8

Mechanical properties of fabrics with seams

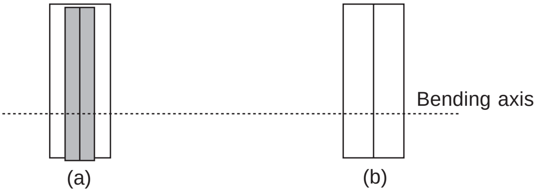
8.1 Introduction

A seam is the assembly method that joins fabric pieces together to form the parts or whole of a garment. Seam assembly is the method most typically used on garments. In order to create a seam, a fabric is cut into pieces and sewn together with stitches. Various seams can be obtained by combining different fabric cutting, joining and stitching parameters, and this will lead to substantial variation in fabric drape performance. Thus, investigation of the impact of a seam on fabric drape performance can help with understanding, evaluation and assurance of the appearance of the final garment.

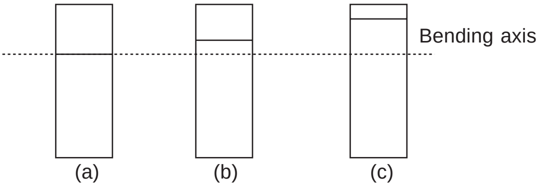
8.2 Effect of seams on fabric bending/drape properties

8.2.1 Classification of fabric seams

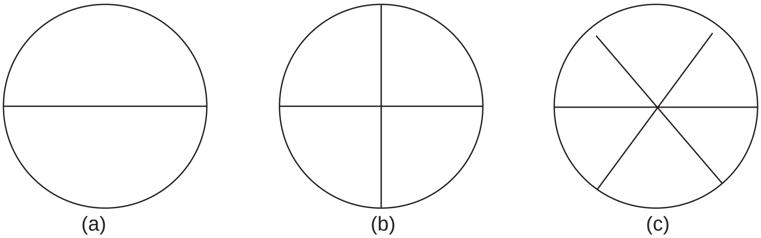
The plain seam is the one most extensively found in apparel. It is the simplest seam type – a single row of lockstitches joins two pieces of fabric together. Thus, investigation of the effect of a plain seam on fabric drape has significant value for both the textile and the clothing industries. Plain seams can be classified into four types, i.e. vertical seam, horizontal seam, radial seam and circular seam. A vertical seam is a plain seam lengthwise sewn in the middle on a rectangular fabric strip, and is perpendicular to the bending axis as shown in Fig. 8.1. A horizontal seam is a plain seam located in the direction parallel to the bending axis of a fabric cantilever (see Fig. 8.2). Fabrics with both vertical and horizontal seams will drape in two dimensions. Radial seam refers to the kind of plain seam which is sewn across a circular specimen through its centre, as illustrated in Fig. 8.3. Usually, a radial seam drapes under its own weight perpendicular to the tangent of the pedestal, while a circular seam is the kind of plain seam sewn around a circular specimen with a radius from the specimen's centre, as illustrated in Fig. 8.4. A circular seam



8.1 Fabric strip with vertical seams: (a) back side of fabric with seam allowances; (b) front side of fabric with a plain seam at centre.



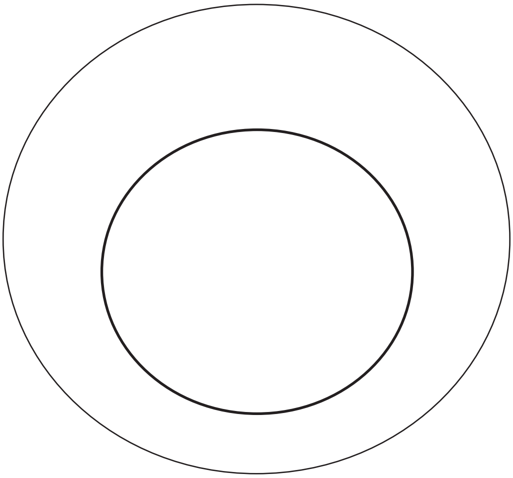
8.2 The horizontal seam at three positions from the free tip end respectively: (a) 0 mm; (b) 25 mm; and (c) 5 mm.



8.3 Radial seams along different directions: (a) one radial seam on the weft of a fabric; (b) two radial seams on the warp and weft of a fabric; (c) four radial seams on the warp, weft, 45° and 135° bias directions.

can be located either in-plane or out-of-plane of the pedestal, depending on the seam position. It drapes in a direction parallel to the circumference of the pedestal. Fabrics with radial and circular seams thus usually drape in three dimensions.

Another seam classification method is based on the direction of drape: vertical seam drape is associated with vertical and radial seams while horizontal seam drape is associated with horizontal and circular seams. Hence the difference between vertical and radial seams lies in the fact that fabrics with a vertical seam drape in two dimensions while fabrics with a radial seam drape in three dimensions. In addition to this, measuring methods for drape of fabrics with vertical and radial seams are also different. Usually, bending length is used to evaluate drape of fabrics with a vertical seam while drape of fabrics with radial seams can be evaluated using the drape coefficient.



8.4 A circular seam on a circular fabric.

Both horizontal and circular seams drape horizontally to the gravity. Similarly, bending length is used to evaluate two-dimensional drape of fabrics with a horizontal seam while the drape coefficient is used to evaluate three-dimensional drape of fabrics with a circular seam. Therefore, horizontal and vertical seams will greatly influence fabric bending properties while circular and radial seams are more associated with drape properties.

8.2.2 Effect of seams on fabric bending properties

Dhingra and Postle (1980–81) measured bending rigidity by the KES system. Two plain seams, one vertical (perpendicular) and one parallel (horizontal) to the bending axis, were tested. With the introduction of the vertical seam, bending properties were greatly increased and they were further increased when the seam allowance was increased to 10 mm. Since the seam allowances of the vertical seam are clamped by the fabric holders during testing, their relative movement is restricted. Their results for bending rigidity from the KES fabric tester may not reflect the real drapeability as measured by the fabric cantilever test. Moreover, the range of seam allowances used in the experiment was kept to 1–10 mm; a limitation which made it difficult to fully trace out the drapeability of a seamed fabric. In contrast, they reported that the parallel (horizontal) seam had little influence on the bending rigidity of fabric. However, the experimental result cannot reflect the real drape situation of the seamed cantilever because the parallel seam can be parallel to any points from the free end to the hanging edge of the fabric cantilever. Differences may exist on a fabric cantilever with a parallel seam on different positions and with different seam allowances. Cantilever tests on fabrics with vertical and parallel seams with a wide range of seam allowances and different seam positions are needed to investigate the validity of the argument.

8.2.3 Effect of seams on fabric drape properties

The study of fabric drape is undoubtedly very important for the appearance of the final garment but fabrics must be sewn to form a garment. Thus in practical situations, any assessment of the drape performance of a garment must take into account the influence of seams.

From the work of Suda and Nagasaka (1984a,b), the effect of the seam and hem of a flared skirt on the drape profile was studied by bonding narrow strips of non-woven fabrics at the edge or along the radial directions of circular fabrics. They observed that the bending rigidity of the bonded part increased with the width and the number of bonded layers of the non-woven fabric. In the samples with bonding only at their edge, the drape coefficient increased, and there was a negative correlation between the number of nodes formed and the rigidity of the bonded layers. In the case of samples with bonded strips in radial directions, the fourth layer of non-woven fabric seemed to have a distinctive influence on node formation. They concluded that the bending coefficient of the bonded part increased with the width and number of bonded layers of the non-woven fabrics.

Although thread balance during sewing, thread crimps, width, layers and thickness of the seamed piles (Ajiki, 1985; Gupta, 1992; Mahar *et al.*, 1982a,b) are important factors affecting the drape of fabrics, the existence of seam allowance is also a key factor. In fact, a seam with seam allowance is commonly found on a garment. The effect of seam on fabric drape is not related only to the thread characteristics of the seam, but is also influenced by variations in seam allowance and seam directions (Suda and Nagasaka, 1984a,b). Suda and Nagasaka developed a good three-dimensional fabric drape simulation of the effect of seam directions and seam layers. However, the results were limited due to the method used of sticking a fabric stripe on fabrics. Using a real seam would make the tests more effective. Dhingra and Postle (1980–81) on the other hand, demonstrated bending properties of seamed fabrics with seam allowances in directions vertical and horizontal to the bending axis. However, their experiments were restricted to the KES bending tester; the results were also limited by the narrow range of tested specimens and seam allowances. Real two-dimensional drape from the fabric cantilever is not fully reflected in their results.

