Part XI
Conclusion

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THE DIVERSITY OF FIBRE FAILURE

The pictures in this book really speak for themselves, and this has been augumented by explanations in the text. Only brief summary remarks are appropriate in this last chapter. The overwhelming impression of thirty years of detailed research on fibre breakage is of great diversity of form, but we can now see a pattern emerging.

Although the classification is still a bit ragged at the edges and will be improved by further research, we have identified 18 types of fibre breaks, or fibre ends resulting from other causes, as described in Chapter 1 and shown in Fig. 1.5. The classification resulted mainly from the tests on single fibres, which are reported in Chapters 3–21, but was also influenced by some supplementary observations. In laboratory tests the factors causing break are well defined, but the same types of break can also be found in the case studies of wear in use in the later chapters. In Table 50.1 we have listed the occurrence of these classified forms of broken and other fibre ends, as they appear in plates throughout the book; and some other effects in fibres are listed in Table 50.2. It must be noted that the information in the tables is limited, and reference should be made to the detailed account in the referenced chapter for full details: for example, some of the examples listed are variant forms of the classified breaks, and others occur in fibres in unusual circumstances or after degradation.

Table 50.1 — Classified breaks and other fibre ends (see Chapter 1 and Fig. 1.5)

Note:
(i) Where four or more pictures in a plate are referenced, the individual numbers are not included, e.g. **4B** and not **4B(2),(3),(5),(6)**; but otherwise individual pictures are identified, e.g. **4C(1),(3)**.
(ii) * — see other forms of splitting *, and comment in text.
(iii) References up to Chapter 21 indicate failure in scientific experiments on single fibres, but references after Chapter 22 show failures in textiles in testing, processing or use.

(A) TENSILE FAILURES	
Type 1: brittle (not always easily distinguished from granular)	
carbon	**4C(1),(3)**
carbonized acrylic	**35G(2),(4)**
carbonized rayon	**35F(5),(6)**
ceramic	**4B**
cotton	**29D(5),(6) 32D(4),(5),(6) 35C(4)**
glass	**4A 17A(1) 26C(1),(2) 26H(7)**
Monvelle	**21C(3)**
nylon	**16B(4) 16D(4)**
polyester	**16B(5) 16F(2)**
rayon	**34E(2),(3),(4)**
silicon carbide	**21C(4),(5),(6)**
silk	**43A(5),(6)**
spandex (Lycra)	**4C(4),(5),(6)**
wool	**43B(4),(5)**
Type 2: ductile	
Monvelle	**21C(2)**
nylon	**5A 5B 5C 5D 5E(4) 5F(1),(2) 6A(3),(4) 12E(2) 16A 16C(1) 16D(3) 17A(2) 24A 24B(2)**
polyester	**5B(5),(6) 5E(1),(2),(3) 5F(3),(4) 21B(1),(2)**
polypropylene	**5E(5),(6)**

Type 3: mushroom (high-speed)

nylon	**6A 20A(2) 24A(5),(6) 24B(3) 31C(2),(3) 37A(1),(2) 40F 40H(5) 45A 45B 45C 46F**
Qiana	**31F(3)**
polyester	**6A(6) 24G(6) 24H(3a) 26B(3) 37A(3) 37C(1) 39G(5) 46E**

Type 4: axial split*

HMPE	**7C**
Kevlar	**7A 7B 11E 14A(2),(3) 14C(6) 21D(1) 40H(6)**
nylon	**7C(5),(6)**

