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.

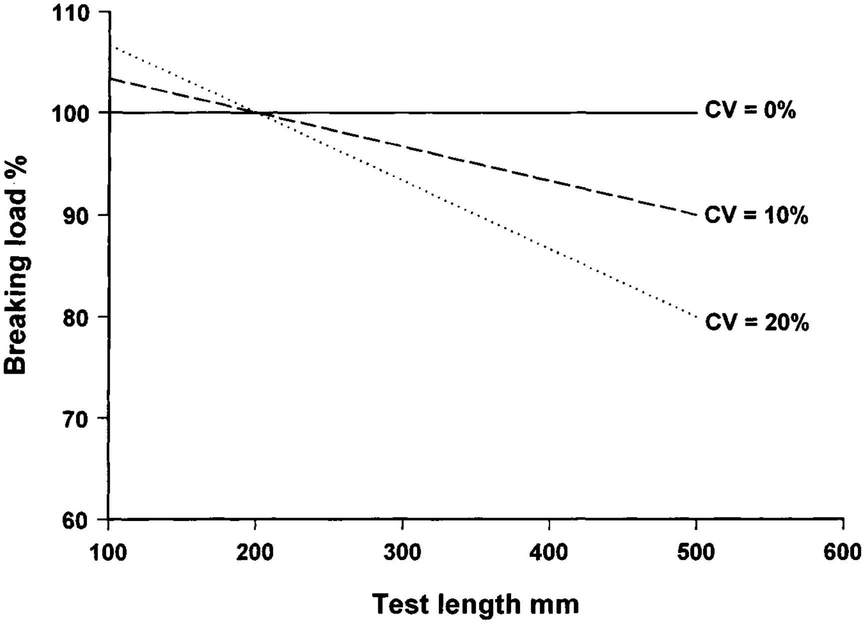
Consider a uniform material of strength 10N but with weak spots of strength 8N every 100mm along its length. If the portion tested in each test is only 10mm long then the probability of a weak spot in that length is 1 in 10. Ten tests will yield nine of 10N and one of 8N which gives an average value 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.

