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Finishing of technical textiles

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7.1 Introduction

The name textile finishing covers an extremely wide range of activities, which are performed on textiles before they reach the final customer. They may be temporary, for example the way bed sheets are pressed before packing, or they may be permanent, as in the case of a flame-retardant tenting fabric. However, all finishing processes are designed to increase the attractiveness or serviceability of the textile product. This could involve such techniques as putting a glaze on an upholstery fabric, which gives it a more attractive appearance, or the production of water-repellent finishes, which improve the in-service performance of a tenting fabric. Thus a further aim of textile finishing may be described as improvement in customer satisfaction, which finishing can bring about. This improvement in the perceived value of a product to the consumer forms the basis of modern ideas on product marketing. Technical textiles are defined as those materials with non-clothing applications. Thus the fashion aspects of textiles will be ignored, although aesthetic aspects of say upholstery and drapes will be covered.

7.2 Finishing processes

The finishing processes that are available can be divided into four main groups, which are:

- **Mechanical processes:** these involve the passage of the material through machines whose mechanical action achieves the desired effects. A heating process, the purpose of which is usually to enhance these desired effects, frequently accompanies this.
These mechanical finishes, which will be discussed in detail later in this section, are:
 - **Calendering:** compression of the fabric between two heavy rolls to give a flattened, smooth appearance to the surface of the fabric.

- **Raising:** plucking the fibres from a woven or knitted fabric to give a nap effect on the surface.
- **Cropping:** cutting the surface hairs from the a fabric to give a smooth appearance, often used on woollen goods where the removal of surface hair by a singeing process is not possible.
- **Compressive shrinkage:** the mechanical shrinking of the warp fibres in woven fabrics so that shrinkage on washing is reduced to the desired level.
- **Heat setting:** this is a process for the stabilisation of synthetic fibres so that they do not shrink on heating.
- **Chemical processes:** these may be described as those processes that involve the application of chemicals to the fabric. The chemicals may perform various functions such as water repellency or flame retardancy, or may be used to modify the handle of a fabric. Chemical finishes are normally applied in the form of an aqueous solution or emulsion and may be applied via a variety of techniques, the main one being the pad mangle, which is illustrated in Fig. 7.1.

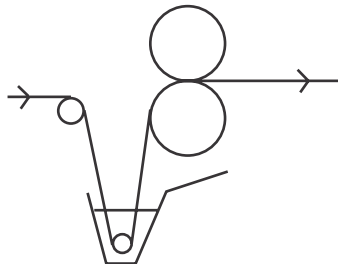
After the padding or the application stage of the chemical finishing the fabric is usually dried to remove the water from the fabric and some form of fixation of the finish is then performed. This commonly takes the form of a baking process, where the fabric is subjected to a high temperature for a short period, which enables the applied chemicals to form a more durable finish on the fabric than would otherwise be achieved.

Surface coating is a most important part of the finishing of technical textiles and as such deserves a separate chapter (see Chapter 8).

7.3 Mechanical finishes

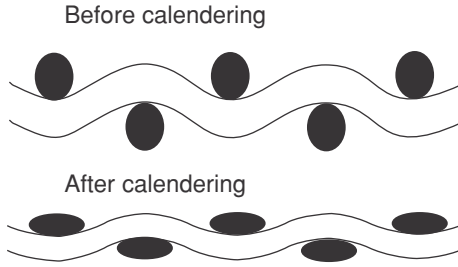
7.3.1 Calendering

Calendering may be defined as the modification of the surface of a fabric by the action of heat and pressure.¹ The finish is obtained by passing the fabric between heated rotating rollers (or bowls as they are frequently called), when both speed of rotation and pressure applied are variable. The surfaces of the rollers can be either smooth or engraved to provide the appropriate finish to the fabric, while the actual construction of the rollers may be varied from hardened chromium-plated steel to elastic thermoplastic rollers.



Pad mangle

7.1 Simple pad mangle.



7.2 Flattening effect on fabric of calendaring.

7.3.1.1 Effects which may be achieved by calendaring

Calendaring is done for many purposes but the main effects are:

- smoothing the surface of the fabric
- increasing the fabric lustre
- closing the threads of a woven fabric
- decreasing the air permeability
- increasing the fabric opacity
- improving the handle of a fabric, i.e. softening
- flattening slubs
- obtaining silk-like to high gloss finishes
- surface patterning by embossing
- consolidation of nonwovens.

