5
Strength and elongation tests

5.1 Introduction

The level of strength required from a yarn or fabric depends on its end use. For some end uses it is the case that the higher the strength of the materials, the better it is for its end use. This is particularly true for yarns and fabrics intended for industrial products. However, fabrics intended for household or apparel use merely need an adequate strength in order to withstand handling during production and use. It is generally the case that a higher-strength product can only be obtained by either making a heavier, stiffer fabric or by using synthetic fibres in place of natural ones. In either case changes are produced in other properties of the material, such as the stiffness and handle, which may not be desirable for a particular end use.

5.2 Definitions

See also reference [1].

5.2.1 Units

It is important when measuring strength to be clear about the distinction among mass, weight and force. The mass of a body is the term used to denote the quantity of matter it contains, it is a fixed property of an object and does not depend on where it happens to be. The SI unit of mass is the kilogram (kg).

Force can only be defined in terms of what it does. Force is that which changes a body's state of rest or of uniform motion in a straight line. In other words a force causes a body to accelerate. The SI unit of force the newton (N) is defined in terms of the acceleration produced when the force acts on a mass of one kilogram. A newton is defined as the force that when applied to a mass of one kilogram gives it an acceleration of one metre per second per second. In a strength test the result should be measured in units of force rather than units of mass.

Gravitational force pulls all bodies towards the Earth. If a mass of one kilogram is allowed to fall freely in a vacuum towards the Earth it acquires an acceleration of about $9.8 m/s^2$. Using the definition of the newton this implies that the force acting on it must be 9.8N. If the kilogram is resting on the Earth's surface it will press down on the surface with a force of 9.8 N. This force is what is known as the weight of a body and it is the quantity that is measured by a spring balance. However, the force of gravity on a body varies slightly from place to place on the earth, consequently the weight of an object changes, which is why units of force are preferred to weights for strength measurements.

5.2.2 Breaking strength; tensile strength

This is the maximum tensile force recorded in extending a test piece to breaking point. It is the figure that is generally referred to as strength. The force at which a specimen breaks is directly proportional to its cross-sectional area, therefore when comparing the strengths of different fibres, yarns and fabrics allowances have to be made for this.

The tensile force recorded at the moment of rupture is sometimes referred to as the tensile strength at break [1]. This figure may be different from the tensile strength defined above as the elongation of the specimen may continue after the maximum tensile force has been developed as shown in Fig. 5.1 so that the tensile strength at break is lower than the tensile strength.

5.2.3 Stress

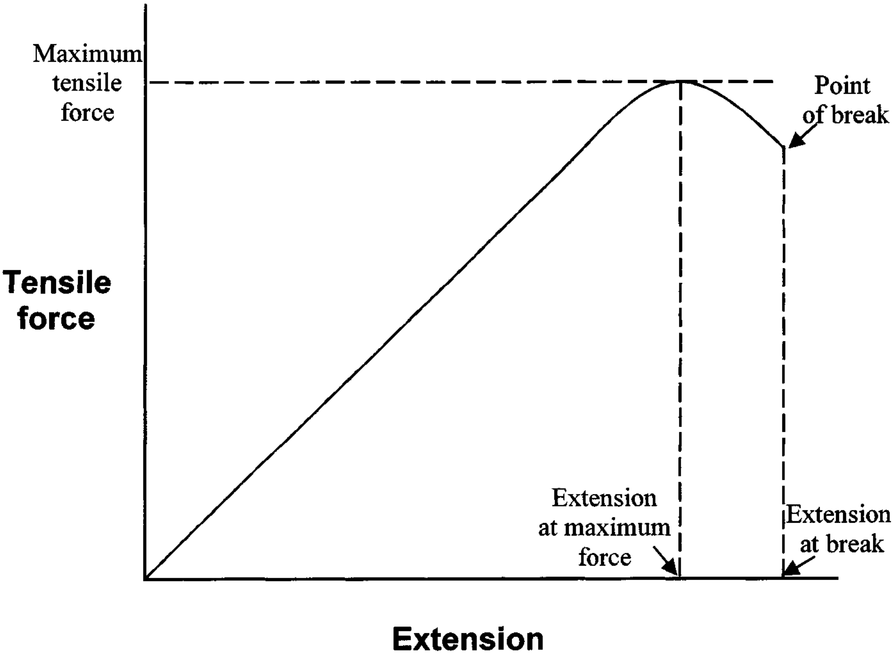
Stress is a way of expressing the force on a material in a way that allows for the effect of the cross-sectional area of the specimen on the force needed to break it:

$$\text{Stress} = \frac{\text{force applied}}{\text{cross-sectional area}}$$

In the case of textile materials the cross-sectional area can only be easily measured in the case of fibres with circular cross-sections. The cross-sections of yarns and fabrics contain an unknown amount of space as well as fibres so that in these cases the cross-sectional area is not clearly defined. Therefore stress is only used in a limited number of applications involving fibres.

5.2.4 Specific (mass) stress

Specific stress is a more useful measurement of stress in the case of yarns as their cross-sectional area is not known. The linear density of the yarn is



5.1 A force extension curve.

used instead of the cross-sectional area as a measure of yarn thickness. This allows the strengths of yarns of different linear densities to be compared. It is defined as the ratio of force to the linear density:

$$\text{Specific stress} = \frac{\text{force}}{\text{linear density}}$$

The preferred units are N/tex or mN/tex, other units which are found in the industry are: gf/denier and cN/dtex.

5.2.5 Tenacity

Tenacity is defined as the specific stress corresponding with the maximum force on a force/extension curve. The nominal denier or tex of the yarn or fibre is the figure used in the calculation; no allowance is made for any thinning of the specimen as it elongates.

5.2.6 Breaking length

Breaking length is an older measure of tenacity and is defined as the theoretical length of a specimen of yarn whose weight would exert a force sufficient to break the specimen. It is usually measured in kilometres.

5.2.7 Elongation

Elongation is the increase in length of the specimen from its starting length expressed in units of length. The distance that a material will extend under a given force is proportional to its original length, therefore elongation is usually quoted as strain or percentage extension. The elongation at the maximum force is the figure most often quoted.

5.2.8 Strain

The elongation that a specimen undergoes is proportional to its initial length. Strain expresses the elongation as a fraction of the original length:

$$\text{Strain} = \frac{\text{elongation}}{\text{initial length}}$$

5.2.9 Extension percentage

This measure is the strain expressed as a percentage rather than a fraction

$$\text{Extension} = \frac{\text{elongation}}{\text{initial length}} \times 100\%$$

Breaking extension is the extension percentage at the breaking point.

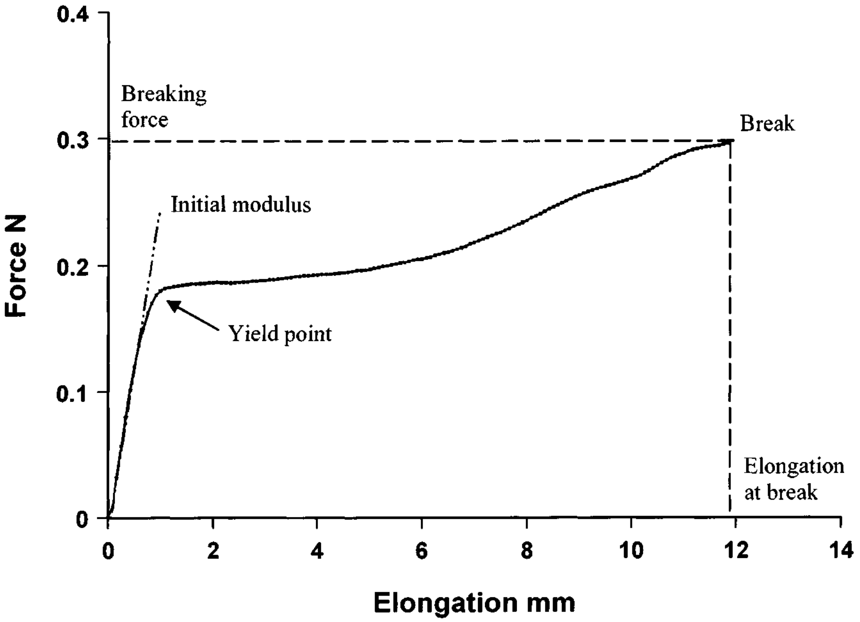
5.2.10 Gauge length

The gauge length is the original length of that portion of the specimen over which the strain or change of length is determined.

5.3 Force elongation curve

When an increasing force is gradually applied to a textile material so that it extends and eventually breaks, the plot of the applied force against the amount that the specimen extends is known as a force–elongation or stress–strain curve. The curve contains far more information than just the tensile strength of the material. The principal features of a force elongation curve, in this case of a wool fibre, are shown in Fig. 5.2. The use of the force elongation curve as a whole allows a better comparison of textile materials to be made as it contains more information about the behaviour of the material under stress than do the simple figures for tensile strength and elongation.

The most important features of the curve are as follows.

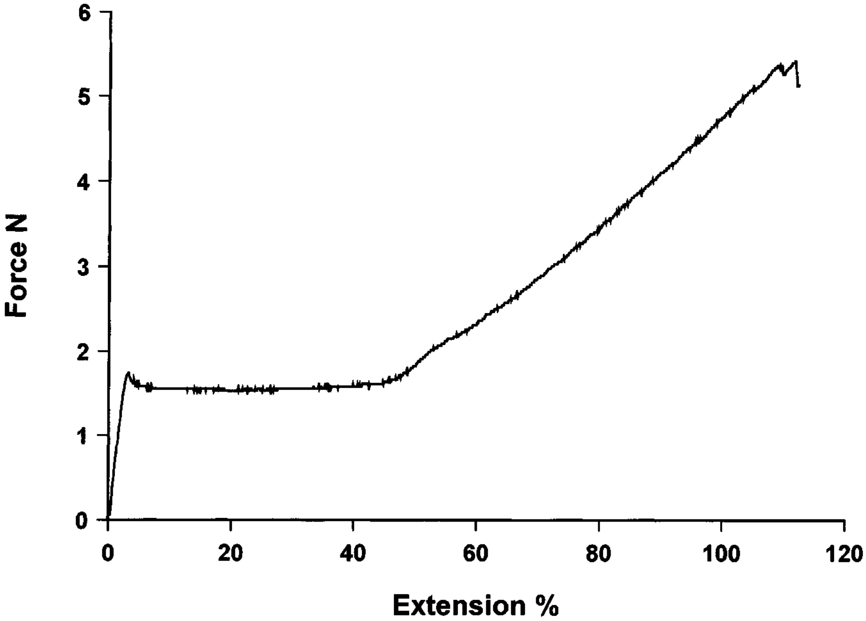


5.2 A typical force elongation curve.

5.3.1 Yield point

Depending on the material being tested, the curve often contains a point where a marked decrease in slope occurs. This point is known as the yield point. At this point important changes in the force elongation relationship occur. Before the yield point the extension of the material is considered to be elastic, that is the sample will revert to its original length when the force is removed. Above the yield point in most fibres, some of the extension is non-recoverable, that is the sample retains some of its extension when the force is removed. This is an over-simplification as in practice there is no clear demarcation between elastic and non-elastic behaviour of textile materials as not all the extension is recoverable even in the elastic region. The change in properties is seen at its most marked in undrawn or partially oriented material (Fig 5.3) because at this point the orientation of the polymer molecules is improved and the material is said to 'draw'. The material continues to extend without an increase in the applied force until it reaches a limit. When the material has finished drawing, the rest of the force extension curve represents the properties of the drawn material which has a higher tenacity owing to the improved orientation.

The yield point is not a definite point on the curve; more often there is a region of continuous change in the curvature between the two different



5.3 A force extension curve for partially oriented yarn.

parts of the curve. Therefore in order to measure the force or extension at which it occurs it is necessary to define it. There are four possible methods of defining the yield point.

Slope threshold

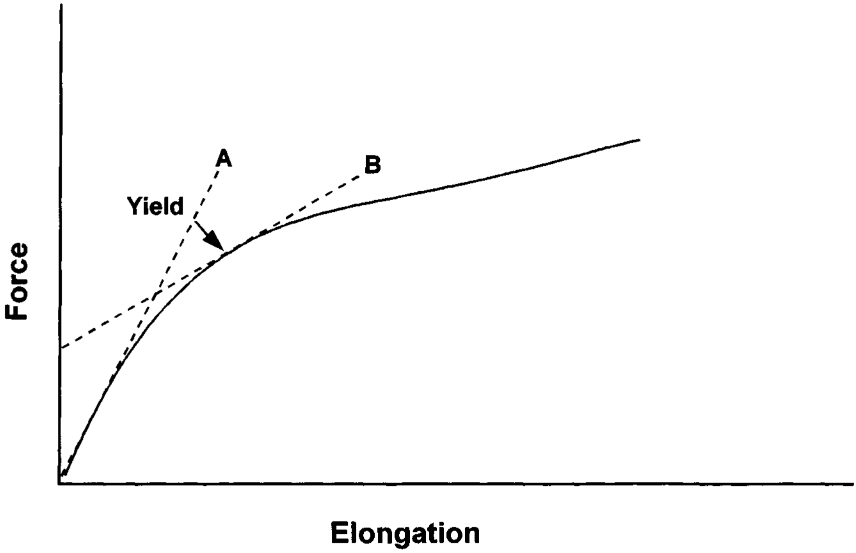
In this method the slope of the initial linear region is determined, shown as A in Fig. 5.4 and the point where the slope of the curve decreases to a specified fraction of the initial slope shown at B is taken as the yield point.

Offset yield

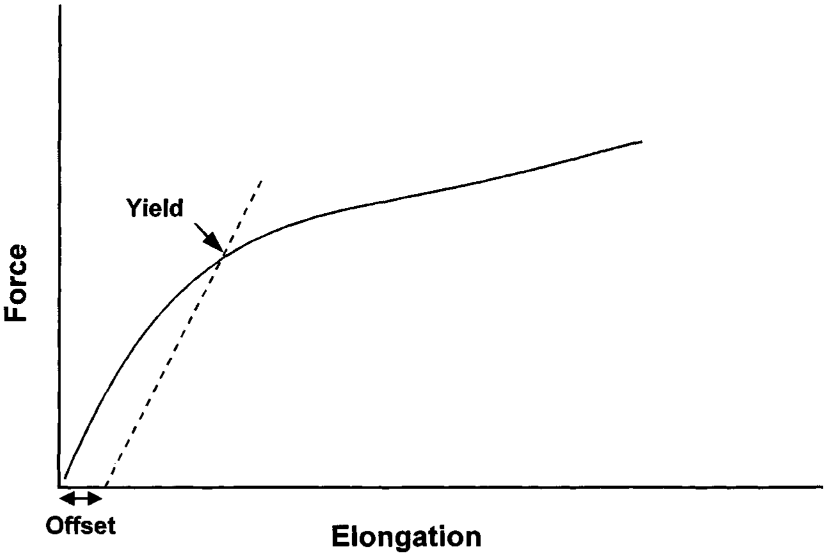
In this method the slope of the initial linear region is determined as before. The offset yield point is then defined as the point on the curve where a line parallel to the initial linear modulus region of the curve, but offset from it by a definite value of extension, intersects the test curve. This is shown in Fig. 5.5.

Zero slope method

In this method the point at which the slope of the test curve falls to zero is found. This method is only applicable to certain specimens such as that shown in Fig. 5.6 where the slope actually falls to zero.