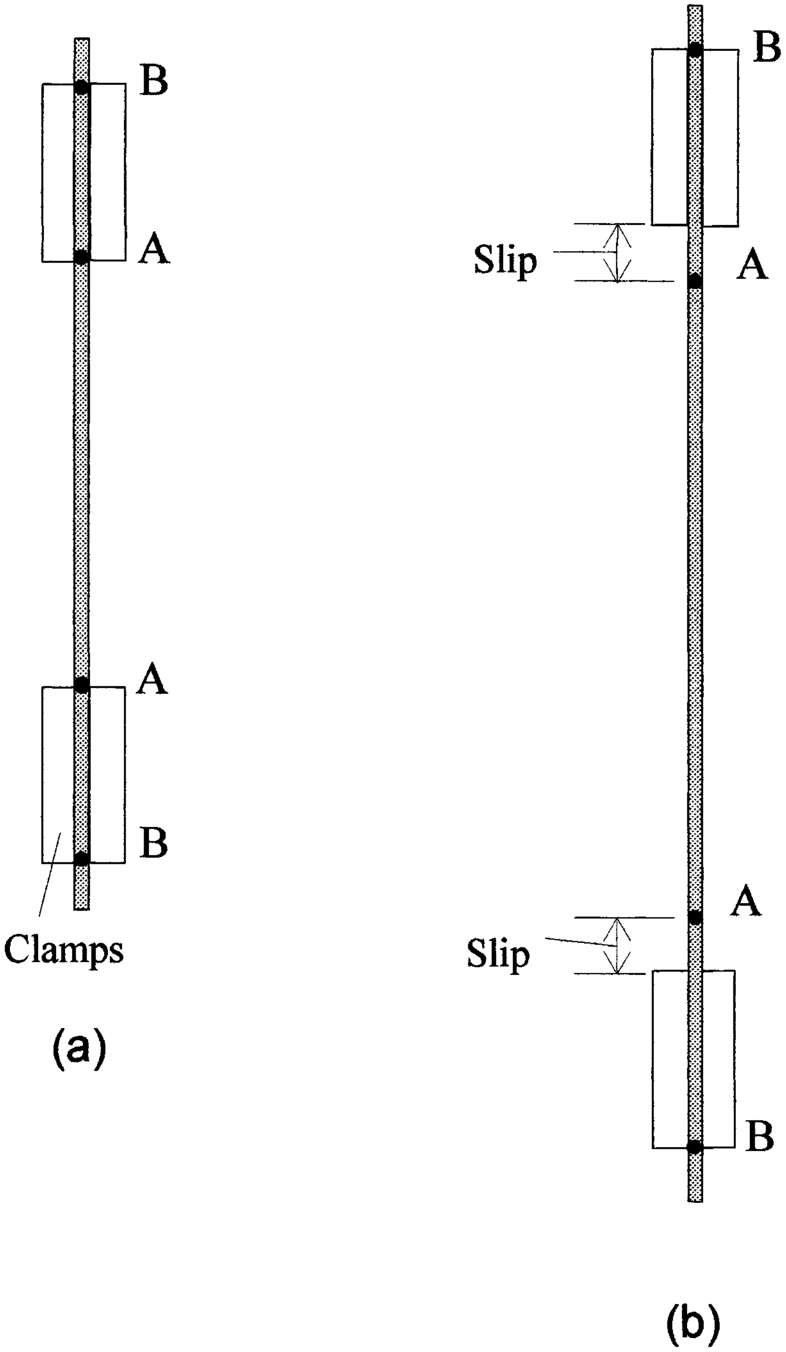
5.4.6 Clamping problems

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.

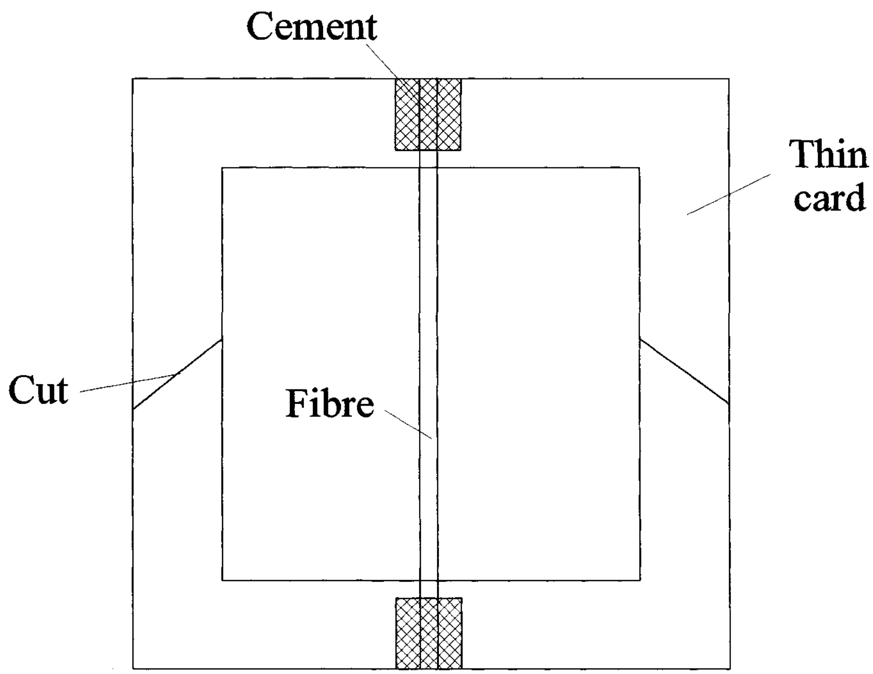
High-tenacity yarns and fabrics such as Kevlar and carbon fibre are particularly susceptible to these problems because the gripping forces need to be high. The fibre strength is also easily reduced by any damage due to gripping. In such cases special ones may have to be designed in order to spread the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

