7

DRAWING-IN AND TYING-IN

Key Words: *dent, denting plan, drawer-in, drawing-in, drawing-in draft, drop wires, heddles, pattern chain, pointed draft, reacher-in, reed plan, skip draft, straight draft, tying-in, warp stop motion.*

During slashing the exact number of warp yarns required in the fabric is wound onto the loom (or weaver's) beam. The warp ends are then passed through the *drop wires* of the *warp stop motion*, the *heddles* of the harness frames and the *dents* of the reed. This can be achieved either by drawing-in or tying-in, the choice depending upon whether or not the new warp is different from the warp already on the loom.

Drawing-in

This is the process of drawing every warp end through its drop wire, heddle eye and reed dent as shown in Fig. 7.1. Drawing-in can be performed manually or by means of automatic machines.

Manual Drawing-in

The warp beam is taken from the slashing room to the drawing-in area, where there are frames on which the drop wires, harness frames and reed are supported in the order in which they are found on the loom.

A length of warp yarn, just enough to reach to the other side of the frame, is unwound. Leasing of the warp at this stage simplifies separation of the yarns. In normal practice, two operators sit facing each other across the frame and the

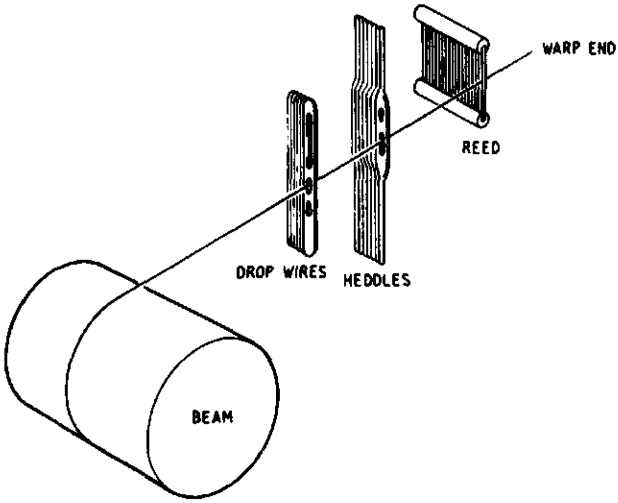


Fig. 7.1. Schematic diagram for drawing-in

operator facing the reed (the *drawer-in*) passes a hooked needle through the heddle eyes and drop wires. The needle hook is then exposed to the second operator (the *reacher-in*) on the other side of the frame; the reacher-in selects the correct yarn in its proper order and puts it on the hook so that when the needle is pulled out the yarn is threaded through the two loom parts. This is done according to a plan known as the *drawing-in draft* (D.I.D.). The yarns are then threaded through the reed dents as required by the *denting plan* or *reed plan* (R.P.).

To prevent the ends from being pulled back through the system, groups of ends are tied together by knots. The operators then tie together all three elements (drop wires, harness frames and reed) to prevent any end breakage during movement of the beam, which is then ready to be placed on the loom.

Machine Drawing-in

Hand drawing-in is a time consuming operation, and it has been made fully automatic. There are two systems available, namely:

(1) Three machines each performing a single operation; a wire-pinning machine, a drawing-in machine and a reed-denting machine.

(2) One machine for drawing the warp through all the elements.

The machines used in these processes employ a *pattern chain* to control a selector finger which selects the warp threads separately and delivers them to a hook which draws them through the required element. The machines are very expensive and require a special type and shape of heddle. Accessories are needed to facilitate the preparation of the machine for drawing-in. Examples include a pattern punching machine and a heddle counter to determine the number of heddles required on every harness frame. A certain level of efficiency and continuous use of the equipment are necessary if the use of such machines is to be economically justifiable. A modern warp drawing machine may be able to handle some 6000 ends per hour, but the speed achieved is dependent on the specific conditions (see Table 7.1). Machines are available to deal with one or two warps, flat or leased, and with different widths.

The Drawing-in Draft

This indicates the pattern in which the warp ends are arranged in their distribution over the harness frames. Wherever possible, the ends which are to be woven similarly should be drawn through the same harness frame. This rule is applied when the density of warp yarns does not exceed 8 end/cm (20 end/inch) on a single row harness or 16 end/cm (40 end/inch) on a double row harness (see Fig. 7.2). For example, a plain weave fabric with 32 end/cm (80.end/inch) will require either 2 double-row harnesses or 4 single-row harnesses. For dobby weaves it is recommended that the

TABLE 7.1

Tying-in Rates for Typical Cases

Case Number	1	2	3	4
Yarn type	Cotton	Spun rayon	Filament acetate	Worsted
Yarn count	36/2	25/2	154/41	2/50
Yarn linear density	33 tex	48 tex	17 tex	18 tex
Type of warp	Flat sheet	Flat sheet	1 × 1 lease	1 × 1 lease
End/cm	35	24	35	31
End/inch	90	60	90	80
No. harness frames	8	16	6	12
Type of draft	Skip	Skip	Straight	Skip
Banks of drop wires	4	4	4	6
Ends/dent in the reed	2	4	2	4
Av. speed in ends/hr	4800	3800	5000	4000

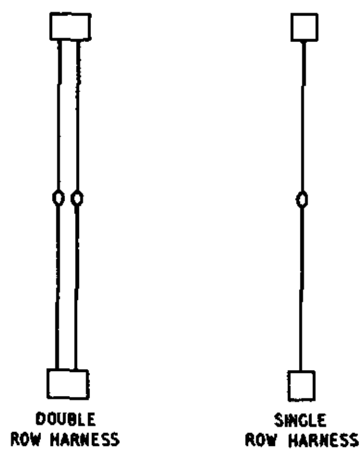


Fig. 7.2.

number of ends per harness should be as nearly equal as possible.

There are three different methods for the yarn arrangement in the drawing-in draft, these are:

(1) *Straight draft* (Fig. 7.3(a)).
(2) *Pointed draft* (Fig. 7.3(b)).
(3) *Skip draft* (Fig. 7.3(c)).

These represent both the harnesses and the warp ends; each vertical row in the draft represents one end and each horizontal row represents one harness. The bottom horizontal row is normally the first or the front harness. The harness capacity of the loom to be used must be known before the drawing-in draft can be decided. The drawing-in draft must be known not only to the drawer-in but also to the weaver, who will be able to draw broken ends during weaving. Any misdrawn end will produce a fault in the fabric.