8.3 Effect of two-dimensional seams on fabric bending/drape properties – horizontal seams

Peirce (1930) considered the evaluation of bending length in the case of general and stiff fabrics. For general fabric, fabric weight is evenly distributed in the fabric cantilever. Another specific method is set up for very stiff fabric in which the fabric weight is added and concentrated at the free end of the fabric cantilever. Postle and Postle (1992) provided a very detailed explanation of the distributed and concentrated weight effects of fabric bending. Grosberg's model (Grosberg and Swani, 1966) is able to specify the real situation existing on the fabric cantilever with both distributed and concentrated weight. However, their research was limited to the situation without seams. A parallel (horizontal) seam will bring in an additional weight from seam allowance at any positions of the fabric cantilever. The weight distribution on a seamed fabric is no longer restricted to only the distributed weight and the weight concentrated at the tip end. A method thus needs to be established to evaluate the fabric deflections from a fabric cantilever with a parallel (horizontal) seam. Seam allowances and seam positions can be varied on the seamed fabric cantilever. Thus, the draped effect can be measured by using Peirce's flexometer principle.

Horizontal seams play an important role in altering the drape of fabric, and this is an essential factor to be considered in both the clothing and upholstery industries. It affects the structural design of a garment with respect to features such as the appearance in the shoulder joins and the waist line as well as the hem. At the time of writing, only a few papers have been presented in this area and they contribute valuable but limited findings. From the scattered information, it has been found that the drape of fabric decreases and stiffness increases when a vertical seam is introduced (Dhingra and Postle, 1980–81; Suda and Nagasaka, 1984a,b). Nevertheless, literature on the effect on drape of a horizontal seam is limited.

8.3.1 Theory

In Peirce's mathematical expression (as shown in equation 8.1), bending length c from the fabric cantilever can be evaluated either by measuring the extended fabric length l with a fixed angle or by measuring an angle from the extension of a fixed length:

$$c = l\,(\cos 0.5\theta\,/8 \tan \theta\,)^{1/3} \tag{8.1}$$

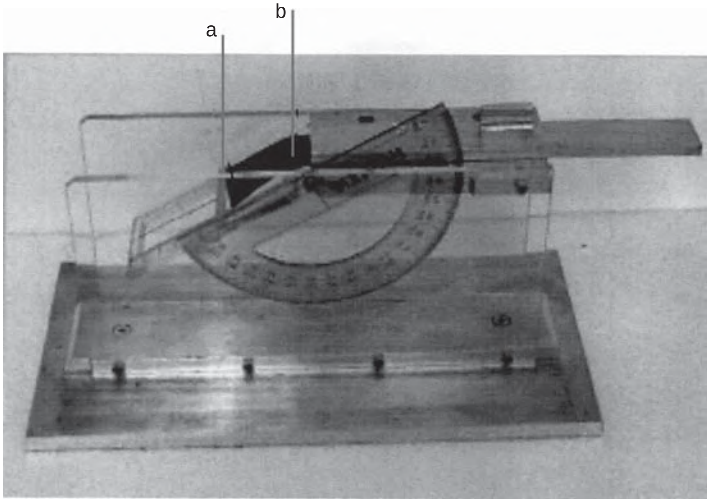
A bending tester from the Shirley Institute (1957) is specially designed to measure an extended length l with a fixed angle. The extended fabric bends under its own weight until the free end intercepts a plane at an angle of 41.5° from the horizon. With this fixed angle, the expression $(\cos 0.5\theta/8 \tan \theta)^{1/3}$ in equation 8.1 will be equal to 0.5. Thus, the bending length is calculated by a simple formula from equation 8.2. Since $\theta = 41.5°$, $(\cos 0.5\,\theta/8 \tan \theta)^{1/3} = 0.5$, then

$$c = 0.5l \tag{8.2}$$

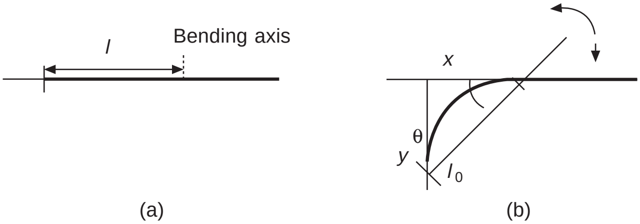
More recently, the experimental process has been further simplified. The FAST-2 bending meter (De Boos and Tester, 1990) can be used to measure the bending length using the same concept as Shirley, but with a photocell detector attached to detect the length of *l* and experimental results recorded directly from the computer. The effect of the position of a horizontal seam on a cantilever cannot be measured with either the Shirley or the FAST bending meter when the seam position varies with the extended fabric length *l* in the experiments. Peirce's flexometer (Peirce, 1930) is an instrument for measuring the drape of a fabric cantilever using bending angle θ from the fixed extended fabric length.

8.3.2 The flexometer

The flexometer can be used as a testing instrument for measuring the bending angle of a fabric cantilever with a constant length *l*. In a fabric cantilever with a horizontal seam, the seam can be placed in different positions on the fabric cantilever. Thus, the numerical value of bending length obtained from equation 8.2 is not applicable. On the other hand, a flexometer is a suitable instrument for measuring the bending angle from a constant extended fabric length *l*. To measure the bending angle and the chord l_0 from the hanging edge to the free end of a fabric cantilever, a modified flexometer is adopted as shown in Fig. 8.5, in which a guide is used to fix the required fabric length *l* from all specimens as shown in Fig. 8.6a. A hollow plate planted with a thin ruler at the centre is used to measure the chord l_0. The compass for measuring the bending angle is attached to the plate and can be rotated as shown in Fig. 8.6b. The values of bending angle θ and chord l_0 from the extended fabric length can thus be recorded. The horizontal *x* and vertical *y* displacements of



8.5 Modified flexometer: (a) a thin ruler for measuring the chord l_0; (b) a guide for fixing extended fabric length *l*.



8.6 Measurement of bending angle θ and chord l_0; (a) before deflection; (b) during deflection.

a fabric cantilever can be evaluated from the value of l_0 as shown in equations 8.3 and 8.4 respectively:

$$x = l_0 \cos \theta \tag{8.3}$$

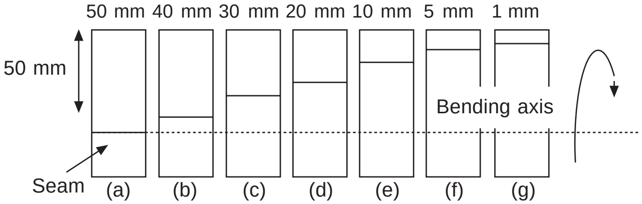
and

$$y = l_0 \sin \theta \tag{8.4}$$

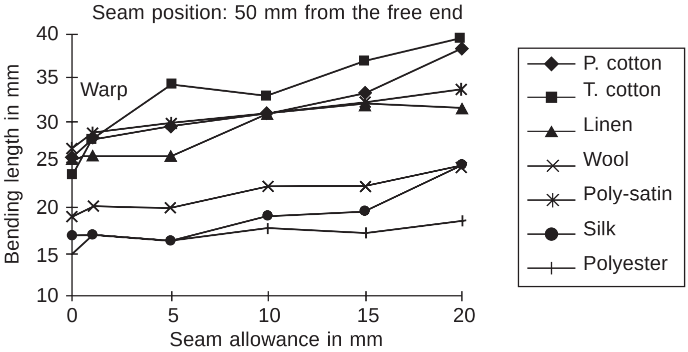
8.3.3 Effect of seam allowance on drape of fabric cantilevers with a horizontal seam

The effect of seam allowance on the drape of a fabric cantilever with a horizontal seam can be represented by bending length – the smaller the value of the bending length, the larger the drapeability of the fabric cantilever. It has been found that the influence of seam allowances on drape of a fabric cantilever is highly dependent on the seam position, as well as the warp and weft directions of fabrics.

When a horizontal seam is added on a fabric cantilever, three situations will arise. Firstly, there is a horizontal seam on the supporting plane of the fabric cantilever when it is placed at the hanging edge as in the test of Fig. 8.7a. Then, in all other situations, the seam is out of the supporting plane. In the second situation, the seam allowance of a horizontal seam may be partially free hanging on the fabric cantilever as can be found from the test shown in



8.7 Extended fabric with a horizontal seam at different locations (50 mm, 40 mm, 30 mm, 20 mm, 10 mm, 5 mm and 1 mm respectively from the free tip end).



8.8 Bending length against seam allowance of fabric cantilever with a horizontal seam at the hanging edge (seam position: 50 mm from the free end).

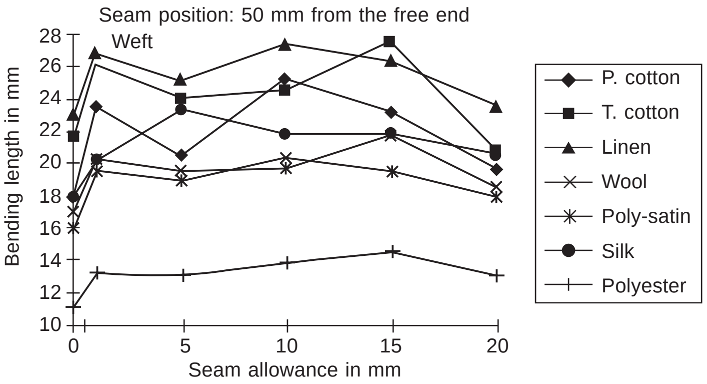
Fig. 8.7b. In the third situation the seam allowance may be just appended to the hanging edge as can be found in Fig. 8.7c. Also, in the final situation, the seam allowance of a horizontal seam may be totally free hanging on the fabric cantilever as shown in Fig. 8.7d–g. Thus, different end results for the drape of fabric cantilevers can be observed in each supporting situation.