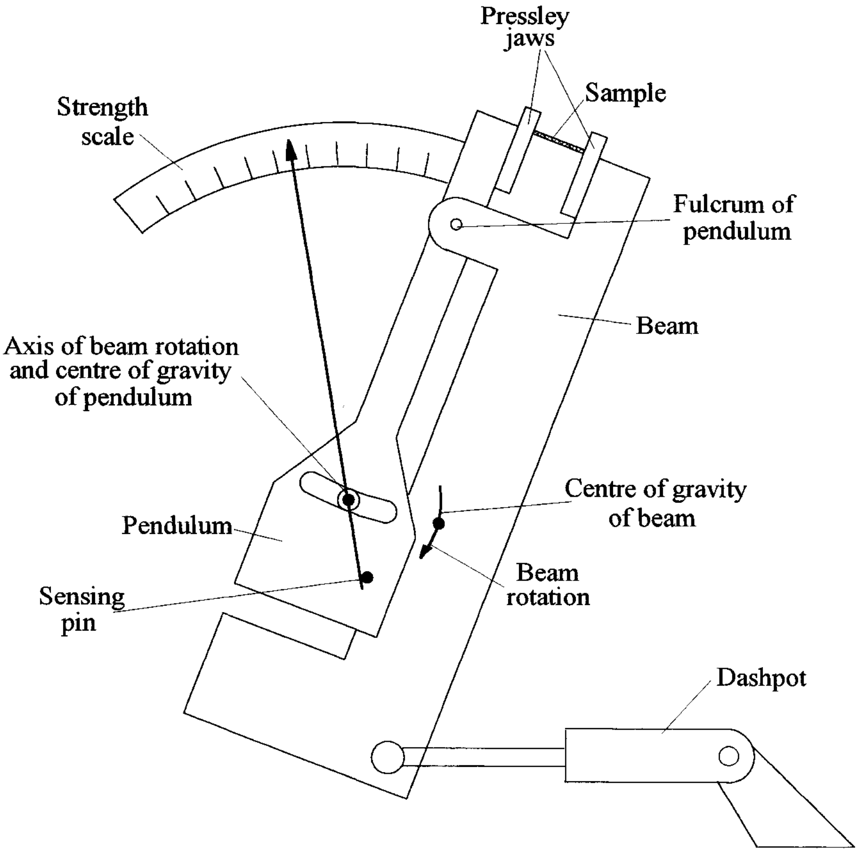
$$PI = \frac{\text{force (lbf)}}{\text{mass (mg)}}$$

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 500 mm and the speed is adjusted so that yarn break is reached in 20 ± 3 s. Before each test a pre-tension of 0.5 cN/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 ± 0.1 in (250 ± 3 mm) or alternatively by agreement 20 ± 0.2 in (500 ± 5 mm) and uses a time to break of 20 ± 3 s.

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 5000 mm/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 20 s was used. More tests will enable better prediction of the statistically few weak spots as 50 tests may only test the first 50 m 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 1.5m (1.5yd) reel tested at a speed of 300mm/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 1.0m (1yd) reel broken at a speed of 300mm/min.
3 Fifty turns on a 1.0m (1yd) reel broken in a time of 20s.

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 1yd skein is 5% higher than that for a 1.5yd 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 1.5yd wrap reel to give a total length of 120yd. 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:

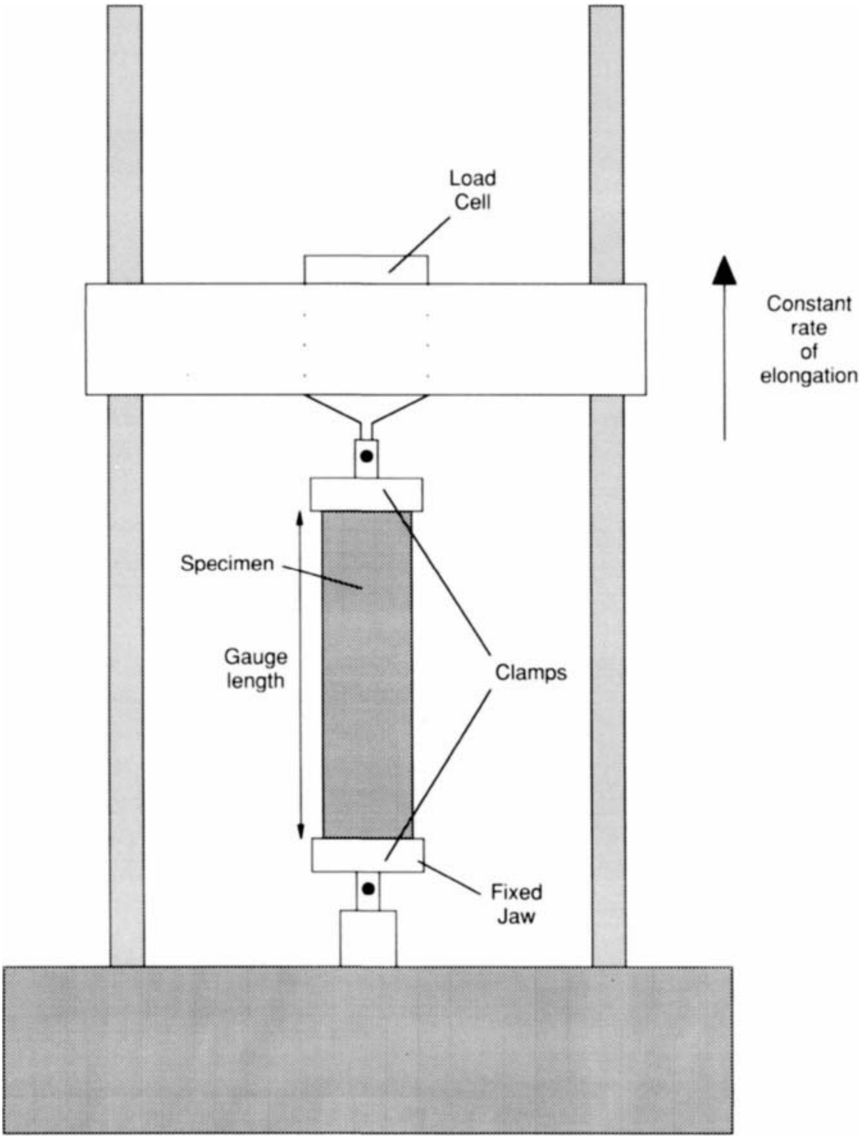
$$\text{Tenacity (N/tex)} = 0.000{,}047 \times \text{CSP (lbf} \times \text{CC)}$$

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 60mm × 300mm and then frayed down in the width equally at both sides to give samples which are exactly 50mm 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 50mm/min and the distance between the jaws (gauge length) is set to 200mm. The sample is pretensioned to 1% of the probable breaking load. Any breaks that occur within 5mm 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