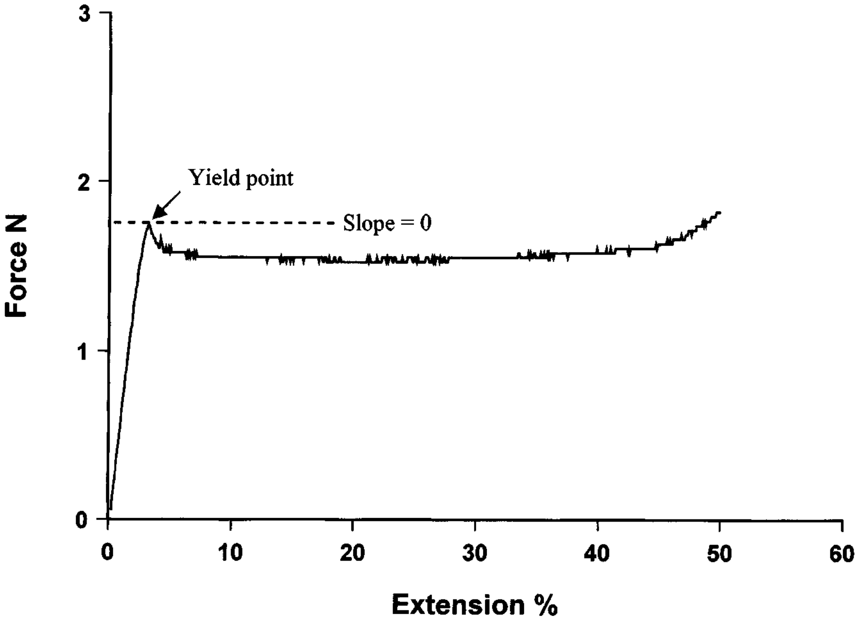
5.4 Yield point by the slope threshold method.



5.5 Yield point by the offset yield method.

Meredith's construction

In this method suggested by Meredith [2] the line joining the origin with the breaking point is first constructed. The yield point is then defined as the point on the curve at which the tangent is parallel to this line as shown in



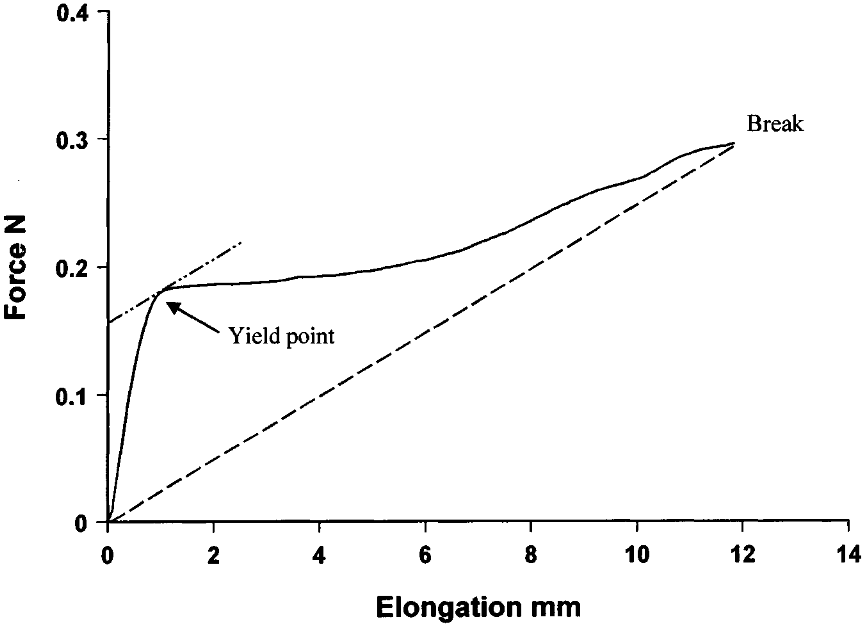
5.6 Yield point by the zero slope method.

Fig. 5.7. This is not an easy method to implement automatically with commercial software packages.

5.3.2 Modulus

The slope of the first linear part of the curve up to the yield point is known as the initial modulus (Young's modulus) and it is the value generally referred to when speaking of modulus without qualification. Modulus as a general term means the slope of the force elongation curve and it is a measure of the stiffness of the material, that is its resistance to extension. The higher the modulus of a material, the less it extends for a given force. If the curve is plotted in terms of stress against strain the units of modulus are the same as those of stress, that is force per unit area such as pascals. If the curve is plotted in terms of force against elongation the units of modulus are those of force/elongation and they depend on whether the elongation is measured in distance, percentage extension or strain.

The use of computer software to record and analyse force elongation curves means that the ways of specifying the modulus of a curve have to be clarified. It is no longer possible to lay a rule on the curve and judge the best position by eye. There are a number of possible moduli that may be measured.



5.7 Meredith's construction for yield point.

Young's modulus

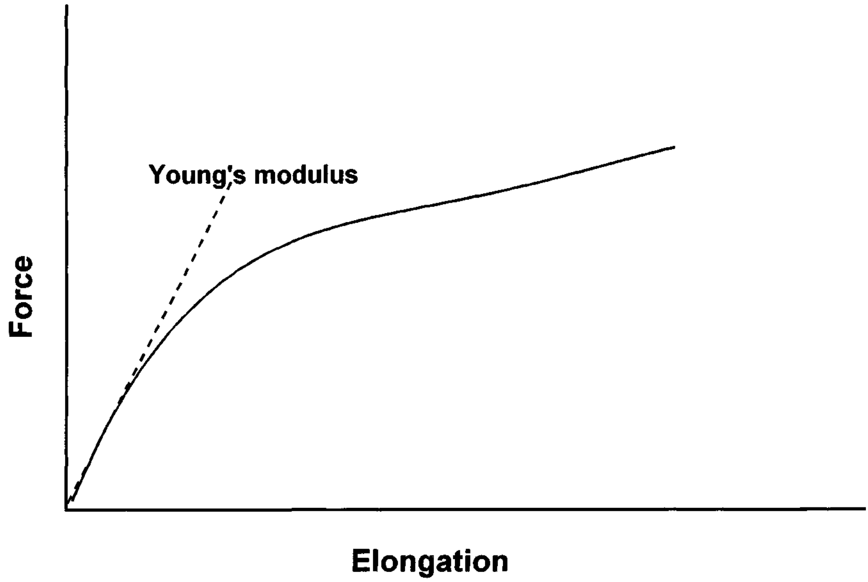
This value is obtained from the slope of the least squares fit straight line made through the steepest linear region of the curve as shown in Fig. 5.8.

Chord modulus

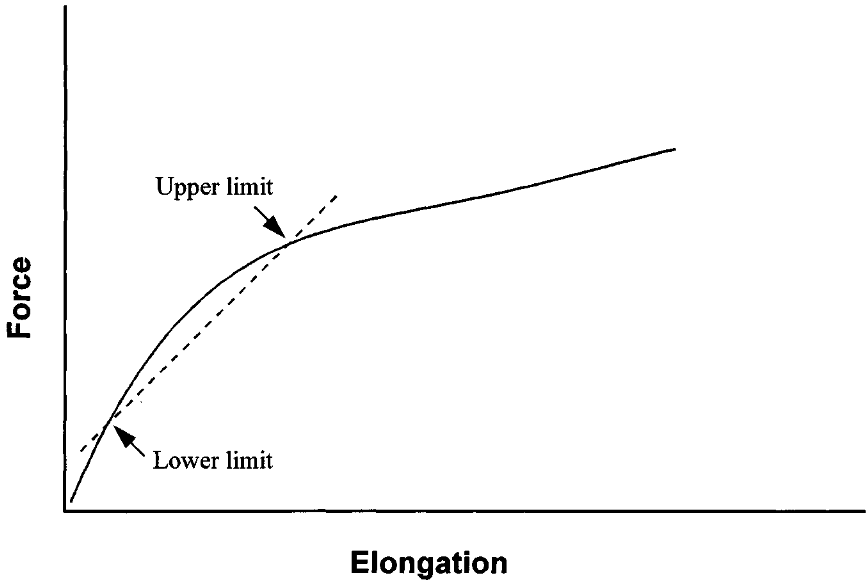
This value is the slope of the straight line drawn between two specified points on the curve as shown in Fig. 5.9. It is not necessary to know the details of the curve between the two points as the value can be derived from measurements of the difference in force between two given values of extension or the difference in extension between two given values of force.

Secant modulus

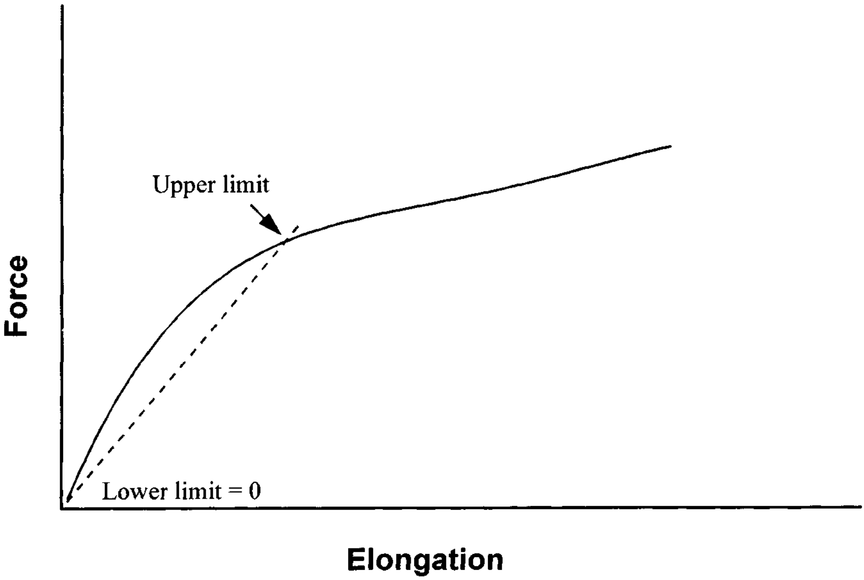
This value is the slope of the straight line drawn between zero and a specified point on the curve as shown in Fig. 5.10. It is often measured simply as the value of extension at a given force or alternatively as the value of force at a given extension. As a measurement it is sensitive to the amount of extension given to the sample as it is being loaded into the clamps.



5.8 Young's modulus.



5.9 Chord modulus.



5.10 Secant modulus.

Tangent modulus

This value is the slope of the straight line drawn at a tangent to the curve at a specified point as shown in Fig. 5.11. This is the mathematically correct value for the slope of a continuously changing curve. It is not easy to obtain by simple methods but can be readily measured by computer software.

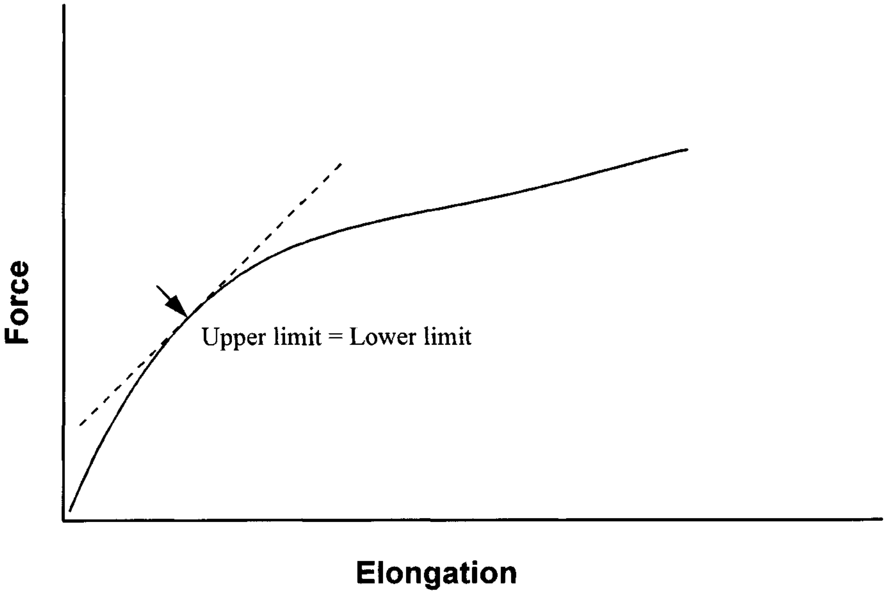
5.3.3 Work of rupture

The work of rupture is a measure of the toughness of a material as it is the total energy required to break the material. Consider a small section of the force extension curve as shown in Fig. 5.12. Within this small section the force can be considered to be constant at a value F. This force increases the sample in length by an amount dl, therefore

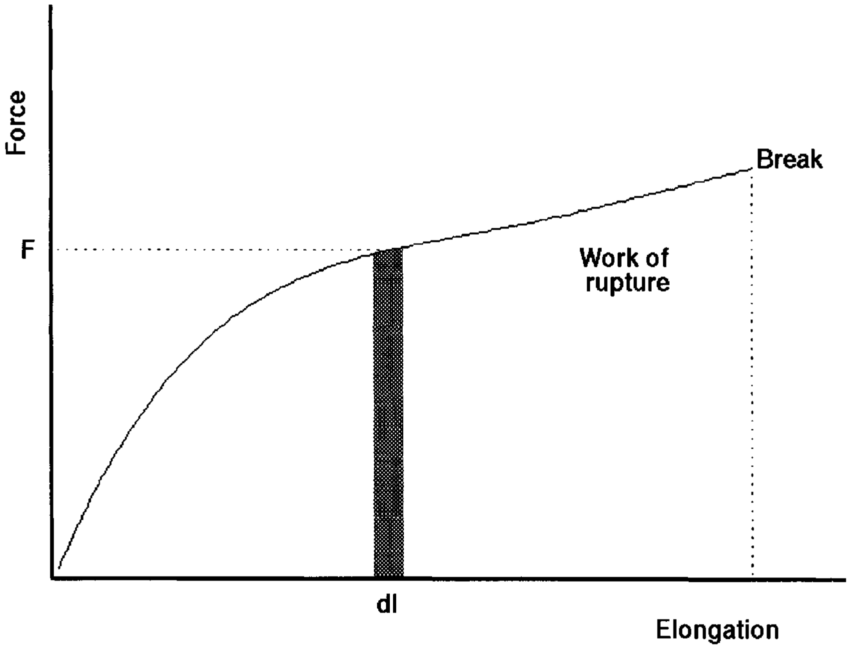
$$\text{Work done} = \text{force} \times \text{displacement} = F\,dl$$

From this the total work done in breaking the material which is the work of rupture is:

$$\text{Work of rupture} = \int_0^{\text{break}} F\,dl$$



5.11 Tangent modulus.



5.12 Work of rupture.

This integral is equivalent to the area under the force extension curve. The SI unit of work is the joule.

The work of rupture of a material is proportional to its cross-sectional area or, more conveniently for yarns and fibres, their linear density as the breaking load is proportional to this. The work of rupture is also proportional to the original length of the material as the elongation of the material is dependent on this. Therefore in order to compare materials it may be necessary to use the specific work of rupture:

$$\text{Specific work of rupture} = \frac{\text{work of rupture}}{(\text{mass/unit length}) \times \text{initial length}}$$

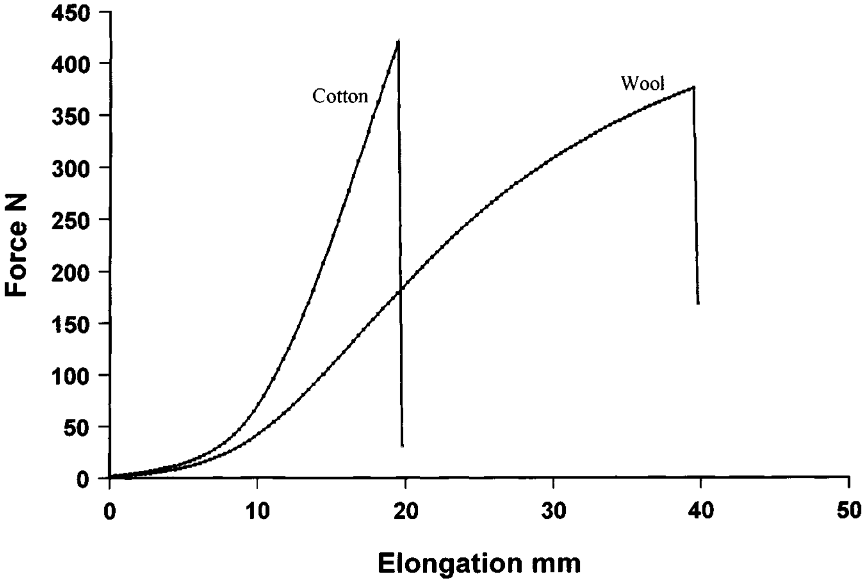
For comparative purposes when the tests use a common gauge length the initial length may be omitted from this formula.