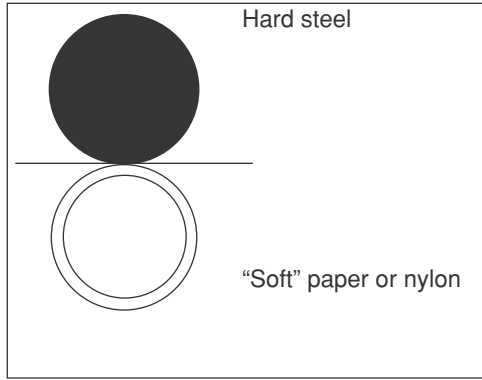
The flattening of the fabric is illustrated in Fig. 7.2, which shows the effect of the flattened yarn structure. This gives a greater light reflectance than the original rounded yarn structure.

7.3.1.2 Types of calender

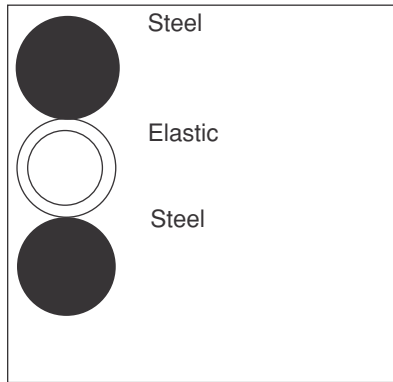
In general calenders usually have between two and seven rollers, with the most common being the three-bowl calender. Perhaps the most important factor in calender design is the composition of the rollers and the surface characteristics of these.² Textile calenders are made up from alternate hard steel and elastic bowls. The elastic bowls are made from either compressed paper or compressed cotton, however, a lot of modern calenders are made with a thermoplastic thick covering, which is usually nylon 6. The latter have the advantage that they are less liable to damage from knots, seams and creases than cotton and paper bowls, damage that would then mark off onto the calendered fabric. In fact the development of the 'in situ' polymerisation technique for nylon 6 has enabled the simple production of elastic rollers from this material. Because of this improved performance, nylon 6 covered rollers often enable the required effects to be achieved in a single nip thus reducing the overall number of bowls.

In two-bowl calenders (Fig. 7.3), it is normal to have the steel bowl on top so that the operator can see any finish. This type of arrangement is often used with the nylon bottom bowl mentioned previously, especially where the calender is used for glazing or the embossed type of finishes.

The arrangement where two steel bowls are used together only occurs in exceptional circumstances, for example, in the compaction of nonwovens. Here both bowls



7.3 Two-bowl calender.



7.4 Three-bowl calender.

are usually oil heated so that some form of permanent setting occurs. Finally, the arrangement with two elastic bowls is not common but is sometimes used on cotton knitgoods to obtain a soft handle.

The three-bowl calender (Fig. 7.4) was developed from the two-bowl calender and with this type of calender it is normal to use only the top nip, with the bowls arranged steel–elastic–steel. The bottom bowl is used to keep the central elastic bowl smooth and thus assist in the finishing. The same arrangement also serves the same purpose on embossing calenders, where there is the possibility of permanent indentation from the top roller.

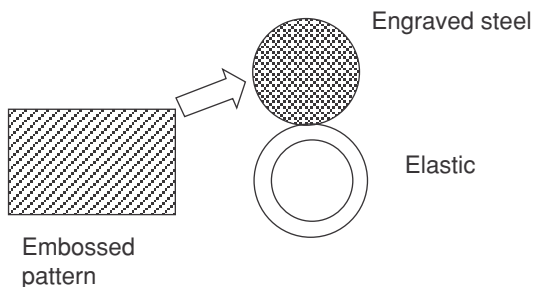
Pressure used in all of the above calenders can be varied between 10 and 40 tonnes, with running speeds up to 60 m min^{-1} . However, these are very much average figures with figures as low as 6 tonnes for a 1 m wide calender to as high as 120 tonnes for a 3 m wide calender. In addition, running speeds of 20 m min^{-1} are used on an embossing calender, while on a glazing calender speeds of over 150 m min^{-1} have been quoted.

The temperatures which are used in calender rollers can, of course, vary from room temperature to 250°C . However, it must be stressed that temperature control is of vital importance, with a tolerance of $\pm 2^\circ\text{C}$ being commonly quoted. Some generalisations can be made as follows:

- Cold bowls give a soft handle without much lustre; warm bowls (40–80 °C) give a slight lustre.
- Hot bowls (150–250 °C) give greatly improved lustre, which can be further improved by the action of friction and waxes.

