# Objective evaluation of fabric handle

10.1 Handle

Fabric end uses can be roughly divided into industrial, household and apparel. Fabrics for industrial uses can be chosen on straightforward performance characteristics such as tensile strength, extension and resistance to environmental attack. However, fabrics intended for clothing have less emphasis placed on their technical specification and more on their appearance and handling characteristics such as lustre, smoothness or roughness, stiffness or limpness and draping qualities. Handling the fabric is one of the ways of assessing certain of these properties. 'Handle', the term given to properties assessed by touch or feel, depends upon subjective assessment of the fabrics by a person. Terms such as smooth, rough, stiff or limp depend strongly on the type of fabric being assessed, for instance the smoothness of a worsted suiting is different in nature from that of a cotton sateen. Because of the subjective nature of these properties attempts have been made over the years to devise objective tests to measure some or all of the factors that go to make up handle. Fabric stiffness and drape were some of the earliest [1] properties to be measured objectively.

10.1.1 Bending length

A form of the cantilever stiffness test is often used as a measure of a fabric's stiffness as it is an easy test to carry out. In the test a horizontal strip of fabric is clamped at one end and the rest of the strip allowed to hang under its own weight. This is shown diagrammatically in Fig. 10.1.

The relationship among the length of the overhanging strip, the angle that it bends to and the flexural rigidity, G, of the fabric is a complex one which was solved empirically by Peirce [1] to give the formula:

$$G = ML^3 \left(\frac{\cos\frac{1}{2}\theta}{8\tan\theta} \right)$$
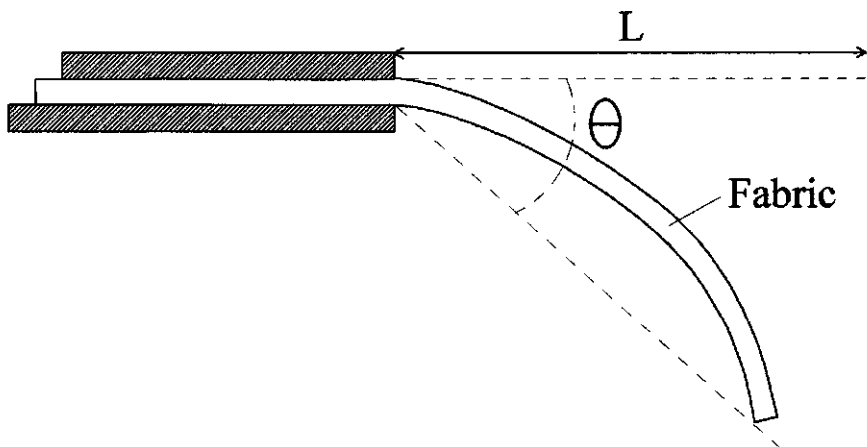
10.1   Bending length.

where L = length of fabric projecting,
    θ = angle fabric bends to,
 M = fabric mass per unit area.

From this relationship Peirce defined a quantity known as the bending length as being equal to the length of a rectangular strip of material which will bend under its own mass to an angle of 7.1° [1]. The bending length is dependent on the weight of the fabric and is therefore an important component of the drape of a fabric when it is hanging under its own weight. However, when a fabric is handled by the fingers the property relating to stiffness that is sensed, in this situation, is the flexural rigidity which is a measure of stiffness independent of the fabric weight.

The bending length is related to the angle that the fabric makes to the horizontal by the following relation:

$$C = L\left(\frac{\cos\frac{1}{2}\theta}{8\tan\theta}\right)^{1/3}$$

where C = bending length.

When the tip of the specimen reaches a plane inclined at 41.5° below the horizontal the overhanging length is then twice the bending length. This angle is used in the Shirley apparatus (Fig. 10.2) to increase the sensitivity of the length measurement and the slide on this instrument is directly calibrated in centimetres.
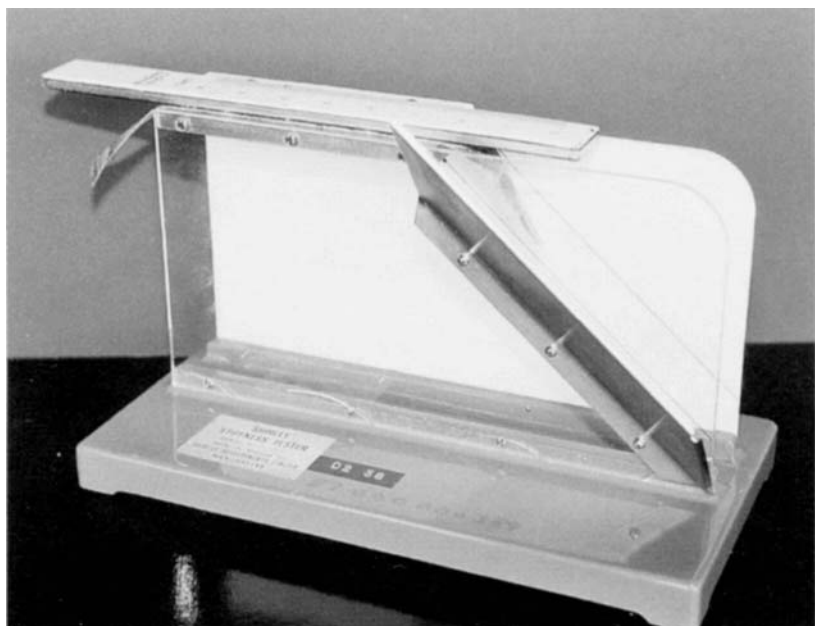
10.2   The Shirley stiffness test.

10.1.2 Shirley stiffness test

This test [2] measures the bending stiffness of a fabric by allowing a narrow strip of the fabric to bend to a fixed angle under its own weight. The length of the fabric required to bend to this angle is measured and is known as the bending length.

The test specimens are each 25 mm wide and 200 mm long; three are cut parallel to the warp and three parallel to the weft so that no two warp specimens contain the same warp threads, and no two weft specimens contain the same weft threads. The specimens should not be creased and those that tend to twist should be flattened.

Before the test the specimens are preconditioned for 4 h (50 °C >10% RH) and then conditioned for 24 h. If a specimen is found to be twisted its mid-point should be aligned with the two index lines. Four readings are taken from each specimen, one face up and one face down on the first end, and then the same for the second end.

The mean bending length for warp and weft is calculated. The higher the bending length, the stiffer is the fabric.

Flexural rigidity

The flexural rigidity is the ratio of the small change in bending moment per unit width of the material to the corresponding small change in curvature:

$$\text{Flexural rigidity } G = M \times C^3 \times 9.807 \times 10^{-6} \mu N\,m$$

where C = bending length (mm),
     M = fabric mass per unit area (g/m^2).

Bending modulus

The stiffness of a fabric in bending is very dependent on its thickness, the thicker the fabric, the stiffer it is if all other factors remain the same. The bending modulus is independent of the dimensions of the strip tested so that by analogy with solid materials it is a measure of 'intrinsic stiffness'.

$$\text{Bending modulus} = \frac{12 \times G \times 10^3}{T^3} N/m^2$$

where T = fabric thickness (mm).

10.1.3 Hanging loop method

Fabrics that are too limp to give a satisfactory result by the cantilever method may have their stiffness measured by forming them into a loop and allowing it to hang under its own weight. A strip of fabric of length L has its two ends clamped together to form a loop. The undistorted length of the loop l_0, from the grip to the lowest point, has been calculated [1] for three different loop shapes: the ring, pear and heart shapes as shown in Fig. 10.3. If the actual length l of the loop hanging under its own weight is measured the stiffness can be calculated from the difference between the calculated and measured lengths $d = l - l_0$:

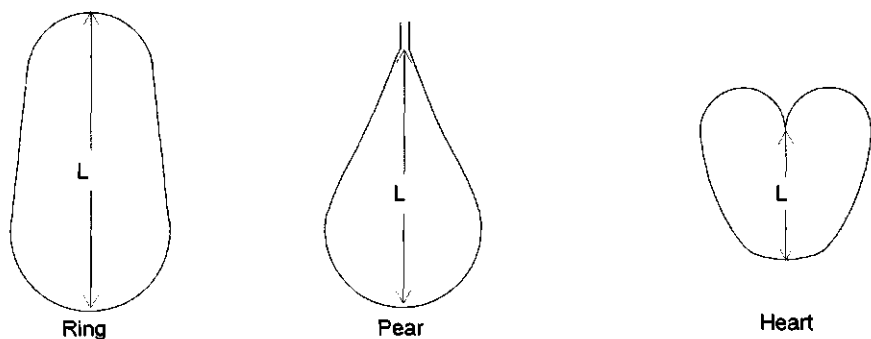Ring loop: $l_0 = 0.3183L$ $\theta = 157° \dfrac{d}{l_0}$

Bending length $C = L0.133 f_2(\theta)$

Pear loop: $l_0 = 0.4243L$ $\theta = 504.5° \dfrac{d}{l_0}$

Bending length $C = L0.133 f_2(\theta)/\cos 0.87\theta$

Heart loop: $l_0 = 0.1337L$ $\theta = 32.85° \dfrac{d}{l_0}$

Bending length $C = l_0 f_2(\theta)$ $f_2(\theta) = \left(\dfrac{\cos\theta}{\tan\theta}\right)^{1/3}$

10.3   Different shapes of hanging loops.

10.1.4 Drape

Drape is the term used to describe the way a fabric hangs under its own weight. It has an important bearing on how good a garment looks in use. The draping qualities required from a fabric will differ completely depending on its end use, therefore a given value for drape cannot be classified as either good or bad. Knitted fabrics are relatively floppy and garments made from them will tend to follow the body contours. Woven fabrics are relatively stiff when compared with knitted fabrics so that they are used in tailored clothing where the fabric hangs away from the body and disguises its contours. Measurement of a fabric s drape is meant to assess its ability to do this and also its ability to hang in graceful curves.

Cusick drape test

In the drape test [3] the specimen deforms with multi-directional curvature and consequently the results are dependent to a certain amount upon the shear properties of the fabric. The results are mainly dependent, however, on the bending stiffness of the fabric.

In the test a circular specimen is held concentrically between two smaller horizontal discs and is allowed to drape into folds under its own weight. A light is shone from underneath the specimen as shown in Fig. 10.4 and the shadow that the fabric casts, shown in Fig. 10.5, is traced onto an annular piece of paper the same size as the unsupported part of the fabric specimen. The stiffer a fabric is, the larger is the area of its shadow compared with the unsupported area of the fabric. To measure the areas involved, the whole paper ring is weighed and then the shadow part of the ring is cut away and weighed. The paper is assumed to have constant mass per unit area so that the measured mass is proportional to area. The drape coefficient can then be calculated using the following equation:
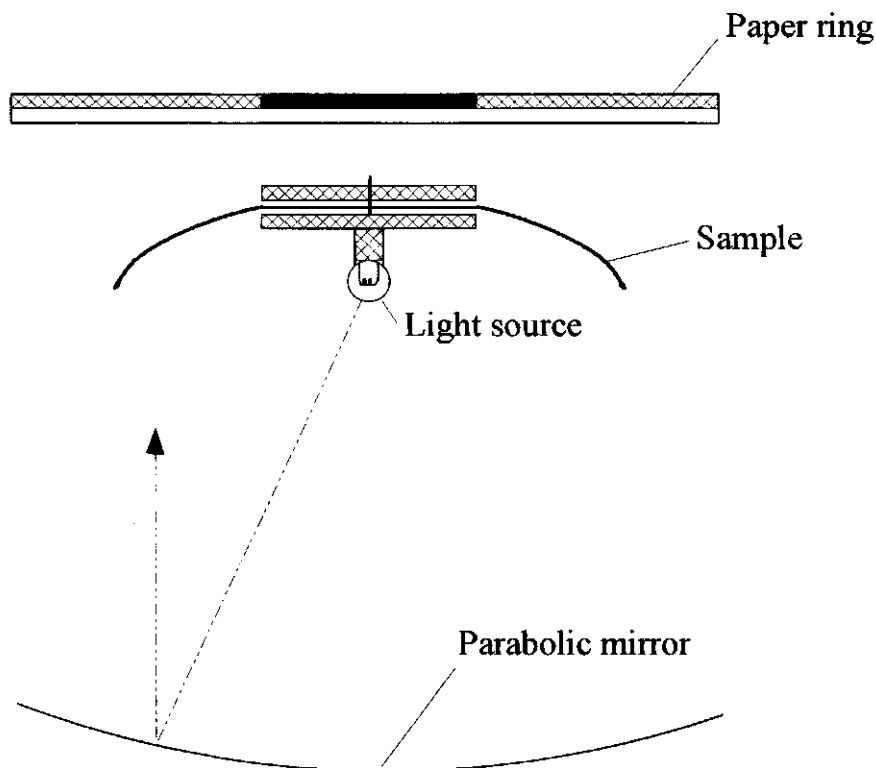
10.4   The Cusick drape test.

$$\text{Drape coefficient} = \frac{\text{mass of shaded area}}{\text{total mass of paper ring}} \times 100\%$$

The higher the drape coefficient the stiffer is the fabric.