Type 5: granular (not always easily distinguished from brittle)

acetate	**8A(4),(5),(6) 17C(3),(4)**
acrylic	**8B 8C 8F(1),(2) 12F(3),(4) 17B 23A(4)**
alginate	**21F(1),(2),(3)**
alumina	**8D(4) 8H**
bacterial fibres	**21G**
carbon	**8D(5),(6) 8G 26H(8) 26I 40D(5)**
cotton	**18B(1),(2),(3) 31G(6)**
flax	**21A(3)**
hair	**19B 19C 19H(5)**
jute	**21A(1),(2)**
Nomex	**21B(3),(4)**
nylon	**16B(1),(2),(3) 16C(1) 16D(3),(5),(6) 26A(5) 39H**
PBI	**8D(3)**
polyester	**8F 16B(6)**
PVA	**8D(1),(2)**
PVC	**21B(5)**
seed-fibre	**21A(4)**
silk	**21A(5),(6) 31C(6)**
Tencel	**8E**
wool	**19A 23K(5) 43B(6)**
rayon	**8A(1),(2),(3) 12G 17C(1) 25E(3) 28E(6) 30C(6) 33F(3),(6)**

Type 6: independent fibrillar*

cotton	**9A**
PTFE	**21B(6)**

Type 7: stake-and-socket

hair	**19D(2),(3),(4) 19J(1),(2) 19J(1),(2)**
nylon	**39J(1),(2)**
polyester	**16D(1),(2) 16E 26B(5),(6) 34G(4),(5),(6)**
polypropylene	**40K(2)**

FATIGUE FAILURES

Type 8: tensile fatigue*

nylon	**11A 11B 24I(4),(5) 31A(6) 40G(4)**
Nomex	**11D(1),(2),(3)**
polyester	**1A(4),(5),(6) 11C 24H(3b)**
polypropylene	**11D(4),(5)**

Type 9: bending — kinkband failure

acrylic	**12F(3)**
aramid	**39M 39N**
flax	**39K(5)**
HMPE	**39O**
nylon	**12B 40G(3)**
polyester	**12A 39L(3)**
wool	**33H(7) 33I 33K 33L(1),(2)**

Type 10: bending — single or multiple split*

acrylic	**12F 31B(7),(8),(9) 33D(6)**
aramid	**39M 39N**
hair	**19F(6)**
HMPE	**12H(5),(6) 12I 39O**
Kevlar	**21D(5)**
nylon	**12B(1),(3),(5) 12C(1) 12D(1),(2) 12E(2) 25G(1),(2) 31A(2),(4),(5) 40B(2),(6)**
polyester	**12A(4),(5) 12C(2) 12D(3),(4),(5) 12E(3) 25E(5),(6) 25G(6)**
polypropylene	**12F(5),(6)**
silk	**31F(5),(6)**
wool	**19F(1),(3),(4) 28A(6) 33J 33L(4),(5),(6) 33M**

Type 11: biaxial rotation — multiple split*

acrylic	13D(4) 33D(5)
cotton	18C 24C(2),(3),(5)
hair	19D(5),(6)
Kevlar	21D(6)
modacrylic	13D(5)
nylon	13A 13B(1),(2),(3) 13D(2),(3) 16C(4) 29E(4),(5),(6)
polyester	13A(4) 13B(5),(6) 13C 13D(1) 16C(3) 25D(5) 28E(3) 29E(3) 31D(5),(6) 34F(3)
polypropylene	13B(4)
PVA	13D(6)
wool	19E 33B(2),(3)

Type 11a: multiple split — torsional fatigue*

nylon	17A(5),(6)
polyester	17D

Type 11b: multiple split: uncertain combinations of bending and twisting fatigue*