8.3.3.1 Seam at the hanging edge

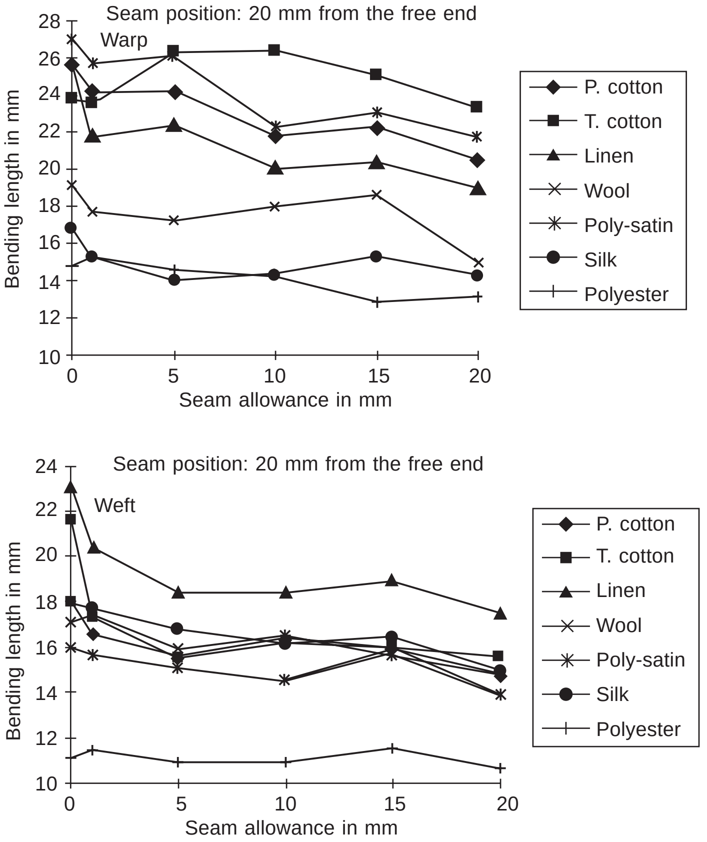
When the seam is put on the hanging edge, that is the bending axis, it is located at 50 mm from the free end of the extended fabric as shown in Fig. 8.7a. The experimental result for fabric bending on the warp is shown in Fig. 8.8. It has been found that the increase in seam allowance in this position increases the bending length. Fabrics are stiffer and drape less with increased seam allowance. On the other hand, the result for fabric bending on the weft is different, as can be seen from Fig. 8.9. It is found that when a horizontal seam is introduced with a small seam allowance of 1 mm, the bending length increases sharply. When the seam allowance is further increased from 1 mm, the bending length does not change significantly. However, the bending length decreases when the seam allowance is increased from 15 mm to 20 mm. As a result, fabric bending in different fabric directions behaves differently when the seam allowance is changed.

8.3.3.2 Seam near the free tip end

When a horizontal seam is found near the free tip end of a fabric cantilever, the seam will be entirely free hanging on the fabric cantilever as shown in Figs 8.7d–g. No seam allowance is appended to the hanging edge in this situation. In the example of Fig. 8.7f, the addition of a horizontal seam and the increase in seam allowance cause a decrease in bending length and an increase in drapeability of a fabric cantilever. From Figs 8.10a and b, it can



8.9 The bending length against seam allowance of fabric cantilever with a horizontal seam at the hanging edge (seam position: 50 mm from the free end).

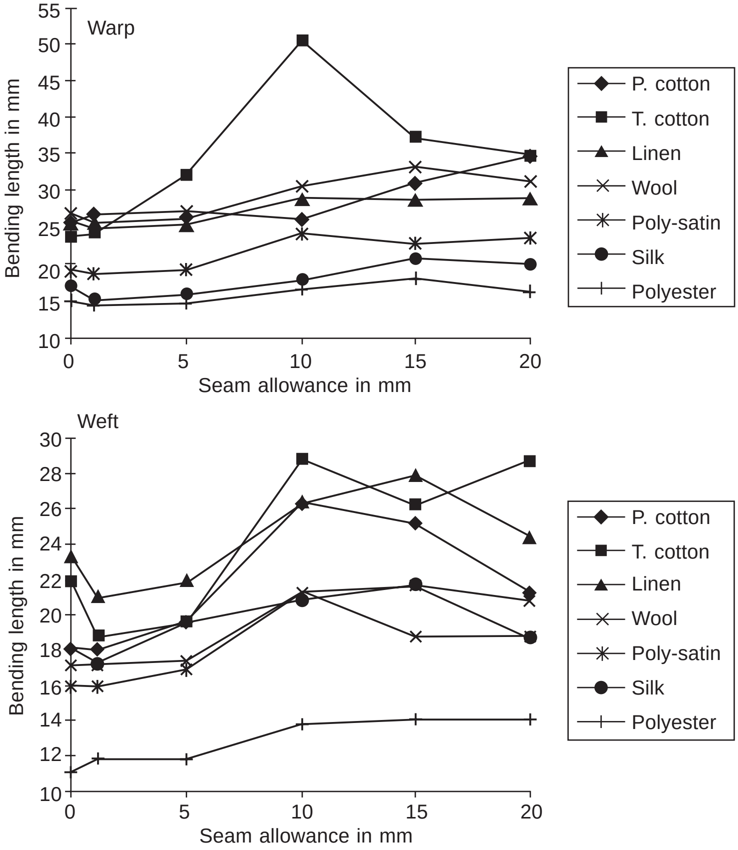


8.10 The bending length against seam allowance of fabric cantilever. Seam allowance of a horizontal seam is free hanging (seam position: 20 mm from the free end).

be seen that with increased seam allowance bending length reduces on fabric cantilevers in both the warp and weft directions.

8.3.3.3 Seam near the hanging edge

When a seam is located near the hanging edge with a large value of seam allowance, the seam allowance will partially append to the hanging edge. Seam allowance placed at 40 mm from the free end in Fig. 8.7b represents this situation. Figures 8.11a and b show the effects of seam allowance on bending length of fabric cantilevers in the warp and weft directions respectively. The seam is free hanging when *SA* is less than 10 mm. Thus, bending length and stiffness of the fabric cantilever will decrease when the fabric cantilever is seamed with 1 mm *SA*. Then, a gradual increase in seam allowance from



8.11 The bending length against seam allowance of fabric cantilever with a horizontal seam at 40 mm from the free end.

1 mm to 10 mm increases the bending length. Nevertheless, it is found that bending length increases sharply at 10 mm *SA* on the weft direction of the fabric cantilever where the edge of seam allowance is just appended to the hanging edge. When *SA* is increased to 20 mm, the further increase moderates the increased rate of bending length on the warp of the fabric cantilever, but greatly reduces the bending length and increases the drapability on the weft of the fabric cantilever.

8.3.4 Effect of seam position on drape of fabric cantilever with a horizontal seam

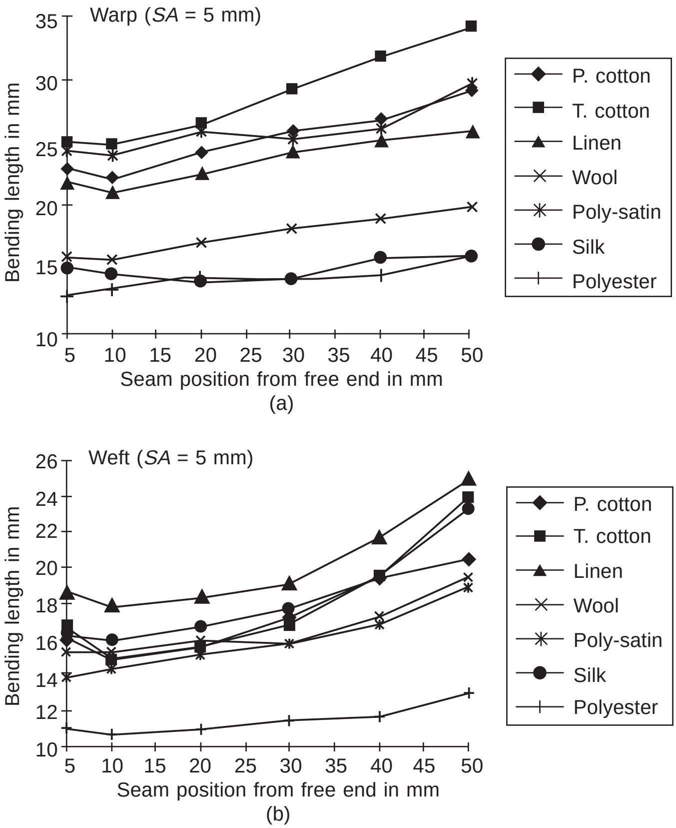
8.3.4.1 Completely free hanging of seam allowance

A horizontal seam with seam allowance 5 mm is generated at different positions on a fabric cantilever. The seam allowances are free hanging along the fabric cantilever when the seam is draping out of the platform. The positional effect of a horizontal seam on the drape of the fabric cantilever can be seen from Figs 8.12a and b. It has been found that the bending length of the fabric cantilever increases when the horizontal seam is moved away from the free tip end. A small value of bending length can be found when the seam is placed near the free tip end and a large value can be observed when the seam is positioned at the hanging edge of the fabric cantilever. The increased seam position gives rise to an increase in bending length which is steadier on the warp than on the weft of fabric cantilevers.