At least two specimens should be used, the fabric being tested both ways up so that a total of six measurements are made on the same specimen.

There are three diameters of specimen that can be used:

- A 24 cm for limp fabrics; drape coefficient below 30% with the 30 cm sample;
- B 30 cm for medium fabrics;
- C 36 cm for stiff fabrics; drape coefficient above 85% with the 30 cm sample.

It is intended that a fabric should be tested initially with a 30 cm size specimen in order to see which of the above categories it falls into.

When test specimens of different diameter are used, the drape coefficients measured from them are not directly comparable with one
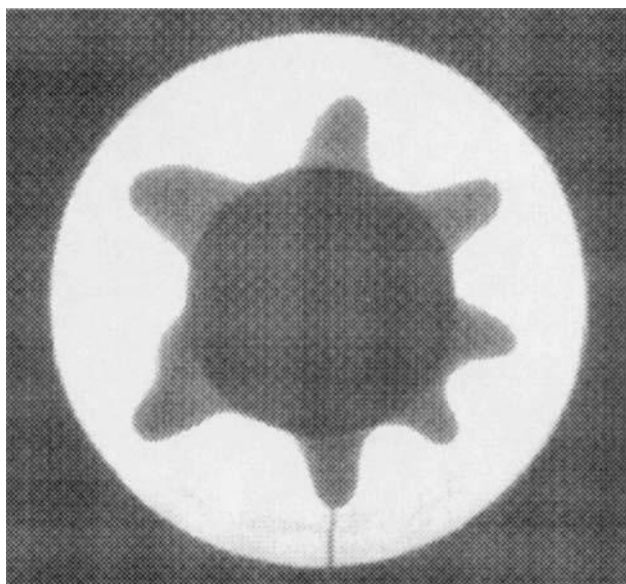
10.5   Drape test, top view of draped fabric.

another. Figure 10.6 shows a drape tester fitted with a video camera and computer for instantaneous measurement of the drape coefficient.

10.1.5 Crease recovery

Creasing of a fabric during wear is not a change in appearance that is generally desired. The ability of a fabric to resist creasing is in the first instance dependent on the type of fibre used in its construction. Some fibre types such as wool and cultivated silk have a good resistance to creasing whereas cellulosic materials such as cotton, viscose and linen have a very poor resistance to creasing. Many fabrics have resin finishes applied during production in order to improve their crease resistance. This test was originally developed to test the efficiency of such finishes.

The essence of the test [4] is that a small fabric specimen is folded in two and placed under a load for a given length of time to form a crease and it is then allowed to recover for a further length of time and the angle of the crease that remains is measured.

The magnitude of this crease recovery angle is an indication of the ability of a fabric to recover from accidental creasing. Some types of fabrics, owing to limpness, thickness and tendency to curl, give rise to ill-defined crease recovery angles and therefore imprecise measurements. Many wool and wool mix fabrics come under this heading, therefore a different test using smaller specimens is used in this case.

10.6   Drape test.

The test can be carried out in two atmospheres, either the standard one or at 90% RH and 35 °C.

Twenty rectangular specimens are tested, each measuring 40 mm × 15 mm, half of the specimens cut parallel to the warp and half parallel to the weft.

In the test the specimens are folded in two, the ends being held by tweezers. Half the specimens are folded face to face and half of them back to back. The specimens are then placed under a 10 N load for 5 min. They are then transferred immediately to the holder of the measuring instrument and one leg of the specimen is inserted as far as the back stop. The instrument is adjusted continuously to keep the free limb of the specimen vertical as shown in Fig. 10.7. The crease recovery angle is measured, by reading the scale when the free limb is vertical, 5 min after the removal of the load.

The following mean values are calculated

        warp face to face   weft face to face
        warp back to back   weft back to back

When a fabric is creased the resulting deformation has two components: one is the displacement of fibres and yarns relative to one another and the second is the stretching of the fibres on the outside of the curve. The
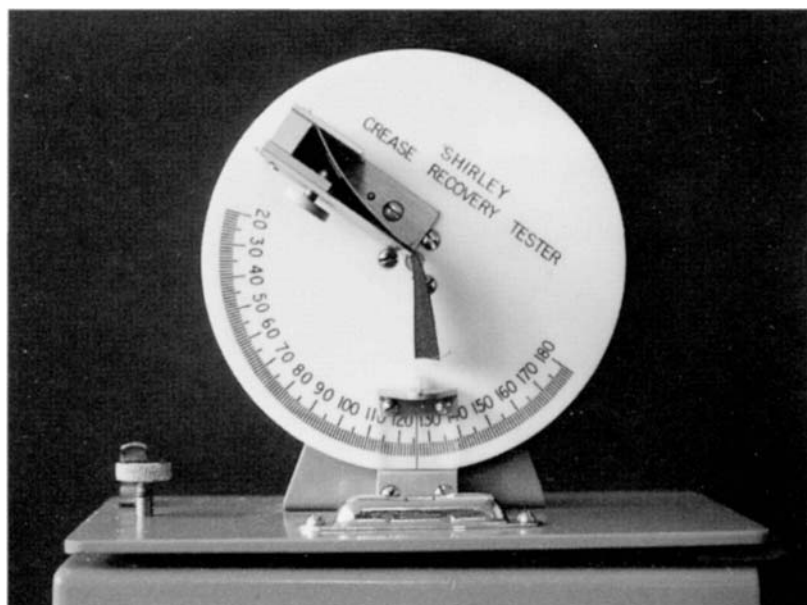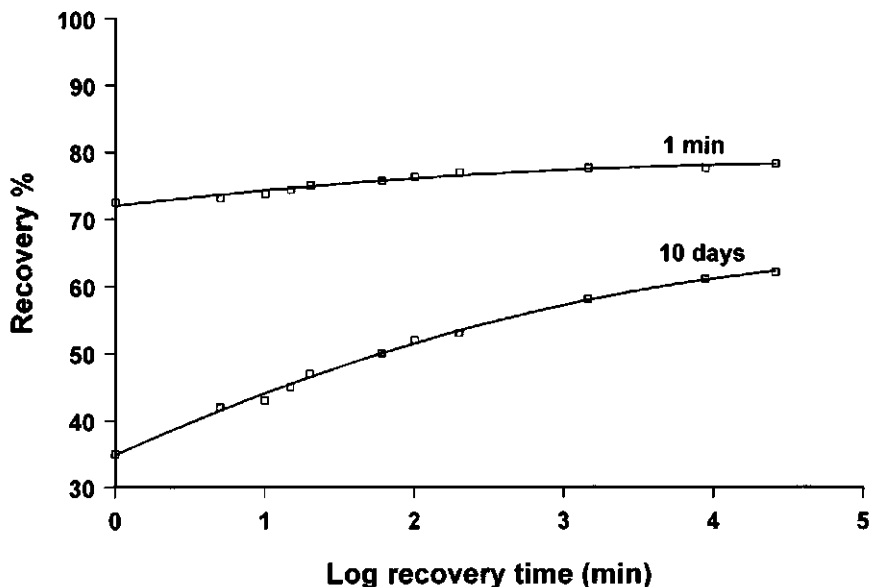
10.7 Crease recovery.

relative importance of these two mechanisms depends on the radius of the curve that the fabric is bent into. The smaller the radius of curvature, the more likely it is that the fibres are actually stretched rather than the curvature being accommodated by fibre displacement.

The unaided recovery of the fabric from creasing depends on the elastic recovery of the fibres, in particular whether the stored elastic energy is sufficient to overcome the friction that resists the movement of the yarns and fibres. Crease recovery in both resin treated and untreated cotton fabrics has been found [5] to increase with decreasing curvature but tending to the same limiting value at less than 100% recovery. This is thought to be because the crease recovery at low curvatures is governed by the frictional effects associated with fibre movement and at high curvatures by the elastic response of the fibre. The effect of the resin treatment is to improve the fibres' elastic recovery but it does not markedly affect the internal friction of the fabric which is dependent on structural factors such as tightness of weave.

The elastic recovery of the fibres is dependent on the time-related effects, such as stress relaxation, detailed in section 5.3.4. Hilyard et al. [5] have shown that the recovery from creasing of a fabric is a function of both the time the crease is maintained and the time allowed for recovery. There is an initial rapid recovery which takes place after removal of the restraint followed by a much slower rate of recovery which decreases with time.

10.8   Improvement in crease recovery as a function of recovery time for two different loading times: 1 min and 10 days. From [5].

The recovery with time of two identical samples, one creased for 1 min and the second creased for 10 days, is shown in Fig. 10.8 which is based on data from [5].

10.1.6 Fabric thickness

It might be expected that the thickness of a fabric is one of its basic properties giving information on its warmth, heaviness or stiffness in use. In practice thickness measurements are rarely used as they are very sensitive to the pressure used in the measurement. Instead fabric weight per unit area is used commercially as an indicator of thickness.

Besides fibres a fabric encloses a large amount of air, which among other things, is responsible for its good thermal insulation properties. When a fabric is compressed, the space between the fibres is decreased until they eventually come into contact with one another. Three stages in the deformation of a fabric have been identified [6]. Firstly the individual fibres protruding from the surface are compressed. The resistance to compression in this region comes from the bending of the fibres. Secondly contact is made with the surface of the yarn, at which point the inter-yarn and/or inter-fibre friction provides the resistance to compression until the fibres are all in contact with one another. In the third stage the resistance is provided by the lateral compression of the fibres themselves.
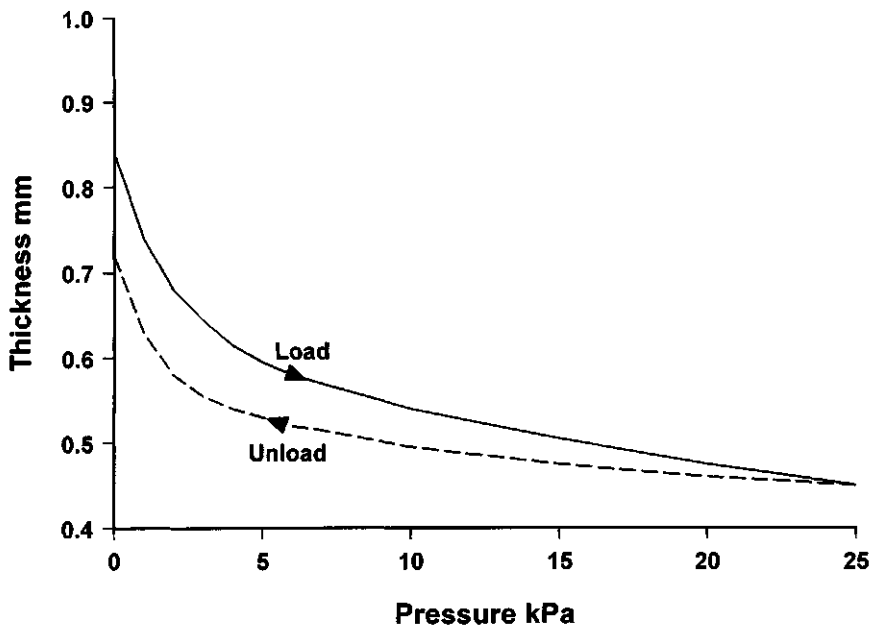
10.9   The change in thickness with pressure.

