peeling away of fibre layers.

A third severely worn and extensively damaged coverall was made of Proban-treated cotton, to give flame resistance. There were holes near the trouser hems, which had been shortened by turning up the original hem and stitching in place, and the complete back portion of the right hem was missing. The trouser seat had a T-shaped tear which had been patched and darned. Seams and edges of fabric were heavily abraded, and there were small holes in various places in the garment. Velcro-type fastenings down the front opening, and on pocket flaps and cuff tabs, had been worn considerably, although they still operated. Another Proban-treated coverall, somewhat less damaged, was also examined.

The different pattern of gross wear, for example the lack of holes at the knees, indicates a different pattern of use of these coveralls. However, detailed examination shows a difference in fabric and fibre breakdown, which must be attributed to the effect of the Proban treatment. The general impression of abraded surfaces is that they are not as hairy as untreated cotton fabric surfaces. Abrasion of the fabric surface shows broken fibre ends sitting in the crevices of the weave, **35C(1)**, which is typical of wear in cotton fabrics, but there is less fibrillation and peeling of fibres on the yarn crowns than with the untreated cotton shown in **35B(3)**. There is a general tendency for fibres to split along their length, following the spiral angle of the cellulose fibrils, **35C(2)(3)**, before they fail through breaks which are often sharp and angled, **35C(4)**, although some are more fibrillated, **35C(5a)**. Many broken fibres, either at the weave interstices or at the edges of holes, have rounded ends, **35C(5b)**, due to further wear. Some places, where neatly rounded ends occur, are associated with orange or white discoloration of the navy-blue fabric, suggesting that some chemical damage has occurred.

In the Velcro fastening, **35C(6a,b)**, the ends of some of the hooks had broken off.

Tank crews need garments giving a high degree of thermal protection in case of fire, and a typical coverall is made from a Nomex (meta-aramid) fabric. Three used coveralls showed few signs of wear and tear. Although the fabric surface had been generally abraded, there was no yarn breakage or holes, even in regions where severe wear is common. The worst damage was due to scuffing, particularly in the groin and seat region.

Fibre breakdown is of three types. Firstly, there is peeling leading to fibrillation of fibre surfaces, **35D(1)**, which can cause complete breakage, **35D(2)**, albeit with some coarse splitting. This extensive fibrillation is unusual, and seems to be a special feature of Nomex. Secondly, along scuff lines, **35D(3)**, the fibres are often sharply broken, **35D(4)**. Thirdly, there is the common form of multiple splitting, **35D(5)**, due to bending and twisting.

At the inner trouser seam in the crotch region, a band of webbing has been sewn across the top of the leg. There has been severe abrasion of this seam, and short tufts of broken fibres can be seen in the crevices of the twill weave: these fibres have stubby, bushy ends, **35D(6)**.

Another Nomex coverall had been used as the control in an experimental study of three types of garments containing carbonized fibres to give superior fire resistance. All the garments had been subject to wear trial by completing a specified number of circuits of an assault course.

The Nomex coverall had completed 30 circuits and been laundered six times. There was considerable damage in the knee region, with weft-way slits in the fabric, and there was also a slit near the waistband, where fabric had abraded over a zip fastener. In other parts, where there had been a more gentle rubbing, the fabric had a fuzzy appearance. Wear at seams and edges was not excessive.

In addition to some tangling of surface fibres, the fuzzy appearance is probably due to the characteristic Nomex peeling, which occurs where wear is slight, **35E(1)**, moderate, **35E(2a)**, or severe, **35E(2b)**. However, in the knees, where there is hard rubbing on obstacles of the assault course, there is much more severe damage, **35E(3),(4)**. Fibres have broken after severe scraping, and their ends are curled over in the direction of rubbing.

Fabric covering the zip fastener has been badly abraded, partly because it stands proud of material on either side of the zip, and partly because it is sewn firmly in place over the hard surface of the zip. There is a marked contrast between the material directly over the zip, **35E(5a)** and fabric in an adjacent area, **35E(5b)**. The scraping of fibres on yarn crowns over the zip is shown in **35E(6a)**, whereas the nearby fibres are undamaged, **35E(6b)**.