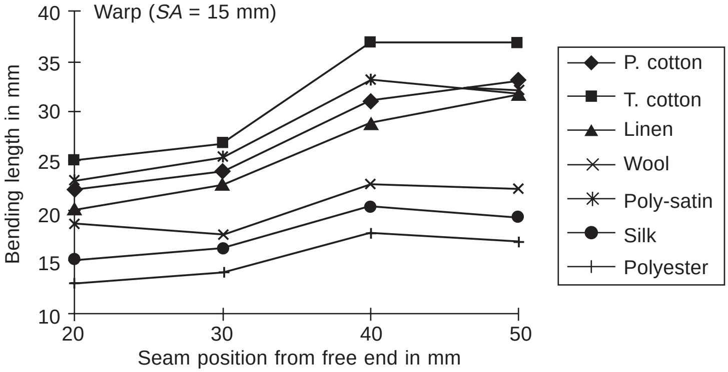
8.3.4.2 Partially free hanging of seam allowance

If either the seam allowance is too wide or the seam is too near the hanging edge, then the horizontal seam is not completely free hanging on the fabric cantilever. If the edge of seam allowance on a horizontal seam is too wide and appended to the hanging edge, the bending length will not increase markedly. A decrease in bending length can be seen on some fabrics as shown in Fig. 8.13. For fabrics such as twill cotton, wool, polyesters and silk, the bending length will be notably reduced from the seam positions of 40–50 mm from the tip end of the fabric cantilever since the seam with allowance 15 mm is still appended to the hanging edge of the fabric cantilever.

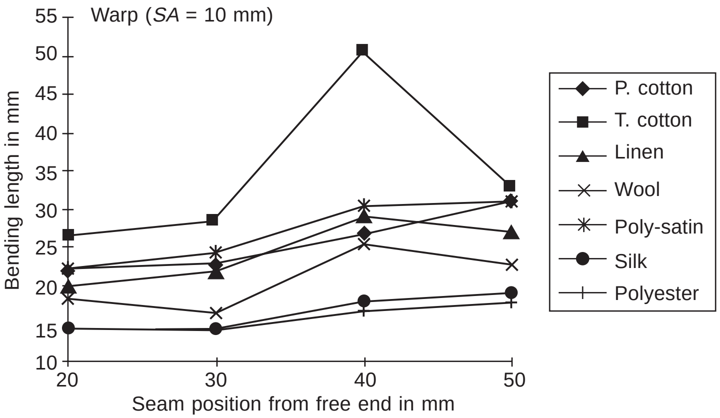
On the other hand, if a horizontal seam on a fabric cantilever is set in a position such that the edge of the seam allowance is just appended to the hanging edge (i.e. the edge of the seam allowance is dabbed to the edge of the hanging platform) the bending length of the fabric cantilever is increased for heavy weight fabrics. In Fig. 8.14, a prompt increase in bending length can be seen on the fabric cantilever with seam allowance of 10 mm at the seam position 40 mm from the tip end. An increase in bending length at this



8.12 Bending length against seam position on the weft of fabric cantilever with a horizontal seam (seam allowance = 5 mm).



8.13 Bending length against seam position of fabric cantilever with a horizontal seam. Seam allowance is partially free hanging on the fabric cantilever at the seam positions of 40–50 mm from the free end (seam allowance = 15 mm).

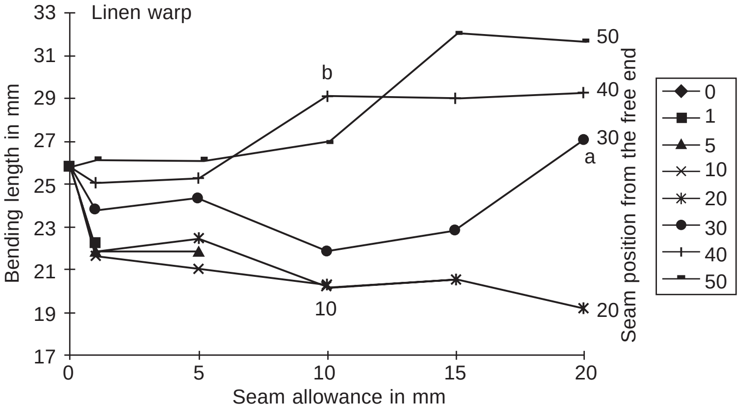


8.14 Bending length against seam position of fabric cantilever with a horizontal seam. Bending length promptly increases on heavy weight fabrics when seam allowance is dabbed to the hanging edge at the seam position of 40 mm from the free end (seam allowance = 10 mm).

seam position is obviously found for the heavy weight fabrics such as wool, linen and twill cotton.

8.3.4.3 Example using linen fabric

The linen fabric shown in Fig. 8.15 is an example which describes the effect of seam position and seam allowance on drape of a fabric cantilever. The bending length of linen with the seam position at 50 mm from the free end is greater than that at 40 mm. Bending length measured from the seam



8.15 The bending length against seam allowance of linen fabric.

position at 30 mm is greater than that at 20 mm and 20 mm is greater than 10 mm. Nevertheless, it is difficult to compare the variance of bending length when the seam positions are less than 10 mm from the free end. Generally speaking, when a horizontal seam is positioned far from the hanging edge of a fabric cantilever, bending length will be smaller.

On the other hand, increase in seam allowance will either increase or decrease the drape of a fabric cantilever. Bending length of a fabric cantilever with a horizontal seam increases when the seam allowance is positioned at the hanging edge along the warp direction; otherwise, bending length decreases when the seam allowance is freely hanging along both fabric directions.

Moreover, the seam with seam allowance just dabbed to the hanging edge will markedly increase the stiffness of fabric. This situation can be seen at points a and b from the example of a linen fabric shown in Fig. 8.15. The seam allowance and seam position are 10 mm and 40 mm at point b, 20 mm and 30 mm at point a, respectively. The two seams with seam allowances are just dabbed to the hanging edge. Thus, bending length is instantly increased.

8.4 Effect of two-dimensional seams on fabric bending/drape properties – vertical seams

Dhingra and Postle (1980–81) studied the effect of a plain seam on bending rigidity using the KES-F bending tester. It was found that a plain seam has little effect on fabric shear rigidity and hysteresis, but has a great deal of influence on bending rigidity. The effect was found to be especially significant with the vertical seam. They also pointed out that the bending hysteresis and the bending rigidity were strongly affected by seam allowances. When $SA =$ 1 mm, the ratio of bending hysteresis of seamed fabric was 9–11 times that of the no-seam fabric. This ratio was increased to 26–33 times the unseamed fabric when SA was increased to 10 mm. The investigation provides useful information for the study of fabric bending with a plain seam.

In another study by Shishoo *et al.* (1971), it was found that bending rigidity of a seamed multi-layer fabric was about 4–10 times that of the single one. The bending length of the multi-layer fabric was the approximated sum of that of the individual single layer fabrics.

Ajiki (1985) found that bending rigidity was affected by the level of sewing thread crimp in the seams. The sewing thread crimp is a linear function of thickness multiplied by the stitch density of the composite fabric layers. In addition, bending rigidity increased with the increase in the number of layers of fabrics.

Mahar *et al.* (1982a,b) reported that bending rigidity of fabrics was related to the balance of the thread tension. They joined two layers of fabrics with a row of lockstitches without obtaining any seam allowance. The bending properties were tested on both the top and bottom of the two-ply fabrics. An asymmetric bending moment was obtained on each side of the fabric sheets if the thread tension was not balanced.

Among the studies, thread crimp, number of layers and thickness of the seamed sheets are the the important factors affecting fabric bending. However, the effect of seam on fabric bending is also related to the existence of seam allowance. In practice, a seam with seam allowance is commonly found on a garment. Dhingra and Postle's (1980–81) study provides fundamental understanding of the effect of a vertical seam on fabric bending of woven fabrics.