acrylic	23C(4) 31B(2),(5),(6) 33D(2),(3),(4)
cotton	23A(7) 25A 25C(1),(4) 27L(8) 29C(3) 30B(5),(6) 30D(4) 31D(2),(4) 31G 32A(2),(4) 32B(5) 34B 34C(2),(3),(6) 34D(3),(4) 35A(2),(4) 35B 35C(2),(3),(5a) 40I(6)
flax	20I(b),(e),(h) 42A(5)
hair	19H(1)
Kevlar	21D(3),(4)
Nomex	35D(5),(6)
nylon	24B(6) 24D(2) 24E(1) 24F(3) 25I(3),(5) 29F(2),(6) 33G(5),(6) 38A(2),(3),(6) 38B(6) 40F(6) 40J(2),(3),(4)
polyester	24F(6) 24H(5a) 25F(3),(4),(5) 26B(2) 28B(5) 28E(2),(4) 29A(5),(6) 29B(2),(3) 30B 30C(3),(4),(5) 34D(3),(4) 34E(2),(3),(6) 34F(2) 34G(2) 34H(5),(6)
polypropylene	39I(5) 40K(2)
silk	42B(5)
unknown	28A 30B
wool	25B(4) 25D(1),(4) 28A(4) 28B 28C(4),(5),(6) 28D(3),(4),(5) 28F(5),(6) 30A(2),(4),(5) 33A(2) 33B 33C(6) 33G 42C

Type 12: surface wear

acrylic	14E
cotton	14A(5)
hair	19D(6) 19F(5)
Kevlar	14A(1),(2),(3) 14C(5),(6)
nylon	12E(5) 14B 14D
polyester	12E(6) 14C
rayon	12G(4) 14A(6)
wool	14A(4) 19E(5) 19F(1),(2) 25B(6) 25D(1),(3) 28D(1),(2),(6) 28G 30D(1),(2)

Type 13: surface peel and split*

cotton	23K(1) 25A(5) 32B(6) 35A(6)
flax	42A(6)
Nomex	35D(1),(2) 35E(1),(2),(4)
nylon	14B 24F(1),(2) 24I(2),(3) 25H 25I(4) 26A(4) 29F(4),(6) 31A(6) 31E(4),(5),(6) 38A(2) 38B(3),(4) 38C 39A 39B(4),(5),(6) 39C 39D 39E 40B(2),(3) 40E(3) 40G(1),(2) 40H(4)
polyester	14C 23K(1),(4),(5) 24F(4),(5) 25D(6) 25E(1),(2) 25F(4),(6) 29B(4) 34H
polypropylene	33E(5),(6)
rayon	32A(5),(6) 32D(2)
silk	31C(5) 42B
wool	25D(3)

Type 14: rounded

acrylic	33D(6)
cotton	25A(6) 25C(4) 31D(2) 34C(2) 35C(5b)
nylon	29E(4),(5) 29F(3) 38A(6) 40B(6) 40H(4)
polyester	25F(5) 29E(2) 31D(6) 34D(3),(4)
rayon	28E(5)
silk	42B(5),(6)
wool	23G(2) 28A(5) 28B(4),(6) 28D(3),(4) 28F(6) 30A(6) 30D(3) 33M(6)

Type 15: transverse pressure — crushing, scraping, blunt cut, impact, etc.	
acetate	**20C(2)**
acrylic	**20C(4) 20F(5),(6) 23A(2),(3) 44A(5)**
cotton	**20B(3),(4) 23A(7) 25C(5) 28F(3) 34B(3),(4) 34C(3),(4)**
flax	**20I(c),(f),(i)**
Nomex	**35E(6a)**
nylon	**20A(2) 20G 23B(5) 24B(4),(5),(6) 24E(2),(3),(6) 25C(6) 25H(5) 25I(5) 33C(4) 33E(1) 33G(3) 37B(1),(5),(6) 37C 37D 38A(4),(6) 38D 38E(3),(6) 38F(2),(3),(6) 39D(6) 39I(4),(6) 40F(3),(4) 40H(3) 45A 45B 45C**
polyester	**20A(6) 20F(4) 23A(1) 23B(5) 24D(4) 24G 37B(3) 39L(5)**
polypropylene	**40G(6)**
rayon	**20B(6) 25C(3) 33F(1),(2)**
unknown	**23B(3a) 35C(7)**
wool	**19G(1) 20C(6) 23B(6) 23I 23J**
Type 16: sharp cut	
acetate	**20C(1)**
acrylic	**20C(3) 20F(3),(7)**
aramid	**20G(1),(2)**
cotton	**20B(1),(2)**
glass	**26C(3),(4),(5)**
nylon	**20A(1),(3),(4) 37B(4) 45A 45B 45C**
polyester	**20A(5) 20F(1),(2) 23B(4)**
rayon	**20B(5)**
wool	**20C(5) 23G(1)**
Type 17: melt — bulbous ends and other melting effects	
acrylic	**20E(4)**
cotton	**20F 25J(3)**
nylon	**20D(1),(2) 21E 37A(5) 38F(2) 39F 39I(6) 40J(1)**
polyester	**20E(3) 23B(1),(2) 24E(3) 24G(3),(4) 24H(4),(5),(6) 25J(5b),(6) 25K(3),(4),(6) 29A(1) 34D 34E(1) 34F(4),(5),(6) 37A(4),(6) 39G**
rayon	**20F(1),(2)**
unknown	**23B(3b)**
wool	**20E(5),(6) 25K**
Type 18: natural fibre ends	
cotton	**23A(5),(6)**