Matsudaira and Qin [6] consider that in the first and third stages of compression elastic deformation is taking place, whereas in the second stage it is frictional forces that have to be overcome both in compression and also in the subsequent recovery. The forces, which cause the fabric to regain most of its original thickness after compression, come from the elastic recovery of the fibres from bending and lateral compression.

Figure 10.9 shows the change in thickness with pressure for a soft fabric together with the recovery in thickness as the pressure is removed. The steep initial slope of the curve makes it very difficult to measure thickness with any accuracy as a small change in pressure in this region causes a large change in measured thickness. Thickness at zero pressure always has to be obtained by extrapolation of the curve, as a positive pressure is needed to bring any measuring instrument into contact with the fabric surface.

The hysteresis between the loading and unloading curves is due to the internal friction of the fabric. The difference in thickness at a given low pressure between the loading and unloading cycles can be used as a measure of resilience. There is, however, a time element involved as the fabric thickness can recover slowly with time after being compressed.

Matsudaira and Qin [6] consider that it is the second stage of the loading curve that contains information about the handle of the fabric. The greater is the radius of curvature of the transition between the first and third stages, the softer is the fabric in compression.

10.10   Surface hairs ×30.

Optical methods have been put forward as a way of measuring fabric thickness as they do not require any physical contact with the fabric surface. However, the problem of such methods is that of defining precisely where the surface starts. Most fabrics have loose fibres that protrude some way above the surface as shown in Fig. 10.10 and the density of these increases as the surface is approached. In brushed and raised fabrics these surface fibres are an important part of the fabric thickness as is shown in Fig. 10.11. Defining the critical point where the fibres end and the surface proper begins therefore relies on the judgement of the operator, unlike measurements involving surface contact where an agreed pressure can be used. A fabric made from continuous filament yarns is shown in Fig. 10.12 for comparison.

10.1.7 Shear

The behaviour of a fabric when it is subjected to shearing forces is one of the factors that determines how it will perform when subjected to a wide variety of complex deformations during use. The ability of a fabric to deform by shearing differentiates it from other thin sheet materials such as paper or plastic film. It is this property that enables it to undergo more complex deformations than two-dimensional bending and so conform to the contours of the body in clothing applications.
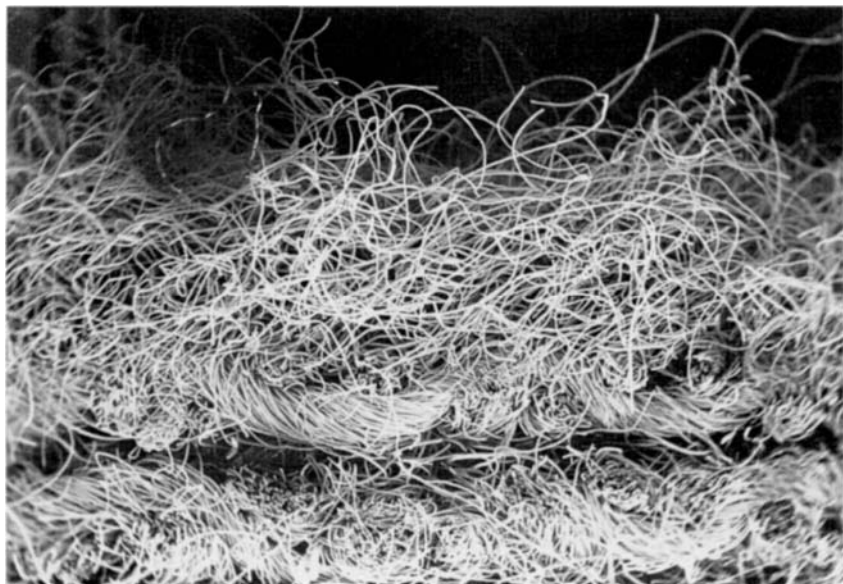
10.11   A fabric with a raised finish ×16.
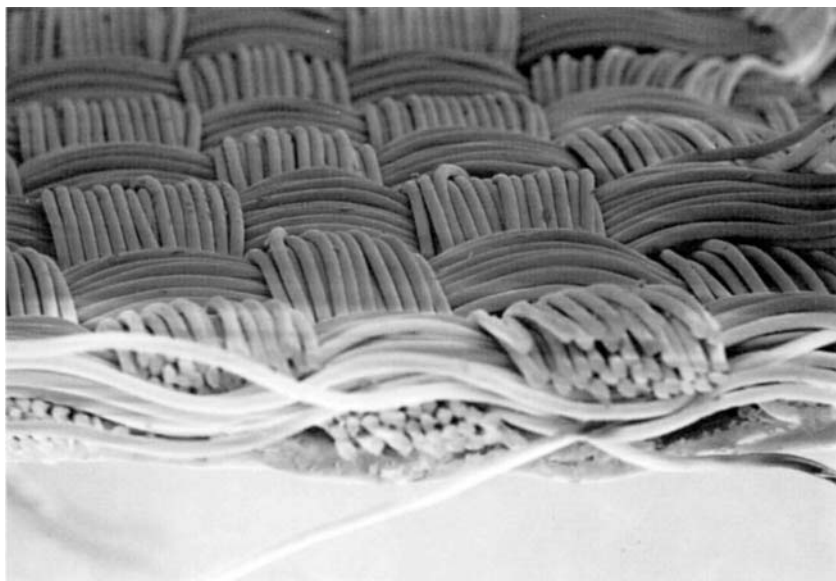
10.12   A continuous filament fabric ×60.
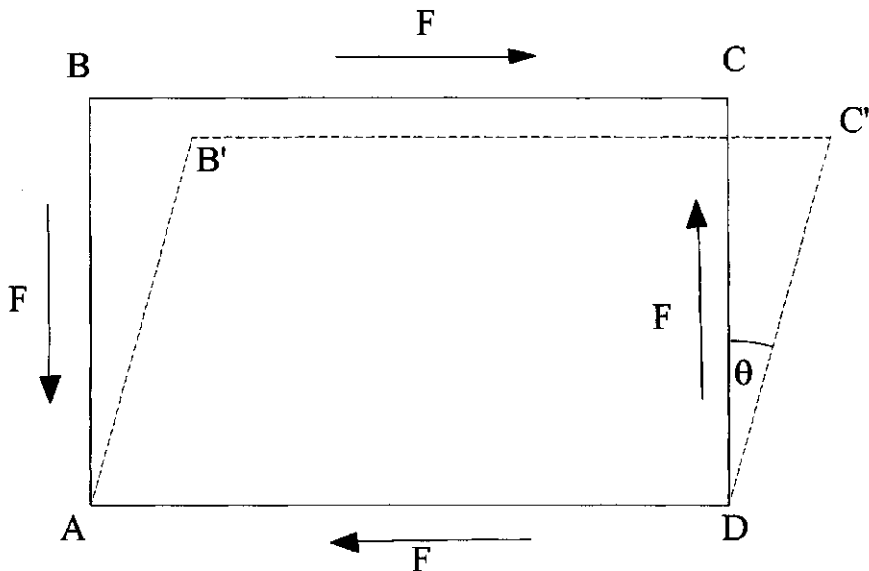
10.13   The distortion due to shear.

The behaviour in shear of textile materials cannot be analysed by the means which are applied to homogeneous materials; however, a simplified analysis of the shear of fabrics has been developed by workers in this area [7]. The basic situation is shown in Fig. 10.13: a rectangular element of material ABCD is subjected to pairs of equal and opposite stresses F which are acting parallel to the side of the element. In the case of simple shear it is assumed that the element deforms to a position shown by AB'C'D in such a way that its area remains constant. The shear strain is defined as the tangent of the change in angle between the side of the element θ. For elastic materials there is a linear relationship between shear stress F and the shear strain $\tan\theta$:

$$F = G\tan\theta$$

where G is the shear modulus.

However, the shear deformation that is found in fabrics is not in general a simple shear at constant area nor does it confrm to any other simple theoretical model such as the length of the sides of the original rectangle remaining constant.

The forces acting when a material is in shear as shown in Fig. 10.13 are equivalent to an extension acting along the diagonal AC and a corresponding compression which acts along the diagonal BD. In practice these forces give rise to problems in measuring shear properties because fabrics subjected to compressive forces in the plane of the material will
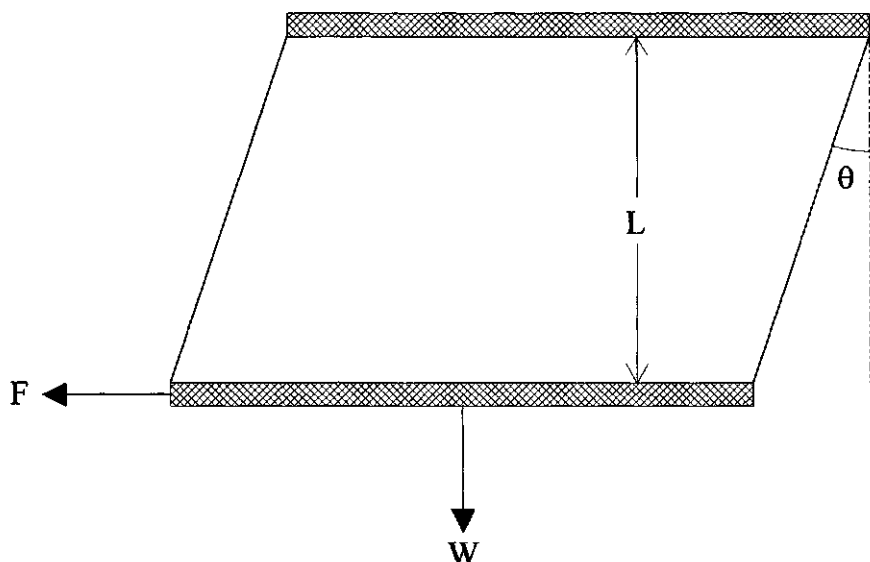
10.14   Diagram of shear test method.

tend to buckle at very low values. It is possible to delay the onset of buck-ling by putting the fabric under tension so as to oppose the compressive force.

A method used [8] to measure shear is shown diagrammatically in a simplified form in Fig. 10.14. In the method the fabric is held rigidly by clamps at the top and bottom. A vertical force W is applied to the fabric by using a weighted bottom clamp in order to delay the onset of buckling. The horizontal force F which is required to move the bottom clamp laterally is measured together with the shear angle θ. However, in this experimental configuration the applied force F is not equal to the shearing force as a quantity $W\tan\theta$ has to be subtracted from the applied force. This factor arises because as the clamp is displaced laterally it is also raised vertically so that an extra force of $W\tan\theta$ has to be supplied in order to do this. Therefore:

Effective shear force $= F - W\tan\theta$

The force is usually expressed as force per unit length.

Treloar has shown [8] that the errors associated with the onset of wrin-kling can be reduced by the use of a narrow specimen with a reduced dis-tance between the clamps instead of a square one. A height:width ratio of 1:10 is considered to be the limit for practical measurements.