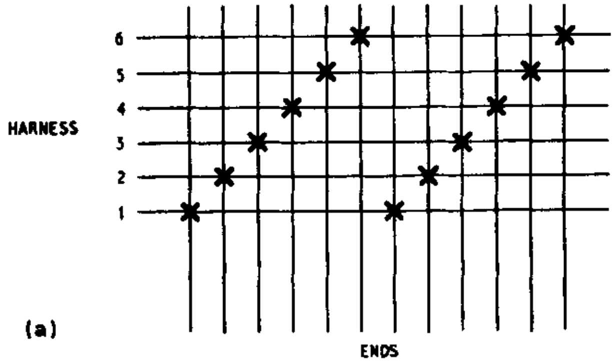
The drawing-in draft varies with different fabric designs as discussed in Chapter 9.

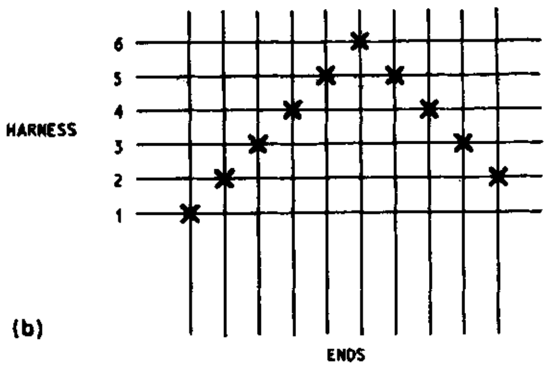
The Reed Plan

The reed plan indicates the arrangement of the warp ends in the reed dents. It is general practice to draw more than one warp end in a reed dent. This allows the use of reasonable wire dimensions and number. Normally 2 ends/dent for the body of the fabric and 4 ends/dent for the selvage is a reasonable combination. However, in many cases, 3 or 4 ends/dent are used. The reed plan can be either regular or irregular depending on whether or not the same number of ends per dent is used regularly across the width of the body of the warp. Some designs require the use of different numbers of ends per dent in the body of the fabric to produce certain effects in the fabric.

Tying-in

Tying-in is used when a fabric is being mass produced. The tail end of the warp from the exhausted warp beam is tied to





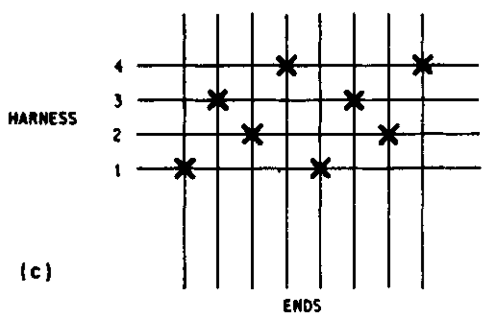


Fig. 7.3. (a) Straight draft. (b) Pointed draft. (c) Skip draft

the beginning of the new warp. Two types of machine are used:

(1) *Stationary machines.* The tying-in takes place in a separate room away from the loom.
(2) *Portable machines.* These are used at the loom.

Stationary machines have the disadvantage that they necessitate moving the exhausted beam and all its parts from the loom and taking it to and from the tying-in department. However, they have the advantage of permitting maintenance of the loom to be carried out.

The time taken to tie-in a complete warp depends mostly upon the total number of ends in that warp, but it is also affected by secondary factors which tend to retard productivity. For example, a color stripe must be tied in proper register and the operator will have to stop tying if there has been a broken end in order to adjust the machine to give proper register. The count and type of yarn (together with the reed and heddle details) determine the type of knot to be used and this affects the rate of knotting. Also the nature of the yarn can affect the breakage rate during knotting, and thus influence the total time needed for tying-in.

The capacity of warp-tying machines has remained unchanged for years. A capacity of about 600 knots/min appears to be the maximum. The machine can deal with flat warp or leased warp and with a warp width of about 5m (5 yd). The sequence of operations is normally as follows:

(1) The machine selects the warp ends from the new beam.
(2) It selects the corresponding end from the old beam.
(3) It ties the two ends together and moves to the next.

Following the tying-in process, all knots are pulled through to the cloth roller, the drop wires, heddles and reed; the loom is now ready for operation.

A similar process can be used where similar (but not identical) fabrics are to be produced. Obviously, identical drawing-in draft and reed plans are required.

8

THE FUNDAMENTALS OF FABRIC STRUCTURE

Key Words: *aspect ratio, basis weight, biaxial load, cover factor, contraction, covering power, crimp, crimp exchange (crimp interchange), crimp factor, fabric construction, fabric extension, hand, jamming, plain weave, slit film, square construction, uniaxial load.*

The Structure of a Weave

The warp and filling may be interlaced in a variety of patterns to produce fabrics which are surprisingly flexible and yet are strong and durable. These characteristics arise from the structure of the fabric itself and also from the structure of the yarns which are used to make it. Obviously, if stiff wire were used to make a fabric, the fabric would also be stiff, and this would be the case no matter what type of weave was used. On the other hand, it is possible to weave very flexible strands into fabrics with a very wide range of stiffnesses depending on the fabric structures used.

The way in which the component yarns are assembled enables a very wide range of patterns to be made, merely by varying the weave. These patterns, which can be either large or small, are obviously important in textiles which are used for their decorative effect.

Varying the weave varies the facility with which the component yarns can move relative to one another, with the result that the shear characteristics of the material are affected and, in turn, the drape.

Theoretically, it is possible to design a fabric structure to produce the characteristics demanded, but in practice this is not quite so easy as it may sound. For example, often it is

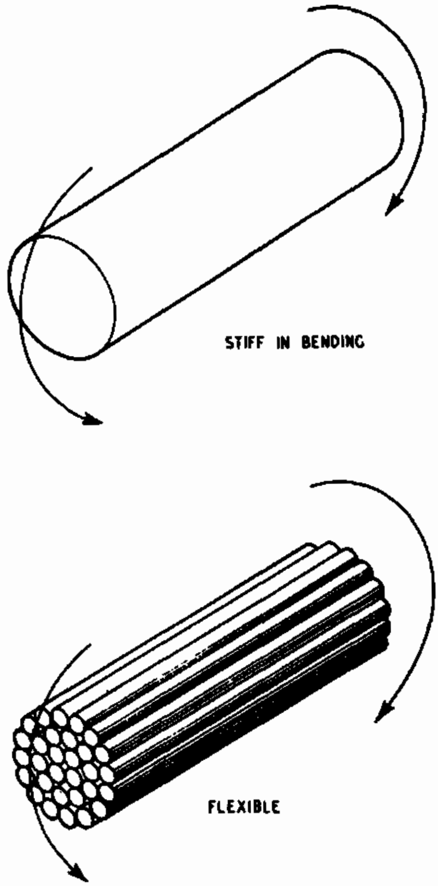


Fig. 8.1

difficult to obtain a complete specification of the fabric needed for a given end use, particularly when it is fashion rather than utility which dictates the sort of material to be used. Complete case histories of the many types of fabrics are available in well documented forms, and the motivation to reduce the matter to fundamental principles is reduced.