The first fire-resistant coverall, made of 75% carbonized viscose/25% Nomex, had also undergone 30 circuits of the assault course with six launderings. The damage to the knees was severe and extensive, with a $2\frac{1}{2}$-inch slit of warp yarns in the right knee, allowing weft yarns to fray out. In an area 8×6 inches in the other knee, four holes were darned, with slits extending into the thigh region. There is pilling and matted surface hair in many parts, and a small hole over the zip fastener. The coverall sheds black fragments of carbonized fibre with lengths down to 20 μm.

An inside surface, **35F(1)**, shows a few broken carbonized filaments but otherwise is little damaged. However, the outside region of the worn knee was very disturbed and thin near holes, **35F(2)**. Yarns extracted from this region were found to have thinned down to a few Nomex fibres, **35F(3)**.

The second coverall contained less Nomex (15%) and a different type of carbonized viscose (85%), and showed extensive damage after only 10 circuits of the assault course and one laundering. Many holes in the right knee had been patched, and the left knee had a crescent-shaped hole, $4\times3\frac{1}{2}$ inches in size. The areas round the holes were very thin, down into the shin regions. In various places abrasion has caused the surface to become hairy, with some development of pilling. Short carbonized fibre fragments, with lengths from 25 to 110 μm, are easily broken off when handling the garment.

Fabric in the worn knee region shows many yarn breaks, **35F(4)**, with the carbonized viscose fibres showing a sharp, brittle fracture, **35F(5)**. Broken fragments can also be seen in this region, **35F(6)**.

The third coverall contained 15% Nomex, but the 85% carbonized fibre was oxidized PAN (polyacrylonitrile), not viscose; it also showed much more severe damage after 10 circuits and one laundering, than the control 100% Nomex garment after 30 circuits and six launderings. Each leg had crescent-shaped holes about 4 × 3 inches in size. There were some holes elsewhere, and much of the fabric had become hairy. This garment shed short fragments of the oxidized acrylic fibres.

A lightly worn area on the back of the garment does show some fibre breakage, **35G(1)**. The breaks go sharply across the fibres, **35G(2)**. Over the zip fastener the wear is much more severe, **35G(3)**, and the breaks are sharp and brittle, **35G(4)**. In the most severely worn region of the yarn, the oxidized PAN fibres are broken at each yarn cross-over, and only the few Nomex fibres provide continuity, **35G(5)**.