7.3.1.3 Types of finish

- **Swissing or normal gloss:** a cold calender produces a smooth flat fabric. However, if the steel bowl of the calender is heated then in addition to smoothness the calender produces a lustrous surface. If a seven-bowl multipurpose calender is used then a smooth fabric with surface gloss on both sides is produced.
- **Chintz or glazing:** this gives the highly polished surface which is associated with glazed chintz. The effect is obtained by heating the top bowl on a three-bowl calender and rotating this at a greater speed than that of the fabric. The speed of this top bowl can vary between 0 and 300% of the speed of the fabric. In certain cases where a very high gloss is required, the fabric is often preimpregnated with a wax emulsion, which further enhances the polished effect. This type of calendaring is often called friction calendaring.
- **Embossing:** in this process the heated top bowl of a two-bowl calender is engraved with an appropriate pattern which is then transferred to the fabric passing through the bowls. The effect can be made permanent by the use of thermoplastic fibres or in the case of cellulose by the use of an appropriate crosslinking resin.
- **Schreiner or silk finishing:** this is a silk-like finish on one side of the fabric. It is produced (see Fig. 7.5) by embossing the surface of the fabric with a series of fine lines on the surface of the bowls. These lines are usually at an angle of about 30° to the warp threads. The effect can be made permanent by the use of thermoplastic fabric or, in the case of cotton, by the use of a resin finish. This finish is particularly popular on curtains and drapes because of the silk-like appearance this type of finish gives to the product.
- **Delustering:** this is commonly achieved by passing the fabric through the bottom two bowls of a three-bowl calender, where these are elastic. However, steel bowls with a special matt finish have been manufactured that are very effective for this purpose.
- **Chasing:** the fabric is threaded through the calender in such a way as to press the fabric against itself several times. It is common to use a five- or seven-bowl calender, the fabric passing through each nip of the calender in two or three layers.



7.5 Principle of Schreiner calender.

- **Palmer finishing:** in this type of finish the damp fabric is carried on the inside of a felt blanket round a steam-heated cylinder, often called a Palmer drier. The face of the fabric, which is run on the surface of the heated cylinder, takes a light polish from the cylinder, while the back of the fabric, which is in contact with the felt blanket, takes a roughened effect from the cylinder. This finish is particularly popular for cotton drill fabric.

These descriptions of calendering should not be regarded in any way as complete and for a more complete description the reader is recommended to contact the calender manufacturers. Some of these are Küsters in Germany, Parex Mather in the UK, Kleinewefers in Germany and Metallmeccanica in Italy.

7.3.2 Raising

Raising is the technique whereby a surface effect is produced on the fabric that gives the fabric a brushed or napped appearance. It is achieved by teasing out the individual fibres from the yarns so that they stand proud of the surface.³ The way this was done originally was to use the seedpod of the thistle, which was known as a teasel. These teasels were nailed to a wooden board and the fabric was drawn over them to produce a fabric with a hairy surface, which had improved insulating properties. This method has largely been superseded by the use of rotating wire brushes, although where a very gentle raising action is required, such as in the case of mohair shawls, teasels are still used.

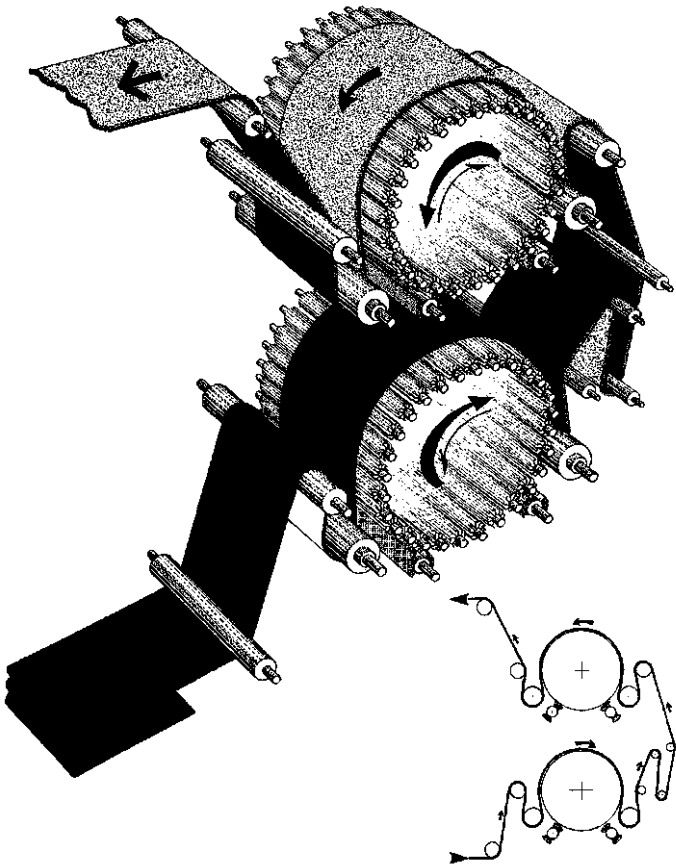
7.3.2.1 Modern raising machines

All modern raising machines (see Fig. 7.6) use a hooked or bent steel wire to tease the fibres from the surface of fabric. The most important factor in the raising operation is the relationship between the point and the relative speed of the cloth. The raising wires or 'card' wires are mounted on a flexible base, which is then wrapped around a series of rollers, which are themselves mounted on a large cylindrical frame, illustrated in Fig. 7.6.