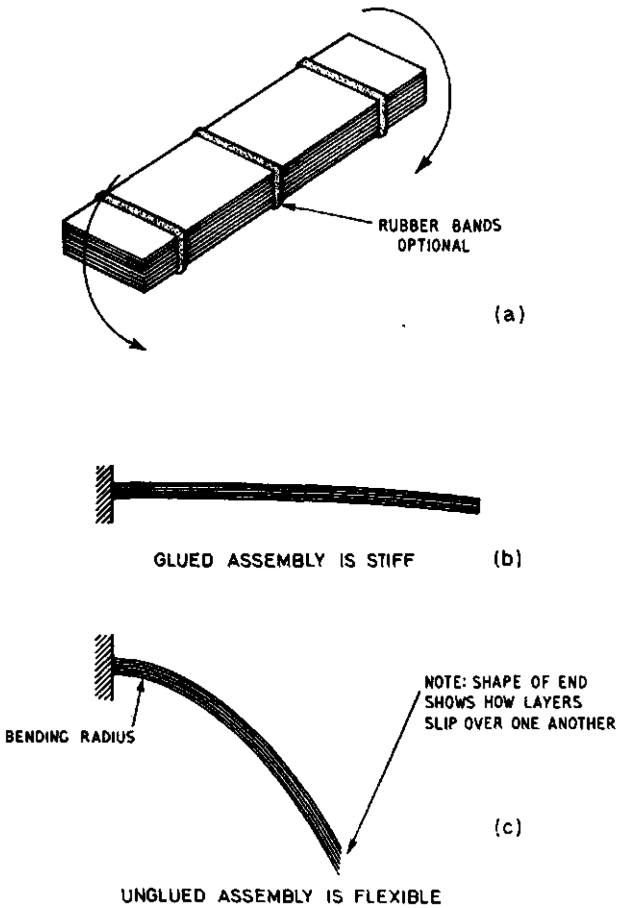


Fig. 8.2

Also, it is far from easy to analyze a fabric in scientific terms, let alone synthesize the characteristics; in general, therefore, the art of fabric analysis and synthesis has been based on craft knowledge rather than science. However, the scientific approach can provide a deeper understanding of the factors involved and, for this reason, a simplified scientific analysis of some fabric structures will be made.

The Stiffness of Various Assemblies of Fibers

If a rod is divided into portions in the fashion indicated in Fig. 8.1, then the stiffness of the assembly will be reduced. If the rod is divided into many component fibres, the stiffness will be further reduced. It is the smallness of diameter of the individual fiber that makes possible the high degree of flexibility which is normally associated with a textile material. To take the fullest advantage of the inherent flexibility, it is necessary to give the individual fiber the greatest freedom of movement possible and, in particular, the amount of shear energy which can be transmitted from one fiber to its neighbors should be at a minimum (in other words, the fibers should be able to slip over one another).

Two paper models may be used to demonstrate this relationship between flexibility and structure. In both models, similar strips of paper are arranged in the form of a rectangular prism as shown in Fig. 8.2. In the one case, the strips are fixed together only at one end. In the other case, the strips are glued together using a minimum of glue. The first model will be found to be extremely flexible and the minimum bending radius when held as a cantilever will be very small (see Fig. 8.2(c)). The glued model will be very stiff because the elements cannot slip over one another and cannot act independently.

A textile material lies usually between these two extremes. Sometimes fibers are bonded together, which tends to make the structure stiff. Frequently, the fibers are held together by frictional forces arising from the disposition of the components in the structure. The effect of frictional forces can be simulated by placing rubber bands around the first (unglued) model. When the rubber bands exert a fairly small lateral force, the assembly is stiff for the first small increment of distortion because the frictional forces are not overcome and the assembly behaves as a stiff solid body. A large

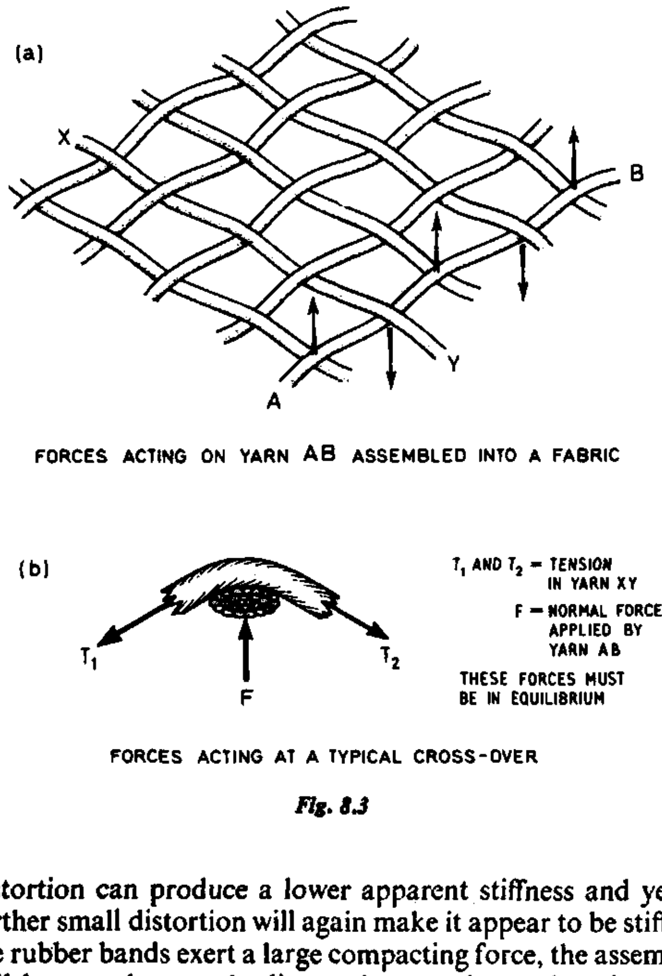
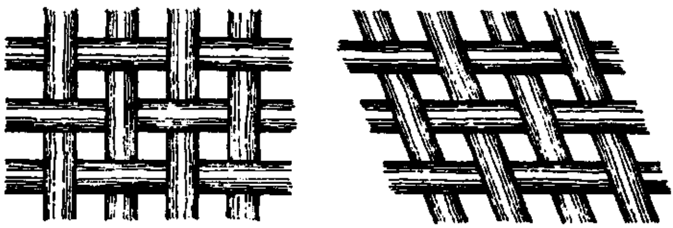