The work of rupture gives a measure of the ability of the material to withstand sudden shocks of a given energy. If a mass m is attached to a thread and dropped from a height h it will acquire a kinetic energy equal to mgh. The thread is capable of withstanding the shock of the fall if its work of rupture is greater than mgh. If the work of rupture is less than this the thread will break. The capacity of a textile material to absorb energy is obviously useful in such applications as car seatbelts or climbing ropes where the ability to safely slow down a moving body is important. It also has importance in other areas which are not so obvious such as tearing resistance or abrasion resistance where high-energy absorption improves these properties. Figure 5.13 shows the force elongation curves of two fabrics of similar tensile strength. The cotton fabric has a slightly higher strength but a work of rupture of 2.36 J whereas the wool fabric has a work of rupture of 8.02 J.

5.3.4 Time dependence

Even in the initial straight line region of the force extension curve textile materials do not behave as strictly elastic materials. Their behaviour is fitted better by a viscoelastic model [3] as the relationship between applied stress and resultant strain contains a time-dependent element. This implies that when the material is extended by an applied force there is, besides the elastic component, a further component whose action opposes the applied force but whose magnitude depends on the speed of extension. This second component decays relatively slowly with time. When the applied force is subsequently removed, the same component also acts to resist the internal elastic forces that bring about contraction.

This time dependence is seen when a yarn or fabric is extended by a given amount and then held at that extended length. If the force required to do this is monitored, it is found to rise immediately to a maximum value and

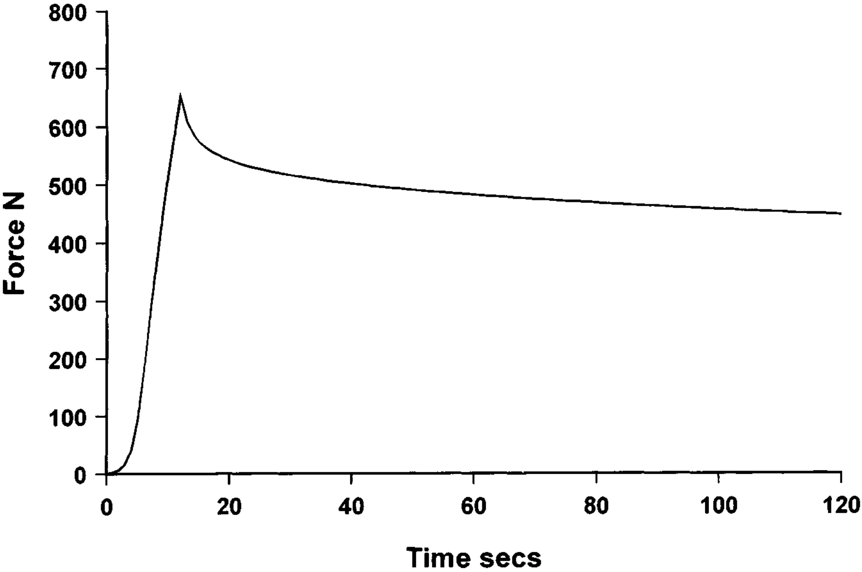


5.13 Two fabrics with different work of ruptures.

then slowly decrease with the passage of time as is shown in Fig. 5.14; this phenomenon is known as stress relaxation.

If instead of a fixed extension, a fixed force is applied to the material, there is found to be an initial extension of a magnitude that is expected from the force extension curve followed by a further slow extension with time. This behaviour is known as creep and its magnitude is an important property to consider when assessing materials that have to be kept under load for a long period of time, such as geotextiles. As the level of force, usually expressed as a percentage of the tensile strength, increases, the rate of creep increases. The rate of creep also increases with increasing temperature. Depending on the level of force and the type of fibre, creep can continue indefinitely until the material fails. The level of force should be set so that the time to failure is longer than the expected life of the product.

After a textile material has been subject to a force even for a short period of time the complete removal of the force allows the specimen to recover its original dimensions, rapidly at first and then more slowly with perhaps a small amount of residual extension remaining. This remaining extension is known as permanent set. As a simplified explanation the instantaneous extension can be considered to be composed of two quantities, the elastic extension, which is completely recoverable, and the plastic or permanent extension, which is not recoverable. According to this simplified



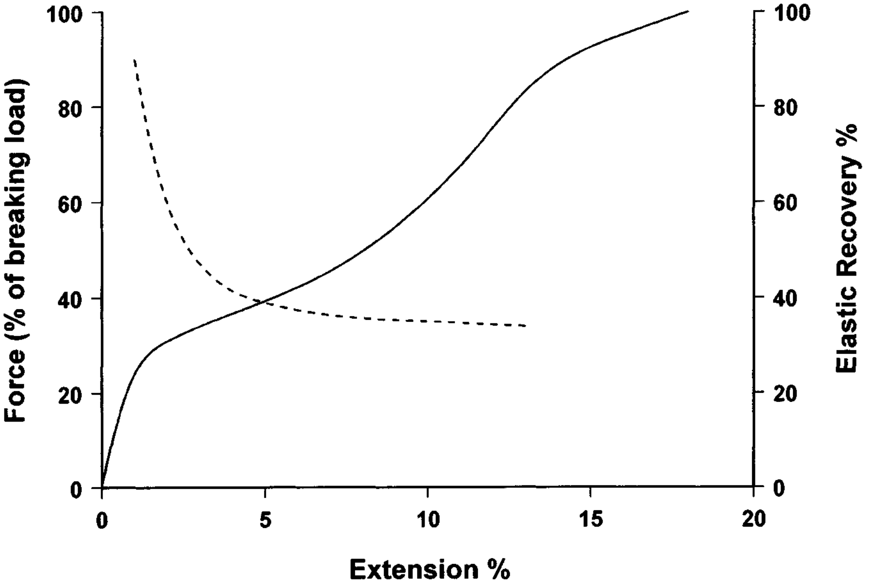
5.14 The decay of load with time.

theory when a material is subject to forces below its yield point then most of the extension is recoverable, whereas if the force is sufficient to take the material beyond its yield point a fraction of the extension will be permanent. This simplified theory does not account for the creep or stress relaxation behaviour which can only be understood if the viscoelastic properties of textile materials are taken into consideration.

A more complex behaviour due to viscoelastic properties can be found when a yarn is cycled between two different force levels [3]. If the yarn is allowed to relax from the higher of the two force levels, the force falls off with time as described above. If, however, the yarn is subjected to a number of cycles between the two forces and then allowed to relax from the lower force level the force increases and reaches a steady value with time, instead of decreasing.

5.3.5 Elastic recovery

When textile materials are stretched by forces that are below the level of their breaking strength and are then allowed to recover, they do not immediately return to their original length. How much of the original length they recover depends on the force used, the length of time the force is applied for and the length of time allowed for the recovery. Farrow [4] uses the following equation as a measure of how much a material recovers its original length after deformation:

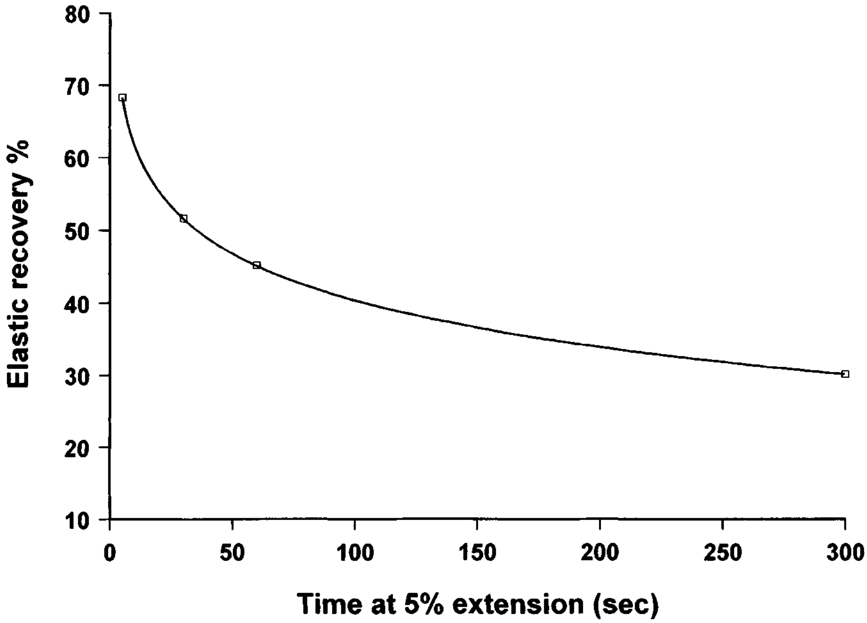


5.15 Dotted line shows the decrease in elastic recovery of acrylic yarn (RH scale) with increasing extension. Solid line shows the force extension curve for the yarn, LH scale. From data in [4].

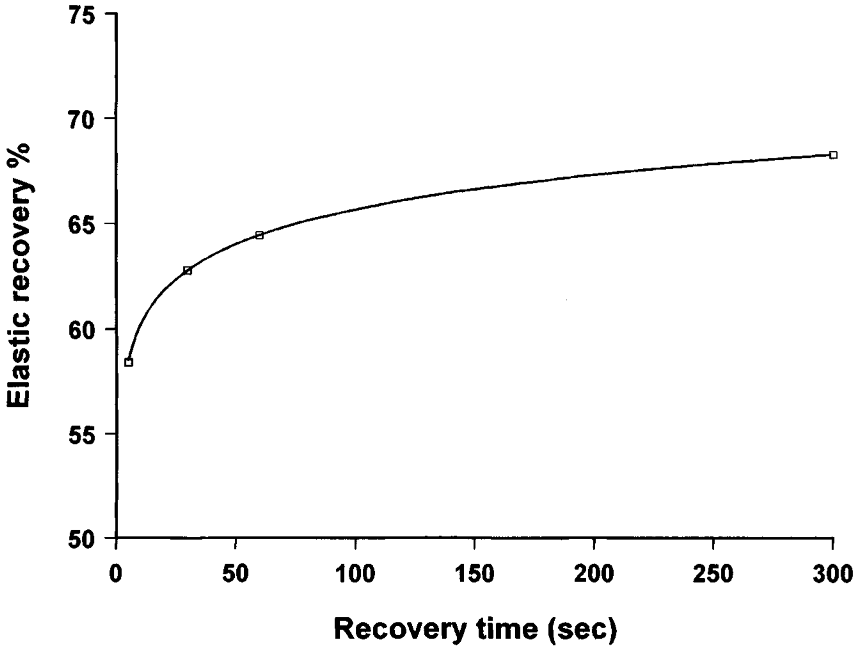
$$\text{Elastic recovery} = \frac{\text{recovered extension}}{\text{imposed extension}} \times 100\%$$

Perfectly elastic materials will have a value of 100%. It was found experimentally [4] that the percentage recovery decreased steadily with increasing extension of the material up to the yield point where the recovery decreased sharply. This is shown in Fig. 5.15 where a plot of elastic recovery against extension is superimposed on the force extension curve for acrylic fibre. The elastic recovery changes in nature in the region of the yield point.

The elastic recovery is also a time-dependent phenomenon, the recovery depending, among other factors, on the time the material is held at a given extension [5, 6]. The longer it is held at a given extension, the lower is the level of recovery. This effect is shown in Fig. 5.16 where the elastic recovery of a sample of cellulose acetate from a fixed extension of 5% is plotted against the time held at that extension. The recovery is comparatively large for very short periods of time under extension but decreases quite markedly when held at that extension for longer periods. If, on the other hand, the material is held at a given extension for a fixed length of time before removal of the force, the elastic recovery increases with time, rapidly at first and more slowly later [5, 6] as shown in Fig. 5.17.



5.16 Decrease in elastic recovery of cellulose acetate with increased time held at 5% extension. From data in [5].



5.17 Increase in elastic recovery of cellulose acetate with recovery time from 5% extension. From data in [5].

Table 5.1 Elastic recovery of carpet fibres from 59% extension (5 min extension, 5 min recovery time in each case)

Fibre type	Recovery (%)
Evlan	34
Fibro	40
Courtelle	54
Nylon	85
Polypropylene	85
Wool	72

Source: from [3].

The extent of recovery from extension is a property which is dependent on the type of material [6] as shown in Table 5.1. This difference helps to account for the variation in resilience properties which are displayed by these materials in diverse applications such as the resistance to flattening of carpet tufts, the recovery of fabrics from creasing and the resistance of fabrics to abrasion.

5.4 Factors affecting tensile testing

5.4.1 Type of testing machine

There are three different ways of carrying out tensile tests with regard to the way of extending the specimen, each of which is historically associated with a particular design of testing instrument:

1. Constant rate of extension (CRE) in which the rate of increase of specimen length is uniform with time and the load measuring mechanism moves a negligible distance with increasing load.
2. Constant rate of traverse (CRT) in which the pulling clamp moves at a uniform rate and the load is applied through the other clamp which moves appreciably to actuate a load measuring mechanism so that the rate of increase of load or elongation is usually not constant and is dependent on the extension characteristics of the specimen. This type of mechanism is usually associated with older types of machine where the load is applied by swinging a weighted pendulum through an arc. The angle that the pendulum has travelled through at the breaking point is then a measure of load. The mechanism is arranged to record the maximum height of the pendulum.

3 Constant rate of loading (CRL) in which the rate of increase of the load is uniform with time and the specimen is free to elongate, this elongation being dependent on the extension characteristics of the specimen at any applied load.

Most modern machines operate on the constant rate of extension principle where the moving jaw is driven by a screw thread moving at a constant rotational speed. The construction of the machine depends on its ultimate load capacity. Larger machines have the beam carrying the load cell supported by a separate screw at each end. Some of the smaller models, intended for low load applications, use only one screw, the upper specimen clamp being supported on the end of a cantilever. The most important consideration is that any flexure of the machine, at the maximum load, should be less than the expected accuracy of extension measurement. The extension, in the absence of an extensometer, is derived from measuring the load at fixed time intervals, thus relying on the accuracy of the crosshead speed for deriving the distance travelled. If accurate measurement of extension is required, an extensometer should be used. This piece of equipment monitors the distance apart of two points on the actual specimen, so avoiding any problems of jaw slip or different extension behaviour near the jaws. These accessories are more important for materials with low extensions and are not normally used for most textile applications where strength measurement is the main concern.

The speeds of crosshead movement found on these instruments range from 0.5 to 500 mm/min or up to 1000 mm/min in some cases. These are all relatively slow speeds compared with those encountered in shock loading applications. To achieve higher speeds a completely different form of drive is required such as is found in pendulum testers.

The load in these strength testers is measured via a load cell in which the deflection of a comparatively stiff beam is measured using either a strain gauge or a linear displacement transducer. This gives a system in which the change in position with increasing load is negligible. The accuracy of the load measurement depends on the capacity of the load cell. Most instruments are quoted as being accurate to within ±1% of the indicated load. This accuracy, however, does not extend to the lower end of the load cell range. The Instron 1011 model, for instance, specifies an accuracy of ±1% of the reading or ±0.2% of the load transducer range in use, whichever is the greater. Therefore with a 5000 N load cell with its lowest load range of 500 N this translates to an accuracy of not better than ±1 N. To obtain the greatest accuracy it is necessary to use load cells at the upper end of their capacity limit. This implies that if fibres, yarns and fabrics are all to be tested with the same machine, then three different load cells of appropriate ranges are needed.

5.4.2 Specimen length

The length of sample under test is known as the gauge length and in most textile tests it is equal to the distance between the inner edges of the clamps. This length has an important effect on the measured strength of the material because of the influence of weak spots on the point of failure.

A material when put under stress will always break at its weakest point. Therefore the longer the length of material that is stressed, the greater will be the probability of finding a weak spot within the test length. The value of strength measured will then be that of the weak spot and not an average value for the whole length.