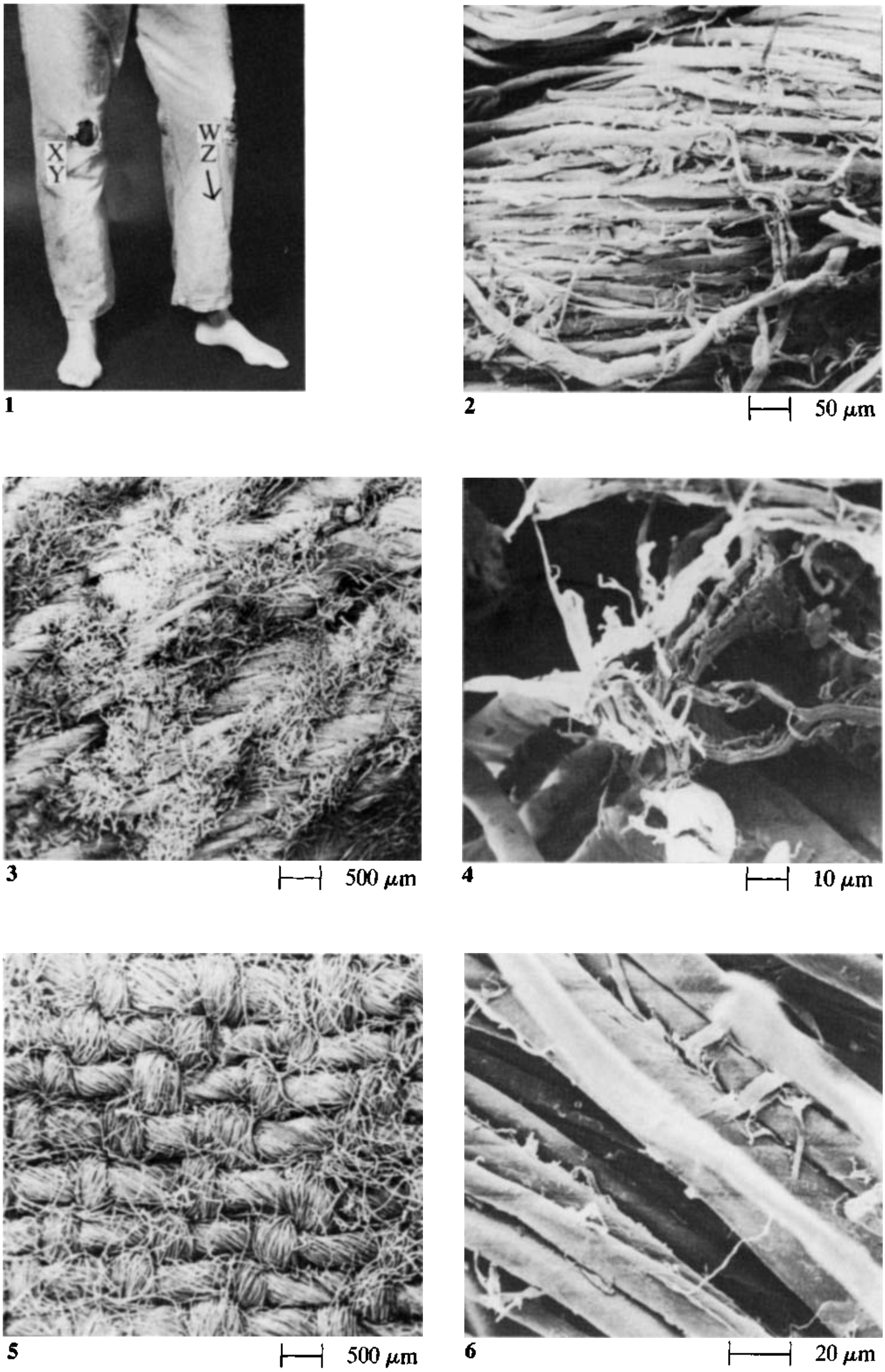


Plate 35A — Severely worn cotton army coverall after extensive use.
(1) General view with identification of regions illustrated in detail. (2)–(4) From region W on **34A(1)**, worn area across edge of a patch on left knee. (5),(6) From region X on **34A(1)**, inside surface of fabric at right knee.