The raising action is brought about by the fabric passing over the rotating rollers and the wire points teasing out the individual fibres in the yarn. Because there are a large number of points acting on the fabric at any one time, the individual fibres must be sufficiently free to be raised from the fibre surface. This is a combination of the intrafibre friction and the degree of twist in the raised yarns. Thus for 'ideal' raising, the yarns should be of low twist and be lubricated. One further point to note is that because the fabric runs in the warp direction over the machine, only the weft threads are at right angles to the rotating raising wires and therefore only the weft threads take part in the raising process.

7.3.2.2 Raising action

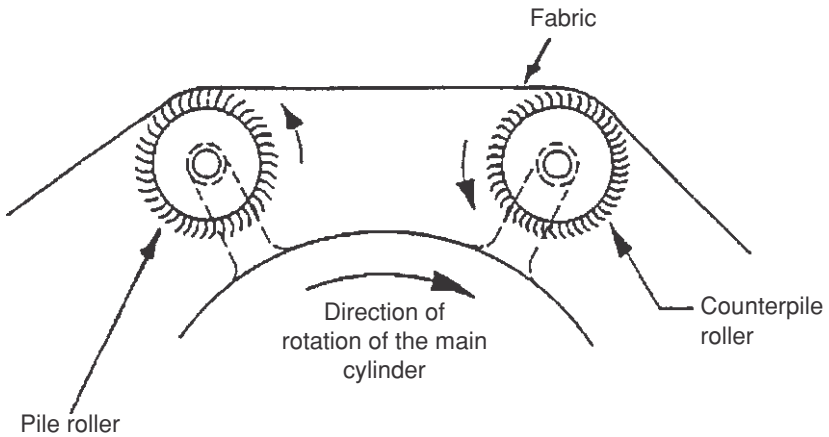
From Fig. 7.6 it can be seen that both the card wire rollers and the cylinder to which these are attached may be rotated; it is the relative speed of these in relation to that of the fabric that produces the various raising effects that may be achieved. There are two basic actions in raising and these are governed by the direction in which the card wires point and the relative speed of rotation of these in relation to the fabric. These actions are called the pile and the counterpile actions and are shown in Fig. 7.7.



7.6 The modern raising machine.

In the counterpile action, the working roller rotates in the opposite direction to that of the cylinder with the points of the wire moving in the direction of rotation. This action pulls the individual fibres free from the surface.

In the pile action, the points of the wire are pointing away from the direction of movement of the fabric. This results in an action where the raised fibres are subject to a combing action which tends to tuck back the fibres into the body of the fabric.



7.7 The raising action.

The most common raising action uses a combination of both of these actions, producing an even raise over the whole of the fabric surface. Control of the raising action has been achieved by measurement of the surface roughness of the raised fabric.⁴ It is therefore possible to control the exact height of the nap on the surface of fabrics.

7.3.3 Shearing

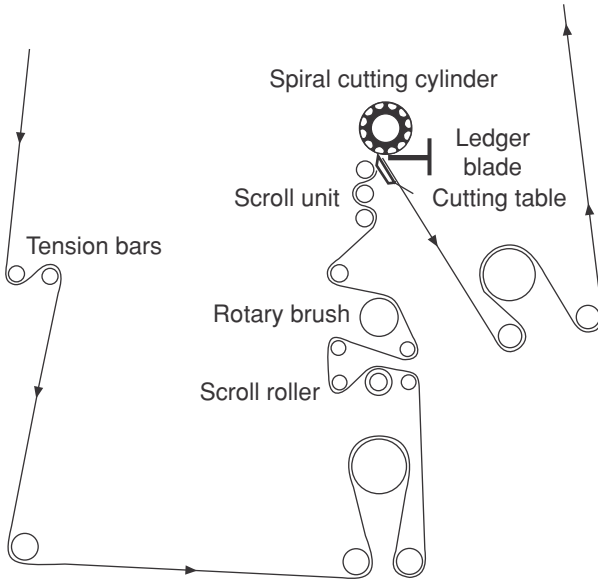
This is a process by which the fibres which protrude from the surface of a fabric, are cut to an even height. The principle used in this technique is similar to a lawn mower in that a spiral cutter rotates against a stationary blade and cuts off any material protruding from the fabric surface.⁵