Table 50.2 — Other effects in fibres
Note: *fibre splitting — see note in Table 50.1

1. Adhesion between fibres	
nylon	**39E(3) 39H(3)**
2. Characteristic cotton break: split and tear*	
cotton	**18A 18B(4) 26A(3) 29D(4)**
3. Fibrillation*	
cotton	**18C(3) 24J 29C(2) 29D(2) 32B(2),(6) 34C(6)**
flax	**38G(3),(4) 42A(2),(4)**
hair	**19C(6) 19I(6)**
Kevlar	**21D(3),(4) 23D 26G(1) 39I(1),(2),(3) 39Q(2),(3) 39R(1),(3),(4)**
Nomex	**35D(1),(2) 35E(1),(2)**
nylon	**12D(6) 39A(3),(6) 39B(4),(5) 39C(1),(5),(6) 39D(2)**
silk	**30E 42B**
Technora	**26G(1),(2),(4)**
Tencel	**21F(7),(8)**
Vectran	**39R(5)**
wood-pulp	**23D(1),(2)**
4. Granular break in flex fatigue	
acrylic	**12F(4)**
rayon	**12G**
5. Kinkband (without break) — see also Table 50.1 (type 9) and 50.4 (3)	
aramid	**39M 39N**
HMPE	**39O 39P**

Kevlar	7B(3)
nylon	33C(5)
polyester	12A(1),(2)
rayon	12G(2)

6. Melt-tail

nylon	39F(2),(3) 40F(5),(6)
polyester	37A(3),(4) 39G(4)
spandex	4C(6)

7. Partial break — not including many examples of multiple splitting

acetate, tensile	8A(5)
acrylic, tensile	8B(4)
Kevlar, buckling	21D(2)
nylon, flex fatigue	12A(3),(4),(5)
nylon, tensile	5A(2)
nylon, tensile fatigue	11A(3),(4),(5)
polyester, flex fatigue	12A(3),(4),(5)
polyester, tensile	5B(5),(6) 5F(3),(4)

8. Sheet peel

cotton	24C(6) 29C(2) 30D(5),(6) 30E(1),(2) 31E(3) 32A(1),(2),(3) 32C 32D(1),(2),(3) 34A 35B(3)
flax	42A(2) 42E(1),(2)
HMPE	12H(4) 12I

9. Snap-back, coiling and other recovery after break

Kevlar	7B
Monvelle	21C(1)
nylon	12E(1) 25H(3),(5) 38B(4) 38C(2),(4) 39C(1)
polyester	6A(6) 14C(2),(4) 24D(4) 24G(3),(5),(6) 24H(2)

10. Step and axial split in tensile failure*

cotton	18B(2) 23K(6)
flax	21A(3)
hair	19B 19C 19I(1)
jute	21A(1),(2)
polyester	21B(2)
wool	19A(3),(4),(5)