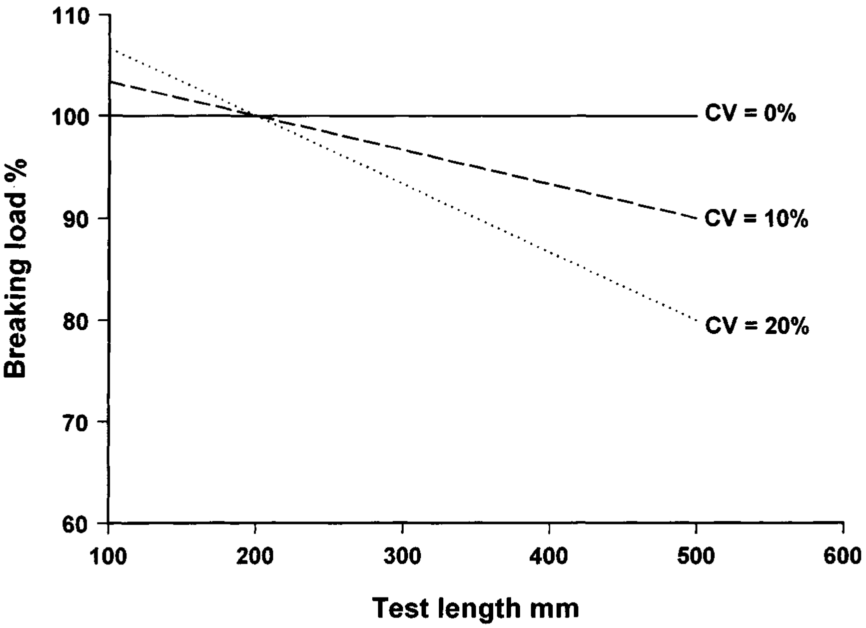
Consider a uniform material of strength 10N but with weak spots of strength 8N every 100mm along its length. If the portion tested in each test is only 10mm long then the probability of a weak spot in that length is 1 in 10. Ten tests will yield nine of 10N and one of 8N which gives an average value of 9.8N. If the test length is increased to 50mm then the probability of a weak spot in the test is increased to five out of ten so that ten tests will give five of 10N and five of 8N, thus giving an average strength of 9.0N. If the test length is 100mm and above then each test will contain a weak spot so that the average strength will be 8.0N.

This is a much simplified illustration: in practice the faults will be randomly distributed along the length of the material with a normal distribution of strengths around the mean value. Figure 5.18 [7] shows the effect of test length on yarn strength for yarns of different coefficients of variation of breaking load. The lines are based on a test length of 200mm as standard. The strength of a fault-free yarn would not change with test length as shown by the line labelled CV = 0%. As the yarn variability increases, the effect of test length on the measured strength also increases as shown by the lines for coefficients of variation of 10% and 20%.

5.4.3 Rate of loading and time to break

The measured breaking load and extension of textile materials is influenced by the rate of extension that is used in the test. The rates of extension that can be used are governed by the maximum speed attainable by the strength tester used. Most universal strength testers have a restricted range of speeds, whereas automatic yarn strength testers can operate at much higher speeds because of the number of tests that are carried out on yarns.

Most materials show an increase in breaking strength with increasing rate of extension together with a decrease in extension [7]. However, some materials [8–10] reach a maximum at speeds below the highest tested and then show a slight fall. The changes in strength at increasing rates of extension are due to the more or less viscoelastic nature of textile materials which



5.18 The effect of testing length on breaking force.

means that they require a certain time to respond to the applied stress. Different types of fibre respond differently and also different yarn and fabric constructions react differently. With filament yarns the stress is directly applied to the fibres so their response depends on the fibre type, whereas in the case of staple fibre yarns there has to be a realigning of the individual fibres in order to spread the load. Vangheluwe [9] shows that for cotton yarns the modulus increases with increasing strain rate although the tenacity and extension reach maxima at intermediate speeds.

5.4.4 Effect of humidity and temperature

Humidity of the testing atmosphere greatly affects the strength and extension of textile materials. This is to assume that the material is in equilibrium with the testing atmosphere as it is the water content of the fibres that matters. The effect varies with the regain of the fibre; hydrophobic materials are hardly affected whereas those with high regains change the most. Wool, silk and viscose lose strength and cotton, linen and bast fibres increase in strength. The difference in the load extension curve between wet and dry wool is shown in Fig. 2.1.

The temperature of the test does not have such a large effect within the range of normal room temperatures at which tests may be carried out. At very low temperatures some fibres may become brittle and at higher temperatures fibre strength may be degraded.

5.4.5 Previous history of the specimen

Changes that a material has undergone prior to it being tested may have a large effect on the measured values of strength and elongation. For example, a specimen may have been strained beyond its yield point in which case its measured strength and elongation will be different from the original material. Alternatively stretching an undrawn or partially oriented material will increase its draw ratio and so increase its strength. A material that has had some form of chemical treatment such as bleaching or that has been exposed to light may be degraded by such treatment and so have lower properties than the original material. Indeed, tensile tests may be used in fault finding to determine whether the material has been overstretched or been subject to chemical degradation.

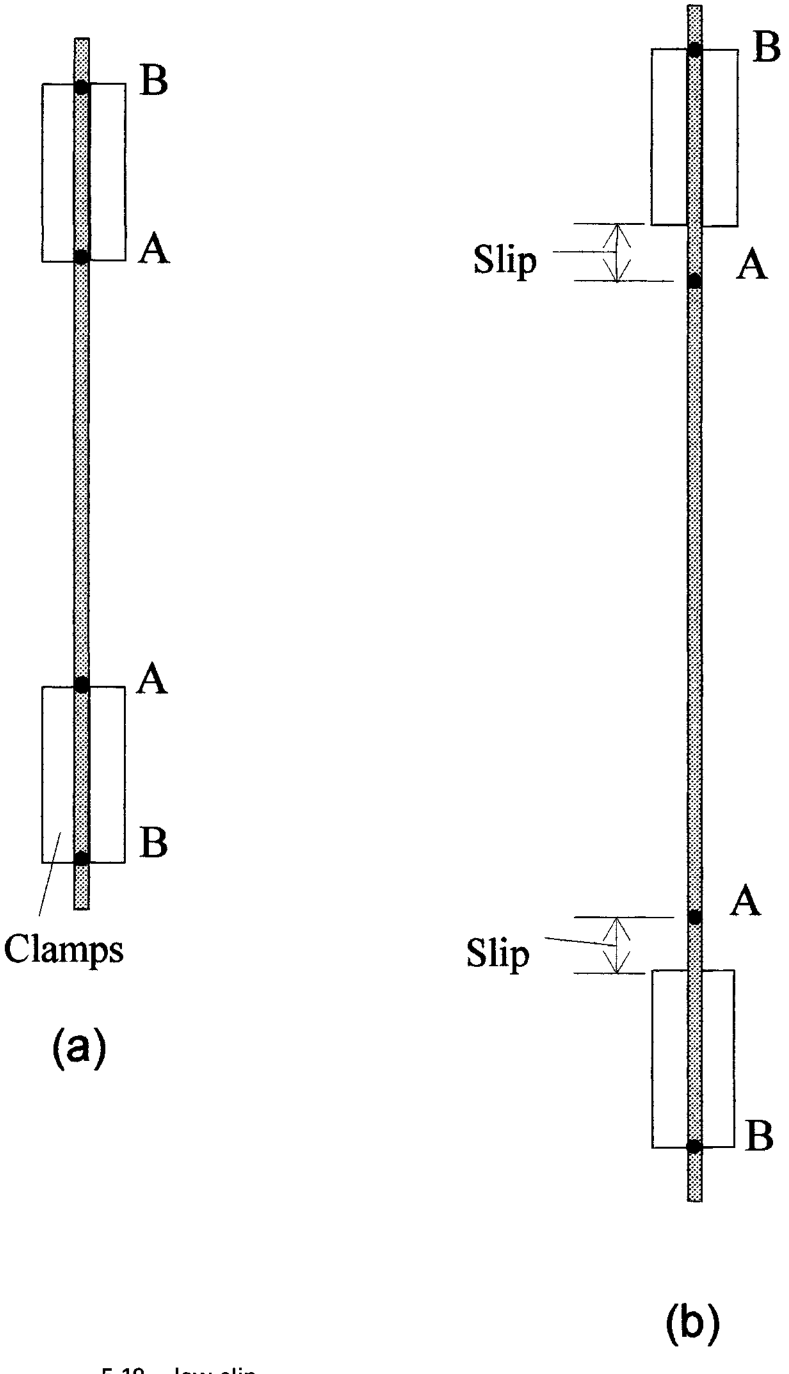
5.4.6 Clamping problems

During a tensile test textile materials are normally clamped between the faces of two jaws by lateral pressure. This clamping arrangement can give rise to two sorts of problem: slippage of the sample at the jaws or damage of the sample by the jaws, depending on whether the clamping pressure used is too low or too high.

Jaw slip

The total clamping force holding the sample in place is governed by the friction of the clamp faces, the clamping pressure and the length of the jaw in contact with the specimen. If the clamping pressure is low, part of the specimen within the jaws can extend as well as that part of the specimen outside the jaws that is being strained. In Fig. 5.19(a) point A, which was initially at the edge of the clamp before the test began, has moved out of the clamp by a small amount as shown in Fig. 5.19(b) just before failure. This means that the measured extension is higher than the real value. The problem has a greater effect at low clamping pressures and with low friction jaw faces. The amount of jaw slip can be estimated by measuring the elongation at various test lengths and extrapolating the resulting graph of elongation against test length to zero test length where there should be zero elongation. Any elongation above zero at this point is then due to slippage.

A related problem is that of the whole sample slipping through the jaws eventually pulling out in some cases. The problem may only be detected



5.19 Jaw slip.

by observing the specimen for movement during the test. If the movement is undetected the recorded extension will be higher than the actual value. Alternatively only part of the yarn or fabric may slip through the jaws due to the clamping of the outer edges of the sample not being as efficient as that of the main part. This problem lowers the recorded strength as not all the elements of the sample are contributing to the strength. Clamp jaws that are soft enough to mould to the specimen can help with this problem.

Jaw breaks

Jaw breaks are premature breaks due to damage to the test specimen by the clamps. They are identified as such because they occur close to the jaw edge and they have the effect of reducing the measured strength of the sample. The problem is particularly acute with hard jaw faces because the clamping forces needed are higher due to their low friction. Jaws with rubber faces which are soft and have a high coefficient of friction reduce the problem and are often used to grip fabrics. Capstan type grips are often used for yarns. With these the yarn is led round a smooth surface of large radius before the actual clamp so that part of the load is taken by the surface friction between the yarn and the capstan.

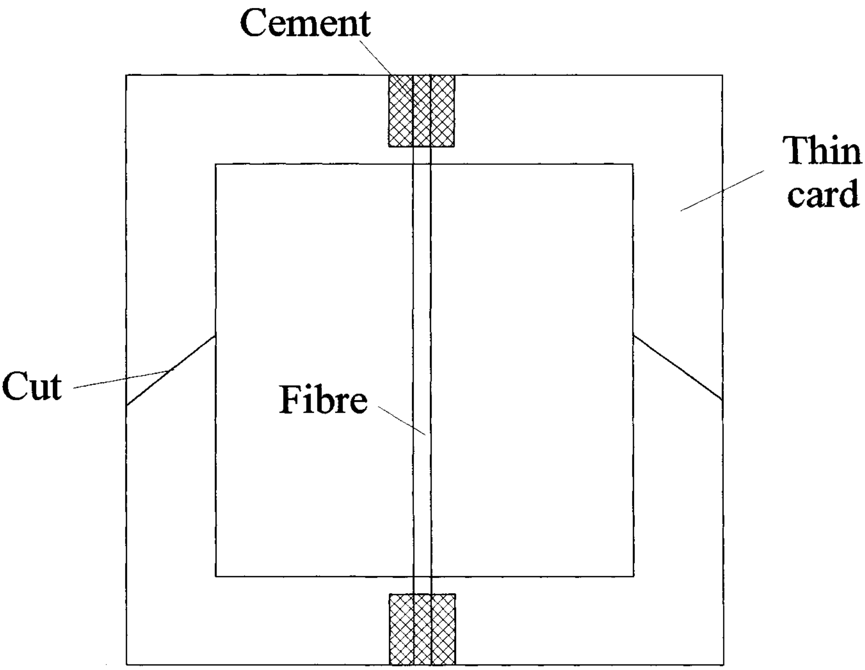
High-tenacity yarns and fabrics such as Kevlar and carbon fibre are particularly susceptible to these problems because the gripping forces need to be high. The fibre strength is also easily reduced by any damage due to gripping. In such cases special ones may have to be designed in order to spread the load.

5.5 Fibre strength

Carrying out strength tests on fibres is difficult and time consuming. This is because, particularly with natural fibres, the individual strengths of the fibres vary a great deal and therefore a large number have to be measured to give statistical reliability to the result. Furthermore individual fibres are difficult to handle and grip in the clamps of a strength testing machine, a problem that increases as the fibres become finer. For these reasons single fibre strength tests are more often carried out for research purposes and not as routine industrial quality control tasks. Tests on fibre bundles, which overcome the problems of fibre handling and number of tests needed for accuracy, are carried out as part of the normal range of tests on cotton fibres.

5.5.1 Single fibre strength

Tests on single fibres can be carried out on a universal tensile tester if a suitably sensitive load cell is available. Also required are lightweight clamps



5.20 A holder for single fibres.

that are delicate enough to hold fibres whose diameters may be as low as 10–20 μm. A problem encountered when testing high-strength fibres is that of gripping the fibres tightly enough so that they do not slip without causing jaw breaks due to fibre damage. If the fibres cannot be gripped directly in the testing machine jaws they are often cemented into individual cardboard frames which are themselves then gripped by the jaws. The cardboard frames, shown in Fig. 5.20, have an opening the size of the gauge length required. When they are loaded into the tensile tester the sides of the frame are cut away leaving the fibre between the jaws. The cement used is responsible for gripping the fibres, therefore the samples have to be left for a sufficient time in the frames for the cement to set.

In addition to the standard strength testing machines there are a number of instruments available solely for fibre strength testing. These include the WIRA single fibre strength tester, the Lenzing Vibrodyn and the Textechno Fafegraph HR. The advantage of these machines is the easier loading of the fibre specimen due to the special clamping arrangements in use.

The US standard for single fibre strength [11] specifies a gauge length of either $\frac{1}{2}$ in or 1 in (12.7 or 25.4 mm). Up to 40 fibres should be tested depending on the variability of the results. The elongation rate depends on the expected breaking elongation

under 8%	10% of initial specimen length/min
8–100%	60% of initial specimen length/min
over 100%	240% of initial specimen length/min

With fibres that have crimp a pretension of 0.3–1 gf/tex (2.9 to 9.81 mN/tex) can be used to remove the crimp.

The British standard [12] specifies gauge lengths of 10, 20 or 50 mm with a testing speed adjusted so that the sample breaks in either 20 or 30 s. The number of tests is 50 and the level of pretension is set at 0.5 gf/tex (4.9 mN/tex).

5.5.2 Bundle strength

Pressley fibre bundle tester

The Pressley tester is an instrument for measuring the strength of a bundle of cotton fibres. Before they are mounted in the instrument the cotton fibres are combed parallel using a hand comb into a flat bundle about 6 mm wide. The special leather-faced clamps are removed from the machine and placed in a mounting vice so that they lie adjacent to each other, thus giving zero specimen length. The bundle is placed across the two jaws and clamped in position by the top jaws. When the clamps are removed from the mounting device the fringe of fibres protruding from the outer edges of the clamps is trimmed off leaving a known length of fibre within the jaws.