This principle is illustrated in Fig. 7.8, which shows the fabric passing over the cutting bed and the protruding hairs on the surface being caught between the rotating head of the spiral cutter and the ledger blade. By raising and lowering the height of the cutting bed, the depth of cut may be varied. Obviously the cutting action produces a great deal of cut pile and this must be removed by strong suction otherwise a large amount of fly rapidly accumulates. In order to achieve an even cut and a smooth surface, several passes through the machine are required or a single pass through a multiple head machine is required. Average speeds of about 15 m min^{-1} are commonly encountered.

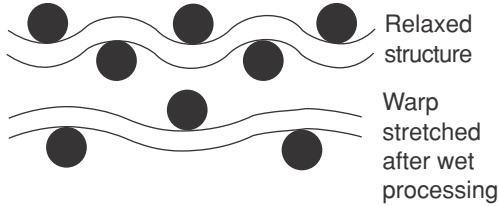
One important use for this technique is the production of pile fabrics from a looped terry fabric. When this type of fabric is sheared the top of the loops of the terry fabric are cut off and a velvet like appearance is produced. When knitted loop pile fabrics are sheared, knitted velour is produced that has found a great deal of use in upholstery fabric.

7.3.4 Compressive shrinkage

The shrinkage of fabrics on washing is a well-known phenomenon. It is caused in part by the production and processing stresses on the fabric. Production stresses are introduced into the fabric by the yarn tension and also by the tension which is nec-



7.8 Shearing or cropping.



7.9 Fabric relaxation.

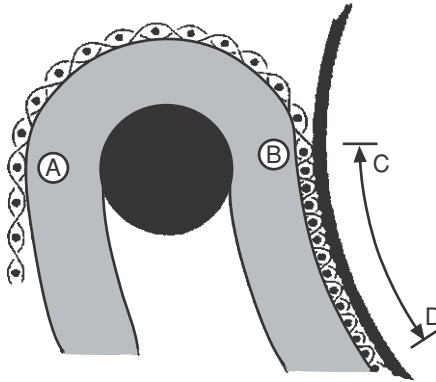
essary for the satisfactory production of fabric. Processing stresses are introduced during the bleaching, dyeing and finishing of fabric when the fabric is pulled in the warp direction. This tends to remove the warp crimp from the fabric as illustrated in Fig. 7.9.

In order to replace the warp crimp and thus minimise warp shrinkage, a process known as compressive shrinkage is carried out on the fabric to replace the crimp that has been pulled out in the preparation and finishing processes. This may be illustrated in the following way. A strip of fabric is placed on a convex rubber surface and gripped at each end of the rubber. As the rubber is allowed to straighten, the length of the fabric exceeds that of the rubber as illustrated in Fig. 7.10. However, if the fabric could be stuck to the surface of the rubber then the fabric would be subjected to compression and warp crimp would be introduced.

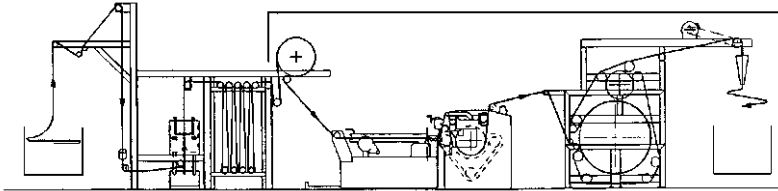
This principle then is applied to the compressive shrinking machine, where the cloth is fed in a plastic state onto a thick rubber belt at point A as shown in Fig. 7.11. While the belt is in the convex position for A to B the fabric merely lies on the surface, but at point B the belt starts to wrap its way round a large heated cylinder and thus changes from a convex to a concave shape. Thus the surface of the rubber belt contracts and the fabric, which is held onto the surface of the rubber, is



7.10 (a) Fabric under tension, (b) tension relaxed.



7.11 Shrinkage belt.



7.12 Complete shrinkage range.

subject to a warp compression over the region C to D. The actual degree of shrinkage which takes place is controlled by the amount of fabric fed onto the rubber belt and the pressure between the heated metal cylinder and the belt, which increases or decreases the concave shape of the rubber belt. The principles of compressive shrinkage have also been reviewed.⁶

A sketch of the complete compressive shrinkage range is shown in Fig. 7.12.