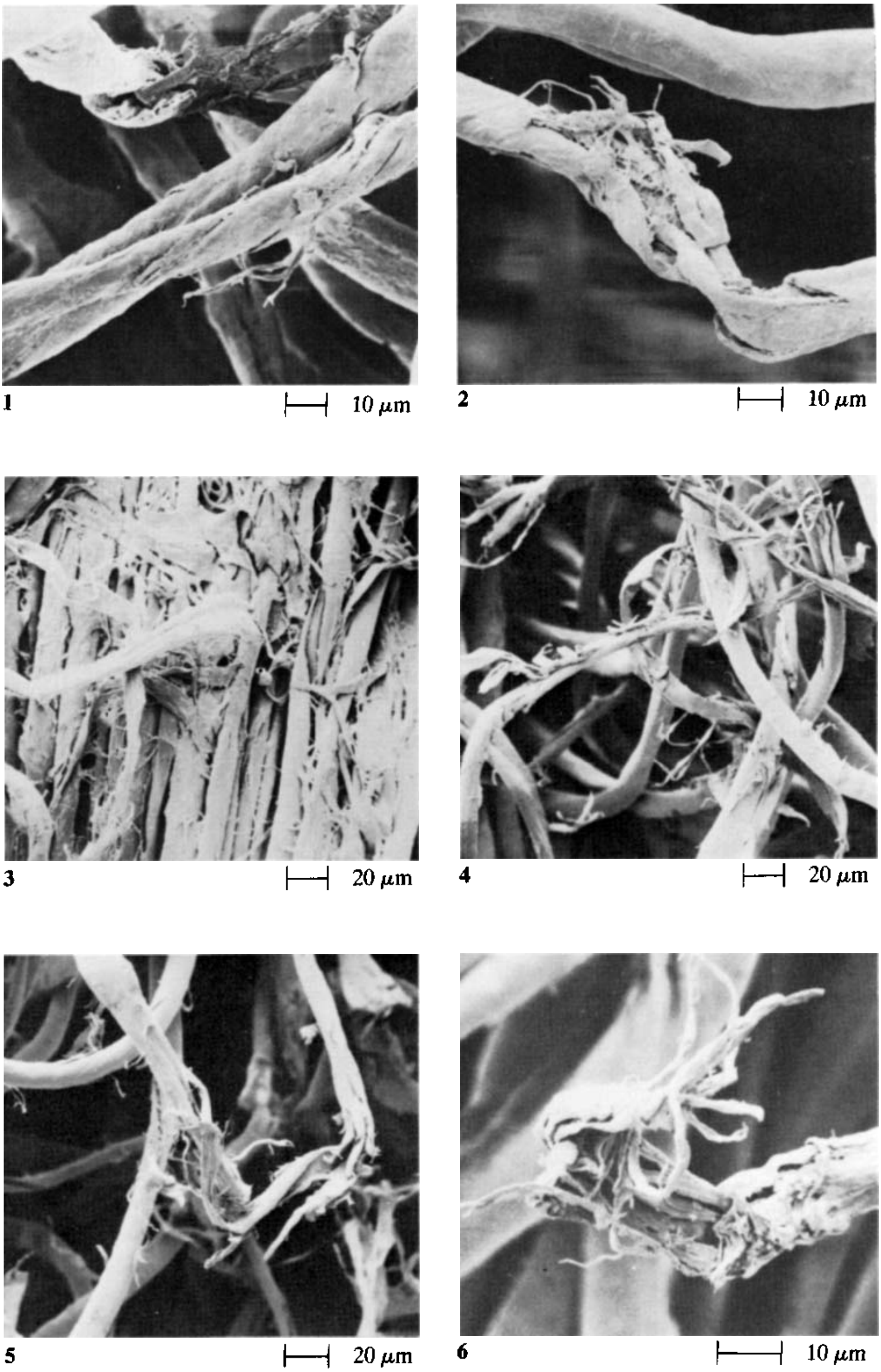
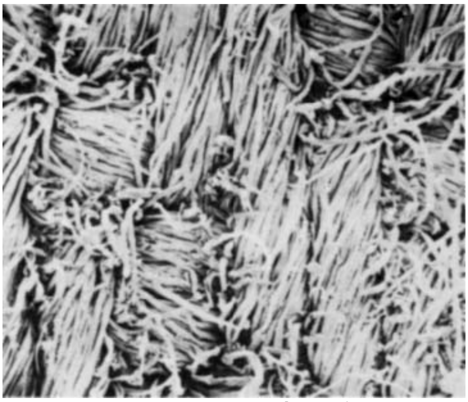
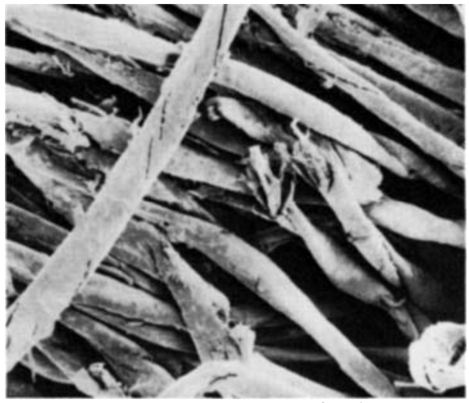


Plate 35B — Severely worn army coverall (continued).
(1) From region Y on **34A(1)**, at a worn crease on the leg. (2) From region Z on **34A(1)**, worn area on left shin.

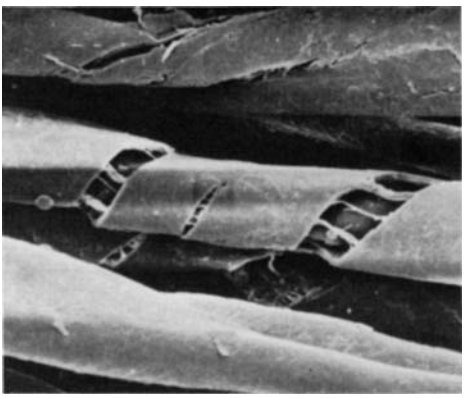
From less severely worn coverall, used by second corporal.
(3) Between holes on left knee. (4) Outer surface of right shoulder. (5) Across a crease, outer surface just above knee. (6) Near worn left knee, inside surface of fabric.