11. Surface and transverse cracks (various causes)

acetate	8A(4),(5),(6) 17C(3),(4)
acrylic	17B(1),(2)
cotton	29D(5)
flax	42D(6)
glass	26D(3),(4)
Kevlar	21D(2)
nylon	12E(4) 16A(6) 33E(3)
polyester	16C(2) 16E(1) 16F(1) 16G(5) 24H(5),(6) 33E(4) 34G(1b),(2) 40C
polypropylene	40H(1),(2) 40K(4),(5),(6)
rayon	8A(1),(2),(3) 17C(2) 33F(4),(5)
wool	43A(4)

12. Tensile fatigue split*

acrylic	11D(6),(7),(8)
Kevlar	11E
wool	19D(1)

13. Transverse stress: axial split*

carbon	26I(1),(4)
Technora	26G(1),(2)

14. Twist anomaly

cotton	18C(4)

15. Twist split*

acrylic	17B(4),(5),(6)
cotton	18C(1),(2)
Kevlar	17C(5),(6)
nylon	5D(6) 17A(3),(4) 24B(5),(6)

16. Void formation

nylon	5A(3),(4) 21E(4),(5)

Fibre failure by splitting, which is a common mode of breakage in the wear of materials in use, is a difficult form to identify, because similar effects can arise from different causes and are classified as different types. The single-fibre test, which most clearly leads to multiple splitting breaks, is the biaxial rotation fatigue test, discussed in Chapter 13 and listed as type 11. The fibres are subject to cyclic bending plus an imposed torque. However, either single or multiple splitting can occur as a result of flex fatigue and the associated shear, without any twisting, as discussed in Chapter 12 and listed as type 10. There are differences in appearance: biaxial rotation fatigue splits are usually short, typically about five fibre diameters in length, and are twisted in opposite directions on either side of the centre point; whereas flex splits are usually much longer and have no twist. Where we can assign a break with reasonable confidence to one of these types, either from the appearance or because the test conditions are known, they are so listed in Table 50.1. Multiple splitting can also occur through pure torsional fatigue, although this has not been much studied: one example is listed as 11a in Table 50.1. Where we cannot be sure of the cause of multiple splitting, but it is regarded as due to some combination of bending and twisting fatigue in fibre asemblies, the examples are listed in 11b in Table 50.1.

But splitting can also occur in other circumstances, and all the forms of splitting are marked * in Table 50.1 and 50.2. Some types of fibre split very easily, and some types of stress promote splitting. Where the lateral intermolecular forces are weak in oriented fibres, a simple tensile failure leads to axial splitting: type 4 in Table 50.1. An extreme variant of this effect is the independent fibrillar break: type 6 in Table 50.1. Sometimes, shear stresses cause separate tensile breaks to join by an axial split: type 10 in Table 50.2. The shear stresses in twisted fibres intensify the tendency to split, and examples are as listed in Table 50.2 (12); a special case, involving untwisting at a reversal point, is the characteristic break of cotton, Table 50.2 (2). Transverse stresses can also cause axial splitting: type 13 in Table 50.2. The characteristic tensile fatigue break in melt-spun fibres, type 8 in Table 50.1, gives single, or occasionally multiple, splits; in other fibres splitting is the dominant response to tensile load cycling, type 12 in Table 50.2; and surface shear forces can also give rise to forms of splitting, listed among type 13 in Table 50.1. Finally fibrillation, Table 50.2 (3), is really an extreme form of multiple splitting.

In the interpretation of the reasons for splitting in fibres, it is therefore necessary to take account of the nature of the fibres, the circumstances of failure and the appearance of the break.

The other tensile breaks in Table 50.1 are easily identified, and are discussed in the relevant chapters. Kinkband breakage in bending fatigue is also a well-defined form, discussed in Chapter 12. Wear, type 12 in Table 50.1, is really a macroscopic manifestation of the detailed effects of surface peeling, listed as type 13.