7.4 Heat setting

The main aim of the heat setting process is to ensure that fabrics do not alter their dimensions during use. This is particularly important for uses such as timing and driving belts, where stretching of the belt could cause serious problems. It is important to examine the causes of this loss in stability so that a full understanding can be obtained of the effects that heat and mechanical forces have on the stability of fabrics. All fabrics have constraints placed on them by their construction and method of manufacture, but it is the heat-setting mechanism that occurs within the fibre that will ultimately influence fabric dimensions.

7.4.1 Heat-setting mechanisms

The first attempt to describe the various mechanisms of heat setting synthetic fibres was that of Hearle.⁷ He describes the various techniques which have been used to set fabrics into a given configuration and leaving aside the chemical methods of stabilisation, these techniques may be described as influencing the following:

1. chain stiffness
2. strong dipole links
3. hydrogen bonds
4. crystallisation.⁸

all of which are influenced by temperature, moisture and stress.

Hydrogen bonding is the most important of the factors which influence setting, and nylon has a strong hydrogen-bonded structure whereas polyester has not. Thus relaxation of nylon can occur in the presence of water at its boiling point. In fact one of the common tests for the nylon fabrics used in timing belts is a 5 min boil in water.

7.4.2 Fibre structure

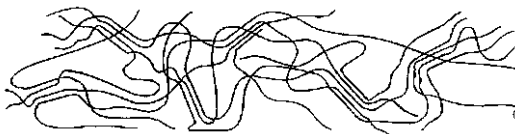
All fibre-forming molecules consist of long chains of molecules. In fact, a typical nylon molecule will have a length which is some 5000 times the molecule diameter. X-ray diffraction techniques have confirmed that all synthetic fibres contain crystalline and non-crystalline regions. In nylon and polyester these crystalline regions occupy about 50% of the total space in the fibre.

It can be shown that these ordered or crystalline regions are small compared to the overall length of the polymer chain. To explain this phenomenon the polymer chains cannot be perfectly aligned over the whole length of the molecule, but must pass through alternating regions of order and disorder. The picture that thus emerges is one of short crystalline regions connected by relative regions of disorder. This view of molecular structure is now an accepted model and is known as the fringed micelle model. Figure 7.13 represents this scheme for a disorientated polymer.

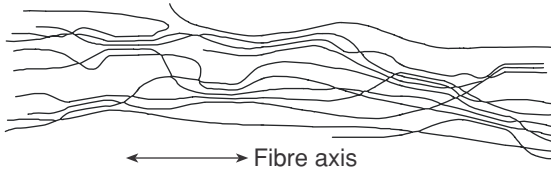
The short parallel areas represent regions of order where adjacent chains pack in an ordered fashion. The non-parallel regions are where the chains do not pack together in a regular fashion, creating the non-crystalline regions or amorphous regions in the fibre.

7.4.3 Polymer orientation

During the processing of both polyester and nylon, the fibres are spun through fine holes and have a structure similar to that in Fig. 7.13. However, to develop the



7.13 Undrawn fibre.



7.14 Drawn fibre.

strength in the fibre these fibres are then cold drawn to create an orientated structure, which is illustrated in Fig. 7.14. Once the chains have been orientated then the fibres show a much greater resistance to applied loads and a greater stiffness, hence the reason for cold drawing.

7.4.4 Transition temperatures

In the previous section the crystalline and amorphous regions of the polymer were discussed. These do have an effect on two important parameters:

- **Glass transition temperature:** this represents the temperature at which molecular movement starts in the amorphous regions of the polymer, and was given the name because it is the temperature at which the polymer changes from a glassy solid to a rubbery solid. This is the temperature at which segmental loosening takes place and hence dyeing can only take place above this temperature.
- **Melting point:** at this point the forces holding the molecules in the crystalline regions of the fibre are overcome by the thermal energy and the polymer melts. In both polyester and nylon these temperatures are separated by about 150°C.

7.4.5 Heat shrinkage

All textile fibres are subjected to a cold drawing process and hence when they are heated above the point at which molecular motion sets in, they will progressively shrink until they reach the point of thermodynamic equilibrium represented by Fig. 7.13. In other words the cold drawing process is reversed by the application of heat.