More refined versions of this apparatus have been designed [9] to fit directly onto standard tensile testing machines so that shearing can take
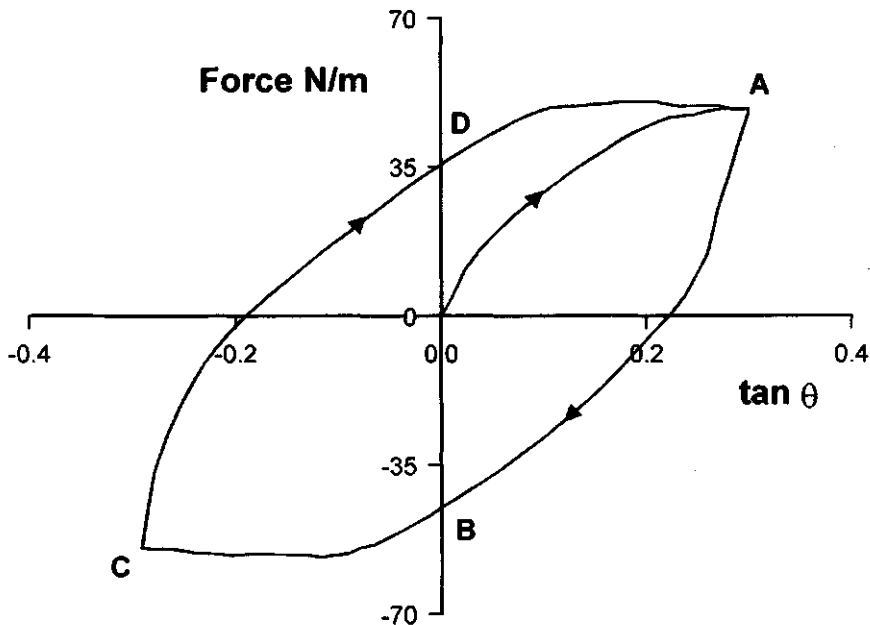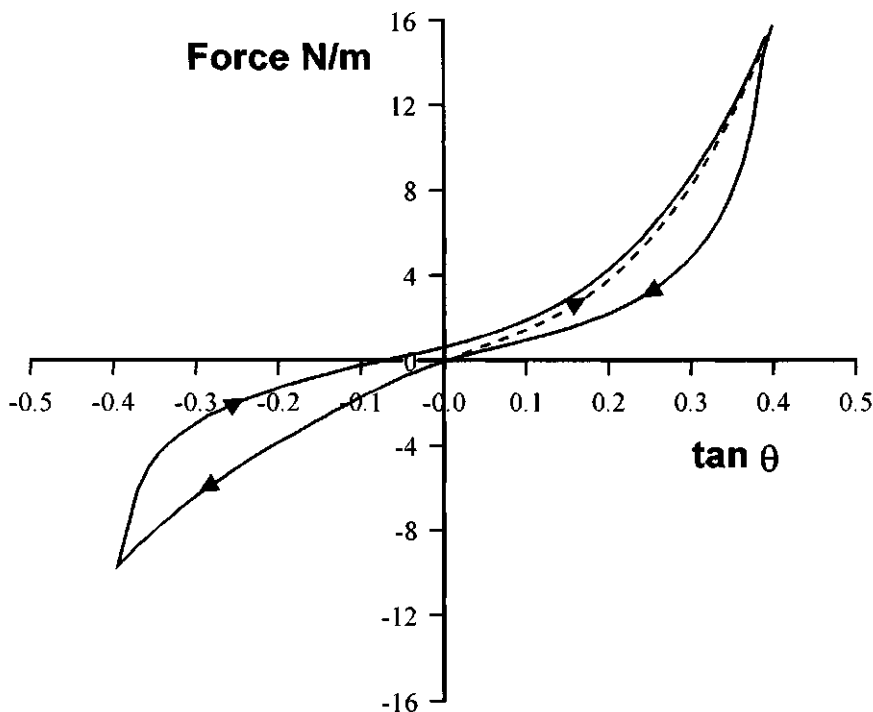
10.15   An example of shear.

place in each direction. With such apparatus a full shear stress–strain curve can be plotted over one full cycle, a specimen of which is shown in Fig. 10.15. Initially the line from the origin is followed to A, at which point the load is reversed and the line then goes through B to C. At this point the sample has been sheared to the same angle in the opposite direction, the load is again reversed and the sample is taken through a further half cycle back to A. The path through ABCD will then be followed on any subsequent shearing cycle. It can be seen from this example that hysteresis occurs when the direction of shear is reversed. This is due to the fact that when a fabric is sheared, most of the force expended is used in overcoming the frictional forces that exist at the intersection of warp and weft. These frictional forces always oppose the applied shearing force whichever direction it is applied. Figure 10.16 shows a fabric that has a lower shear stiffness than that shown in Fig. 10.15.

A number of ways of quantifying shear behaviour have been proposed [9, 10]; these include:

1   The initial shear modulus given by the slope of the curve at the origin.
2   The shear modulus at zero shear angle given by the slope at points B and D (Fig. 10.15).
3   The hysteresis at zero shear angle given by the length BD in the diagram.

10.16   A further example of shear.

10.1.8 Bias extension

Kilby [11] has derived a formula which gives the Young's modulus for a fabric in directions which are at an angle to the warp direction. From this work Leaf and Sheta [12] have shown that if a fabric is extended in a direction that makes an angle of 45° with the warp threads the Young's modulus in that direction (bias direction) E_{45} is connected to the shear modulus G by the following equation:

$$\frac{1}{G} = \frac{4}{E_{45}} - \frac{1 - \sigma_2}{E_1} - \frac{1 - \sigma_1}{E_2}$$

where E_1 and E_2 are the Young's moduli in the warp and weft directions and σ_1 and σ_2 are the fabric Poisson's ratios.

Generally the modulus in the bias direction is much lower than in the warp and weft directions so that the modulus in the bias direction is determined predominantly by the shear modulus. If the warp and weft moduli are much greater than the bias modulus it may be possible to simplify the expression to give:
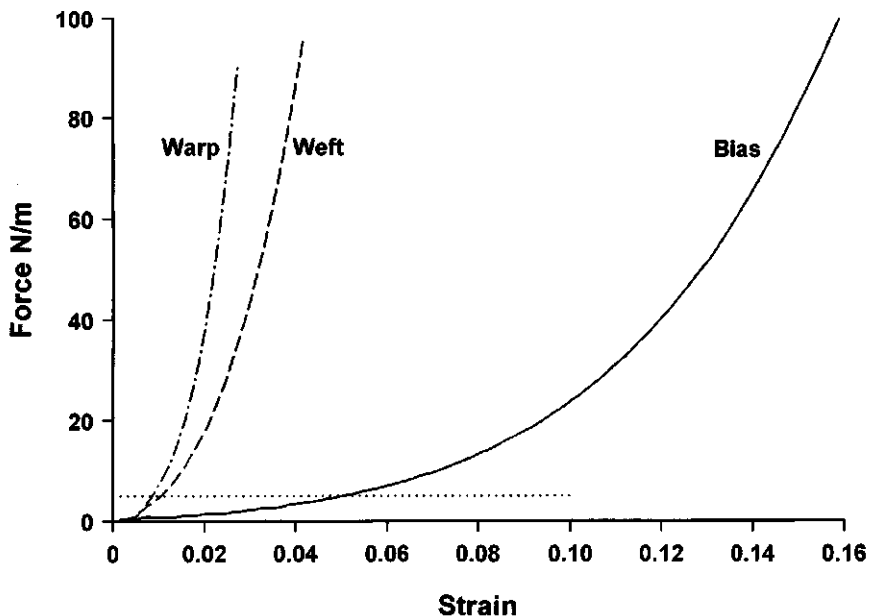
10.17   Force extension curve of warp, weft and bias directions.

$$E_{45} \approx 4G$$

However, Leaf and Sheta [12] demonstrated that when the measured values of warp and weft moduli and Poisson's ratios are taken into account they can significantly alter the calculated shear modulus for some fabrics. Figure 10.17 shows the initial force extension curves for the warp, weft and bias directions of the fabric sample whose shear deformation is shown in Fig. 10.16. The horizontal dotted line corresponds to a force of 5 gf/cm, which is the force which is used in the bias extension measurement for the FAST system (see below).

Spivak and Treloar [13] also analysed the bias extension of fabrics but made the assumption of inextensible warp and weft yarns so that a fabric acts like a trellis pivoted at the thread intersections as shown diagrammatically in Fig. 10.18. They calculated that the shear strain in simple shear is equivalent to:

$$\tan\theta \approx 2e + e^2$$

where e is the bias extension.

For infinitesimal strains this reduces to

$$\text{Shear strain} = 2e$$

Weft   Warp

Bias extension
e
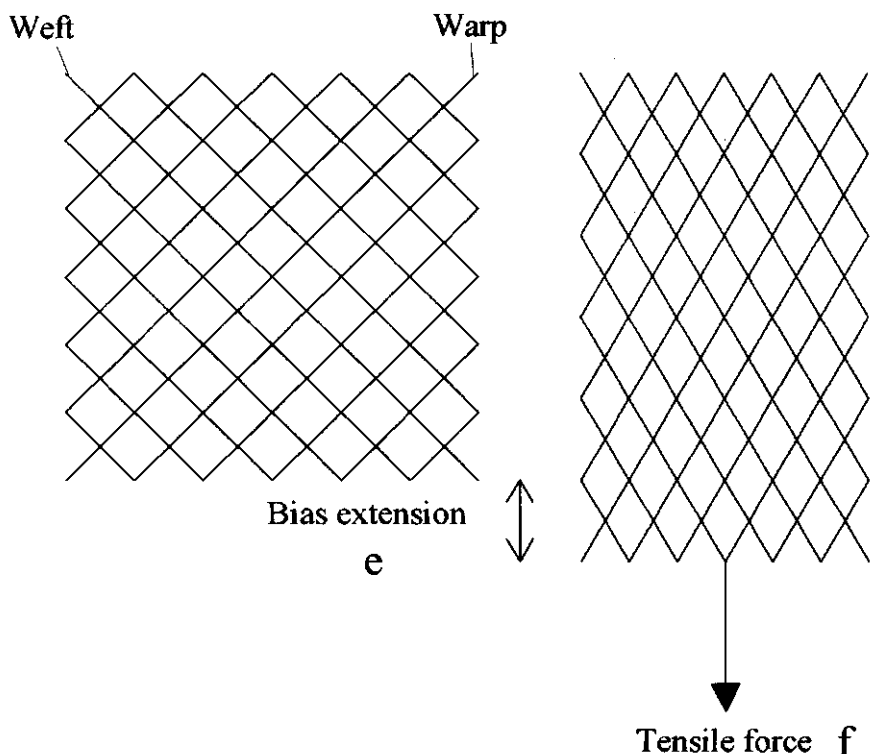
Tensile force f

10.18   The distortion due to bias extension.

The corresponding shear stress for infinitesimal strains is:

$$F - W\tan\theta \approx \frac{f}{2}$$

where f is the applied tensile force and F and W have the same meanings as in simple shear above. The forces are usually expressed in terms of force per unit length.

Spivak and Treloar [13] found experimentally that there were inconsistencies between the fabric properties measured in simple shear and by bias extension. These were considered to be due to a number of factors including: the geometry of the test specimen, the assumption in the analysis that the threads were inextensible and the variation that takes place in the normal stress W during bias extension.

10.1.9 Formability

Lindberg *et al.* [14] investigated the fabric properties that are specifically required in garment construction. Among other properties they identified

the need for a fabric to be able to be compressed in the plane of the fabric without buckling. For instance at the cuff or collar of a garment the fabric is turned over on itself which means that the inner layer of fabric has to conform to a smaller radius of curvature than the outer layer. In order to do this the outer layer has to stretch and the inner layer has to contract. If the fabric is unable to accommodate this change in length the inner layer will pucker. The ability to deform in this manner was given the title of formability and it is a measure of the amount of compression that a fabric can undergo before it buckles.

The measurement of formability is derived from the bending stiffness of the fabric and its modulus of compression. The compression modulus cannot be measured directly as the fabric quickly buckles. It is, however, derived from the extension modulus by assuming that at small strains, around zero on the force extension curve, the slope of the curve is the same at positive and negative stresses as shown in Fig. 10.19. From this assumption:

$$B = CP$$

where B = compression,
    P = force,
    C = compressibility, that is the slope of the force extension curve.
The force required to buckle a sample of fabric of length l is given by:

$$P = k\frac{b}{l^2}$$

where k = constant,
    b = bending rigidity.
Substituting for P in this equation, the amount that a fabric of length l can be compressed before it buckles is then given by:

$$B = k\frac{Cb}{l^2}$$

Within the limits of this equation the product Cb is a specific property of the fabric which determines how much compression it can undergo before buckling. Lindberg terms this product the compression formability F_c. For a given fabric the formability will vary with direction as both the modulus and bending stiffness vary with direction.