8.4.1 Theory

8.4.1.1 Elastic bending theory

By simple bending theory, the moment of resistance of a strip to bending is equal to the applied moment M at equilibrium. The total bending moment M for the whole cross-sectional area about the neutral axis is shown in equation 8.5 where Young's modulus E and radius of curvature R are assumed to be constant along the material strip.

$$M = \frac{E}{R} I = \frac{B}{R} \qquad [8.5]$$

The function $\int y^2 \delta A$ is called the second moment of area I of the cross-section where δA is defined as the area of an element of the cross-section at a distance y from the neutral axis. The neutral axis is a horizontal line which passes through the centroid of the cross-section. The distance of the neutral axis is a vertical distance from the fabric surface to the horizontal line of the neutral axis of the cross-section.

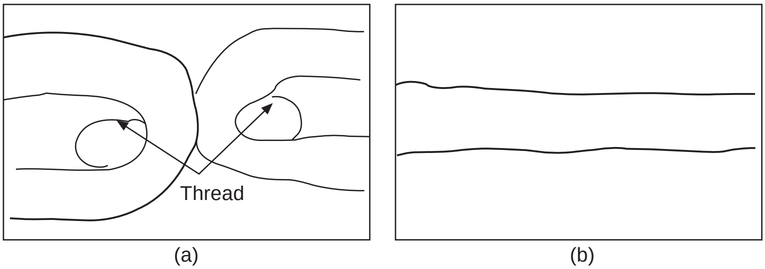
It has been noted that the bending moment changes with second moment of area of the cross-section. From equation 8.6, the bending rigidity of a strip is a linear function of the second moment of area I of the cross-section when Young's modulus E is assumed to be constant along the strip:

$$B = EI \qquad [8.6]$$

Enlightened by this principle, we may attempt to find the relationship between bending rigidity and the second moment of area for fabrics with a vertical seam. It is assumed that $B = \beta I^{\lambda}$, where β and λ are two constants and β may be related to Young's modulus E.

8.4.1.2 Second moment of area of seamed and unseamed fabrics

In order to find the difference between seamed and unseamed fabrics, their cross-sections are magnified under the microscope as shown in Figs 8.16a and b. Comparing the figures, a structural change can be seen for the seamed



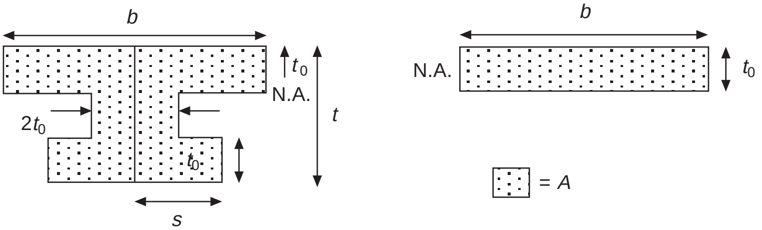
8.16 Cross-section of a fabric strip (× 200) with (a) a vertical plain seam and (b) no seam.

fabric in that seamed parts are forced to bend and seam allowances are formed on the reverse of the fabric. Besides, two gap areas are found between the top fabric and the bottom seam allowances. Both the cross-sectional area and the cross-sectional thickness are significantly increased on the seamed fabric. Sewing thread and seam structure are found to be the general elements affecting the bending properties of a fabric strip.

Geometrical models of the fabric cross-sections for seamed and unseamed fabrics are set up in Figs 8.17a and b. The assumptions followed in the modelling include:

(1) the cross-section of an unseamed fabric is rectangular in shape and the cross-section of the seamed fabric is I-shaped;
(2) free space areas between the top and the bottom plies of the seamed fabric are rectangular in shape;
(3) no external force from the sewing thread, stitch tension and balance of stitch tension is applied on the seamed model;
(4) the increased fabric weight due to the increased seam allowance is assumed to be uniformly distributed along the fabric strip.

For the unseamed fabric, the distance of the neutral axis from the fabric surface of the cross-section y is $t_0/2$ in equation 8.7.



b = width of fabric strip,
t_0 = fabric thickness,
A = cross-section area,
s = width of seam allowance,
t = seam thickness,
N.A. = neutral axis.

(a) (b)

8.17 Geometrical models and cross-section areas of a fabric with (a) a vertical seam and (b) no seam.

$$y = \frac{t_0}{2} \qquad [8.7]$$

The second moment of area I of the cross-section with width b and thickness t_0 can be evaluated from equation 8.8.

$$I = \frac{bt_0^3}{12} \qquad [8.8]$$

However, the cross-section of an unseamed fabric strip shown in Fig. 8.16b is different from a fabric strip with a vertical seam shown in Fig. 8.16a.

From Fig. 8.16a, formation of a vertical seam creates a seam thickness at the cross-section and space areas are found between the top and bottom sheets of a seamed fabric strip. Moreover, a larger cross-sectional area is found for the seamed fabric than the unseamed fabric. Seam thickness t, fabric thickness t_0, width of fabric strip b, width of seam allowance s and the distance of the neutral axis y are the important factors which determine the cross-sectional area of the seamed fabric strip. According to equations 8.9 and 8.10, the distance of the neutral axis y and the second moment of area I_{seam} of the cross-section of the seamed fabric strip can be evaluated respectively using the measurable values of seam thickness t, fabric thickness t_0, width of fabric strip b and width of seam allowance s:

$$y = \frac{t_0(2s - 4t - b) + 2t(t + b)}{2(2s + 2t - 4t_0 + b)} \qquad [8.9]$$

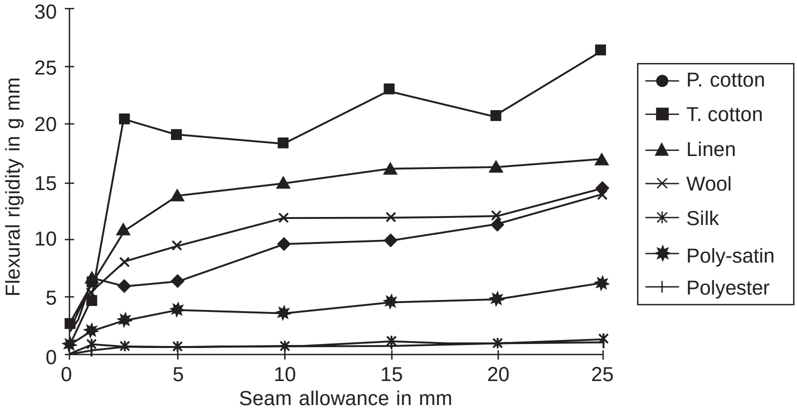
and

$$I_{\text{seam}} = \frac{1}{3}[b(t - y)^3 - (b - 2t_0)(t - t_0 - y)^3 + 2sy^3 - 2(s - t_0)(y - t_0)^3] \qquad [8.10]$$

Rewriting equation 8.10, equation 8.11 is formed.

$$I_{\text{seam}} = \frac{t_0}{3}\left\{\begin{array}{l} 2t^2 + 3(b - 2t_0 - 2y)t^2 + 3[t_0(2t_0 + 4y - b) + 2y(y - b)]t \\ + 2(t_0^2 - 3t_0y + 3y^2)s + [bt_0^2 - 4t_0^3 + 3y(b - 4y)t_0 + 3by^2] \end{array}\right\} \qquad [8.11]$$

I_{seam} is a polynomial function of the seam thickness t in the third order. When a seam is added on a fabric strip with a small seam allowance, the change of I_{seam} is related to the change of t, y and s if t_0 and b are constant. When the seam allowance is small, the change in y will be mainly due to the change in t. Thus, the increased bending moment of a fabric strip from an added seam is mainly due to the increase in seam thickness t. When the seam allowance of a seamed strip is increased and t_0 and b are constant, the seam thickness becomes a constant. I_{seam} changes with y and s only:



8.18 Experimental bending rigidity with the increased fabric weight due to the increase in seam allowance.

8.4.2 Relationship of bending rigidity *B* and second moment of area (I_{seam})

The bending rigidity B of a seamed fabric strip with various seam allowances can be evaluated from experimental bending length c from $B = Wc^3$ as shown in Fig. 8.18 where W is the fabric weight. The calculated results of I_{seam} with different seam allowances are shown in Table 8.1. The relations between the bending rigidity and the second moment of area of different fabrics can be expressed in equation 8.12

$$B = \beta I_{\text{seam}}^{\lambda} \qquad [8.12]$$

where β and λ are constants. The power relation of different fabrics is shown in Table 8.2. The correlation coefficient r averages 0.95 with a high confidence level for all fabrics.