1 200 μm



2 20 μm



3 10 μm

4 50 μm

5a 20 μm

5b 5 μm

6a 1 mm

6b 200 μm

Plate 35C — From a severely worn Proban-treated cotton coverall.
(1) From right knee. (2) From worn pocket flap. (3) From worn seam in crotch. (4) From worn pocket flap. (5a,b) From edge of right cuff, where there was a complete fabric break. (6a,b) Worn Velcro fastening from front opening.

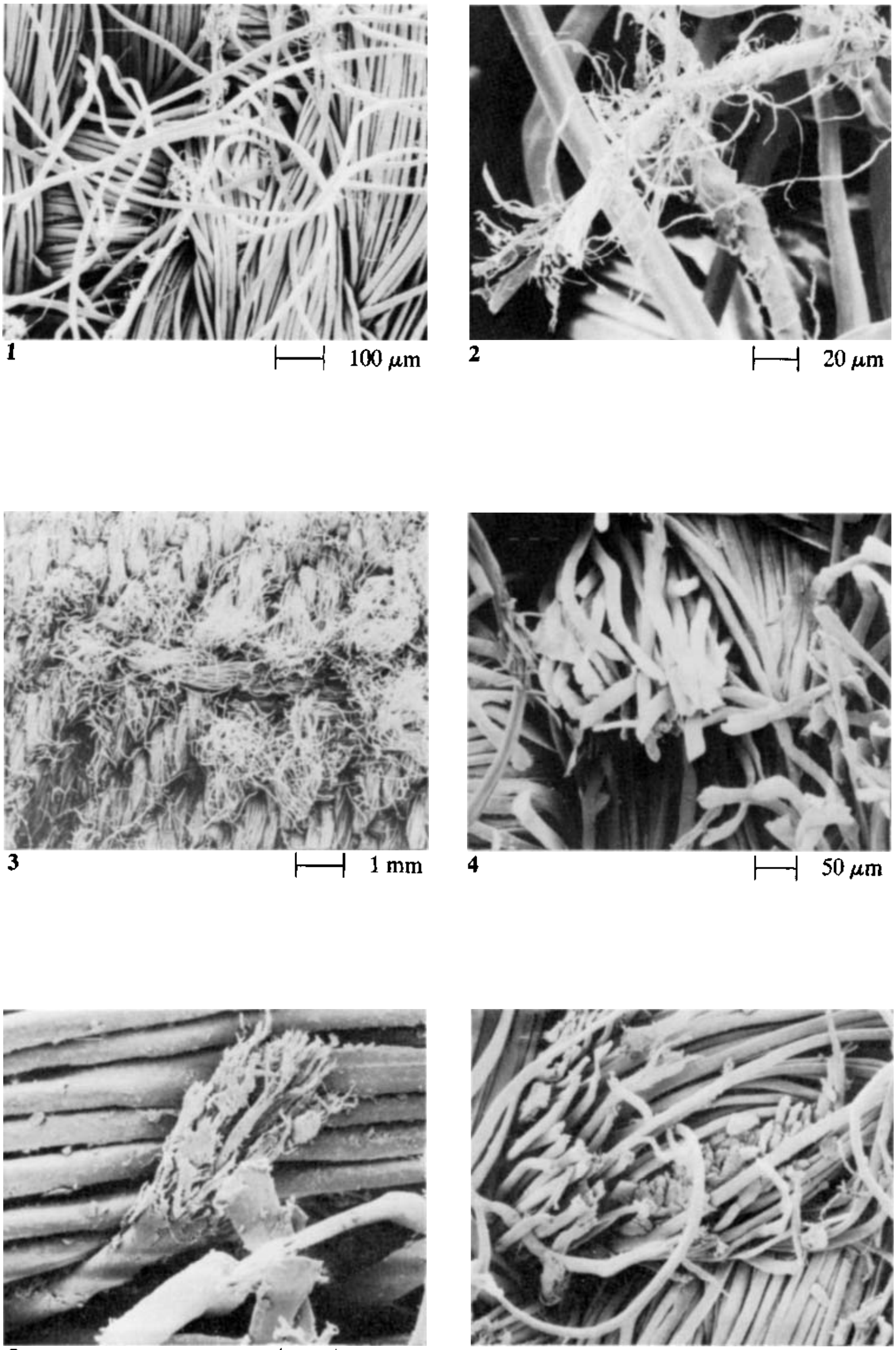


Plate 35D — From Nomex coveralls, used by tank crews.
(1), (2) From mid-shin. (3), (4) From scuff line in seat. (5), (6) From trouser seam.