Fig. 8.3

distortion can produce a lower apparent stiffness and yet a further small distortion will again make it appear to be stiff. If the rubber bands exert a large compacting force, the assembly will have to be grossly distorted to produce other than the solid body stiffness. Thus it is not surprising to find that a sized yarn is stiffer than an unsized one or that a high twist yarn (which has large compacting forces) is stiffer than a low twist yarn.

In the case of fabrics, a material made from sized yarns is much stiffer than that made from unsized yarns or a fabric from which the size has been removed. "Hard" twisted yarns (i.e. highly twisted yarns) will make a fabric stiffer than a fabric made of low twist yarns; also, there will be a difference in the tactile character of the fabric, the fabric from hard twisted yarn feels harsh to the touch whereas the fabric from low twist yarns feels soft.



FABRIC IN NORMAL STATE   SHEAR DEFORMATION IN FABRIC

Fig. 8.4

When assembled into fabric, the yarns exert forces upon one another at the crossovers (Fig. 8.3) and these forces act like the rubber bands in the model. In a very tight structure where considerable yarn tensions are involved, the fabric is likely to be stiff. Conversely, a loose structure is likely to be flexible and soft. A loose structure allows yarns to move more easily over one another at the crossovers, which makes shear deformations easier (see Fig. 8.4). This in turn makes it easier for the fabric to mould to a surface and drape well.

In finishing, the aqueous treatment will often release some of the compacting forces and allow fibers more freedom, with the consequence that yarns and fabrics tend to become softer. Laundering and use generally have a similar effect.

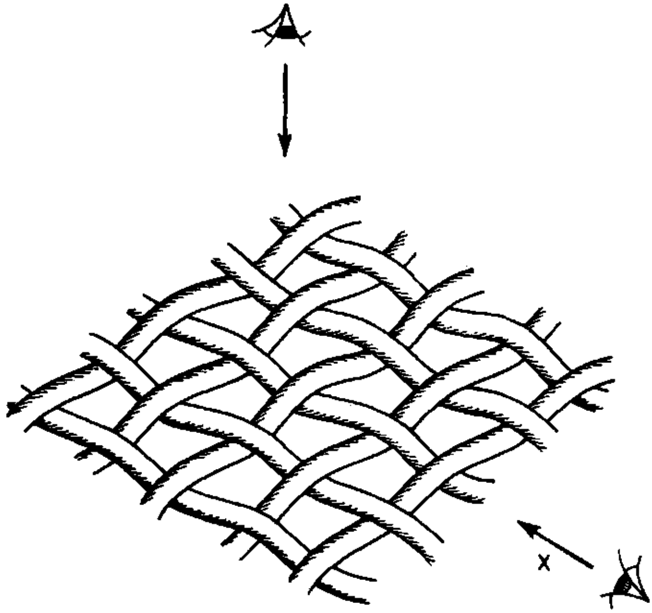


Fig. 8.5

Fabric Geometry

Yarns are interlaced into an interlocking structure to produce a sheet-like material which has a three-dimensional macro structure (Fig. 8.5). The weave shown in Fig. 8.5 is a *plain weave* and although there are many other patterns of weaving, this particular one has been chosen for illustration purposes because it is the simplest.

Frequently, a woven fabric is used to obscure whatever lies beneath it and in such cases the *covering power* of the material is important. There are two aspects of covering power, viz. the optical and the geometrical. The optical aspect is a function of the readiness with which the surface of the material reflects and scatters the incident light. The geometrical aspect is a function of the extent to which the superficial area is covered by the component yarns.

The optical effects are controlled by the nature of the fibers and the surfaces presented to the incident light. Certain fibers are more opaque than others; for example, nylon can be supplied in dull or bright forms, the dull form reflecting more light than the bright form, which transmits

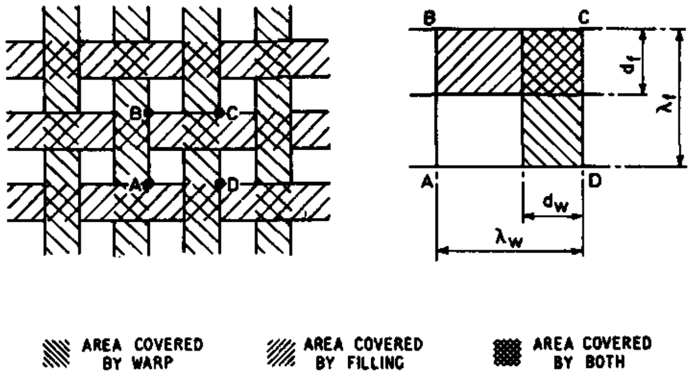


Fig. 8.6. Cover factor

more of the light to give a translucent effect. For a given fiber, optical characteristics are also affected by the structure into which the fibers are fitted. Thus both the yarn and fabric structures will influence greatly the overall optical behavior. Dyeing and finishing will also play a part. Continuous filament yarns tend to be less opaque than staple yarns, high twists tend to produce less covering power than low twist yarns for a given geometry.

The geometrical aspect may be defined by the *cover factor*. (This differs from covering power, which takes into account the optical effects; cover factor is concerned only with the geometry.) Let the cover factor be defined in terms of projected areas. Seen from above, the material illustrated in Fig. 8.5 would appear as shown in Fig. 8.6, and the projected areas are those seen in this way. The diagrams in Fig. 8.6 show in a qualitative manner what is meant by cover factor. It should be noted that 100 per cent cover factor does not mean that the fabric is impermeable. Air can pass quite readily through interstices of the weave and the permeability of the fabric as normally measured is not a direct function of the cover factor. It is, of course, related to it.