When the jaws are loaded into the instrument the upper jaw of the pair is linked to the short arm of a pivoted beam. The longer arm of the beam is inclined at a small angle to the horizontal and has a weight on it which can roll down the slope. As the weight moves away from the pivot the force on the top jaw gradually increases until the bundle breaks. When this happens the moving weight is automatically halted so that the distance along the arm can be measured. As the distance from the pivot is proportional to the force on the fibre bundle, the arm can be directly calibrated in units of force (lbf). At the end of the test the two halves of the bundle are weighed, and as the total length of the bundle is fixed a figure of merit known as the Pressley Index can be calculated:

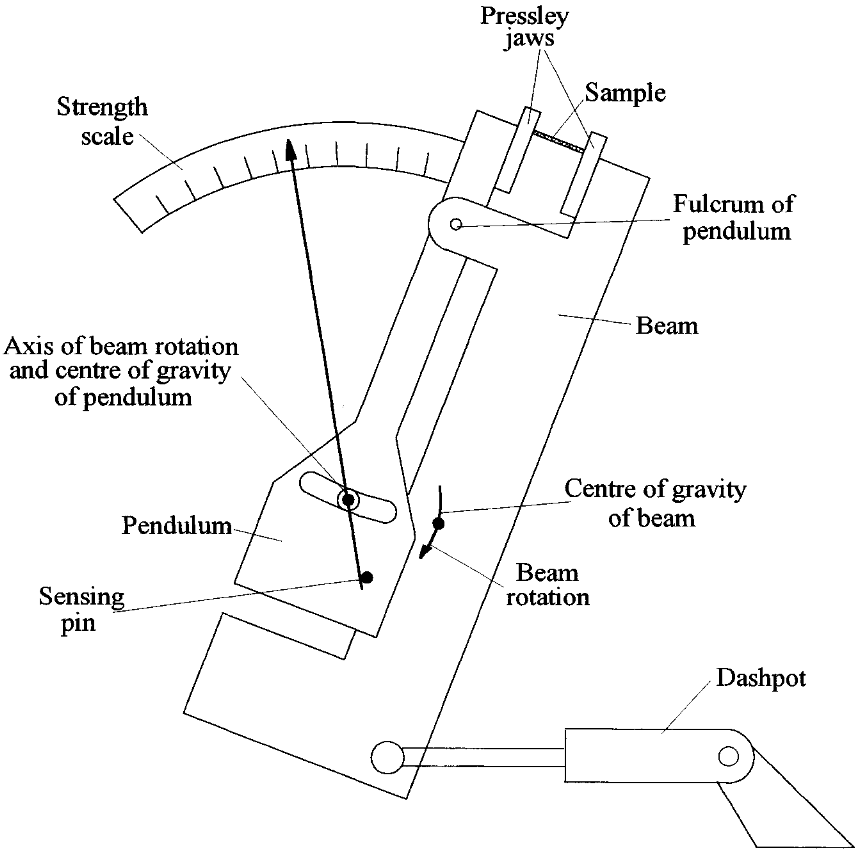
$$\mathrm{PI} = \frac{\text{force (lbf)}}{\text{mass (mg)}}$$

The result can be expressed as gram force per tex by multiplying the index by 5.36 or in mN per tex by multiplying by 52.58. Because the gauge length in this test is zero the extension of the fibres cannot be measured.

Stelometer

The Stelometer is a bundle testing instrument which is capable of measuring elongation as well as strength. The instrument uses the same type of jaws as the Pressley instrument but they have a separation of 3.2 mm ($\frac{1}{8}$ in) as distinct from the zero separation of the Pressley instrument.

The loading of the specimen is carried out by a pendulum system which is mounted in such a way that it rotates about its centre of gravity. This eliminates any inertial effects in loading of the sample which is generally a problem with systems that apply the force using a pendulum. The layout of the instrument is shown in Fig. 5.21: the pendulum is pivoted from the beam but the pivot of the beam is at the centre of gravity of the pendulum. The sample is held between the clamp attached to the beam and the one attached to the pendulum. The beam and the pendulum start in a vertical position but the centre of gravity of the beam is such that when it is released



5.21 The Stelometer.

at the start of the test the whole assembly rotates. As the beam rotates the pendulum moves from the vertical so that it then exerts a force on the sample. The speed of rotation of the beam is altered by dashpot so that the rate of loading is 1 kgf/s. A pointer is moved along a scale graduated in breaking force by the sensing pin on the pendulum. When the sample breaks the pendulum falls away leaving a maximum reading. A separate pointer, not shown in the diagram, indicates the sample extension.

After breaking the bundle all the fibres are weighed allowing the tenacity to be calculated:

$$\text{Tenacity in gf/tex} = \frac{\text{breaking force in kgf} \times 15}{\text{sample mass in mg}}$$

The effective total length of the sample is 15 mm (0.590 in) for a $\frac{1}{8}$in (3.2 mm) gauge length and 11.81 mm (0.465 in) for a zero gauge length so that 11.8 should be used in the above formula if a zero gauge length is used.

The tenacity measured at zero length is greater than that measured at $\frac{1}{8}$in length because of the general effect that shorter gauge lengths have on measured strength. The ratio between the two values will vary with the variability of the material being tested.

The bundle strength of cotton fibres is also measured as part of the high-volume instrument (HVI) set of tests marketed by Motion Control, Inc. and Special Instruments Laboratory, Inc. As part of these tests a fibre beard is formed whose mass is measured at a number of points along the fibre length to form a fibrogram. Based on the results from the fibrogram a point is selected at a certain distance from the clamp to perform a strength test using jaws with a $\frac{1}{8}$in (3.2 mm) separation. Taylor [13] has compared the results from these instruments with those from the standard tenacity tests.

5.6 Yarn strength

The strength and extension results from samples of yarn taken from different parts of a package can be very variable. Yarn made from staple fibres is worse in this respect than yarn made from continuous filaments owing to the fact that the number of fibres in the cross-section of a staple fibre yarn is variable. This means that in order to get a reasonable estimation of the mean strength of a yarn a large number of tests have to be carried out on it. Two types of yarn test are carried out:

1 Tests on single lengths of yarn, usually from adjacent parts of the yarn package. These are sometimes referred to as single thread tests.
2 Tests on hanks or skeins of yarn containing up to 120 metres of yarn at a time which is broken as one item.

5.6.1 Yarn strength: single strand method

Most yarn test standards are very similar. The British Standard [14] lays down that the number of tests should be:

1 Single yarns
   (a) continuous-filament yarns: 20 tests,
   (b) spun yarns: 50 tests.
2 Plied and cabled yarns: 20 tests.

The yarns should be conditioned before testing in the standard atmosphere. The testing machine is set to give a test length of 500mm and the speed is adjusted so that yarn break is reached in 20 ± 3s. Before each test a pre-tension of 0.5cN/tex is applied to the yarn in order to give a reproducible extension value. The mean breaking force, mean extension at break as a percentage of the initial length, CV of breaking force and CV of breaking extension are recorded. The US standard [15] specifies a gauge length of 10 ± 0.1in (250 ± 3mm) or alternatively by agreement 20 ± 0.2in (500 ± 5mm) and uses a time to break of 20 ± 3s.

Because of the large number of results needed for yarn testing, automatic strength testers are available which will carry out any number of tests on a number of different packages without any operator attention. Uster which produces the Tensorapid automatic strength tester, has compiled a booklet of statistics [37] of yarn strengths of various compositions, spinning routes and linear densities. The intention is that individual test results can be compared with the appropriate statistics to see whether the strength falls into the expected range of values. In these statistics breaking strengths are also given for a high rate of extension, that is 5000mm/min.

In many uses it is not the mean strength of the yarn that is important but the frequency of any weak places. These lead to the yarn breaking during weaving for example and so give rise to machine stoppages or faults in the fabric that must be avoided for profitable production. Weak places may be hundreds of metres apart but still cause problems in high-speed production. Therefore it is the variability of the yarn tensile properties as measured by the coefficient of variation of the strength and extension that is of greater importance than the mean values in such cases. The aim of yarn quality control is, by the use of statistics, to predict the infrequent occurrence of weak spots. The trend is to test a greater total length of yarn using higher speeds because otherwise the tests would take too long if the standard test time of 20s was used. More tests will enable better prediction of the statistically few weak spots as 50 tests may only test the first 50m of a yarn package. However, a balance has to be struck between making too few tests and wasting a large percentage of the yarn package.

5.6.2 Yarn strength: skein method

In this method a long length of yarn is wound into a hank or skein using a wrap reel as would be used for linear density measurement, the two loose ends being tied together. The whole hank is then mounted in a strength testing machine between two smooth capstans, which may be free to rotate. The hank is subjected to increasing extension while the force is monitored. When one part of the yarn breaks, the hank begins to unravel. If the yarn was looped over frictionless pulleys, once one end broke the yarn would then unwrap completely and the strength per strand that was measured would be that of the weakest spot. Because of the friction present in the system the force continues to increase until sufficient strands have broken for the hank to unravel, the force passing through a maximum value at some point. This maximum force is known as the hank strength. Because the friction of the yarn against the pulleys plays a large part in the result, the measured hank strength can vary according to yarn friction and the particular machine that it is measured on.

Measuring the strength of a hank or skein of yarn is a method that was used in the early days of textile testing but that is now being replaced by the single strand method, especially since the development of automatic strength testing machines. The main advantage of the hank method is that it tests a long length of yarn in one test. The yarn is expected to break at the weak spots so giving a more realistic strength value and also the same hank can be used for measuring the yarn count. The disadvantage of the test is that it is dependent on the friction between the yarn and the capstans which determines how well the load is spread between the multiple strands of the hank. This means that the results are specific to a particular machine and yarn combination. The test is considered satisfactory for acceptance testing of commercial shipments but not for measurements which have to be reproducible between laboratories. There is a correlation between the tenacity of yarn measured by the skein method and that measured by the single strand method. The value for the skein is always lower than that for the single strand [10]. Other drawbacks to the method are that there is no measure of strength variability and no measure of yarn extension as the distance moved by the capstans is determined by yarn extension and hank unravelling.

The British Standard [16] specifies a hank of 100 wraps of 1 m diameter. This is tested at such a speed that it breaks within 20 ± 3 s, or alternatively a constant speed of 300 mm/min is allowed. If the yarn is spun on the cotton or worsted systems 10 skeins should be tested and 20 skeins if the yarn is spun on the woollen system. The method is not used for continuous filament yarns.

The US standard [17] has three options for hank size:

1 Eighty, 40 or 20 turns on a 1.5 m (1.5 yd) reel tested at a speed of 300 mm/min. Twenty or 40 turns are to be used when the machine capacity is not great enough to break a hank of 80 turns.
2 Fifty turns on a 1.0 m (1 yd) reel broken at a speed of 300 mm/min.
3 Fifty turns on a 1.0 m (1 yd) reel broken in a time of 20 s.

The number of samples tested is the same as that for the British Standard.

The breaking force per strand increases slightly as the perimeter of the skein is reduced as would be expected from a change in gauge length. The breaking strength of a 1 yd skein is 5% higher than that for a 1.5 yd skein.

Count strength product

The count strength product (CSP or LCSP) is a measure used for cotton yarns and is the product of the yarn count and the lea (hank) strength. It is based on measuring the strength of an 80 turn hank made on a 1.5 yd wrap reel to give a total length of 120 yd. The strength is usually measured in pounds force (lbf). The value enables a comparison to be made among yarns of a similar but not necessarily identical count in the same way that tenacity values are used.

Assuming that all 160 strands of the hank have the same strength as the single yarn, the tenacity can be related to the count strength product by the following formula:

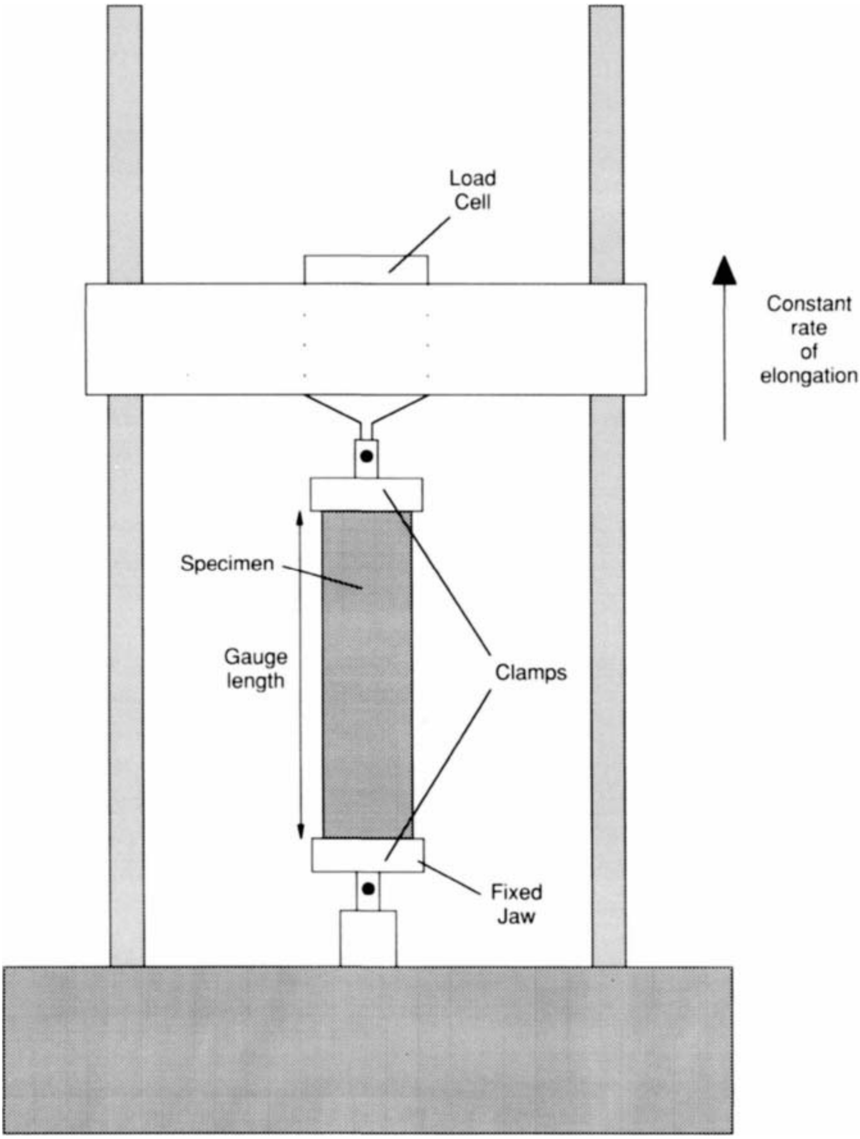
$$\text{Tenacity (N/tex)} = 0.000{,}047 \times \text{CSP (lbf} \times \text{CC)}$$

where CC = cotton count value

5.7 Fabric strength

5.7.1 Strip strength

The British Standard [18] for fabric tensile strength involves extending a strip of fabric to its breaking point by a suitable mechanical means (Fig. 5.22) which can record the breaking load and extension. Five fabric samples are extended in a direction parallel to the warp and five parallel to the weft, no two samples to contain the same longitudinal threads. The specimens are cut to a size of 60 mm × 300 mm and then frayed down in the width equally at both sides to give samples which are exactly 50 mm wide. This ensures that all the threads run the full length of the sample so contributing to the strength and also that the width is accurate. The rate of extension is set to 50 mm/min and the distance between the jaws (gauge length) is set to 200 mm. The sample is pretensioned to 1% of the probable breaking load. Any breaks that occur within 5 mm of the jaws should be rejected and also those at loads substantially less than the average.



5.22 The apparatus for a fabric tensile test.

The mean breaking force and mean extension as a percentage of initial length are reported.