10.1.10 Fabric friction

Fabric friction is subject to the same rules as yarn friction which were outlined in Chapter 4. Two main ways are generally used to measure fabric fric-
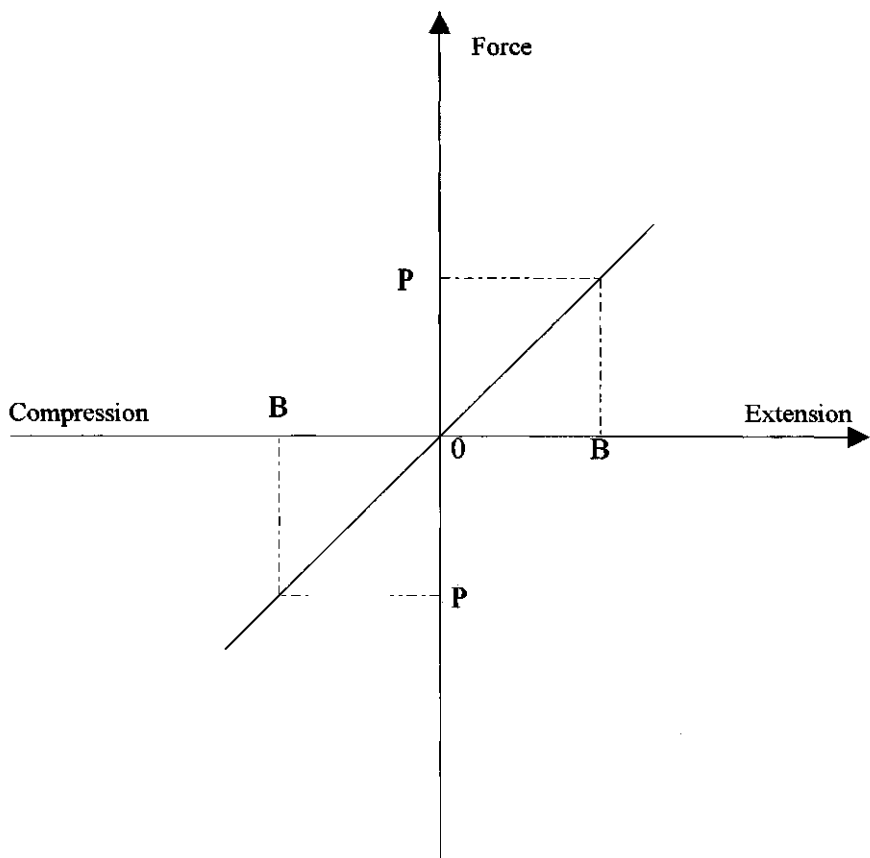
10.19   The slope of a load extension curve around the origin.

tion. One of these methods is shown diagrammatically in Fig. 10.20. In this method a block of mass m is pulled over a flat rigid surface which is covered with the fabric being tested. The line connected to the block is led around a frictionless pulley and connected to an appropriate load cell in a tensile testing machine. This can measure the force F required both to start the block moving and also to keep it moving, thus providing the static and dynamic coefficients of friction from the relation:

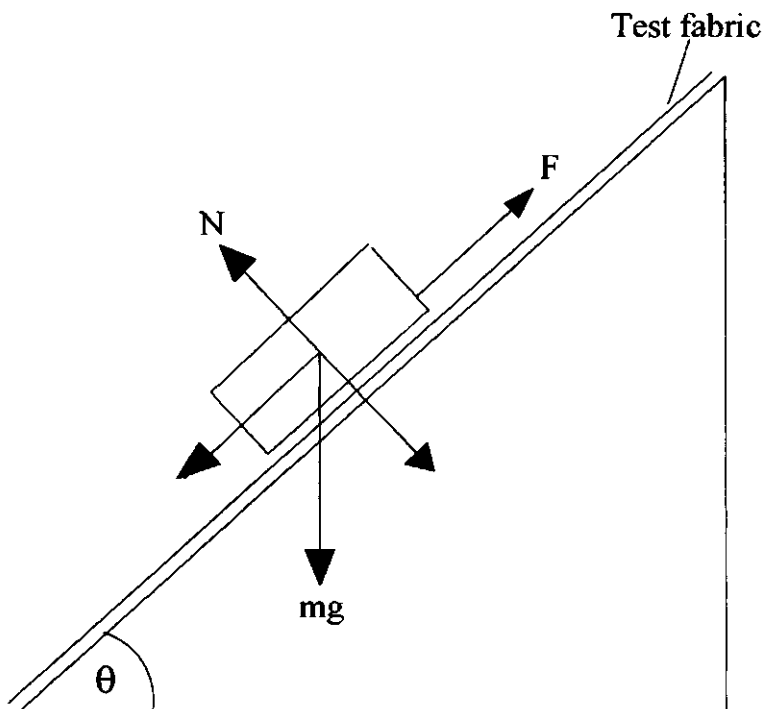$$\text{Coefficient of friction } \mu = \frac{F}{mg}$$

If a chart recorder is available a trace of frictional force can be obtained which contains further information on the frictional properties. Figure 10.21 shows this form of friction measurement as an attachment for a standard tensile tester.
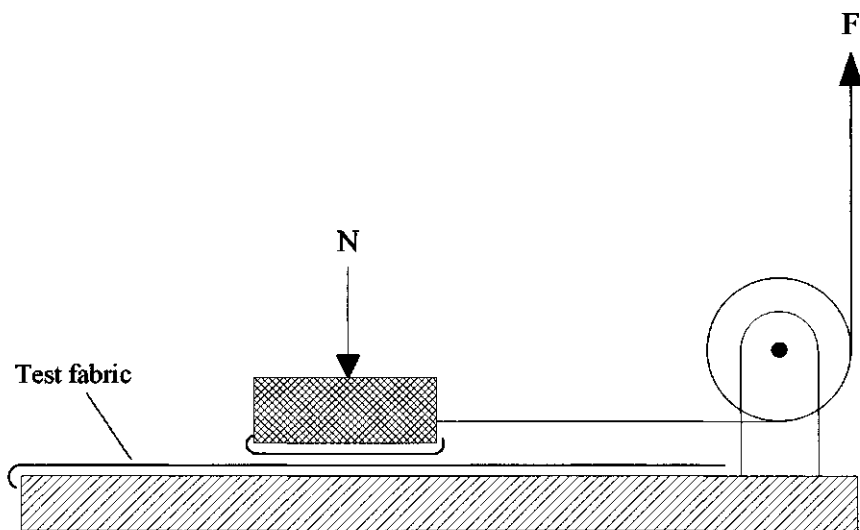
10.20 Friction test.

10.21 Friction apparatus.

10.22   Friction inclined plane.

The coefficient of friction which is measured is specific for the two materials in contact so that the choice of material for the block is important. The block used may be a solid construction of a known material such as wood or steel or it may be covered in fabric. In the case of a fabric covering the choice is between a standard fabric which is used for all friction tests or a portion of the fabric which is being tested. The use of the same fabric for both surfaces is the preferred option as it removes any problems of standardisation of the block surface. A factor that can affect fabric friction measurements is the presence on the fabric of finishes such as softeners which reduce the fabric friction. These can easily be transferred from the fabric to the block so that it needs to be cleaned or covered with a fresh piece of fabric before every test.

The second method used for measuring fabric friction is the inclined plane. This is shown diagrammatically in Fig. 10.22 which shows a block of mass m initially resting on an inclined plane covered with the fabric to be tested. The apparatus is arranged so that the angle of the plane θ can be continuously adjusted until the block just begins to slide. At this point the frictional force F is equal to the component of the mass of the block parallel to the inclined plane:

$$F = mg \sin \theta$$

The normal reaction N is equal to the component of the mass perpendicular to the inclined plane

$$N = mg \cos \theta$$

As the coefficient of friction $\mu = F/N$. Therefore:

$$\mu = \frac{mg \sin \theta}{mg \cos \theta}$$
$$= \tan \theta$$

This procedure as described measures the coefficient of static friction. The coefficient of dynamic friction may be measured by giving the block an initial impetus and determining the angle at which motion just continues.

With textile materials the coefficient of friction is found to be dependent on the normal force N instead of being independent of it as would be expected from Amonton's laws. The relationship:

$$F = aN^n$$

where a is a coefficient (equal to μ only when $n = 1$) and n is the friction index which can vary between 0.67 and 1.0, has been found [15] to fit the experimental data more closely.

10.2 Kawabata system

Fabric handle or hand has traditionally been assessed by experts who arrive at an overall judgement on quality after manipulating the fabric with their hands. This system requires years of experience and can obviously be influenced by the personal preferences of the assessor. Professor Kawabata of Japan has carried out a great deal of work with the aim of replacing the subjective assessment of fabrics by experts with an objective machine-based system which will give consistent and reproducible results [16–18]. It is generally agreed that the stimuli leading to the psychological response of fabric handle are entirely determined by the physical and mechanical properties of fabrics. In particular the properties of a fabric that affect its handle are dependent on its behaviour at low loads and extensions and not at the level of load and extension at which fabric failure occurs. It is this region of fabric behaviour that has traditionally been measured and for which specifications have been written.

10.2.1 Subjective assessment of fabric handle

The first part of Kawabata's work was to find agreement among experts on what aspects of handle were important and how each aspect contributed to

Table 10.1 The definitions of primary hand

Hand		Definition
Japanese	English	
Koshi	Stiffness	A stiff feeling from bending property. Springy property promotes this feeling. High-density fabrics made by springy and elastic yarn usually possess this feeling strongly.
Numeri	Smoothness	A mixed feeling come from smooth and soft feeling. The fabric woven from cashmere fibre gives this feeling strongly.
Fukurami	Fullness and softness	A bulky, rich and well-formed feeling. Springy property in compression and the thickness accompanied with warm feeling are closely related with this feeling (*fukurami* means 'swelling').
Shari	Crispness	A feeling of a crisp and rough surface of fabric. This feeling is brought by hard and strongly twisted yarn. This gives a cool feeling. This word means crisp, dry and sharp sound made by rubbing the fabric surface with itself).
Hari	Anti-drape stiffness	Anti-drape stiffness, no matter whether the fabric is springy or not. (This word means 'spread').
Kishimi	Scrooping feeling	Scrooping feeling. A kind of silk fabric possesses this feeling strongly.
Shinayakasa	Flexibility with soft feeling	Soft, flexible and smooth feeling.
Sofutosa	Soft touch	Soft feeling. A mixed feeling of bulky, flexible and smooth feeling.

the overall rating of the fabric. For each category of fabric four or five properties such as stiffness, smoothness and fullness were identified and given the title of primary hand. The original Japanese terms for primary hand together with their approximate English meaning are shown in Table 10.1. These terms demonstrate the difficulty of describing handle and the apparent overlap of some of the terms used.

Primary hand values were rated on a ten point scale where ten is a high value of that property and one is its opposite. The properties that are regarded as primary hand and the values of these that are considered satisfactory differ among fabric categories such as men's summer suiting,

Table 10.2 Primary hands for men's winter suits

Koshi
Numerii
Fukurami

Table 10.3 Primary hands for men's summer suits

Koshi
Fukurami
Shari
Hari

Table 10.4 Primary hands for women's thin dress fabrics

Koshi
Hari
Shari
Fukurami
Kishimi
Shinayakasa

men's winter suiting and ladies' dress fabrics. Some of the properties considered primary for these categories are shown in Tables 10.2–10.4. The primary hand values are combined to give an overall rating for the fabric in its category. This is known as the total hand value and it is rated on a five point scale where five is the best rating. The primary hand values are converted to a total hand value using a translation equation for a particular fabric category which has been determined empirically.

As a result of this work books of fabric samples for each of the primary hands were produced by the Hand Evaluation and Standardisation Committee (HESC) together with standard samples of total hand in each of five categories:

1   Men's winter/autumn suiting.
2   Men's summer suiting for a tropical climate.
3   Ladies' thin dress fabrics.
4   Men's dress shirt fabrics.
5   Knitted fabrics for undershirts.