Unfortunately, many of the terms used have a variety of meanings in commercial use and it is important that the definitions used should be clearly understood. For example, cover factor is frequently taken to include all the various factors mentioned whereas in other instances it is taken as quoted here. Thus care is needed when using these terms.

Cover Factor

Let d_W = the width of the warp yarn as it lays in the fabric
d_f = the width of the filling yarn as it lays in the fabric
λ_W = the pitch of the warp yarns,
λ_f = the pitch of filling yarns.

The warpwise cover may be defined as

$$\frac{d_w}{\lambda_w} = C_w$$

and the fillingwise cover be defined as

$$\frac{d_f}{\lambda_f} = C_f$$

The percentage fabric cover factor

$$C_{fab} = \frac{\text{total area obscured}}{\text{area enclosed}} \times 100 \text{ per cent}$$

$$= \frac{(\lambda_w - d_w)\, d_f + d_w \lambda_f}{\lambda_w \lambda_f}$$

$$C_{fab} = \frac{\lambda_w d_f + d_w \lambda_f - d_w d_f}{\lambda_w \lambda_f} \times 100 \text{ per cent}$$

$$= \frac{d_f}{\lambda_f} + \frac{d_w}{\lambda_w} - \frac{d_w}{\lambda_w}\frac{d_f}{\lambda_f} \times 100 \text{ per cent}$$

$$= (C_f + C_w - C_f C_w) \times 100 \text{ per cent} \qquad (8.1)$$

Thus if $C_f = 1{\cdot}0$ then $C_{fab} = 100$ per cent irrespective of the value of C_w but as C_w changes so will the permeability; this is an illustration of the lack of direct relationship mentioned earlier. The same argument applies if C_f and C_w are interchanged. A further point is that $C_{fab} \neq 100$ per cent unless either C_f or $C_w = 1{\cdot}0$. With a plain fabric using conventional yarns it is almost impossible to make either C_f or $C_w = 1{\cdot}0$. However, with *slit film*—which has very little thickness as compared to its width—it is possible to approach these values. Also by using other weaves, where the yarns can "pile up" as shown in Fig. 8.7, it becomes possible to approach 100 per cent cover.

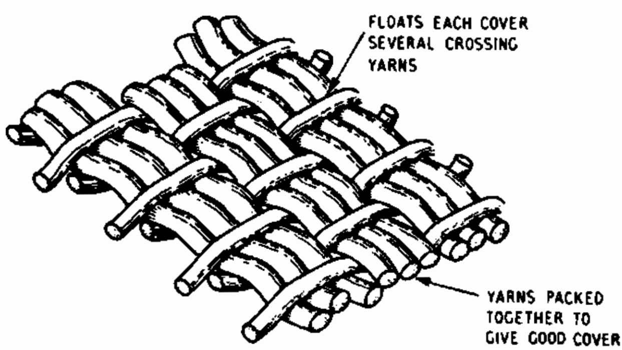


Fig. 8.7

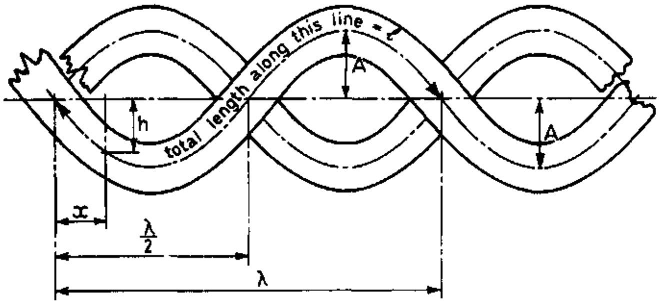


Fig. 8.7(a)

Crimp

The yarn at the edge of a piece of fabric (direction X in Fig. 8.5.), appears to be wavy, as illustrated in Fig. 8.7(a). In general terms, this waviness is called *crimp*. It has important effects on the dimensions and performance of the fabric; for example, the existence of crimp means that the lengths of filling or warp yarn required are greater than the width or length of the cloth. Since the *basis weight* of the fabric (which is usually measured in oz/sq yd) depends not only upon the linear density of the yarns used but also on the total length of the yarns assembled in the fabric, it is apparent that the crimp has to be taken into account. Other parameters are also affected, which will be discussed later.

There are two alternative ways of defining crimp:

(a) *crimp factor* $(S) = \dfrac{(\ell - x) \,.\, 100 \text{ per cent}}{x}$ (8.2)

or

(b) *contraction* $= \dfrac{(\ell - x) \,.\, 100 \text{ per cent}}{\ell}$ (8.3)

where ℓ = length of yarn before crimping,
x = length or width of the fabric.

ℓ and x are measured in the same direction.

Equation 8.2 is often expressed in the form

$$\ell = x(1 + S) \tag{8.2a}$$

A theoretical value for the crimp factor may be obtained by assuming that the yarn is forced into sinusoidal shape as depicted in Fig. 8.7. In other words the shape of the crimped yarn may be expressed mathematically by the following:

$$h = A \sin \frac{(2\pi x)}{\lambda} \tag{8.4}$$

The symbols are described in Fig. 8.7(a).

As shown in Appendix III, the true length of the yarn is given approximately by the following expression:

$$\ell \simeq \lambda \left[1 + \left(\frac{\pi A}{\lambda}\right)^2\right] \tag{8.5}$$

From this latter expression it is simple to derive the crimp factor, namely

$$\text{crimp factor} \simeq \left(\frac{\pi A}{\lambda}\right)^2 \times 100 \text{ per cent} \tag{8.6}$$

This approximation is good for a plain weave but it is necessary to modify it for other weaves.