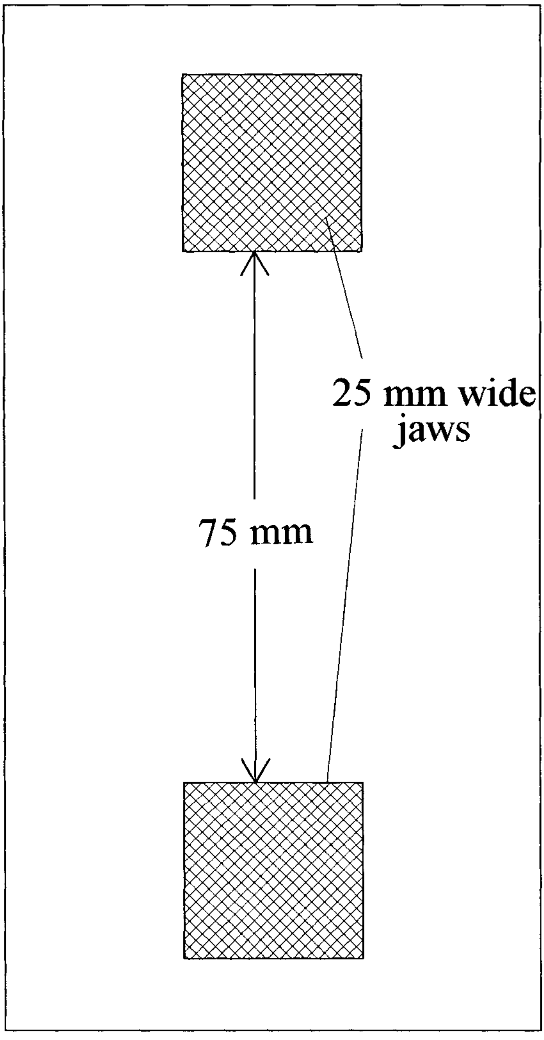
(50 mm) widths where the method of preparation is the same as in the above standard; (2) cut strip in 1 in (25 mm) and 2 in (50 mm) widths which is intended to be used with fabrics such as heavily milled ones which cannot easily be frayed and (3) the grab method which is fundamentally different from 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