The purpose of these standards is to act as a reference to help the experts to produce more uniform assessments of fabric handle.

A problem with the system as originally conceived is that of there being a 'best' fabric in each category; that is, a fabric that scored the maximum points for total hand value in a particular category would be universally regarded as the best fabric that could be produced for that end use. It has been found [19] that although this may be true within one country there are differences between countries in their perception of the mix of properties required for a particular end use.

10.2.2 Objective evaluation of fabric handle

The second stage of Kawabata's work was to produce a set of instruments with which to measure the appropriate fabric properties and then to correlate these measurements with the subjective assessment of handle. The aim was that the system would then enable any operator to measure reproducibly the total hand value of a fabric.

The system which was produced is known as the KESF system and consists of four specialised instruments:

FB1   Tensile and shearing
FB2   Bending
FB3   Compression
FB4   Surface friction and variation

These instruments measure the tensile, compression, shear and bending properties of the fabric together with the surface roughness and friction. A total of 16 parameters are measured, all at low levels of force, which are intended to mimic the actual fabric deformations found in use. The quantities measured are listed in Table 10.5.

The properties are measured in the following ways.

The tensile properties are measured by plotting the force extension curve between zero and a maximum force of 500 gf/cm (4.9 N/cm), the recovery curve as the sample is allowed to return to its original length is also plotted to give the pair of curves shown in Fig. 10.23. From these curves the following values are calculated:

Tensile energy WT = the area under the load strain curve (load increasing)

$$\text{Linearity LT} = \frac{\text{WT}}{\text{area triangle OAB}}$$

$$\text{Resilience RT} = \frac{\text{area under load decreasing curve}}{\text{WT}} \times 100\%$$

The compressional properties are measured by placing the sample between two plates and increasing the pressure while continuously

Table 10.5 The 16 parameters measured by the Kawabata system describing
fabric mechanical and surface properties

Tensile	LT	Linearity of load extension curve
	WT	Tensile energy
	RT	Tensile resilience
Shear	G	Shear rigidity
	2HG	Hysteresis of shear force at 0.5°
	2HG5	Hysteresis of shear force at 5°
Bending	B	Bending rigidity
	2HB	Hysteresis of bending moment
Lateral compression	LC	Linearity of compression thickness curve
	WC	Compressional energy
	RC	Compressional resilience
Surface characteristics	MIU	Coefficient of friction
	MMD	Mean deviation of MIU
	SMD	Geometrical roughness
Fabric construction	W	Fabric weight per unit area
	T_0	Fabric thickness

monitoring the sample thickness up to a maximum pressure of $50\,\text{gf/cm}^2$ $(0.49\,\text{N/cm}^2)$. As in the case of the tensile properties the recovery process is also measured. The quantities LC, WC and RC are then calculated in the same manner as LT, WT and RT above.

In order to measure the shear properties a sample of dimensions $5\,\text{cm} \times 20\,\text{cm}$ is sheared parallel to its long axis keeping a constant tension of $10\,\text{gf/cm}$ $(98.1\,\text{mN/cm})$ on the clamp. The following quantities are then measured from the curve as shown in Fig. 10.24:

Shear stiffness G = slope of shear force–shear strain curve

Force hysteresis at shear angle of 0.5° 2HG = hysteresis width of curve at 0.5°

Force hysteresis at shear angle of 5° 2HG5 = hysteresis width of curve at 5°

In order to measure the bending properties of the fabric the sample is bent between the curvatures -2.5 and $2.5\,\text{cm}^{-1}$ the radius of the bend being 1/curvature as shown in Fig. 10.25. The bending moment required to give this curvature is continuously monitored to give the curve shown in Fig. 10.26. The following quantities are measured from this curve:

Bending rigidity B = slope of the bending moment – curvature curve

Moment of hysteresis 2HB = hysteresis width of the curve

The surface roughness is measured by pulling across the surface a steel wire 0.5 mm in diameter which is bent into a U shape as shown in Fig. 10.27.
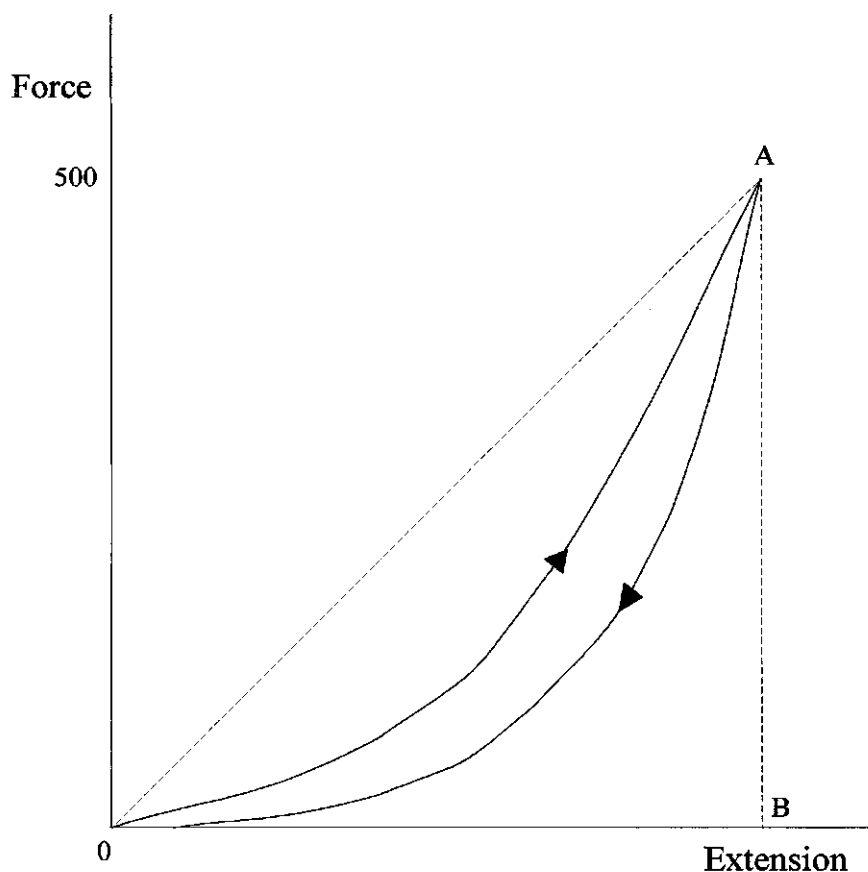
10.23   Load extension curves for KESF.

The contact force that the wire makes with the surface is 10 gf (98.1 mN). A plot of the height variation against distance is shown in Fig. 10.28. The value that is measured is SMD = mean deviation of surface roughness.

The surface friction is measured in a similar way by using a contactor which consists of ten pieces of the same wire as above as is shown in Fig. 10.29. A contact force of 50 gf is used in this case and the force required to pull the fabric past the contactor is measured.

A plot of friction against distance travelled is shown in Fig. 10.30 from which the following values are calculated:
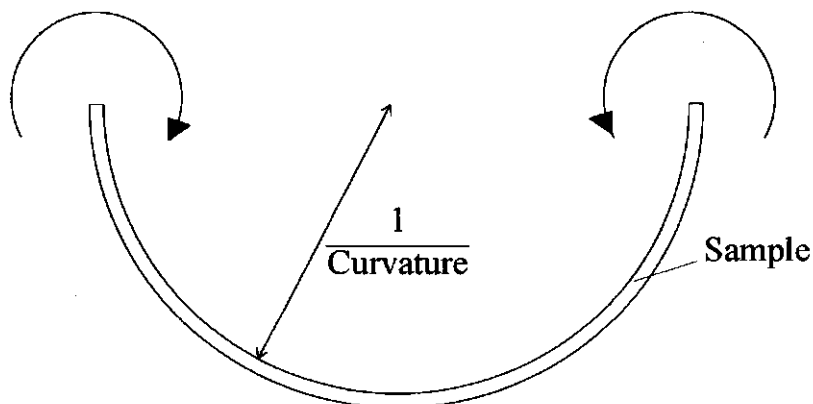
MIU = mean value of coefficient of friction
MMD = mean deviation of coefficient of friction

All these measurements are then converted into primary hand values by a set of translation equations and the total hand values are then
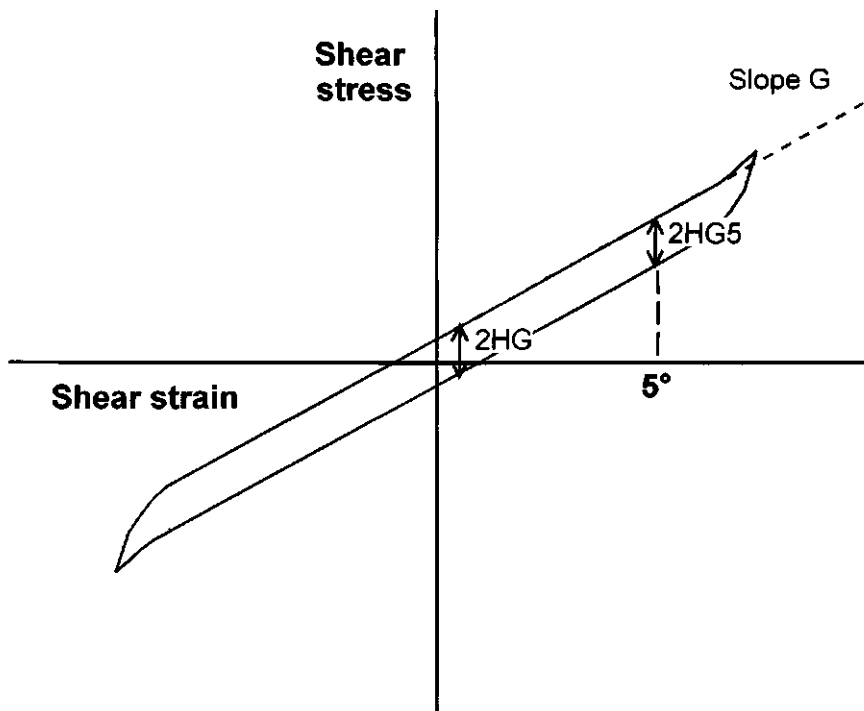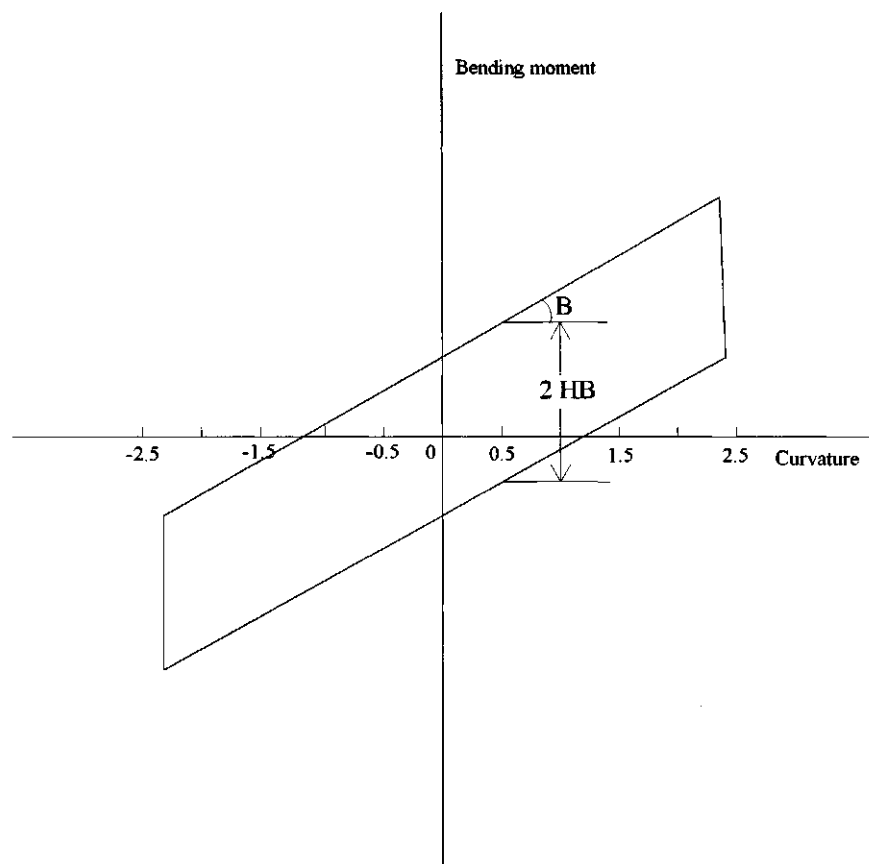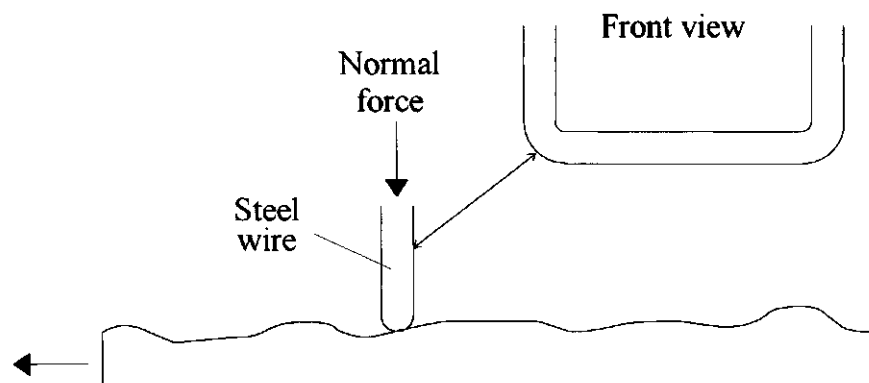
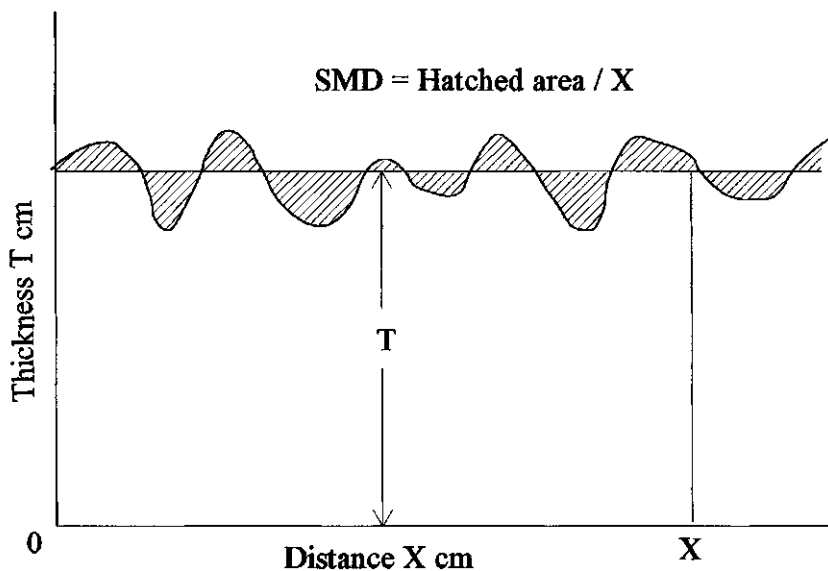10.24   Shear curve for KESF.