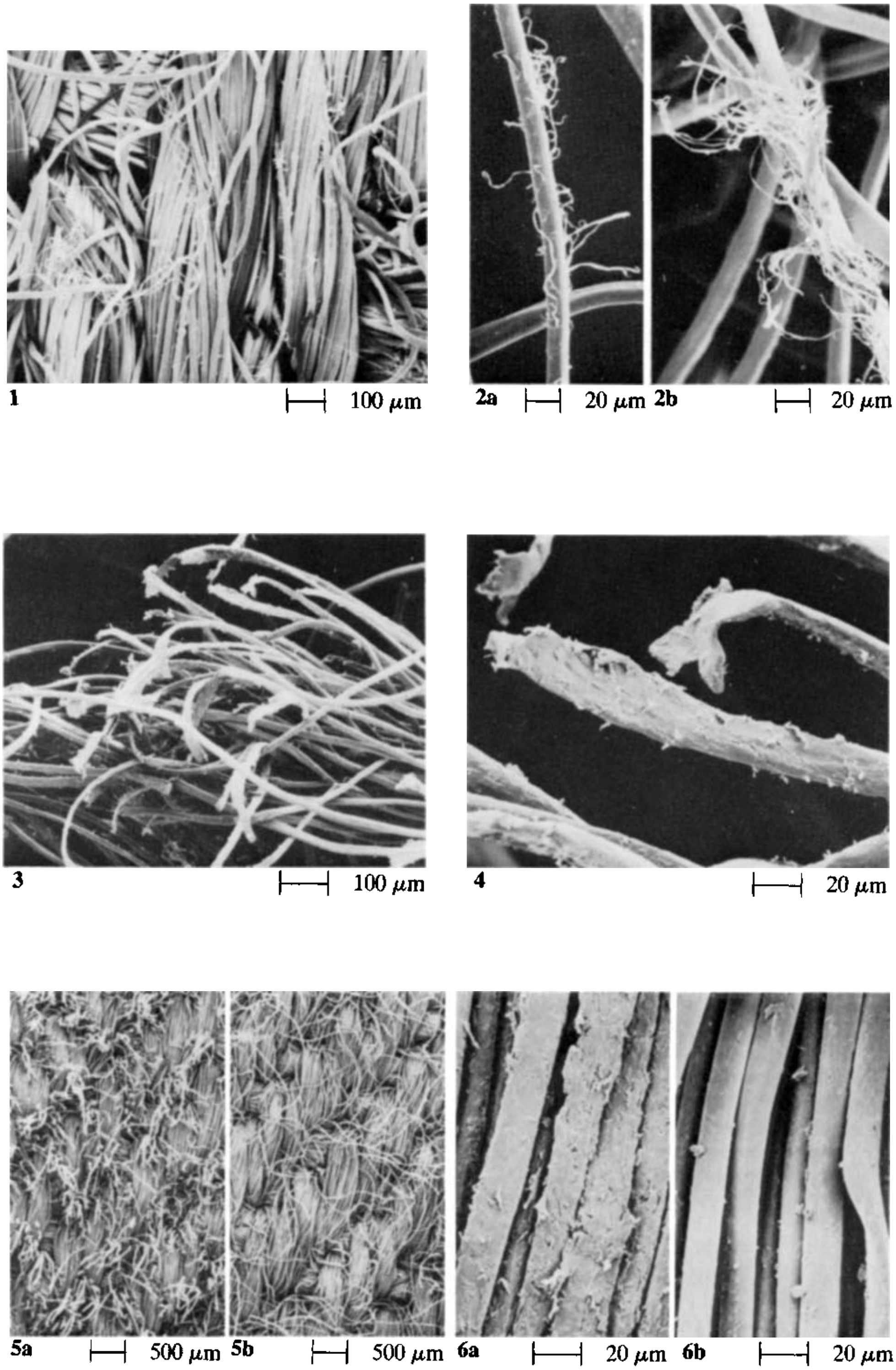


Plate 35E — From Nomex coverall, after 30 circuits of assault course.
(1) From centre back. (2a) From worn area of trouser knee. (2b) From trouser seat. (3), (4) From edge of hole in left knee. (5a), (6a) Directly over zip fastener. (5b), (6b) Adjacent to zip fastener.