From Table 8.2, it is found that the power λ in equation 8.12 of all seven

Table 8.1 Second moment of area in mm^4 of a seamed fabric strip with increased seam allowance

***SA*, mm**	**0**	**1**	**2.5**	**5**	**10**	**15**	**20**	**25**
Plain cotton	0.17	0.45	1.13	1.55	3.70	4.04	4.81	5.57
Cotton twill	0.41	2.04	4.02	3.80	6.24	8.92	10.21	13.60
Linen	0.37	1.06	1.60	2.92	3.50	4.91	6.32	7.52
Wool	0.65	2.24	3.50	4.56	9.21	11.94	18.95	20.49
Silk	0.00	0.04	0.08	0.11	0.17	0.28	0.23	0.42
Poly-satin	0.02	0.20	0.35	0.51	1.06	1.21	1.39	1.77
Polyester	0.01	0.08	0.18	0.15	0.39	0.50	0.72	0.74

Table 8.2 Relation of bending rigidity and second moment of area of fabric strip with various seam allowances

Fabric	**Relation of B and I_{seam}**	***r***
Plain cotton	$B = 5.33\ I_{\text{seam}}^{0.52}$	0.91
Twill cotton	$B = 4.95\ I_{\text{seam}}^{0.70}$	0.93
Linen	$B = 6.53\ I_{\text{seam}}^{0.56}$	0.96
Wool	$B = 2.60\ I_{\text{seam}}^{0.62}$	0.92
Silk	$B = 1.80\ I_{\text{seam}}^{0.41}$	0.95
Polyester satin	$B = 4.24\ I_{\text{seam}}^{0.38}$	0.98
Polyester	$B = 1.10\ I_{\text{seam}}^{0.38}$	0.98
Average		0.95

B = Bending rigidity
I_{seam} = Second moment of area from $SA = 0$ to SA = 25 mm

fabrics is close to 0.5. Thus, substituting 0.5 to the power λ in equation 8.12, equation 8.13 is formed.

$$B = \beta\sqrt{I_{\text{seam}}} \tag{8.13}$$

Linear regressions of plot of bending rigidity against $\sqrt{I_{\text{seam}}}$, where β is a constant on a particular fabric, yield correlation coefficients of B in Table 8.3. The average correlation coefficient of all sample fabrics is 0.9 and the relationship is significant at the 0.05 level. Thus, the bending rigidity from various values of I_{seam} due to the change in seam allowance can be expressed by a simple formula:

Table 8.3 Linear relation of bending rigidity (B) and $I_{\text{seam}}^{0.5}$ of a fabric strip with various seam allowances

Fabric	**Relation of B and $I_{\text{seam}}^{0.5}$ in equation 8.10**	***r***
Plain cotton	$B = 5.43\ I_{\text{seam}}^{0.5}$	0.93
Twill cotton	$B = 7.34\ I_{\text{seam}}^{0.5}$	0.89
Linen	$B = 6.98\ I_{\text{seam}}^{0.5}$	0.94
Wool	$B = 3.30\ I_{\text{seam}}^{0.5}$	0.90
Silk	$B = 1.98\ I_{\text{seam}}^{0.5}$	0.82
Polyester satin	$B = 4.24\ I_{\text{seam}}^{0.5}$	0.95
Polyester	$B = 1.18\ I_{\text{seam}}^{0.5}$	0.90
Average		0.91

B = Bending rigidity
$I_{\text{seam}}^{0.5}$ from $SA = 0$ to $SA = 25$ mm

8.4.3 Relationship of bending length *c* and second moment of area (I_{seam})

The relationship between bending length c and bending rigidity B can be expressed by equation 8.14.

$$B = Wc^3 \tag{8.14}$$

When equations 8.13 and 8.14 are combined, equation 8.15 is formed which shows the relation between the second moment of area (I_{seam}) and the bending length.

$$c = (\beta/W)^{\frac{1}{3}}\ I_{seam}^{1/6} \tag{8.15}$$

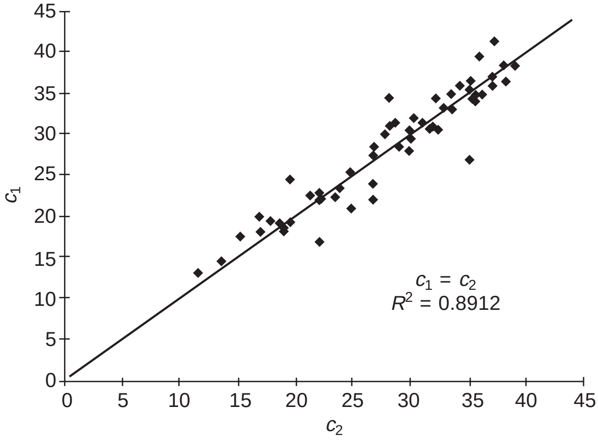
The calculated results of bending length c_2 from equation 8.15 are shown in Table 8.4. As compared with a group of experimental data of bending length c_1 with various seam allowances (as shown in Table 8.5), we found that the correlation coefficients r are high and the predicted slope is 1, that is $c_1 = c_2$, for different fabrics as shown in Fig. 8.19. The overall correlation coefficient is 0.89. Since the correlation coefficient exceeds the critical value of 0.622 at the 0.05 level, the relation of bending length and second moment of area of a vertical seam with various seam allowances shown in equation 8.15 can be accepted at the 0.05 significance level:

Table 8.4 Calculated bending length (c_2) in mm

SA, (mm)	**0**	**1**	**2.5**	**5**	**10**	**15**	**20**	**25**
Plain cotton	24.85	28.14	32.84	33.67	37.03	36.17	35.65	35.14
Twill cotton	26.70	35.09	37.24	35.96	37.08	38.05	38.17	38.97
Linen	26.66	31.60	32.17	34.25	33.47	35.01	35.34	35.52
Wool	22.11	26.69	28.20	28.60	30.27	31.06	32.39	31.85
Silk	13.58	19.54	21.30	22.10	22.16	23.78	22.11	23.39
Polyester satin	16.86	24.68	26.89	27.85	29.82	30.06	29.17	29.86
Polyester	11.56	15.24	17.84	16.97	18.61	19.00	19.54	19.00

Table 8.5 Experimental bending length (c_1) in mm

***SA,* (mm)**	**0**	**1**	**2.5**	**5**	**10**	**15**	**20**	**25**
Plain cotton	21	34.5	33.25	33	36	35	35	36.5
Twill cotton	22	27	41.5	39.5	37	38.5	36.5	38.5
Linen	24	30.75	34.5	36	35	35.5	34.5	34
Wool	17	27.5	31	31.5	32	31.5	30.5	31
Silk	14.5	24.5	22.5	23	22	23.5	21.8	22.5
Polyester satin	20	25.5	28.5	30	28	29.5	28.5	30.5
Polyester	13	17.5	19.5	18	19	18.2	19.2	18.5



8.19 Bending length of seven fabrics from experimental results c_1 and calculated results c_2.

8.4.4 Difference of vertical and horizontal seams on drape of fabrics

The bending length of a fabric with a vertical seam is higher than that with a horizontal seam. Fabrics with a horizontal seam drape more easily than fabrics with a vertical seam. The effect of seam allowance on a horizontal seam is different from that on a vertical seam.

When a horizontal seam is added on a fabric cantilever, three situations are found. First, the seam allowance of a horizontal seam is supported on the plane when it is placed at the hanging edge, which is 50 mm from the free end in Fig. 8.2. In the second situation, the seam allowance of a horizontal seam is just appended to the hanging edge, that is 25 mm seam allowance at a seam position 25 mm from the free end. In the final situation, the seam allowance of a horizontal seam is fully free hanging on the fabric cantilever, which is 5 mm from the free end in Fig. 8.2. Different results for the drape of fabric cantilevers can be observed.

When a seam is located 50 mm from the free end, it is attached to the hanging edge. Bending length increases sharply when *SA* increases from 1 mm to 15 mm. Further increase in seam allowance brings a drop in bending length. When a horizontal seam is free hanging in a fabric cantilever, the addition of a horizontal seam and the increase in seam allowance cause a decrease in bending length. However, if the seam allowance of a horizontal seam is just appended to the hanging edge, bending length increases instantly.

8.5 Effect of three-dimensional seams on fabric bending/drape properties

8.5.1 Drape performance of fabrics with radial seams

8.5.1.1 Relation between vertical seams and radial seams in terms of bending length and drape coefficient

From Fig. 8.20, it can be seen that a linear correlation exists between two-dimensional and three-dimensional drape in terms of bending length c and DC% respectively. For the no-seam fabrics shown in Fig. 8.20a, a linear relation between c and DC% of different fabrics is shown in equation 8.16 with a correlation coefficient of 0.92.

$$DC\% = 4.37c - 33.11 \qquad [8.16]$$

When a seam is added, a linear relation can also be seen between c and DC% as shown in Fig. 8.20b. However, the linear regression becomes equation 8.17 with correlation coefficient of 0.88,

$$DC\% = 3.45c - 42.6 \qquad [8.17]$$

which shows that both the slope and the constant from equation 8.16 are changed with the addition of seams.