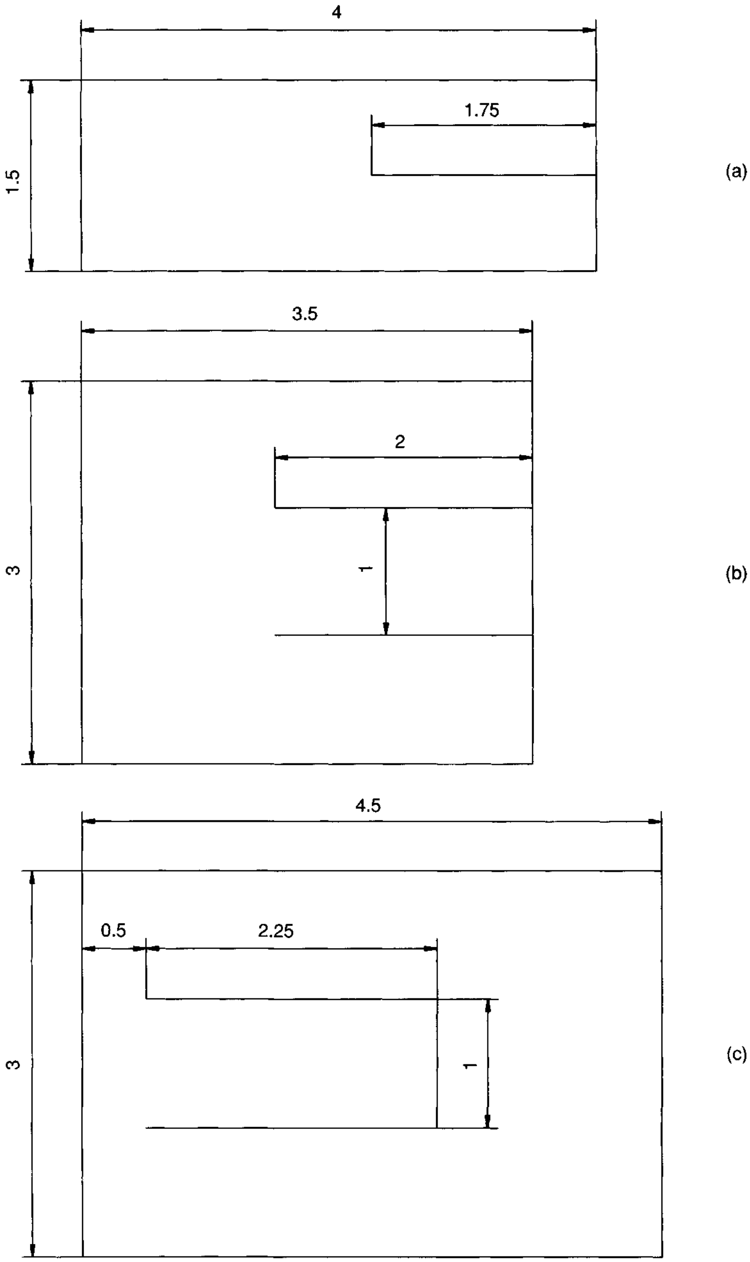


5.23 Grab test sample.

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 50 mm/min (2 in/min) or an optional speed of 300 mm/min can be used.

There are three ways of expressing the result:

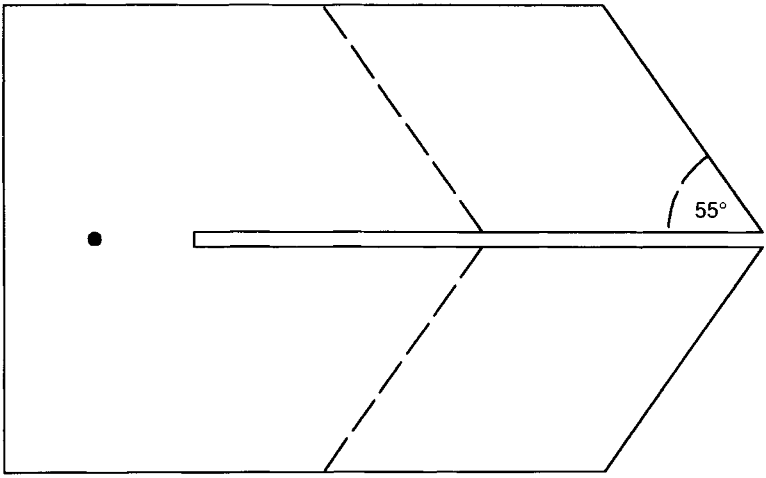
1 The average of the five highest peaks.
2 The median peak height.
3 The average force by use of an integrator.

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

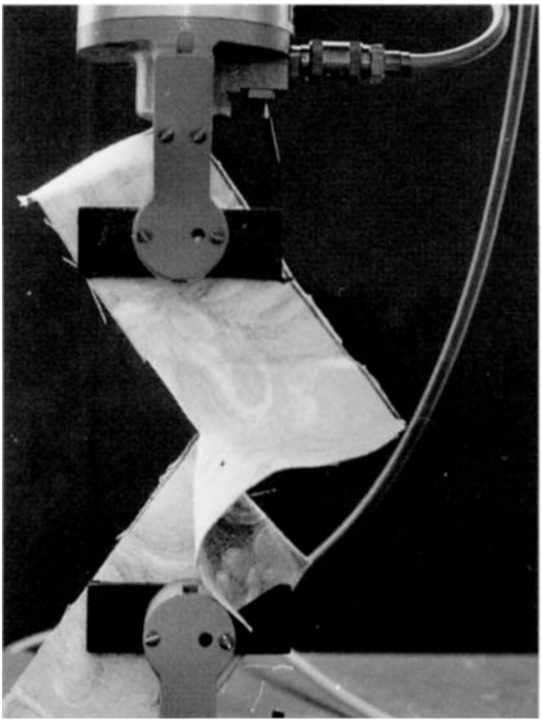
If the direction to be torn is much stronger than the other direction, failure will occur by tearing across the tail so that it is not always possible to obtain both warp and weft results.

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 150 mm long and a mark is made 25 mm from the end of the specimen to show the end of the tear.