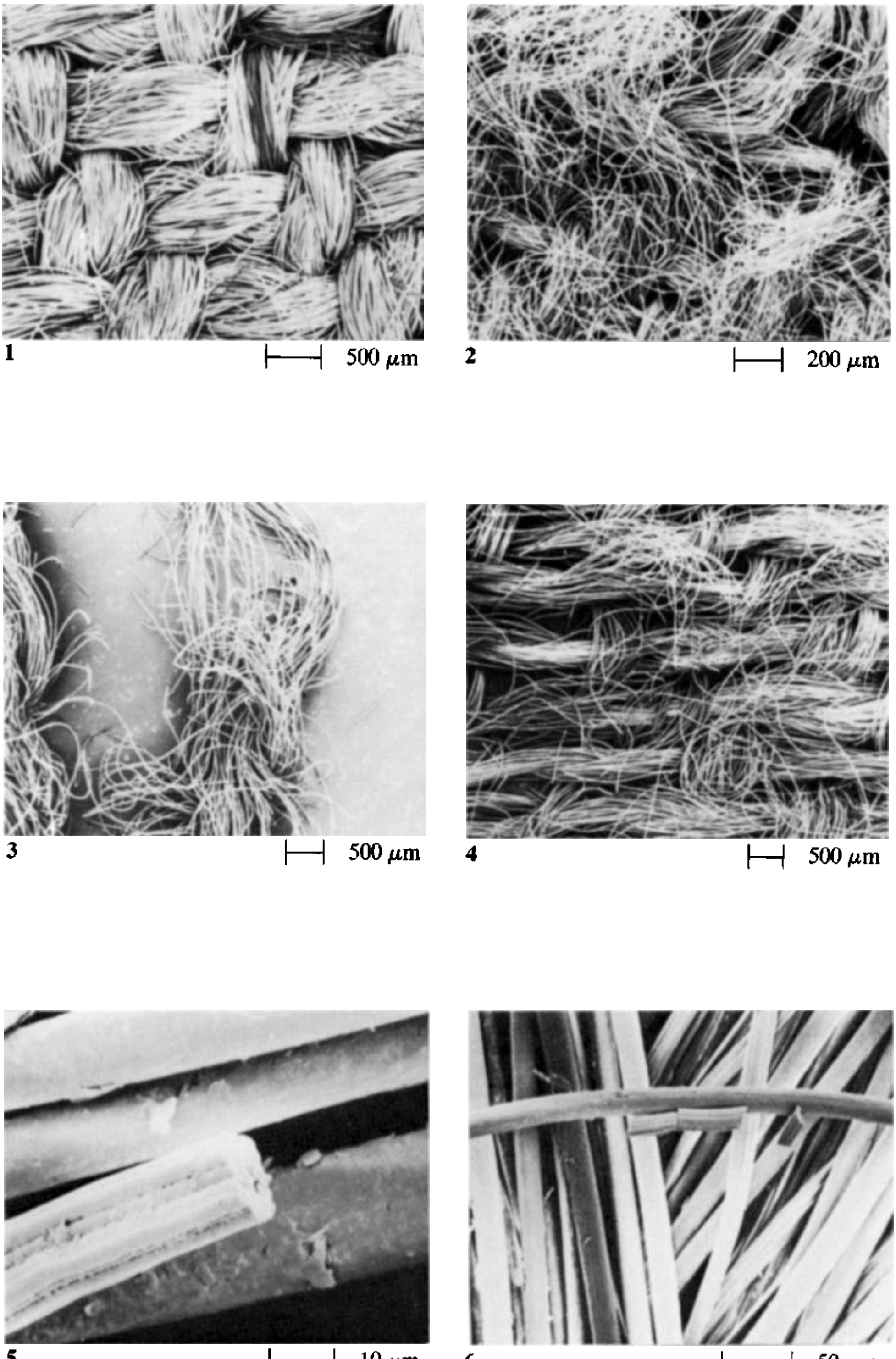


Plate 35F — From 78% carbonized viscose/25% Nomex coverall after 30 circuits of assault course.
(1) Inside surface at knee. (2) Thin area of knee near hole. (3) Yarn extracted from knee area.
From 85% carbonized viscose/15% Nomex coverall after 10 circuits of assault course.
(4)–(6) From worn knee region.