5.7.2 Grab test

The US Standard [19] contains three ways of preparing the fabric specimen for tensile testing. They are: (1) ravelled strip in 1 in (25 mm) and 2 in

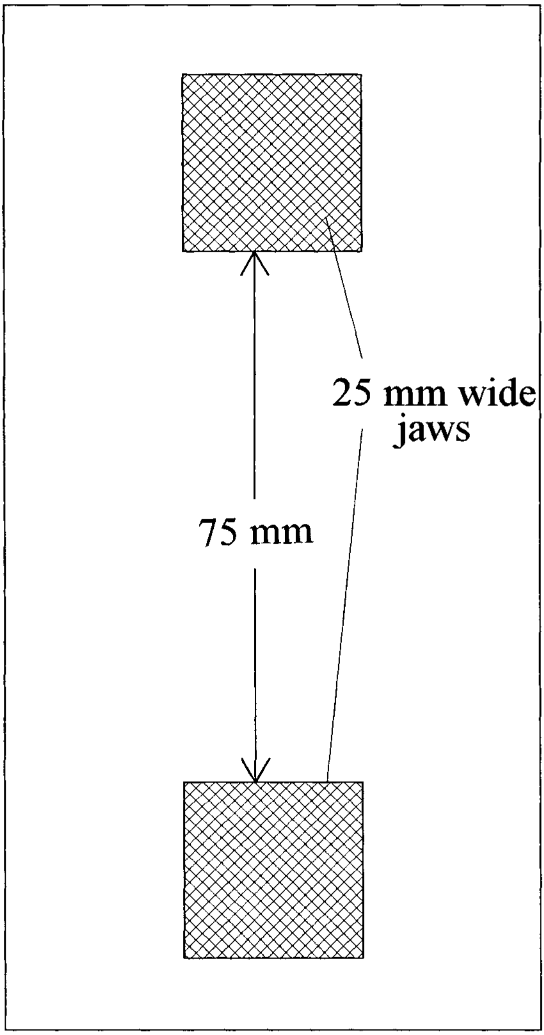
(50 mm) widths where the method of preparation is the same as in the above standard; (2) cut strip in 1 in (25 mm) and 2 in (50 mm) widths which is intended to be used with fabrics such as heavily milled ones which cannot easily be frayed and (3) the grab method which is fundamentally different from the above two methods. The grab test uses jaw faces which are considerably narrower than the fabric, so avoiding the need to fray the fabric to width and hence making it a simpler and quicker test to carry out. The sample used is 4 in (100 mm) wide by 6 in (150 mm) long but the jaws which are used have one of their faces only 1 in (25 mm) wide. This means that only the central 25 mm of the fabric is stressed. A line is drawn on the fabric sample 1.5 in (37 mm) from the edge to assist in clamping it so that the same set of threads are clamped in both jaws. The gauge length used is 3 in (75 mm) and the speed is adjusted so that the sample is broken in 20 ± 3 s. The mounting of the sample in the jaws is shown in Fig. 5.23. In this test there is a certain amount of assistance from yarns adjacent to the central stressed area so that the strength measured is higher than for a 25 mm ravelled strip test.

5.8 Tear tests

A fabric tears when it is snagged by a sharp object and the immediate small puncture is converted into a long rip by what may be a very small extra effort. It is probably the most common type of strength failure of fabrics in use. It is particularly important in industrial fabrics that are exposed to rough handling in use such as tents and sacks and also those where propagation of a tear would be catastrophic such as parachutes. Outdoor clothing, overalls and uniforms are types of clothing where tearing strength is of importance.

5.8.1 Measuring tearing strength

The fabric property usually measured is the force required to propagate an existing tear and not the force required to initiate a tear as this usually requires a cutting of threads. As part of the preparation of the fabric specimens a cut is made in them and then the force required to extend the cut is measured. This is conveniently carried out by gripping the two halves of the cut in a standard tensile tester. The various tear tests carried out in this manner differ mainly in the geometry of the specimen. The simplest is the rip test where a cut is made down the centre of a strip of fabric and the two tails pulled apart by a tensile tester. The test is sometimes referred to as the single rip test, the trouser tear or in the US as the tongue tear test Fig. 5.24(a). What is understood in the UK as the tongue tear test has the specimen cut into three tails Fig. 5.24(b) and (c), the central one is gripped in

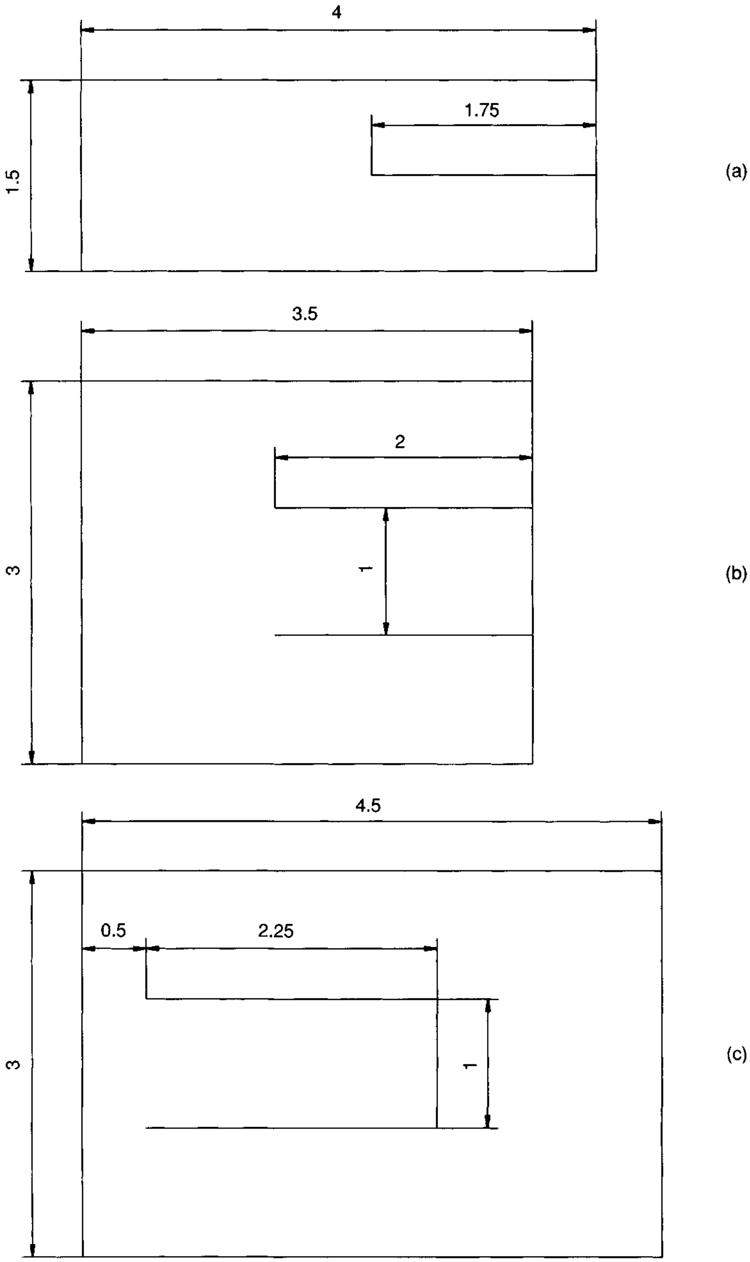


5.23 Grab test sample.

one jaw of the tensile tester and the outer two in the other jaw. This test is also known as the double rip as two tears are made simultaneously.

5.8.2 Single rip tear test

In the US Standard [20] 10 specimens are tested from both fabric directions each measuring 75 mm × 200 mm (3 × 8 in) with an 80 mm (3.5 in) slit part way down the centre of each strip as shown in Fig. 5.24(a). One of the 'tails' is clamped in the lower jaw of a tensile tester and the other side is clamped



5.24 Tear test samples. All dimensions are in inches.

in the upper jaw, the separation of the jaws causes the tear to proceed through the uncut part of the fabric. The extension speed is set to 50mm/min (2in/min) or an optional speed of 300mm/min can be used.

There are three ways of expressing the result:

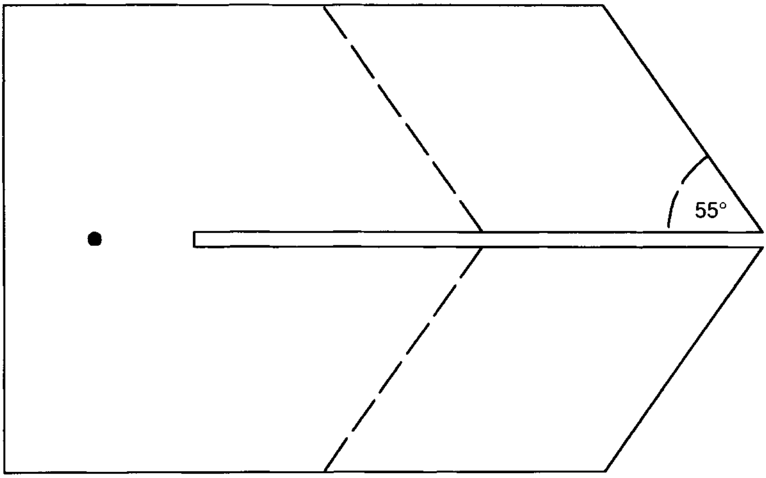
1 The average of the five highest peaks.
2 The median peak height.
3 The average force by use of an integrator.

Depending on the direction the fabric is torn in the test is for the tearing strength of filling yarns or of warp yarns.

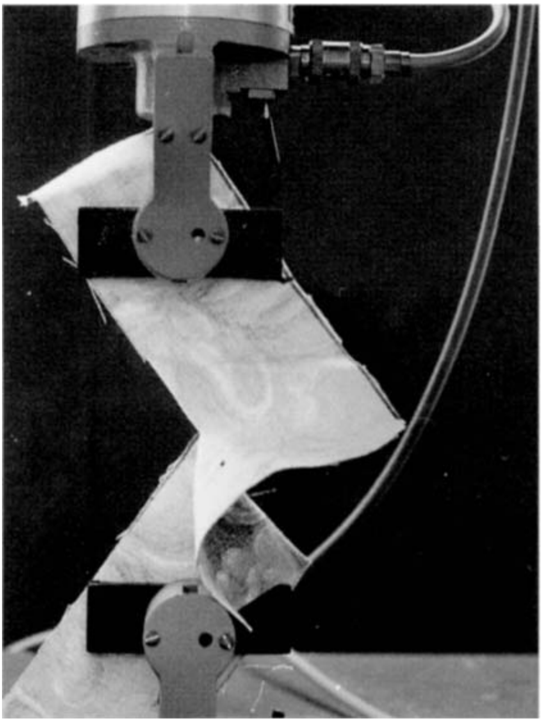
If the direction to be torn is much stronger than the other direction, failure will occur by tearing across the tail so that it is not always possible to obtain both warp and weft results.

5.8.3 Wing rip tear test

The wing rip test overcomes some of the problems which are found with the single rip test as it is capable of testing most types of fabric without causing a transfer of tear [21]. During the test the point of tearing remains substantially in line with the centre of the grips. The design of the sample is also less susceptible to the withdrawal of threads from the specimen during tearing than is the case with the ordinary rip test. The British standard [22] uses a sample shaped as in Fig. 5.25 which is clamped in the tensile tester in the way shown in Fig. 5.26. The centre line of the specimen has a cut 150mm long and a mark is made 25mm from the end of the specimen to show the end of the tear.



5.25 Wing rip sample layout.

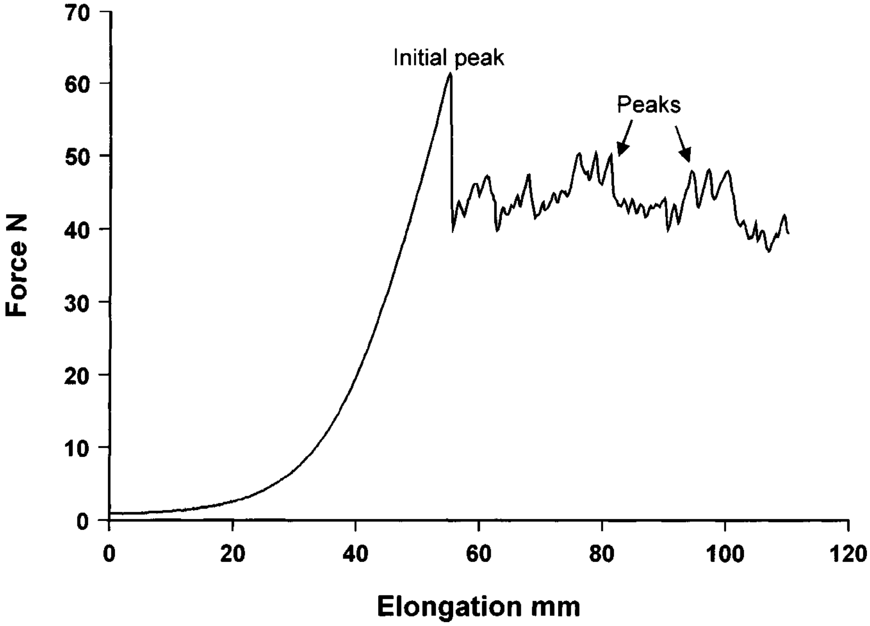


5.26 Sample for tearing strength in tensile tester.

The test is preferred to the tongue tear test though it is not suitable for loosely constructed fabrics which would fail by slippage of the yarns rather than by the rupture of threads.

Five specimens across the weft and five specimens across the warp are tested. The test is carried out using a constant rate of extension testing machine with the speed set at 100 mm/min. The tearing resistance is specified as either across warp or across weft according to which set of yarns are broken.

The results can be expressed as either the maximum tearing resistance or the median tearing resistance. The median value is determined from a force elongation curve such as that shown in Fig. 5.27 and it is the value such that exactly half of the peaks have higher values and half of them have lower values than it. The median tearing resistance value is close to the mean value but it is an easier value to measure by hand methods as it can be determined by sliding a transparent rule down the chart until half the peaks are above the edge of the rule and half below it, at which point the load can be read from the chart.



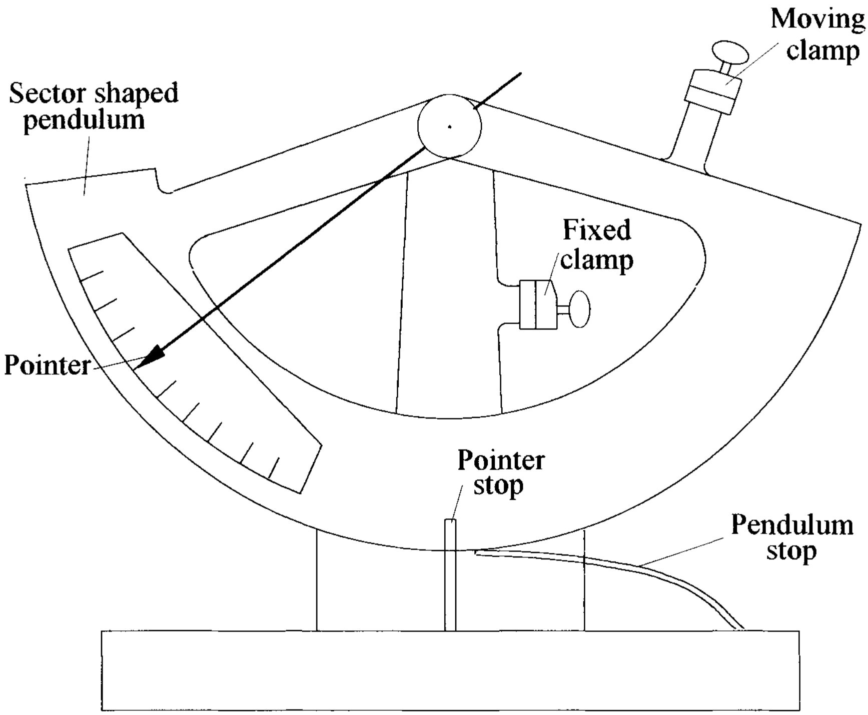
5.27 Tear test force extension curve.

5.8.4 Elmendorf tear tester

The Elmendorf tear tester [23] is a pendulum type ballistic tester which measures energy loss during tearing. The tearing force is related to the energy loss by the following equation:

Energy loss = tearing force × distance
Loss in potential energy = work done

The apparatus which is shown in Fig. 5.28 consists of a sector-shaped pendulum carrying a clamp which is in alignment with a fixed clamp when the pendulum is in the raised starting position, where it has maximum potential energy. The specimen is fastened between the two clamps and the tear is started by a slit cut in the specimen between the clamps. The pendulum is then released and the specimen is torn as the moving jaw moves away from the fixed one. The pendulum possesses potential energy because of its starting height. Some of the energy is lost in tearing through the fabric so that as the pendulum swings through its lowest position it is not able to swing to the same height as it started from. The difference between starting height and finishing height is proportional to the energy lost in tearing the fabric. The scale attached to the pendulum can be graduated to read the tearing force directly or it may give percentage of the original potential energy.