If the warp were made out of stiff bars of metal and both warp and filling were perfectly circular, then the situation shown in Fig. 8.8(a) would exist, and

$$A_f = \frac{(d_f + d_w)}{2} \quad \text{and} \quad A_w = 0$$

This is not a practical situation because such a malbalance is rarely met and there are forces acting which cause the warp to become crimped at least to some extent (see Fig. 8.8(b)). When this crimping takes place, not only is the element of warp moved bodily away from its original position but it is squashed into an eye shape. Hence it is not very meaningful

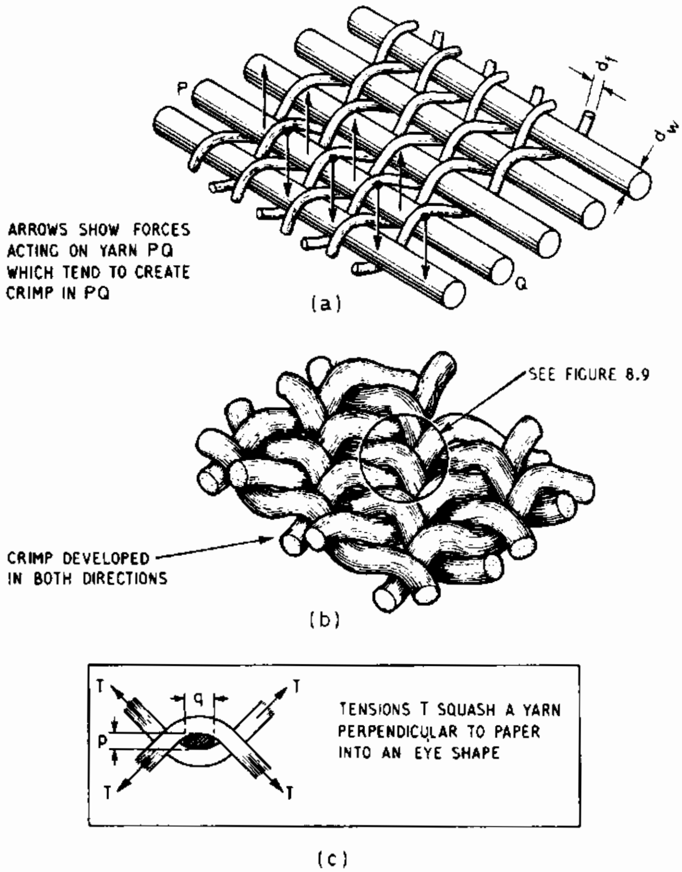


Fig. 8.8

to talk about the yarn diameter (d); rather it is necessary to talk about the yarn depth and width which are shown as p and q in the diagram. The value q, the width, affects the cover factor very strongly and p, the depth, affects the crimp. As a very rough approximation, pq may be taken as proportional to the linear density of the yarn (or inversely proportional to the yarn count) for a given level of twist.

The values of p and q are greatly affected by the yarn twist because a softly twisted yarn will squash much more readily than a hard twisted yarn. Let the ratio p/q be termed the *aspect ratio*. A flat tape, such as is now commonly used for making carpet backing, might have an aspect ratio as low as 0·01 (which means that it will have excellent cover and a low crimp factor), whereas a highly twisted yarn will have an aspect ratio approaching 1·0 (which gives poor cover and high crimp). A normal yarn assembled in a typical fabric might have an aspect ratio varying between 0·6 and 0·9.

As a comparative example of the interrelationship consider two fabrics of the same construction, where $\lambda = 6d$ and where the same yarns are used and the value of p/q is the same for both warp and filling. In the first fabric $p/q = 0{\cdot}5$ and in the second, $p/q = 1{\cdot}0$. If the yarn in the first case is squashed into an elliptical shape, then $pq = d^2$, whence $q = 1{\cdot}41d$ and $p = 0{\cdot}71d$. This is an approximation purely for the purpose of explanation.

In this case $C_f = C_w = \dfrac{2q}{\lambda} = \dfrac{1{\cdot}41d}{3d} = 0{\cdot}47$

The cover factor

$$C_{fab} = (C_f + C_w - C_f C_w)\ 100 \text{ per cent} = 72 \text{ per cent}$$

whereas if the yarn had not squashed, the cover factor would have been only 55 per cent. Assuming the crimp amplitude to be the same in both directions; for the squashed yarn

$$A = p/2 = 0{\cdot}352d$$

and the crimp factor

$$= \frac{(\pi A)^2}{(\lambda)^2} \times 100 \text{ per cent}$$

$$= \frac{(0{\cdot}352\ \pi d)^2}{(6d)^2} \times 100 \text{ per cent}$$

$$= 3{\cdot}4 \text{ per cent}$$

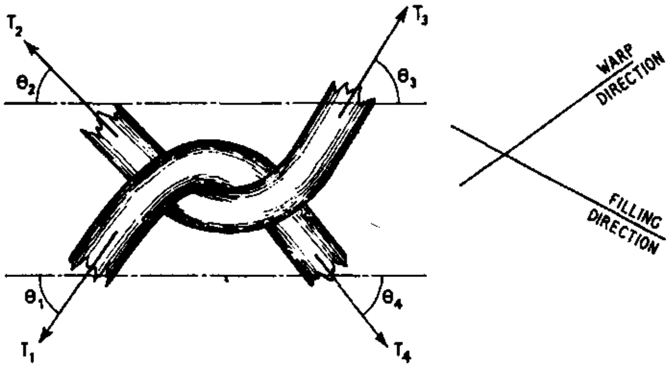


Fig. 8.9(a). An enlargement of inset in Fig. 8.8(b).

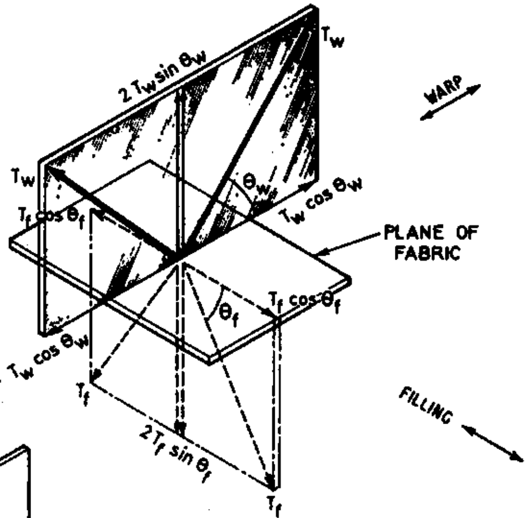
whereas with the unsquashed yarn the crimp factor would have been about 7 per cent. The yarn which squashed would give a basis weight of $(1{\cdot}034/1{\cdot}07)^2 \times 100$ per cent = 92·3 per cent of a similar fabric made from unsquashed yarns.