7.4.6 Heat setting

If the model of the drawn fibre (Fig. 7.14) is considered then it can be observed that in the drawn fibre, the molecules in the amorphous areas, while still random, are much more parallel than in the non-drawn state. Thus if the fibre is held so that shrinkage is prevented and heated above its glass transition temperature, the

molecules in the amorphous areas start to move, and because of their relative orientation, to crystallise. In practice the fibres are usually heated to about 20–40°C below the melting point. It now becomes apparent that the whole process of heat setting is time dependent, because it takes time for the motion of the molecules to line themselves up in the first place and then to crystallise. It is possible to heat set at much lower temperatures than are used in practice. However, if low temperatures are used, the fibres are only stabilised up to the heat set temperature and as soon as this temperature is exceeded, severe shrinkage occurs. In addition the rate of crystallisation decreases with decreasing temperature and heat setting would be a long and tedious process.

Obviously it is the temperature the yarns in the fabric actually achieve that is important in the setting process. This is dependent not only on the fabric construction but also on the method of heating, because it is essential that the setting temperature is achieved quickly and evenly over the width of the fabric. Commonly, stenters are used for this purpose, because temperature control to $\pm 1\%$ over a 2 m width can be obtained. Where contact heating is used, special designs are available to obtain this degree of control.

7.4.7 Essentials of heat setting

From the previous discussion it can be seen that heat setting is a temperature-dependent process and for practical purposes the heat setting temperatures vary for polyester between 190–200°C and for nylon 6.6 between 210–220°C. The fibres must not be allowed to move during the heating process and the heating must be sufficiently long enough to allow crystallisation to take place, after which the fibre must be cooled down to well below the heat setting temperature before being released.

There is an important difference between the behaviour of the two common polyamides (nylon 6 and nylon 6.6) and polyester, because of their different behaviour towards water. Polyester is non-absorbent, so the heat setting behaviour is not affected by water. However, nylon will absorb sufficient water to obtain a temporary set that is based on hydrogen bonding and is destroyed on boiling in water. The consequence of this is that to obtain a permanent set on nylon, the water has to be removed from the fibre so that crystallisation can take place. Therefore nylon tends to be heat set at a higher temperature than polyester.

In summary:

1. Heat the fabric to within about 20–40°C of the fibre melting point.
2. Hold at this temperature under tension for approximately 20 s.
3. Cool fabric before removing tension.

The time–temperature relationship will vary depending on the polymer, the fabric weight and construction.¹⁰ The simple way to determine these is to look at the shrinkage of the finished product, if the material has been correctly heat set then it should show a residual shrinkage of less than 1% on a 5 min immersion in boiling water.

7.5 Chemical processes

It has been suggested that by the end of 2000 some 50% of all textile fibre consumption in industrialised countries will be in technical textiles.¹¹ A large percentage of this will consist of safety equipment and protective clothing and in fact this

comprises the most significant portion of the technical textiles market. Protective clothing must provide resistance to the elements in the workplace, whilst at the same time providing comfort during wear. The customers for these products demand strict compliance with the regulations designed to protect the wearer. One of the most important properties of this type of clothing is its resistance to small burning sources, thus flame resistance combined with easy cleaning is a most important consideration. The flame retardance must be maintained throughout the lifetime of the garment.

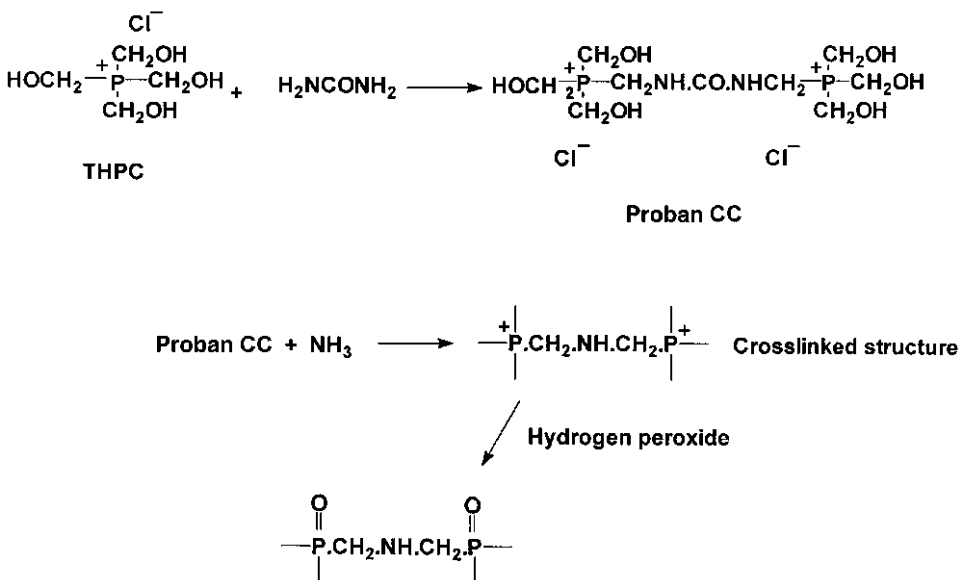
The main regulation governing the use of flame-retardant technical textiles was the Furniture and Furnishing Fire Safety Regulations which were introduced into the UK in 1988.¹²