5.25 Wing rip sample layout.

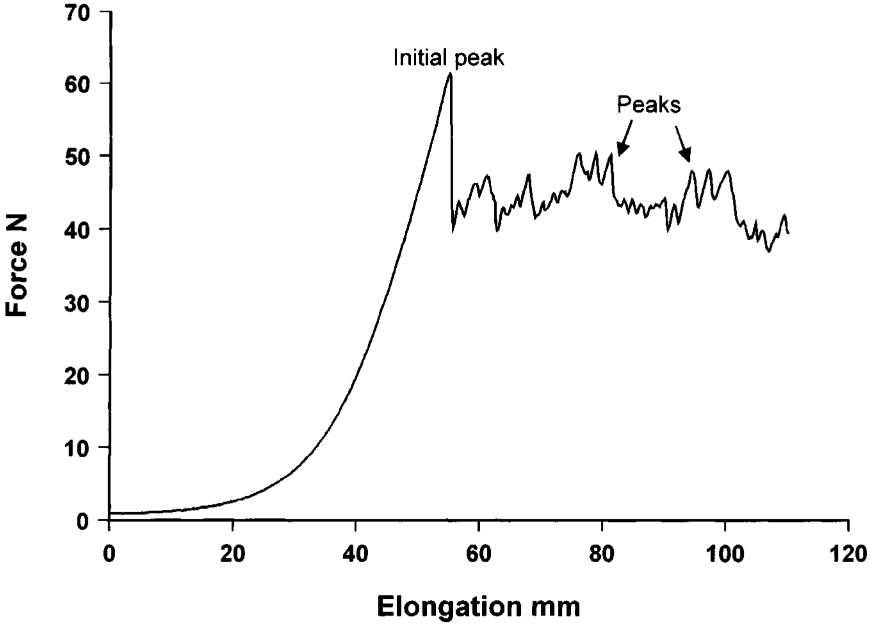


5.26 Sample for tearing strength in tensile tester.

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.



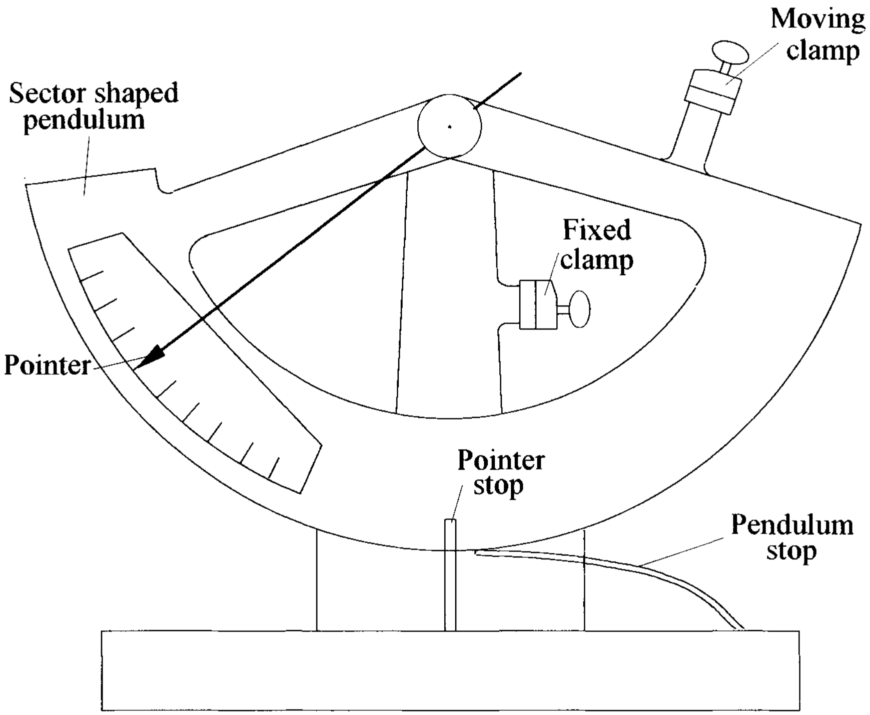
5.27 Tear test force extension curve.

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.