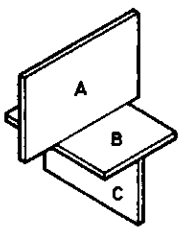
The fabric thickness will be about $2p$ and $2d$ respectively; in other words, the yarn which squashes will give a fabric which is about 71 per cent of the thickness of one in which the yarn does not squash. This affects the flexibility and softness of the fabric which in turn affects the *hand*.

It can be seen from this illustration that crimp is related to many aspects of the fabric. It affects the cover, basis weight, thickness, flexibility, softness, and hand of the fabric. When malbalanced it also affects the wear behavior and appearance of the fabric, because the exposed portions tend to wear at a more rapid rate than the rest. The crimp balance is affected by the tensions in the fabric during and after weaving.

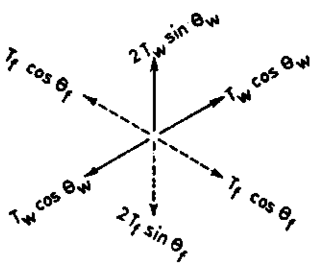
Effect of Tensions

Consider a single cross-over of warp and filling as shown in Fig. 8.9(a) and for simplicity assume that the warp and filling





It may be helpful to consider the above as three planes as shown to the side. The resolved warp tensions act in plane A, the resolved filling tensions in plane C and plane B is that of the fabric



THE RESOLVED FORCES ONLY ARE SHOWN TO THE LEFT

Fig. 8.9(b)

yarns are of the same count and twist. Because of the crimp, the yarn tensions act at various angles to the plane of the fabric and these tensions may be resolved into two directions in the plane of the fabric and one perpendicular to it. The resolved components of the four tensions must balance to give equilibrium. Consider first the components lying in the plane of the fabric. For simplicity assume the tension acting along a given thread is always constant (this is not normally so because of the effects of friction). In the case of the warp direction $T_1 = T_4$ and since $T_1 \cos \theta_1 = T_4 \cos \theta_4$ to give equilibrium in the warp direction, then $\theta_1 = \theta_4$. Since equality of tensions and angles have been assumed, let these be referred to as T_w and θ_w. A similar argument can be applied in the filling direction, therefore T_2 and T_3 can be replaced by T_f also θ_2 and θ_3 by θ_f.

In the direction perpendicular to the plane of the fabric

$$T_1 \sin \theta_1 + T_4 \sin \theta_4 = T_2 \sin \theta_2 + T_3 \sin \theta_3$$

Whence

$$2T_w \sin \theta_w = 2T_f \sin \theta_f \qquad (8.7)$$

Assuming that the crimped yarn is sinusoidal in shape as in Fig. 8.7

$$h = A \sin \frac{2\pi x}{\lambda}$$

$$\frac{dh}{dx} = \frac{2\pi A}{\lambda} \cos \frac{2\pi x}{\lambda}$$

At the point where the yarn intersects the plane of the fabric, $x = 0$ and $\cos (2\pi x/\lambda) = 1{\cdot}0$ therefore $dh\ dx = (2\pi A/\lambda)$ but $dh/dx = \tan\ \theta$. When θ is small $\tan \theta \simeq \sin \theta$. (This is another way of saying $\cos \theta \simeq 1{\cdot}0$; which is true within 10 per cent when the half angle $\theta < 25°$.) Thus for small crimp amplitudes, it is a fair approximation and certainly for the purposes of explanation we may rewrite equation (8.7) as:

$$T_w \tan\theta_w \simeq T_f \tan\theta_f \tag{8.8}$$

Whence

$$T_w \times \frac{2\pi A_w}{\lambda_w} \simeq T_f \times \frac{2\pi A_f}{\lambda_f} \tag{8.9}$$

and

$$\frac{A_f}{A_w} \simeq \frac{\lambda_f}{\lambda_w}\frac{T_w}{T_f} \tag{8.10}$$

In other words, the crimp amplitude is dictated by the tension and spacing of the yarns. If the filling (or the fabric in the filling direction) is kept at low tension whilst the tension in the warp direction is high, then there will be considerable crimp in the filling and very little in the warp. In simple terms, the tension in the warp pulls out the crimp in that direction and in so doing puts more into the filling. This process is called *crimp exchange* (crimp interchange).

Equation (8.10) also shows that the construction of the fabric is important. If there is a high pick density (i.e. the # picks/inch is large or λ_f is small) and a low end density (λ_W is large), then the crimp in the filling will be small and in the warp it will be large unless the tensions are adjusted to compensate for it. This possibility of compensating imbalances in tension by varying the fabric structure or of compensating for the effects of fabric structure by varying the tension is very important. A good understanding of this is essential to the art of weaving.

At the beginning of this section it was arbitrarily assumed that the yarns were all of the same count and twist, but in fact this is rarely so. These factors determine the stiffness of the yarns and, even though the preceding simplified analysis does not show it, the stiffness of the yarns does affect the crimp interchange. Therefore, the equations given are at best no more than an approximation and they should be used with considerable caution; however, it is hoped that they are of help in understanding the process.

If a smooth surfaced fabric is required and the yarns are unequal, then, from purely geometrical considerations, the crimp has to be adjusted so as to bring the crests of the yarns into a single plane. This involves an increase of crimp in the thin yarn and a decrease of crimp in the thick one. Where the twists differ, the amount by which the yarn squashes also differs and this also has to be taken into account. Where ribs are required, the adjustment has to be in the other direction. Bearing in mind that the crimp is related to most other fabric parameters, it will be realized that the matter is complex and is beyond the scope of this book.

Fabric Weight

Generally, the weight of a piece of fabric is the combined weight of the warp and the filling yarns, but if the fabric is in the loom state, allowance must be made for the weight of size material on the warp. Also allowance has to be made for the crimp which changes in finishing. Consider both metric and imperial units.

Let L = length of fabric (meters or yards)
w = width of fabric (meters or inches)
S_w = warp crimp factor
S_f = filling crimp factor
ℓ_w = length of a single warp yarn (meters or yards)
ℓ_f = length of a single filling yarn (meters or yards)
N_w = warp yarn number in cotton count
N_f = filling yarn number in cotton count
n_w = linear density of warp yarn in tex
n_f = linear density of filling yarn in tex
m_w = end density (ends/meter or ends/inch)
m_f = pick density (picks/meter or picks/inch)
w_b = basis weight (g/m^2 or oz/sq. yd.)