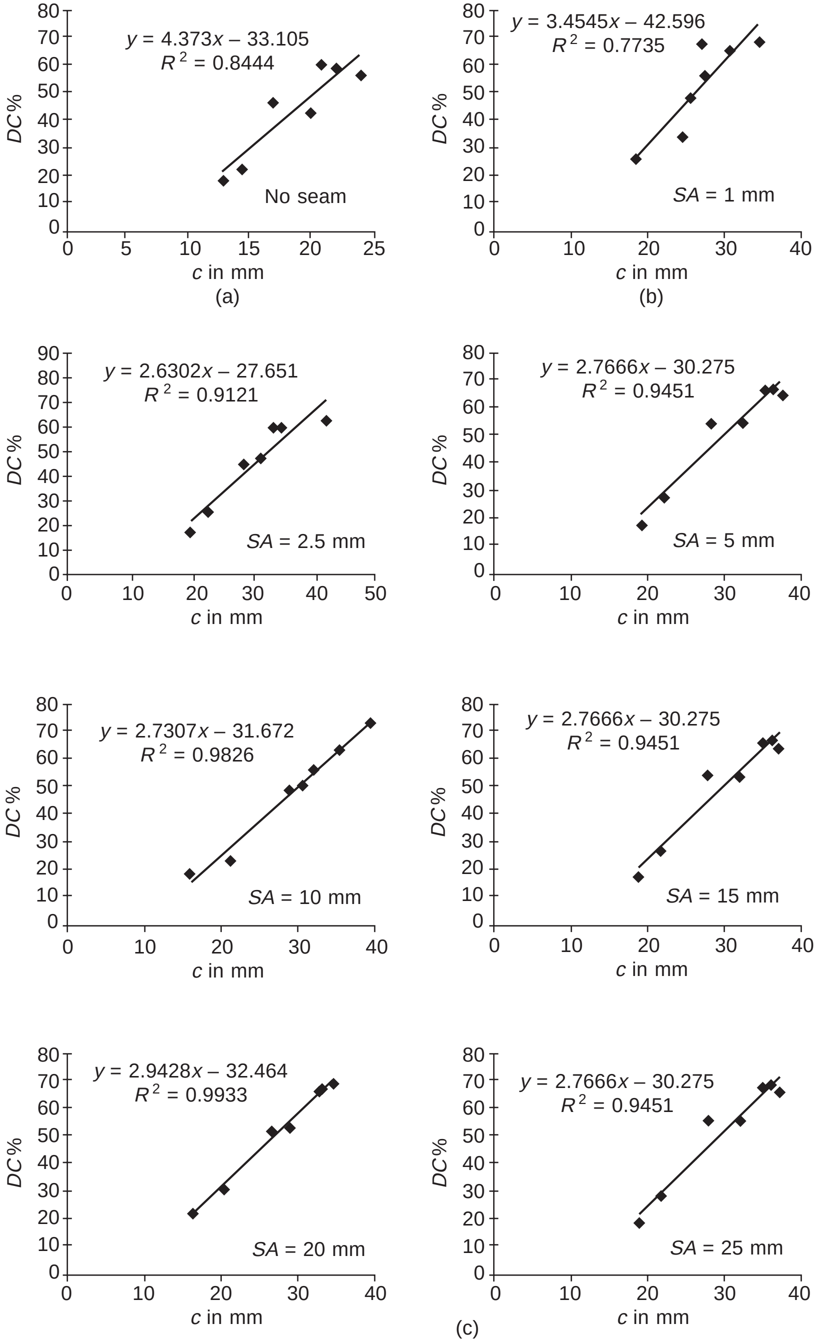
When seam allowance increases from 2.5 mm to 25 mm as shown in Fig. 8.20c, it is interesting to see that all the linear regressions in this SA range are similar to each other. The regressions can be combined and presented in equation 8.18 with correlation coefficient of 0.98.

$$DC\% = 2.79c - 30.97 \qquad [8.18]$$

The linear regression shows that there is no significant change in relationship between DC% and c with SA in the range 2.5–25 mm, which means the change of seam allowance has little effect on the relation between DC% and c. However, the linear relationship of this SA range is different from SA = 1 mm in equation 8.17.

8.5.1.2 Drape coefficient of fabrics with one and two radial seams

The changes in drape coefficients (DC%) for fabrics with one or two radial seams are rather unstable when compared with those with four seams. However, the trends of DC% corresponding to various seam allowances are similar to each other. Generally speaking, drape coefficients increase rapidly with the addition of a seam from SA 0 mm (no seam) to 1 mm. Further increase in DC% is observed on some fabrics when SA is increased from 1 mm to 2.5 mm. However, DC% slightly increases after seam allowance is greater than 2.5 mm. In addition, light weight fabrics such as 100 % silk and 100 %



8.20 Relations between *DC* % and bending length *c* of different fabrics: (a) no seam; (b) seam allowance = 1 mm; (c) seam allowance = 2.5 ~ 25 mm.

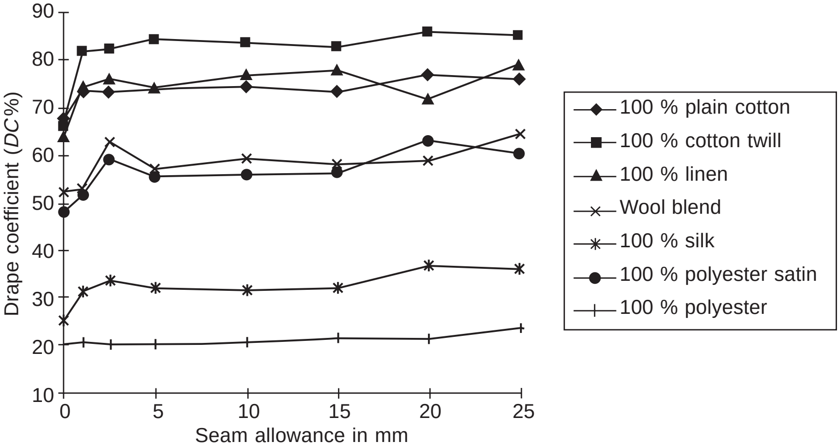
polyester exhibit a much smaller change in *DC*% with the addition of one or two radial seams, which is different from heavy weight fabrics. Thus the effects of both one and two radial seams on light weight fabrics are very limited.

8.5.1.3 Drape coefficient of fabrics with four radial seams

Figure 8.21 shows that drape coefficient (*DC*%) increases when four seams are sewn on the fabric. An increased seam allowance initially increases *DC*% rapidly in the small region located between 1 and 5 mm *SA*; then, a negligible increase in *DC*% occurs on any further increase in seam allowance. The *DC*% of a fabric with four seams is relatively consistent and stable when compared with the results for one or two seams. In an example of 10 mm seam allowance, the change in *DC*% with respect to the seam number is shown in Fig. 8.22. The increased *DC*% with the addition of seams is highest when a fabric has four seams, and is minimal with one seam. In this case, the effect of radial seams on three-dimensional drape is influenced by the increase in seam numbers. Fabric weight also impacts on this effect. In Fig. 8.22 again, it can be shown that heavy weight fabrics have an increase in *DC*% value when seam numbers increase, but the increased seam numbers are less inclined to increase the *DC*% of light weight fabrics.

8.5.1.4 Drape profile of fabrics with radial seams

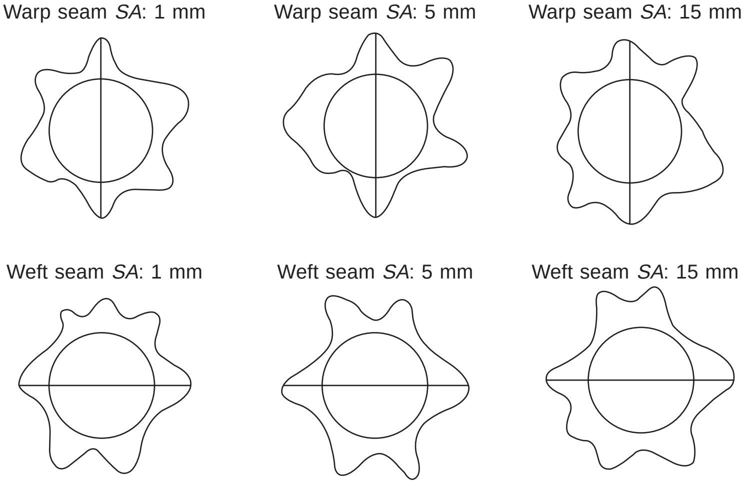
The instability of a draped fabric can be seen on fabrics with no seams, where node numbers may vary on every drape. However, the drape profile is



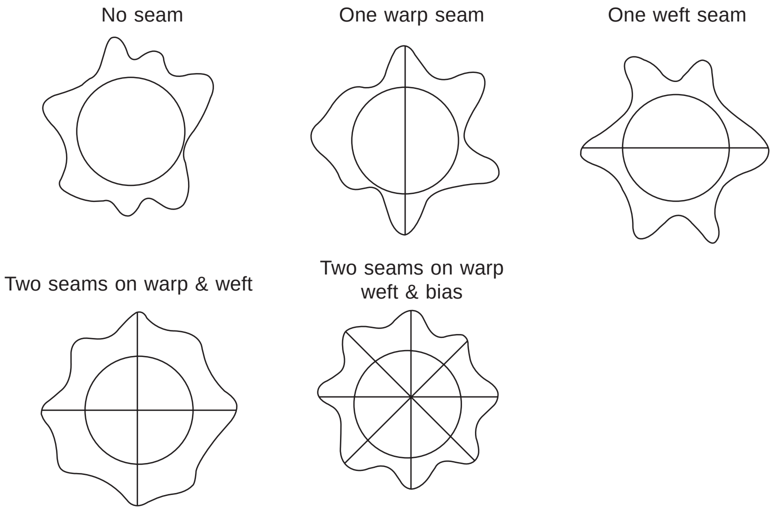
8.21 Drape coefficient (*DC*%) of four radial seams on the warp, weft and two biases.