Among the miscellaneous group, rounding is another macroscopic consequence of continued wear. Type 15 in Table 50.1 comprises a varied and poorly defined collection of failures resulting from high lateral pressures, either relatively localized, as from a blunt knife, or more distributed. In contrast to this, highly localized pressure by a sharp blade cuts through the fibre and causes type 16.

Melting, listed as Table 50.1 (17), includes both the bulbous ends of single fibres, shown in Fig. 1.5, and less localized effects in fibre assemblies.

The effects listed in Table 50.2 are rather varied. Some, namely (2,4,10,12,13 and 15), are specialized forms of fibre break, which should perhaps have been included in the main classification. Others, namely kinkbands (5), partial breaks (7), cracks (11), the twist anomaly in cotton (14) and void formation (16), show intermediate stages of deformation or damage, prior to break. Fibrillation (3) and sheet peeling in cellulosic fibres (8) are ways in which the material of a fibre can disintegrate. Snap-back (9) and the pulling out of melt-tails (6) are events which happen to fibres after break has occurred. Adhesion (1) is an effect between fibres in contact under heat or pressure.

Examples of the influence of external factors, such as various forms of degradation or attack, are listed in Table 50.3.

Table 50.3 — Special external factors

1. Biological degradation	
flax	**43C(2)**
wool	**19G 43C(1),(3)**
2. Bites: insect or animal	
nylon	**37D 38D**
wool	**19G(1) 43C(4),(5)**
3. Burning or carbonization	
cotton	**20F 25J(2a),(3),(4) 43B(1),(2),(3)**
rayon	**20F(2)**

4. Chemical attack: during or prior to test	
glass	**26D(3),(4) 49C**
nylon	**5C(2) 5D(2),(3) 16C(1),(4),(6) 23C(5),(6)**
polyester	**16C(2),(3),(5) 16D(1),(2) 16E 34G(1b),(2)**
polyglycolic acid	**49B 49C**
polypropylene	**40K**
5. Photodegradation	
cotton	**32D(4),(5),(6)**
nylon/elastomer	**40A 40B**
nylon	**16A 37B(2)**
polyester	**16F 16G 40C**
polypropylene	**40H(1),(2)**
wool	**16H**
6. Radiation damage	
nylon	**16D**
7. Soiling or deposits	
cotton	**34C(4)**
Kevlar	**39I(2),(3)**
nylon	**38C(6) 39B(3),(6) 39E(6)**
polyester	**24E(4)**
wool	**43C(6)**
8. Thermal damage	
nylon	**16B 38E(6) 39F(4),(5),(6) 39H**
polyester	**16B(5),(6) 16D(1),(2) 24H(5),(6)**
9. Smearing on surface of fabric or yarn	
cotton	**24J(4) 25A(5) 25C(2),(5) 34B(3),(4) 34C(3),(4)**
flax	**42A(3)**
nylon	**25H(2),(4) 38B(1),(2) 38C(1),(5) 39C(3) 40J(4),(5)**
paper	**25B(2)**
polyester	**25G(4),(5)**
10. Yarn breaks	
cotton	**24C(1),(4)**
nylon	**24B(1) 24D(1)**
polyester	**24D(3)**
polypropylene	**40K(1)**

From an academic viewpoint, a lesson to be learnt from the diversity of forms of break is that it is wrong to try to explain fibre fracture or fibre fatigue in general terms. The particular type of fibre, its history, and the precise test method must be specified. We have been able to give a number of qualitative explanations of different forms of fibre failure. However, a full theoretical development of the subject will need detailed stress or deformation analysis, and this must be related to the polymer physics of fibre structure, which is itself not yet well documented for many types of fibre. Except in a few special cases, such as the brittle fracture of glass fibres, the problems are difficult for at least three reasons: firstly, rupture frequently results from the occurrence of a complex combination of stresses; secondly, large strains commonly develop over distances which spread out widely from cracks; thirdly, most fibres are composed of materials which are anisotropic and non-linear viscoelastic. An understanding of the essential morphology of the failure, which has been opened up by the studies in this book, is necessary if the right approximations are to guide the analysis.