5.28 The Elmendorf tear test.

The apparatus tears right through the specimen. The work done and hence the reading obtained is directly proportional to the length of material torn. Therefore the accuracy of the instrument depends on very careful cutting of the specimen which is normally done with a die. The range of the instrument is from 320 gf to 3840 gf in three separate ranges obtained by using supplementary weights to increase the mass of the pendulum.

When a fabric is being torn all the force is concentrated on a few threads at the point of propagation of the tear. This is why the forces involved in tearing are so much lower than those needed to cause tensile failure. Depending on the fabric construction, threads can group together by lateral movement during tearing, so improving the tearing resistance as more than one thread has to be broken at a time. The peaks that are seen on the load extension curve (Fig. 5.27) are more often from the breaking of a group of threads than from the individual ones. The bunching of threads is also helped by the ease with which yarns can pull out lengthwise from the fabric. The ability to group is a function of the looseness of the yarns in the fabric. Weave has an important effect on this: a twill or a 2/2 matt weave allows the threads to group better thus giving better tearing resistance than a plain weave. High sett fabrics inhibit thread movement and so reduce the assistance effect. Resin treatments such as crease resistance finishes which cause the yarns to adhere to one another also have the same effect. The tensile properties of the constituent fibres have an influence on tearing resistance as those with a high extension allow the load to be shared whereas fibres with low extension such as cotton tear easily. Scelzo *et al.* [24] give a comprehensive account of the factors affecting tear resistance.

5.9 Bursting strength

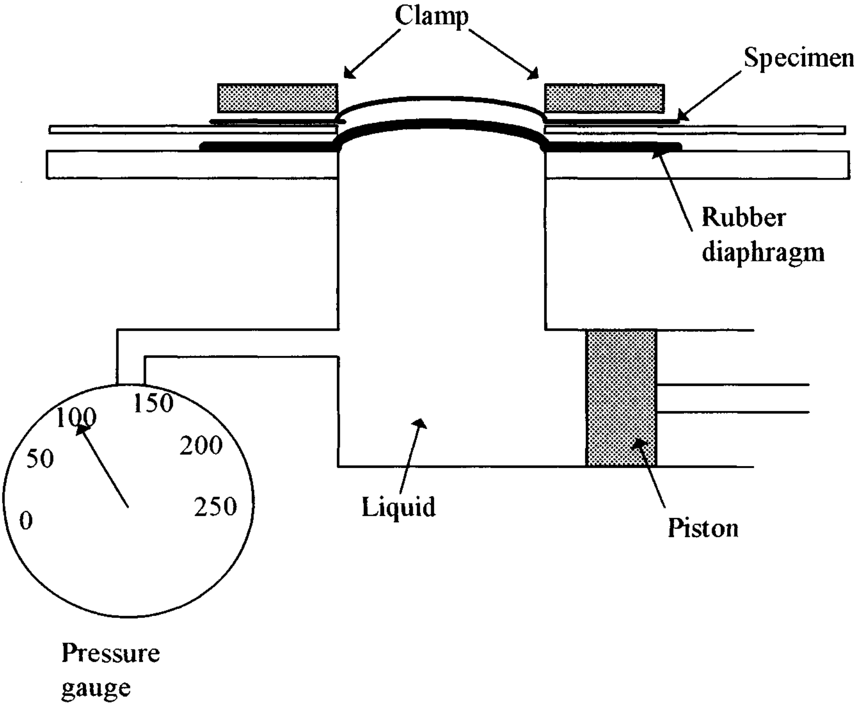
Tensile strength tests are generally used for woven fabrics where there are definite warp and weft directions in which the strength can be measured. However, certain fabrics such as knitted materials, lace or non-wovens do not have such distinct directions where the strength is at a maximum. Bursting strength is an alternative method of measuring strength in which the material is stressed in all directions at the same time and is therefore more suitable for such materials. There are also fabrics which are simultaneously stressed in all directions during service, such as parachute fabrics, filters, sacks and nets, where it may be important to stress them in a realistic manner. A fabric is more likely to fail by bursting in service than it is to break by a straight tensile fracture as this is the type of stress that is present at the elbows and knees of clothing.

When a fabric fails during a bursting strength test it does so across the direction which has the lowest breaking extension. This is because when stressed in this way all the directions in the fabric undergo the same extension so that the fabric direction with the lowest extension at break is the one that will fail first. This is not necessarily the direction with the lowest strength.

The standard type of bursting strength test uses an elastic diaphragm to load the fabric, the pressure of the fluid behind the diaphragm being used as the measure of stress in the fabric. The general layout of such an instrument is shown in Fig. 5.29. The bursting strength is then measured in units of pressure. As there is a sizeable force needed just to inflate the diaphragm this has to be allowed for in the test. The usual way is to measure the increase in height of the diaphragm during the test and then to inflate the diaphragm to the same height without a specimen present. The pressure required to inflate the diaphragm alone is then deducted from the pressure measured at the point of failure of the sample. The relationship between the diaphragm height and the fabric extension is quite complex so that the method is not used to obtain an estimation of fabric extension.

5.9.1 Diaphragm bursting test

The British Standard [25] describes a test in which the fabric to be tested is clamped over a rubber diaphragm by means of an annular clamping ring



5.29 A diaphragm bursting strength tester.

and an increasing fluid pressure is applied to the underside of the diaphragm until the specimen bursts. The operating fluid may be a liquid or a gas.

Two sizes of specimen are in use, the area of the specimen under stress being either 30 mm diameter or 113 mm in diameter. The specimens with the larger diameter fail at lower pressures (approximately one-fifth of the 30 mm diameter value). However, there is no direct comparison of the results obtained from the different sizes. The standard requires ten specimens to be tested.

In the test the fabric sample is clamped over the rubber diaphragm and the pressure in the fluid increased at such a rate that the specimen bursts within 20 ± 3 s. The extension of the diaphragm is recorded and another test is carried out without a specimen present. The pressure to do this is noted and then deducted from the earlier reading.

The following measurements are reported:

Mean bursting strength kN/m^2
Mean bursting distension mm

The US Standard [26] is similar using an aperture of 1.22 ± 0.3 in (31 ± 0.75 mm) the design of equipment being such that the pressure to inflate the diaphragm alone is obtained by removing the specimen after bursting. The test requires ten samples if the variability of the bursting strength is not known.

The disadvantage of the diaphragm type bursting test is the limit to the extension that can be given to the sample owing to the fact that the rubber diaphragm has to stretch to the same amount. Knitted fabrics, for which the method is intended, often have a very high extension.

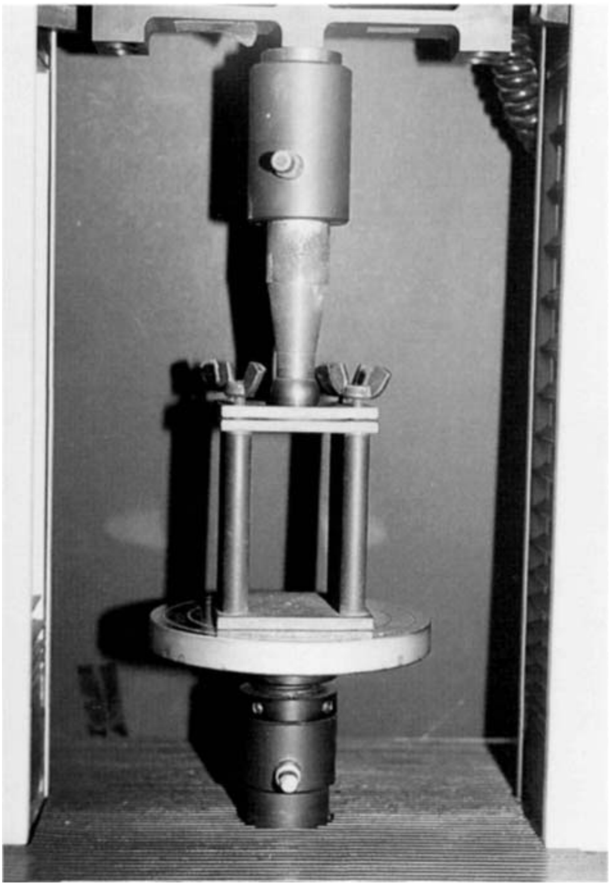
5.9.2 Ball bursting strength

There is not a British Standard for the ball bursting strength of knitted fabrics although a standard does exist for coated fabrics. This test can be carried out using an attachment on a standard tensile testing machine. In the test a 25 mm diameter steel ball is pushed through the stretched fabric and the force required to do so is recorded. The results are not directly compatible with those from the diaphragm type of bursting tests as they are measured in units of force only and not in units of force per unit area. The advantage of the test is that it can be carried out on a standard universal strength tester with a suitable attachment. There is also no limit to the amount a sample can be extended as there is with the diaphragm test.

The US Standard [27] specifies a 1.0000 in diameter ball (25.4 mm) with a clamp diameter of 1.75 in (44.45 mm) and a speed of 12 in/min (305 mm/min). The standard shows an attachment which is used in the tensile mode on a standard strength testing machine. The British Standard for coated fabrics [28] specifies very similar dimensions with a ball diameter of 25.2 mm, a clamp diameter of 45 mm and a testing speed of 5 mm/s. It is simpler when carrying out this test to use an attachment which operates in the compression mode, if the testing machine is capable of this. An example of a compression fixture to carry out this test is shown in Fig. 5.30.

5.10 Stretch and recovery properties

Certain types of clothing, particularly sports wear, is made to be a close fit to the body. The fabric of which such clothing is made has to be able to stretch in order to accommodate firstly the donning and removal of the clothing and secondly any activity that is undertaken while wearing it. So that the garment remains close fitting and does not appear baggy this stretch has to be followed by the complete recovery of the original dimensions. This is usually accomplished by incorporating a small percentage of elastic fibres into the structure. The requirements of a fabric can be gauged from the



5.30 A ball bursting strength attachment.

typical values of stretch that are encountered during the actions of sitting, bending, or flexing of knees and elbows:

- Back flex 13–16%.
- Elbow flex lengthwise 35–40%, circumferentially 15–22%.
- Seat flex 25–30%, across 6%.
- Knee flex lengthwise 35–45%, circumferentially 12–14%.

Standing at rest is taken as the zero value for the purpose of calculating these increases.

There are a large number of tests devised for stretch fabric by various organisations, all following similar procedures but differing widely in many of the important details. There are two quantities that are generally measured: one is the extension at a given load (sometimes known as modulus) which is a measure of how easily the fabric stretches; the other is how well the fabric recovers from stretching to this load, usually measured as growth or residual extension. As a rule of thumb a stretch fabric is expected to recover to within 3% of its original dimensions. The size of load used in the test is important as a load that is high for a light-weight fabric may not put any serious stretch on a heavy-weight fabric. In general the larger percentage of the breaking load which a fabric is subjected to the greater is the residual extension or growth. The load used is therefore an important test detail and one that differs from test to test. The other details on which the tests differ are the number of stretch cycles before the actual measurements, the time held at the fixed load and the time allowed for recovery.

The British Standard of test for elastic fabrics [29] describes a number of tests for elastic fabrics using either line contact jaws or looped specimens. A gauge length of 100 mm is specified for straight specimens and a total length of 200 mm for looped specimens; the results from the two types of specimens are not necessarily comparable. The standard covers both woven and knitted fabrics. Tests include: extension at a specified force, modulus, residual extension and tension decay.

In the test for extension at a specified force the sample is cycled twice between zero extension and the specified force at a rate of 500 mm/min. The elongation at the specified force is measured on the second cycle from the force extension curve.

The modulus can also be determined from the second cycle by recording the force at specified values of elongation.

In the test for residual extension, gauge length marks are made on the sample which is then clamped in the jaws of a suitable tensile tester so that the marks line up with the inner edge of the clamps. The sample is given one preliminary stretch cycle then extended to a specified force which is held for 10 s. It is removed and allowed to relax on a flat, smooth surface and its length is remeasured after 1 min to see how much of its original length it has recovered to give a length L_2.

If the specification requires it the specimen can be remeasured after 30 min to give a length L_3.

The following quantities are calculated:

$$\text{Mean residual extension after 1 min} = \frac{L_2 - L_1}{L_1} \times 100\%$$

$$\text{Mean residual extension after 30 min} = \frac{L_3 - L_1}{L_1} \times 100\%$$

where L_1 is the original gauge length.

Tension decay is measured by holding the sample at a specified elongation for 5 min and determining the decay in force over this period:

$$\text{Tension decay} = \frac{F_1 - F_2}{F_1} \times 100\%$$

where F_1 = maximum force at specific elongation,
F_2 = force after 5 min.

The method also covers the fatiguing and ageing of specimens and the subsequent testing any of the above properties.

The US Standard [30] for woven fabrics uses pairs of specimens, one of which is stretched to a fixed load of 4 lb (1800 g) and the other is subsequently held at a fixed extension for 30 min. Three pairs of samples are taken from the stretch direction each 2.5 in × 22 in (64 mm × 560 mm) and are frayed down to 2.0 in width (50 mm). Two lines are marked on the sample 500 mm apart and it is then clamped in the testing machine with the marks aligned with the edges of the jaws. The samples are cycled three times to the fixed load each cycle taking 5 s. At the fourth stretch the load is held for 10 s and the distance between the lines is measured. The load is then removed and the sample remeasured after 30 s. The quantities measured are: percentage stretch and fabric growth, which is the same as residual extension.

If A = original length, B = length under load and C = length after release:

$$\text{Stretch} = \frac{B - A}{A} \times 100\%$$

$$\text{Growth} = \frac{C - A}{A} \times 100\%$$

The second specimen of each pair is stretched to a fixed extension which is taken to be 85% of the stretch measured in the above section or other agreed figure. This extension is held for 30 min, after which the specimen is removed and the growth measured after 30 s and 30 min.

The US Standard [31] covers knitted fabrics having low power. The fabrics are stretched to a fixed extension for 2 h and the growth measured. The amount of extension is governed by the end use of the fabric as shown in Table 5.2.

Five samples are cut from the wale direction and five from the course direction each 5 in × 15 in (127 mm × 398 mm). Each of these is sewn into a loop and bench marks are made 5 in (127 mm) apart on one side. The loops are held by a rod at each end and the appropriate extension from the above table is held for 2 h. After this time the sample is released and the growth measured at 60 s and 1 h after by a rule which is attached to the specimen.

If it is desired the fabric stretch can be measured at a fixed load which is 5 lbf (22.2 N) for the loose fitting fabrics and 10 lbf (44.5 N) for the form

Table 5.2 Percentage stretch for different end uses

	Stretch (%)	
	Course way	Wale way
Loose fitting (comfort stretch)	30	15
Form fitting (semi-support)	60	35

fitting fabrics. The samples are cycled to the given load four times for 5 s before the actual measurement which is taken after the fifth loading has been held for 10 s. The calculations for growth and stretch are the same as in [30] above.

5.11 Seam strength

Failure at a seam makes a garment unusable even though the fabric may be in good condition. There are a number of possible causes of seam failure:

1 The sewing thread either wears out or fails before the fabric does.
2 The yarns making up the fabric are broken or damaged by the needle during sewing.
3 Seam slippage occurs.

Seam slippage is an inherent property of the fabric and so forms part of the specification for fabrics which are to be made into upholstery and apparel. The other problems listed above are specific to making-up and they depend on the sewing machine used, the sewing thread, the sewing speed, size of sewing needle and stitch length among other factors. Similarly seam strength, although it can be measured in the same way as fabric tensile strength, depends on too many factors to be a useful property of a fabric.