From eqn. (8.2a), length of a single warp yarn

$$\ell_w = L(1 + S_w) \text{ meters or yards}$$

Therefore, total length of warp yarns

$$= m_W\, w\, \ell_W = m_W\, w\, L\,(1 + S_W) \text{ meters or yards}$$

Total length of filling yarns = $m_f w\ L\ (1 + S_f)$ meters or yards

Consider the metric case first.

$$\text{Mass of warp yarn} = \frac{m_W\, w\, L\,(1 + S_W)\ n_W}{1000} \text{ gram} \quad (8.11)$$

$$\text{Mass of filling yarn} = \frac{m_f\, w\, L\,(1 + S_f)\, n_f}{1000} \text{ gram} \quad (8.12)$$

Mass of fabric, excluding size, is the sum of the above

$$= \frac{w\ L}{1000}\ (m_W n_W\,(1 + S_W) + m_f n_f\,(1 + S_f))$$

Basis "weight" W = Mass of fabric ÷ Area

$$= \frac{1}{1000}(m_W n_W\,(1 + S_W)\ + m_f n_f\,(1 + S_f)) \quad (8.13)$$

Now consider imperial units.

$$\text{Weight of warp yarns} = \frac{m_w\, w\, L(1 + S)}{840\ N_W} \text{ pounds} \quad (8.11a)$$

$$\text{Weight of filling yarns} = \frac{m_f\, w\, L(1 + S_f)}{840\ N_f} \text{ pounds} \quad (8.12a)$$

Weight of fabric, excluding size, is the sum of the above but if w is measured in inches (as is normal) then a factor of 36 has to be introduced to calculate the *basis weight* and

$$\text{Basis Weight} = 0.043\ \frac{m_W\,(1 + S_W)}{N_W} + \frac{m_f\,(1 + S_f)}{N_f} \text{ lb/sq.yd.} \quad (8.14a)$$

or in more normal units,

$$W = 0.60\quad \frac{m_W\,(1 + S_W)}{N_W}\ +\ \frac{m_f(1 + S_f)}{N_f} \text{ oz/sq.yd.} \quad (8.14a)$$

Consider a special case in which the fabric has a *square construction*, i.e., the same yarn number for both warp and filling and the same end and pick densities.

$N_w = N_f = N$

$m_w = m_f = m$

In this case the basis weight is given by:-

$$w = 0.69 \frac{m}{N} [(1 + S_w) + (1 + S_f)] \text{ oz./sq.yd.} \qquad (8.15)$$

It must be realized that even if the same yarn number is used for warp and filling, the crimp levels may still be different due to the difference in yarn tension and twist.

Generally speaking, eqn. (8.13) gives the weight of the finished fabric, but it is possible to lose lint which will reduce the weight accordingly. Usually this loss is very small and can be neglected. The loom state basis weight has to be calculated to take into account the amount of size on the warp. Let Z = percentage size pick-up on the warp ÷ 100

Mass of size = eqn (8.11) x Z
or = eqn (8.11a) x Z (8.16)

In metric units, the weight of greige fabric

$$= \frac{w\ L}{1000} (m_w n_w (1 + S_w)(1 + Z) + m_f n_f (1 + S_f) \qquad 8.17)$$

and Basis Weight for greige fabric

$$W_g = \frac{1}{1000} (m_w n_w (1 + S_w)(1 + Z) + m_f n_f (1 + S_f)) \text{ gram/sq meter} \qquad (8.18)$$

in Imperial units, the basis weight for greige fabric

$$W_g = 0.60 \frac{m_W (1 + S_W)(1 + Z)}{N_W} + \frac{m_f(1 + S_f)}{N_f} \text{ oz/sq.yd} \quad (8.18a)$$

Equation (8.14a) is useful when considering finished fabrics and eqn. (8.18) is useful when considering those loom state fabrics which are sold on a weight basis.

Fabric Extension

When fabric is subjected to tension in a single direction, it extends fairly easily until most of the crimp has been removed and then it becomes stiffer. The latter effect is controlled mainly by the character of the yarn. Thus there are two principal mechanisms of extension, the first arising from changes in the fabric structure and the second from changes in the yarn structure. There is no distinct boundary, rather it is a case of a change in emphasis; furthermore, the effect of friction has to be taken into account, but for the present let this be ignored for the sake of simplicity. To show the effect of fabric structure, let the extensibility of the yarn also be ignored. From eqn. (8.2a), the length of a crimped yarn $l = \lambda(1 + S)$, where S = crimp factor = $(\pi A/\lambda)^2$.

After extension let the wavelength = λ_e and the crimp factor be S_e, the length l remains the same, therefore

$$l = \lambda(1 + S) = \lambda_e(1 + S_e)$$

whence

$$\frac{\lambda_e}{\lambda} = \frac{1 + S}{1 + S_e}$$

$$\text{Fabric extension} = \left(\frac{\lambda_e - \lambda}{\lambda}\right) \times 100 \text{ per cent}$$

$$= \left(\frac{\lambda_e}{\lambda} - 1\right) \times 100 \text{ per cent} \quad (8.19)$$

$$= \left(\frac{S - S_e}{1 + S_e}\right) \times 100 \text{ per cent}$$

In other words, the fabric extension is a function of the change in crimp. With inextensible yarns, the initial crimp level would be the limiting extension but, as has been shown earlier, crimp in one direction is only changed at the expense of the crimp in the other direction. For example, if the fabric were subjected to warpwise tension (which tends to straighten out the warp) it could only extend if the crimp in the filling was increased or if the yarns themselves extend. If, for any reason, there was a restraint to prevent the increase in crimp in the filling direction, this would be felt as a change of stiffness in the warp direction. For this reason, behavior when tension is applied in a single direction (*uniaxial load*) is different from behavior when tension is applied in two directions (*biaxial load*). This can be expressed in mathematical terms as follows: From eqn. (8.10)

$$\frac{T_w}{T_f} \cong \frac{A_f \lambda_w}{\lambda_f A_w}$$

$$T_w \cong T_f \frac{S_f}{S_w} \tag{8.20}$$

In other words, when the yarns are in contact and the fabric structure permits free movement, the warpwise tension is a function of the filling tension and the ratio of the crimp factors. When the fabric *jams*, a different situation exists because the crimp can develop no further and the thickness of the yarns prevents any further contraction.