Table 8.6 Node length of two radial seams with four nodes on various fabrics. Node length in cm from the edge of the pedestal

***SA* mm**	**Highest node**	**Seamed node 1**	**Seamed node 2**	**Seamed node 3**	**Seamed node 4**	**Lowest node**
(a) Wool						
0	5.4	–	–	–	–	4
1	5.4	5.4	5.2	5.1	4.9	4.1
2.5	5.5	5.5	5.3	5.2	5.2	4.1
5	5.6	5.6	5.4	5.1	5	4
10	5.7	5.7	5.5	5.3	5.3	3.9
15	5.4	5.4	5.2	5.2	4.9	4.3
20	5.4	5.4	5.4	5.3	5	4.2
(b) Silk						
0	4.2	–	–	–	–	3
1	4.5	4.5	4.5	4.3	4.2	3
2.5	4.7	4.7	4.1	4	3.8	3.5
5	4.5	4.5	4.1	3.8	3.4	3.2
10	4.9	4.9	4.6	4.2	4.1	3.5
15	4.7	4.7	4.6	3.9	3.7	3.2
20	4.9	4.9	4.3	4	4	3.3
(c) Polyester						
0	3.9	–	–	–	–	2.1
1	4.1	4.1	3.9	3.8	3.6	2.6
2.5	4.4	4.4	4	3.6	3.6	2.9
5	4.2	4.2	4.1	3.8	3.5	2.7
10	3.8	3.8	3.6	3.6	3.3	2.5
15	4	4	3.6	3.5	3.5	2
20	4	4	3.6	3.3	3.3	2.6



8.23 The drape profiles of one seam on plain cotton fabric with various seams.



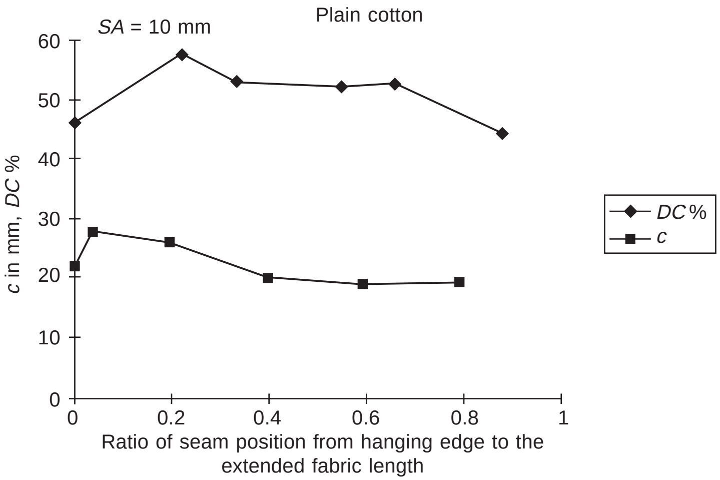
8.24 The drape profile of plain cotton with various seam numbers.

be evenly distributed in an octagonal arrangement along the seam directions. Increasing the seam allowances for four radial seams has little influence on changing the orientation of the drape profile. Drape profiles of fabrics with four radial seams are similar to those for fabrics with two seams, but the former are more stable than the latter and are not affected by variations in seam allowance. The drape profile of the specimen with four radial seams shows no significant change between each drape no matter how many times it drapes on the pedestal, because the free distribution of nodes is highly restricted by the additions of four seams.

From Fig. 8.24, it can be seen that the drape profile of a fabric is greatly affected by the number of radial seams. The more seams are added to a fabric, the more stable is the drape profile. Thus, drape profiles of fabrics with both two seams and four seams have a more regular node arrangement than those with one seam. It is also noted that added seams have less influence on the drape profiles of light weight fabrics: that is, the node number and drape appearance of light weight fabrics cannot be altered significantly by introducing seams and changes in seam allowance.

8.5.2 Drape performance of fabrics with circular seams

Two-dimensional and three-dimensional drape behave similarly when seam positions are changed. Both bending length and *DC*% increase when the seam is located just out of the hanging edge. Bending length and *DC*% decrease when the seam is fully free hanging and far from the hanging edge. In addition, bending length and *DC*% are lowest when the seam moves near the free end.



8.25 DC % and bending length *c* against ratio of seam position from hanging edge of the extended fabric length to the free end (seam allowance = 10 mm).

According to Fig. 8.25, the drape coefficient is highest when a circular seam is located just off the edge of the pedestal. This is because the seam allowance is still hanging at the edge of the pedestal where a supporting path is developed. If the seam is moved further outward from the pedestal, the *DC*% will drop quickly from a 14 cm to a 15 cm seam radius. The *DC*% will decrease continuously as the seam moves to the edge of a fabric. When the seam is located near the edge of the specimen, the drape coefficient is lowest. From these results, it can be seen that the effect of seam position on fabric drape is significant with respect to the *DC*% for fabrics with a circular seam.

The drape profile of a fabric with a circular seam is entirely different from the drape profile of a fabric with radial seams. Nodes do not stay at any specific positions. Moreover, there is no consistent change of node number in the fabric, as shown in Table 8.7.

Table 8.7 The node number of drape shadow, highest and lowest node with respect to different seam radii (*r*)

	Seam radius, *r*							
	0	**7**	**9**	**11**	**12**	**14**	**15**	**17**
Node number	6	6	6	6	4	4	4	4
Highest node length, cm	7.8	8	7.5	8	8.4	8.2	8.5	8
Lowest node length, cm	6.1	5.3	6.5	6.2	7	6.5	6.8	7.2

r is the radius of a circular seam.

8.6 Summary

This chapter has examined the effect of seams on the bending and drape properties of woven fabrics. It is hoped that the results can provide a deeper understanding of drape and bending of a seamed fabric. The following conclusions have thus been reached:

(1) The bending of a fabric strip with a vertical seam is related to the second moment of area of a seamed fabric. Fabric thickness, seam thickness, distance of the neutral axis from the surface of the seam cross-section, width of fabric strip and width of seam allowance are the key elements involved in the analysis of seam structure. The effect of the second moment of area on the bending rigidity of a fabric strip with a vertical seam of various seam allowances can be presented as $B = \beta\sqrt{I_{\text{seam}}}$ from which β is a constant for a particular fabric. The relationship of bending length to the second moment of area of a fabric strip with a vertical seam can be expressed as $c = (\beta/W)^{1/3}\, I_{\text{seam}}^{1/6}$.

(2) Bending of a fabric with a vertical plain seam is mainly affected by the seam structure, which involves the study of fabric thickness, seam thickness, seam allowance, distance of neutral axis from the surface of fabric cross-section and width of the fabric strip. It is found that the 'second moment of area' of the seamed cross-section determines the bending behaviour of a fabric strip with a vertical seam. Bending length and bending rigidity of seamed fabrics are highly related to the second moment of area of the fabric cross-section.

(3) In the cantilever test with a horizontal seam, it can be seen that the bending length of a fabric with a horizontal seam is lower than that of a vertical seam. The location of a horizontal seam is a significant factor in determining the bending length. The nearer the seam is to the free end, the smaller is the bending length. Seam allowance has different effects on bending length according to seam locations.

(4) It has been found that drape coefficient is increased by the addition of a radial seam. The effect of radial seams on fabric drape is clearly shown by the dramatic increase in seam numbers. The *DC*% is highest when a fabric has four seams. The drape profile of an unseamed fabric is not stable and node numbers vary on every drape. The drape profiles of fabrics with one radial seam have irregular node orientations at the unseamed parts. However, the drape profiles of fabrics with four radial seams are more stable and regular. The node numbers are normally fixed at seven or eight in an octagonal arrangement. Increase in seam allowance has little influence on changing the node orientation along the seamed parts of four radial seams.

(5) With respect to fabric drape with a circular seam, the highest drape coefficient has been found when a circular seam is located just out of

the pedestal. Any outward movement of the seam causes *DC*% to fall. The drape coefficient is lowest when the circular seam is located at the edge of the fabric. Hence, varying the seam position of a circular seam has a significant effect on fabric drape.

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