5.11.1 Seam slippage

Seam slippage is the condition where a seam sewn in the fabric opens under load. Some of this gap may close on removal of the load but some of it may be a permanent deformation. Seam slippage is a fabric problem especially for fabrics that contain slippery yarns or that have an open structure or where the number of warp and weft interlacings is low. Such factors mean that one set of yarns may be easily pulled through the other. Seam details such as the seam allowance, seam type and stitch rate can all affect the problem but, in tests for seam slippage, these factors are kept constant. The direction of seam slippage tests is often given as weft (filling) over warp when the weft yarns are being pulled through the warp yarns; in this case the seam would be sewn along the weft direction. The opposite direction would be warp over weft.

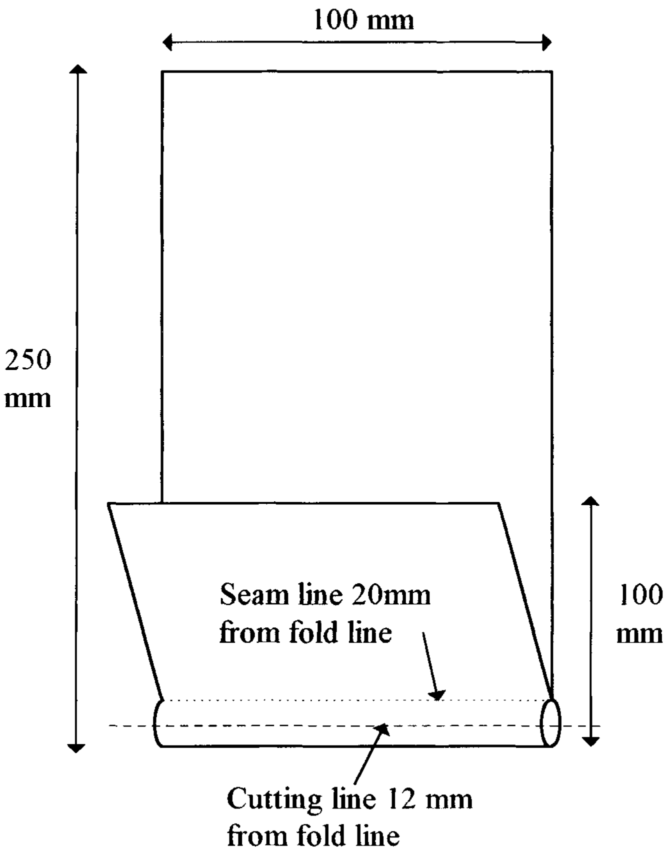
There are three different types of seam slippage test in existence, each of which has its drawbacks. Firstly there is the type where a standard seam is put under a fixed load and the seam gape is measured. In second type a load extension curve is plotted with and without a standard seam and the difference between the two curves is taken as the slippage. The third type does away with a sewn seam and measures the force required to pull a set of pins through the fabric. A variant of the first type is to measure the load required to give a fixed seam opening.

5.11.2 Seam slippage tests

The British Standard test for seam slippage [32] is a test of the second type. Five warp and five weft specimens each 100mm × 350mm are used. Each sample is folded 100mm from one end and a seam is sewed 20mm from the fold line using the special sewing thread and sewing machine settings which are detailed in the standard. The layout of the sample is shown in Fig. 5.31. After sewing the folded part of the fabric is cut away 12mm from the fold line leaving the seam 8mm from the cut edge. A standard strength tester equipped with 25mm grab test jaws is used, the gauge length being set to 75mm.

Just before the test the sample is cut into two parts one with the seam and one without but with each part containing the same set of warp or weft threads. The sample without a seam is first stretched in the tensile tester up to a load of 200N and a force elongation curve drawn. The matching sample with the seam is then tested in the same way making sure that the force elongation curve starts from the same zero position. The horizontal separation between the curves as shown in Fig. 5.32 is then due to opening of the seam.

In order to find the force required to open the seam a given distance, the separation of the curves at a force of 5N is measured and this distance is added to the seam opening specified (usually 6mm but some specifications require 5mm) making appropriate allowance for the horizontal scale of the chart. Next the point on the curves where there is a separation of this distance is located and the value of load at this point is read off the chart. If the curves do not reach the specified separation below 200N then the result is recorded as 'more than 200N'.



5.31 Seam slippage specimen.

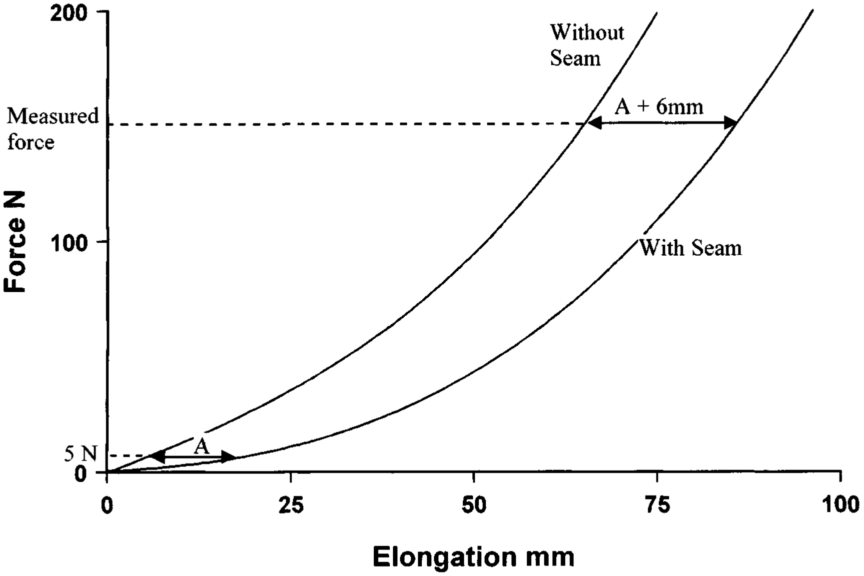
The US Standards [33] and [34] are very similar to the above method except that a load of 1 lbf (4.4 N) is used for correcting for slack in the system instead of 5 N. The required result is the load to produce a seam opening of 6 mm (0.25 in).

5.11.3 Fixed load method

The previous version of BS 3320 used the following method.

Principle

A strip of fabric is folded and stitched across its width. A force is then applied to the strip at right angles to the seam using grab-test jaws and the extent to which the seam opens for a given force is measured.

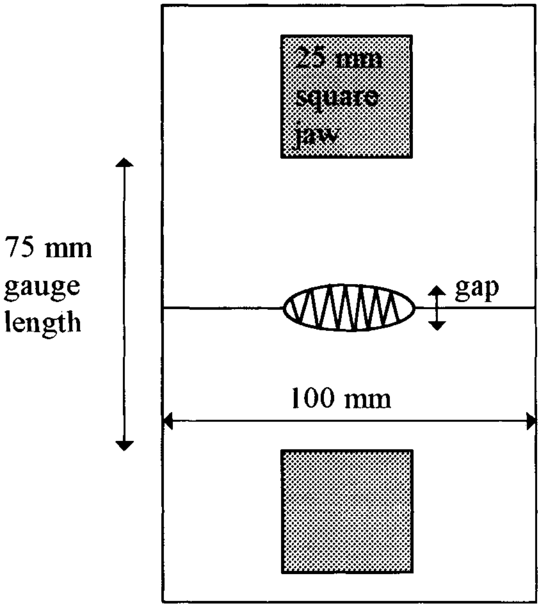


5.32 Seam slippage graph.

The force applied to the seamed specimens is not dictated solely by the mass per unit area of the fabric, instead it depends on the end use of the fabric under test. The most lightly stressed articles such as ladies' dresses, cushions and tickings are tested at a force of 80N; for seams likely to be subjected to greater stress such as in overcoats, suits and overalls a force of 120N is used and for such end uses as upholstery where considerable seam strength is required the seam is stressed to 175N.

Method

Five samples from the warp direction and five samples from the weft direction each 200mm × 100mm are used. Each sample is folded in half and a seam is machined 20mm from the fold, using the special sewing thread and a stitch rate of five stitches per cm. The folded edge is then cut off 12mm from the fold line. The jaws of the strength tester are set to a gauge length of 75mm and its speed is set to 50mm/min. The specimen is clamped in the 25mm wide jaws so that only the centre portion of the fabric and seam is stressed. The load is increased to either 80, 120 or 175N depending on the end use of the fabric and held at that value for 2min. The load is then reduced to 2.5N and held there for a further 2min. The width of the seam opening at its widest place is then measured to the nearest 0.5mm. The mean value for warpwise and for weftwise specimens is reported.



5.33 Specimen for upholstery seam slippage.

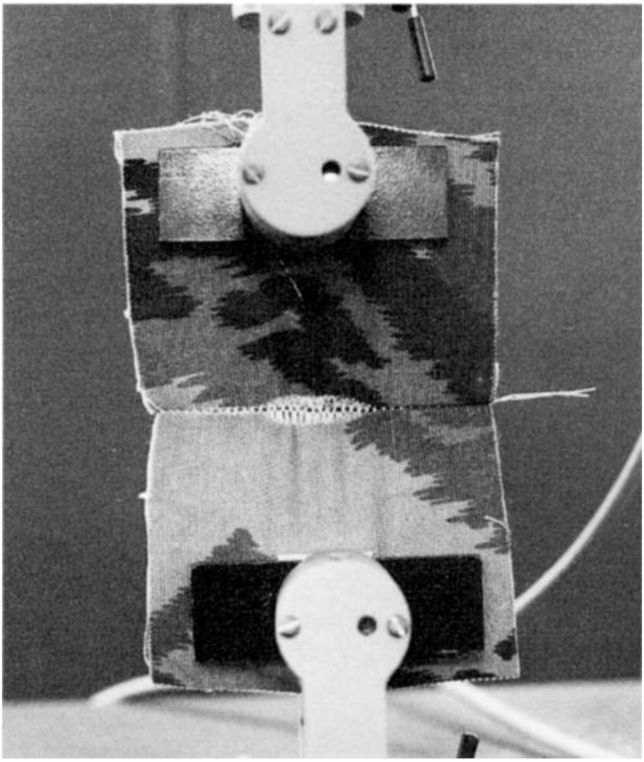
5.11.4 Upholstery seam slippage

The British Standard [35] for seams in upholstery is different from the test used for apparel and is of the fixed load type.

Method

Cut five samples from the warp direction and five samples from the weft direction each 200mm × 100mm. Fold each sample in half and machine a seam 20mm from the fold, using the specified sewing thread and stitch details. Cut off the fold 12mm from the fold line. Set the jaws of the tensile tester 75mm apart and set the speed to 50mm/min. Load the specimen in the jaws using the 25mm jaws so that only the centre of the specimen is clamped as shown in Fig. 5.33. Increase the load to 175N and hold at that for 2min. Reduce the load to 2.5N and hold for a further 2min. Measure the width of the seam opening as shown in Fig. 5.34, at its widest place to the nearest 0.5mm. Give the mean value for warpwise and for weftwise specimens.

The difficulty with fixed load methods is that of measuring the seam opening with any accuracy. It is not always obvious where the opening starts and finishes. Methods that use a pair of load extension curves overcome the



5.34 Seam slippage.

measurement problem but appear to underestimate the amount of slippage due to the high tension allowance (5 N). They also produce the problem of tests with no numerical results due to the seam or fabric failing or the test being stopped before reaching the required seam opening.

The US Standard [36] 'resistance to yarn slippage in woven upholstery fabrics' uses a completely different approach. The fabric sample is impaled on a standard set of pins at a fixed distance from its edge and the maximum force required to pull either the filling yarns over the warp yarns or the warp yarns over the filling yarns is measured. This method avoids the sewing of a standard seam, but the results are not directly comparable with the other methods.

General reading

Morton W E and Hearle J W S, *Physical Properties of Textile Fibres*, 3rd edn. Textile Institute, Manchester, 1993.

References

1. *Textile Terms and Definitions*, 10th edn. McIntyre J E and Daniels P N, eds Textile Institute, Manchester, 1995.
2. Morton W E and Hearle J W S, *Physical Properties of Textile Fibres*, 3rd edn. Textile Institute, Manchester, 1993.
3. Vangheluwe L, 'Relaxation and inverse relaxation of yarns after dynamic loading', *Textile Res J*, 1993 **63** 552.
4. Farrow B, 'Extensometric and elastic properties of textile fibres', *J Text Inst*, 1956 **47** T58.
5. Guthrie J C and Norman S, 'Measurement of the elastic recovery of viscose rayon filaments', *J Text Inst*, 1961 **52** T503.
6. Guthrie J C and Wibberley J, 'The effect of time on the elastic recovery of fibres', *J Text Inst*, 1965 **56** T97.
7. Furter R, *Strength and Elongation Testing of Single and Ply Yarns: Experience with Uster Tensile Testing Installations*, Textile Institute and Zellweger Uster AG, Manchester, 1985.
8. Balasubramanian P and Salhotra K R, 'Effect of strain rate on yarn tenacity', *Text Res J*, 1985 **55** 74.
9. Vangheluwe L, 'Influence of strain rate and yarn number on tensile test results', *Text Res J*, 1992 **62** 586.
10. DeLuca L B and Thibodeaux D P, 'Comparison of yarn tenacity data obtained using the Uster Tensorapid, Dynamat II, and Scott skein testers', *Text Res J*, 1992 **62** 175.
11. ASTM D 3822 Test method for tensile properties of single textile fibres.
12. BS 3411 Method for the determination of the tensile properties of individual textile fibres.
13. Taylor R A, 'Cotton tenacity measurements with high speed instruments', *Text Res J*, 1986 **56** 92.
14. BS 1932 Testing the strength of yarns and threads from packages.
15. ASTM D 2256 Test method for breaking load (strength) and elongation of yarn by the single strand method.
16. BS 6372 Method for determination of breaking strength of yarn from packages: skein method.
17. ASTM D 1578 Test method for breaking load (strength) of yarn by the skein method.
18. BS 2576 Method for determination of breaking strength and elongation (strip method) of woven fabrics.
19. ASTM D 1682 Test methods for breaking load and elongation of textile fabrics.
20. ASTM D 2261 Test method for tearing strength of woven fabrics by the tongue (single rip) method (constant rate of extension tensile testing machine).
21. Harrison P W, 'The tearing strength of fabrics I. A review of the literature', *J Text Inst*, 1960 **51** T91.
22. BS 4303 Method for the determination of the resistance to tearing of woven fabrics by the wing rip technique.
23. ASTM D 1424 Test method for tear resistance of woven fabrics by falling pendulum (Elmendorf) apparatus.

24. Scelzo W A, Backer S and Boyce M C, 'Mechanistic role of yarn and fabric structure in determining tear resistance of woven cloth Part 1 Understanding tongue tear', *Text Res J*, 1994 **64** 291.
25. BS 4768 Method for the determination of the bursting strength and bursting distension of fabrics.
26. ASTM D 3786 Test method for hydraulic bursting strength of knitted goods and non woven fabrics – diaphragm bursting strength tester method.
27. ASTM D 3787 Test method for bursting strength of knitted goods – constant rate of traverse (CRT), ball burst test.
28. BS 3424 Testing coated fabrics Part 6 Methods 8A and 8B. Methods for determination of bursting strength.
29. BS 4952 Method of test for elastic fabrics.
30. ASTM D 3107 Test method for stretch properties of fabrics woven from stretch yarns.
31. ASTM D 2594 Test methods for stretch properties of knitted fabrics having low power.
32. BS 3320 1988 Method for determination of slippage resistance of yarns in woven fabrics: seam method.
33. ASTM D434 Test method for resistance to slippage of yarns in woven fabrics using a standard seam.
34. ASTM D 4034 Test method for resistance to yarn slippage at the sewn seam in woven upholstery fabrics: plain, tufted, or flocked.
35. BS 2543 Specification for woven and knitted fabrics for upholstery Appendix A.
36. ASTM D 4159 Test method for resistance to yarn slippage in woven upholstery fabrics plain, tufted or flocked using a simulated seam.
37. Ulster News, Bulletin No. 31 (Statistics 82), Zellweger Uster, Switzerland, Dec 1982.