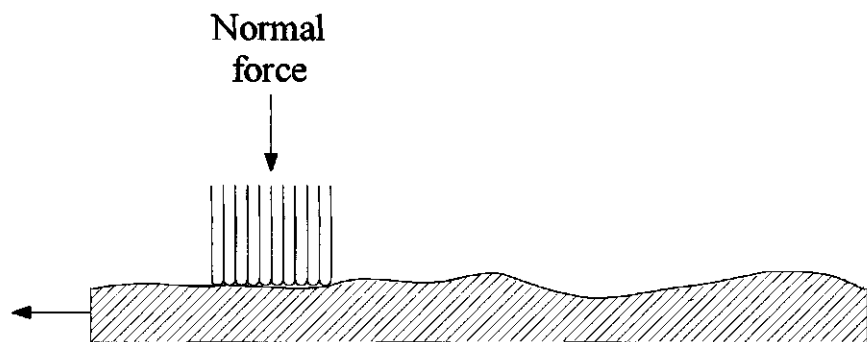10.25   Forces involved in fabric bending.

10.26   Plot of bending moment against curvature.

10.27   Surface roughness measurement.

10.28   Surface thickness variation.

10.29   Surface friction measurement.

calculated from these primary hand values by the use of a second trans-
lation equation. Typical results for a summer suiting fabric are shown in
Table 10.6.

The results can also be displayed in the form of a chart as shown dia-
grammatically in Fig. 10.31. Here the results have been normalised by the
standard deviation of each of the corresponding characteristic values or
hand values using the following relationship:

$$x = \frac{(X - \overline{X})}{\sigma}$$

Table 10.6 Hand values for a summer suiting

Total hand	
THV	3.5
Primary hand	
Koshi	6.1
Shari	6.5
Fukurami	3.5
Hari	6.8
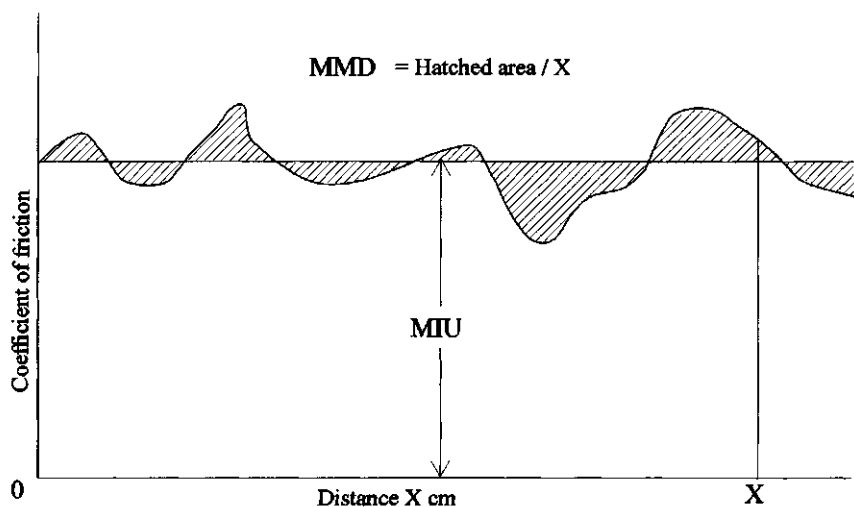
10.30   Surface friction variation. MIU is the mean value of the coefficient of friction.

where: x = normalised mean,
X = measured parameter,
$\bar{X}$ = mean value of property for typical fabric,
σ = standard deviation of property for typical fabric.

By normalising the results they can all be plotted on the same scale. If the values on the chart are joined together a 'snake' chart is produced from which it can be readily seen which fabrics differ from the average. Guidelines can then be drawn on the chart as in Fig. 10.31 showing the good zone into which the parameters of high-quality fabrics fall.

10.3   FAST: Fabric Assurance by Simple Testing

This system is specifically designed by CSIRO for use by tailors and worsted finishers to highlight problems that may be encountered in making a fabric
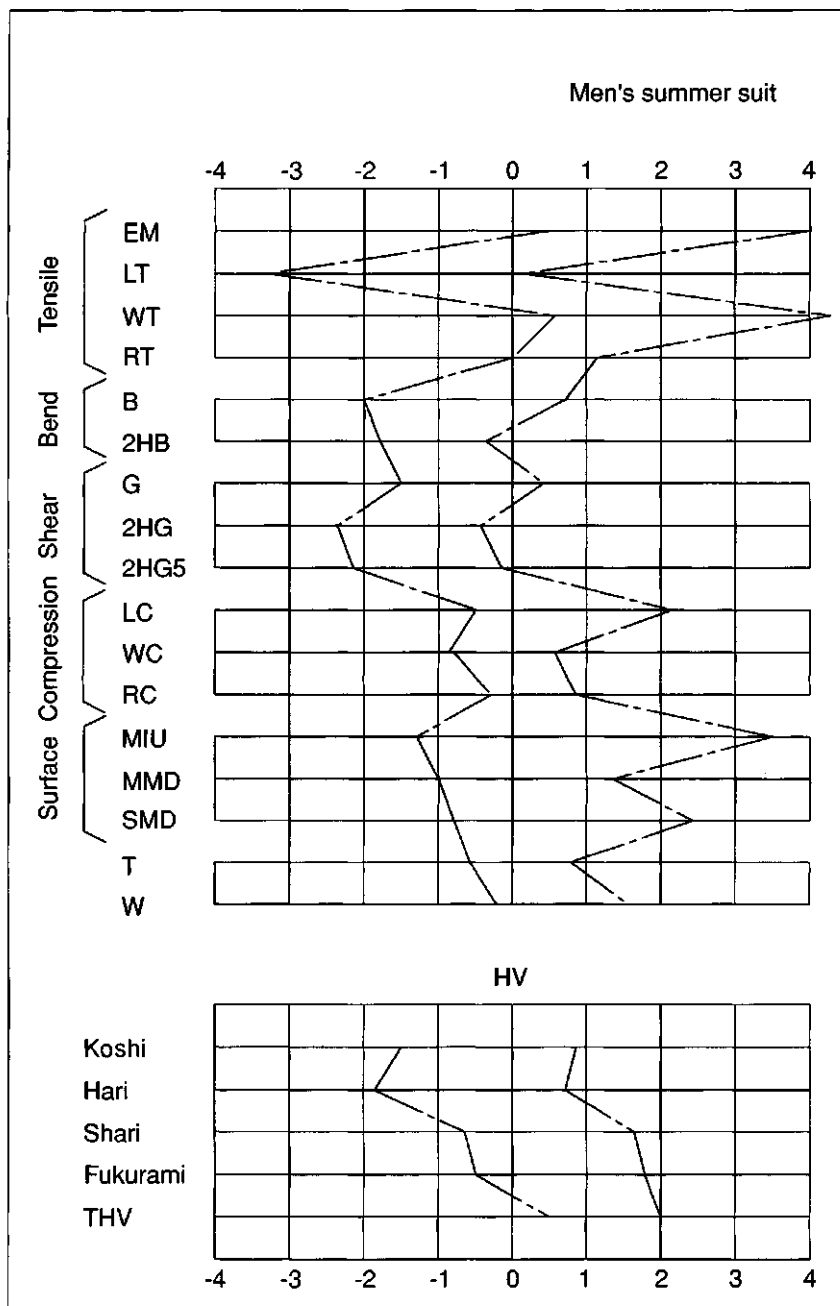
10.31   HESC data chart.

into garments [20]. The system is claimed to be much simpler and more robust than the KESF system.

Most of the parameters measured distinguish between loosely constructed fabrics which readily distort and the more tightly constructed ones which do not distort as easily. The fabrics that are easily distorted can be the source of problems when they are handled because the forces which are involved in cutting them or feeding them into machines can change the shape and size of the fabric. On the other hand firmly constructed fabrics, although they can be handled easily, can give problems in some areas of garment construction where a certain amount of distortion is deliberately introduced into the fabric. Typical areas are moulding and overfeeding of seams where a three-dimensional effect is being produced.

The FAST system comprises four test methods:

FAST 1 Compression meter
FAST 2 Bending meter
FAST 3 Extension meter
FAST 4 Dimensional stability test

The first three methods have purpose-designed instruments whereas the fourth method requires no specialised equipment.

10.3.1 Compression

The fabric thickness is measured on a $10\,cm^2$ area at two different pressures, firstly at $2\,gf/cm^2$ ($19.6\,mN/cm^2$) and then at $100\,gf/cm^2$ ($981\,mN/cm^2$) using the apparatus shown in Fig. 10.32. This gives a measure of the thickness of the surface layer which is defined as the difference between these two values. The fabric is considered to consist of an incompressible core and a compressible surface. The fabric thickness measurements are repeated after steaming on an open Hoffman press for 30s in order to determine the stability of the surface layer.