An understanding of single fibre failure is only part of the story. Fibres are used in assemblies containing millions of fibres or fibre elements. The mechanics of stress distribution within the assembly also needs to be understood, although no more than some qualitative and descriptive comment has been appropriate in this book. But once again the observation of the forms of failure, reported in Chapters 22–43, will provide guidance to future theoretical work, as well as giving immediate practical information on the nature of wear in textile materials and their durability. Some effects in fibre assemblies, involving many fibres, are listed in Table 50.4. They range from the appearance of yarn breaks, through indications of the progressive breakdown in fabrics, to delamination in composites.

From a practical viewpoint the most important conclusion from the studies of wear in use is that the commonest form of failure, in most types of fibre in most applications, is multiple splitting leading to a bushy end, with a subsequent rounding in further wear. Such failures are caused by flexural and torsional fatigue of fibres, although, as discussed above, it is not always possible to identify the particular combination of bending and twisting which leads to failure; and, sometimes, there can be confusion with splitting due to other causes. Other common causes of failure in use are surface peeling and the crushing or mangling effects of transverse pressure.

Table 50.4 — Effects in structures

1. Adhesion loss and delamination in composites	
carbon/epoxy	**40D(4),(6)**
carbon/nylon	**26E(1)**
carbon/PEEK	**26F 26H(4),(5),(6) 26I(6)**
glass/nylon	**26E(3),(4)**
glass/PET	**26C(4),(5) 26E(4),(6) 26H(1),(2),(3)**
nylon/elastomer	**26A(1),(2) 40A(2),(3),(4)**
Technora/epoxy	**26G(5),(7)**
2. Coating failure	
nylon/elastomer	**26B(1)**
3. Fabric damage	
ballistic impact	**40L 46B 46C 46D**
braid break	**24H(1) 24I(1)**
break, hole or severe wear	**28A(1) 29B(1) 29C(1),(4) 29D(1) 31A(1) 31B(1),(4) 31G(1) 32D(4) 33A(1) 34C(1) 34F(1),(4) 35A(1) 35F(2),(3),(4) 35G(5)**
broken fibres in interstices	**25M(1),(2) 35C(1)**
knife cuts	**46B 46C 46D**
tear	**25L(5),(6)**
wear on yarn crowns	**25A(1) 25G(3),(4),(5) 28E(5) 29C(5) 29F(5) 34D(2) 34E(5)**
yarn breaks	**25L**
4. Kinkbands	
composite	**26G(6)**
yarn	**39E(1)**
5. Pilling	
acrylic	**31B(3)**
cotton	**25L(7) 31D(1b) 31E(2a)**
cotton/PET blend	**29E(1) 30B(1) 30C(1),(2)**
nylon	**31C(1)**
Qiana	**31F(2),(3)**
wool/PET blend	**28C(3),(4)**
wool	**30A(1)**
6. Plastic flow in composite matrix	
carbon/epoxy	**26H(1),(2),(3)**
carbon/PEEK	**26F(3),(5) 26H(4),(5),(6)**
glass/PET	**26D**
Technora/epoxy	**26G(5)**

Almost all the examples of tensile failure in Table 50.1 are from the chapters in Parts II and IV of the book, and occur in laboratory tests. Textiles rarely fail in use as a result of the direct application of too large a load, and so the infrequency of tensile breaks is not surprising.

As with single fibre breakage itself, the deformation and sequence of damage within fibre assemblies is diverse and complicated. In order to try and develop understanding, it is necessary to be specific about the product and how it is used. Careful study, starting with little-worn regions and going on to locations of failure, can then elucidate in qualitative terms the mechanisms of wear and ultimately lead to predictions of durability.