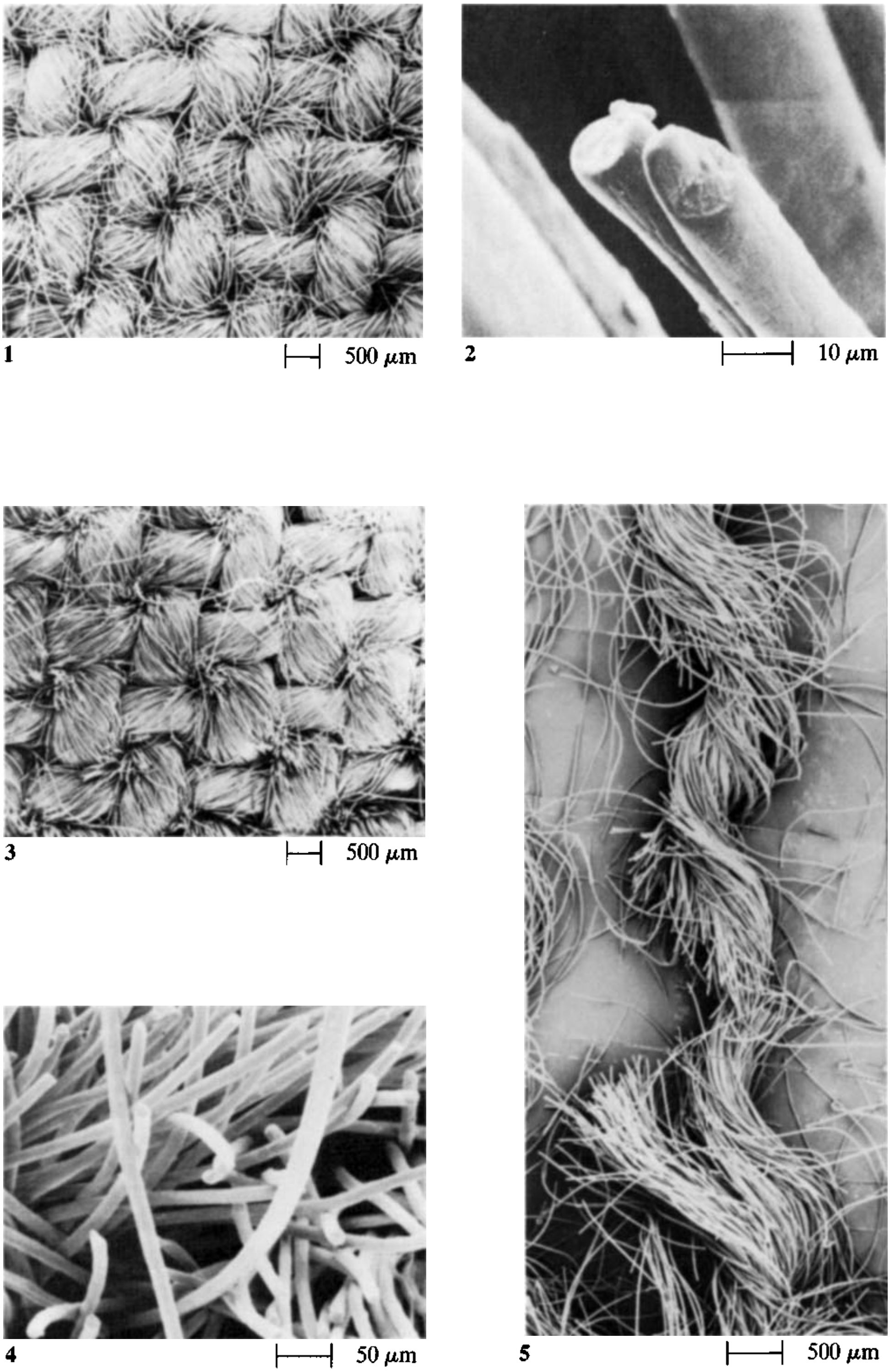


Plate 35G — From 85% oxidized PAN (acrylic)/15% Nomex coverall, after 10 circuits of assault course. (1), (2) From centre back. (3), (4) From fabric over zip-fastener. (5) Warp yarn taken from left knee.