10.3.2 Bending length

The fabric bending length of the fabric is measured using an automated test method, shown in Fig. 10.33, which is similar to that described in BS 3356 but which uses a strip 5cm wide. The bending rigidity, which is related to the perceived stiffness, is calculated from the bending length and mass/unit area. Fabrics with low bending rigidity may exhibit seam pucker and are prone to problems in cutting out. They are difficult to handle on an automated production line. A fabric with a higher bending rigidity may be more
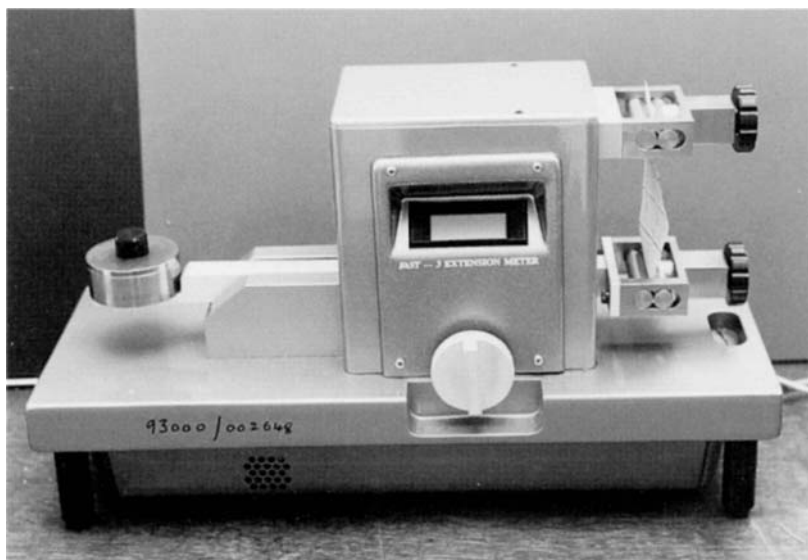
10.32 FAST compression meter.
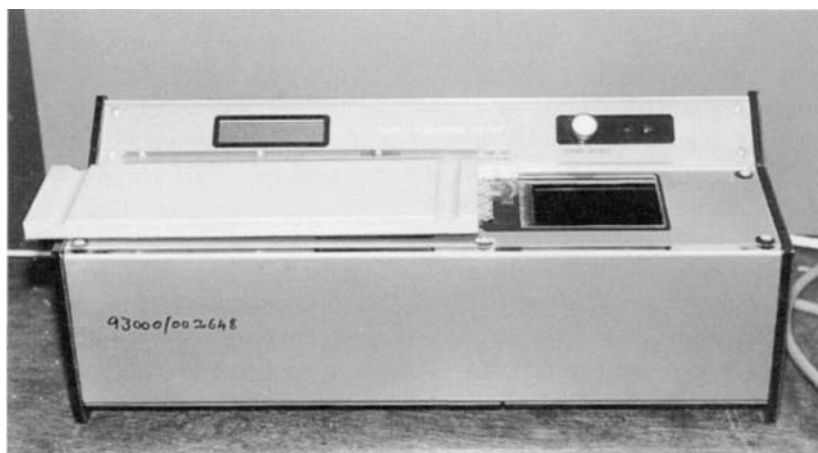
10.33 FAST bending meter.

manageable during sewing, resulting in a flat seam but may cause problems during moulding.

$$\text{Bending rigidity} = 9.8 \times 10^{-6} MC^3 \ (\mu\text{N m})$$

where C is bending length and M is mass per unit area.

10.34   FAST extension meter.

10.3.3 Extensibility

The extension of the fabric is measured in the warp and weft directions at three fixed forces of 5, 20 and 100 gf/cm (49, 196 and 981 mN/cm) (sample size tested 100 mm × 50 mm) using the apparatus shown in Fig. 10.34. The extension is also measured on the bias in both directions but only at a force of 5 gf/cm (49 mN/cm): this enables the shear rigidity to be calculated.
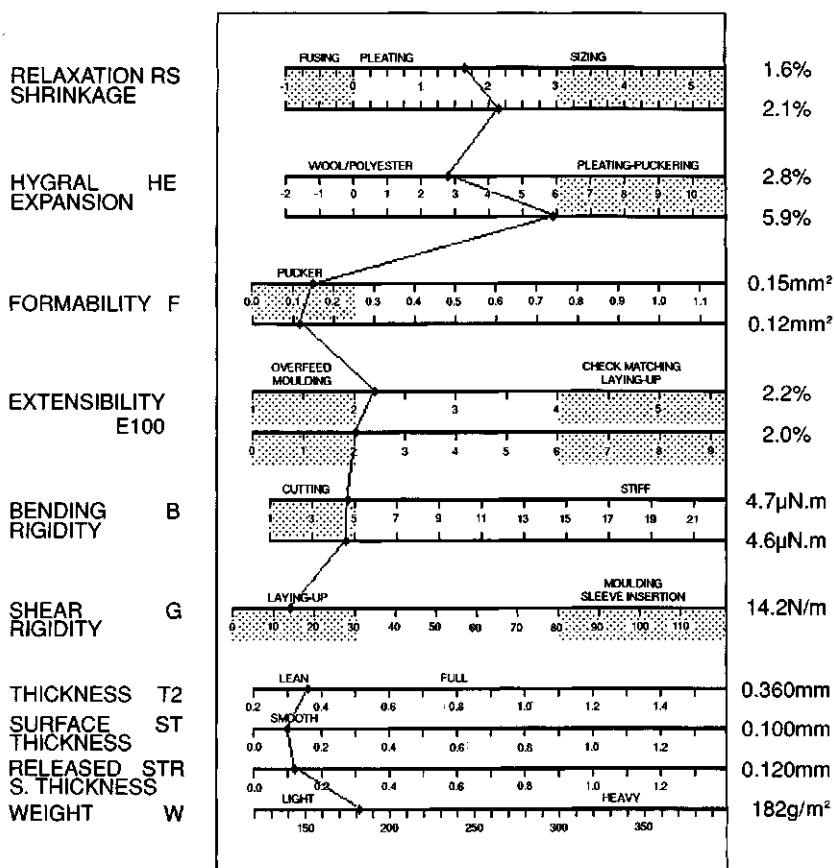
Low values of extension give problems in moulding, produce seam pucker and give difficulties in producing overfed seams. High values of extension give problems in laying up and such fabrics are easily stretched during cutting with a consequent shrinkage to a smaller size afterwards. Problems also occur in cases of high extension with matching checks and patterns owing to the ease with which the material distorts. Low values of shear rigidity have a similar effect to high values of extension as the fabric easily distorts, giving rise to difficulties in laying up, marking and cutting. A high value of shear rigidity means a fabric that is difficult to mould and where there are problems with sleeve insertion.

The formability of the fabric is calculated from the longitudinal compressibility and the bending rigidity. For the purposes of calculation the longitudinal compression modulus is assumed to be equal to the extension modulus. The formability measures the degree of compression in the fabric plane sustainable by it before buckling occurs. Low values of formability indicate a fabric that is likely to pucker when made into a collar or cuff.

F A S T CONTROL CHART FOR TAILORABILITY

FAB.ID   : tw25/75
END USE :   SOURCE:
REMARK :   DATE   :

RELAXATION RS SHRINKAGE	1.6% / 2.1%
HYGRAL HE EXPANSION	2.8% / 5.9%
FORMABILITY F	0.15mm² / 0.12mm²
EXTENSIBILITY E100	2.2% / 2.0%
BENDING RIGIDITY B	4.7µN.m / 4.6µN.m
SHEAR RIGIDITY G	14.2N/m
THICKNESS T2	0.360mm
SURFACE ST THICKNESS	0.100mm
RELEASED STR S. THICKNESS	0.120mm
WEIGHT W	182g/m²

©1989 CSIRO Division of Wool Technology

10.35   FAST chart.

10.3.4 Dimensional stability

In order to measure dimensional stability the fabric is dried in an oven at 105 °C and measured in both the warp and weft directions to give the length L_1.

It is then soaked in water and measured wet to give the wet relaxed length L_2. It is then redried in the oven and measured again to give the length L_3. The following values for dimensional stability are then calculated from these measurements for both warp and weft:

$$\text{Relaxation shrinkage} = \frac{L_1 - L_3}{L_1} \times 100\%$$

$$\text{Hygral expansion} = \frac{L_2 - L_3}{L_3} \times 100\%$$

High values of shrinkage in a fabric produce problems of garment sizing due to panels shrinking; seam pucker may form in the final pressing stage. A small amount of shrinkage (usually below 1%) is required for fabrics intended to be pleated.

A high value of hygral expansion can lead to loss of appearance in humid conditions as the fabric increases in dimensions under such conditions. The seams can also pucker in these conditions as the sewing thread prevents relative movement of the fabrics.

The whole of the results are plotted on a chart, shown in Fig. 10.35, which is similar to the chart produced by the KESF system (Fig. 10.31). The shaded areas show regions where the fabric properties are likely to cause problems in garment manufacture. These limits have been determined from experience and apply only to the worsted suitings for which the system was originally designed.

General reading

Bishop D P, 'Fabrics: sensory and mechanical properties', *Text Progress*, 1996 **26** (3).

References

1. Peirce F T, 'The handle of cloth as a measurable quantity', *J Text Inst*, 1930 **21** T377.
2. BS 3356 Method for determination of bending length and flexural rigidity of fabrics.
3. BS 5058 Method for the assessment of drape of fabrics.
4. BS EN 22313 Textile fabrics. Determination of the recovery from creasing of a horizontally folded specimen by measuring the angle of recovery.
5. Hilyard N C, Elder H M and Hari P K, 'Time effects and the measurement of crease recovery', *J Text Inst*, 1972 **63** 627.
6. Matsudaira M and Qin H, 'Features and mechanical parameters of a fabric's compressional property', *J Text Inst*, 1995 **86** 476.
7. Hearle J W S, 'Shear and drape of fabrics,' in Hearle J W S, Grosberg P and Backer S, 'Structural mechanics of fibres, yarns, and fabrics', Vol 1, Wiley, Chichester, 1969.
8. Treloar L R G, 'The effect of test-piece dimensions on the behaviour of fabrics in shear', *J Text Inst*, 1965 **56** T533.
9. Cusick G E, 'The resistance of fabrics to shearing forces', *J Text Inst*, 1961 **52** T395.

10. Kothari V K and Tandon S K, 'Shear behaviour of woven fabrics', *Text Res J*, 1989 **59** 142.
11. Kilby W F, 'Planar stress–strain relationships in woven fabrics', *J Text Inst*, 1963 **54** T9.
12. Leaf G A V and Sheta M F, 'The initial shear modulus of plain-woven fabric', *J Text Inst*, 1984 **75** 157.
13. Spivak S M and Treloar L R G, 'The behavior of fabrics in shear', *Text Res J*, 1968 **38** 963.
14. Lindberg J, Waesterberg L and Svenson R, 'Wool fabrics as garment construction materials', *J Text Inst*, 1960 **51** T1475.
15. Carr W W, Posey J E and Tincher W C, 'Frictional characteristics of apparel fabrics', *Text Res J*, 1988 **58** 129–136.
16. Kawabata S, *The Standardisation and Analysis of Hand Evaluation*, 2nd edn., The Textile Machinery Society of Japan, Osaka, Japan, 1980.
17. Kawabata S and Masako N, 'Fabric performance in clothing and clothing manufacture', *J Text Inst*, 1989 **80** 19.
18. Kawabata S and Masako N, 'Objective measurement of fabric mechanical property and quality: its application to textile and clothing manufacturing', *Int J Clothing Sci Tech*, 1991 **3** 7.
19. Behery H M, 'Comparison of fabric hand assessment in the United States and Japan', *Text Res J*, 1986 **56** 227–240.
20. Ly N G, Tester D H, Buckenham P, Roczniok A F, Adriaansen A L, Scaysbrook F and De Jong S, 'Simple instruments for quality control by finishers and tailors', *Text Res J*, 1991 **61** 402.