7.5.1 Durable flame-retardant treatments^{13,14}

Fire-retardant technical textiles have been developed from a variety of textile fibres, the choice of which is largely dependent on the cost of the fibre and its end-use. However, the main fibre in this area is cotton and thus treatments of this fibre will be discussed first. Two major flame-retardant treatments are popular. These are Proban (Rhodia, formerly Albright and Wilson) and Pyrovatex (Ciba).¹³

The Proban process uses a phosphorus-containing material, which is based on tetrakis(hydroxymethyl)phosphonium chloride (THPC). This is reacted with urea and the reaction product is padded onto cotton fabric and dried. The fabric is then reacted with ammonia and finally oxidised with hydrogen peroxide. The full reaction scheme is shown in Fig. 7.15.

The Proban process may be summarised as follows:



7.15 Chemistry of the Proban process.

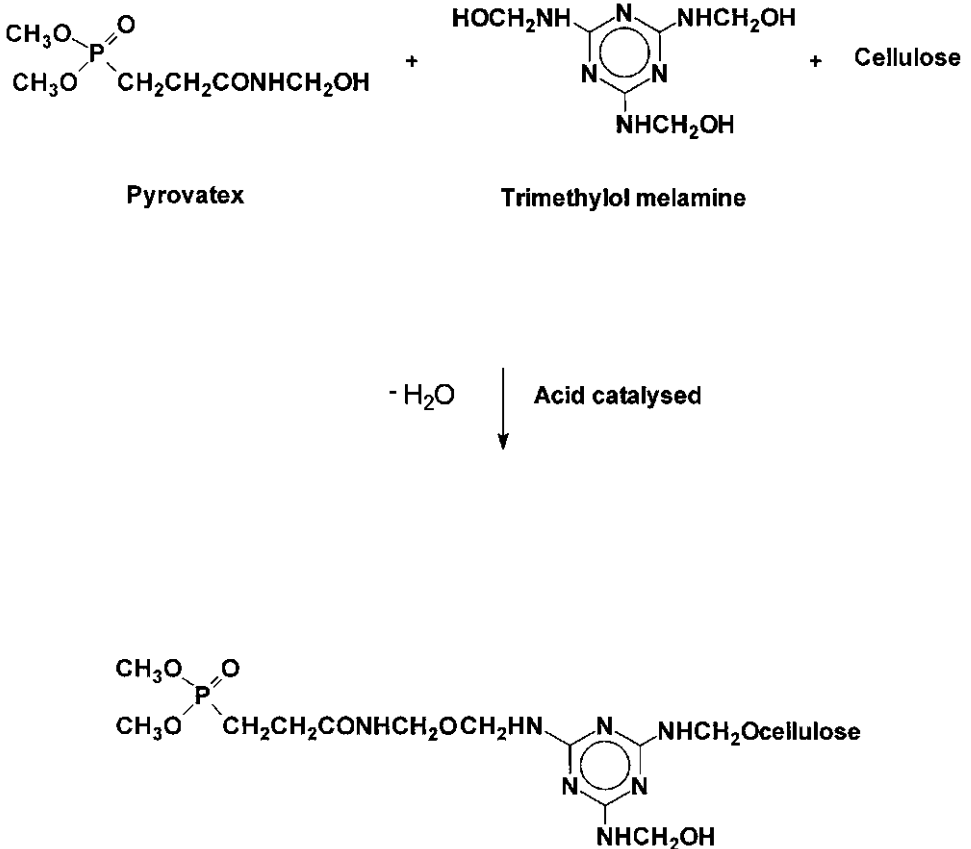
1. Pad the fabric with Proban CC.
2. Dry the fabric to a residual moisture content of 12%.
3. React the fabric with dry ammonia gas.
4. Oxidise the fabric with hydrogen peroxide.
5. Wash off and dry the fabric.
6. Soften the fabric.

The actual chemistry of the process is fairly straightforward and the Proban forms an insoluble polymer in fibre voids and the interstices of the cotton yarn. There is no actual bonding to the surface of the cellulose, but the insoluble Proban polymer is held by mechanical means in the cellulose fibres and yarns. Because of this the Proban treated fabric has a somewhat harsh handle and some softening is usually required before the fabric is fit for sale. The chemistry is shown in Fig. 7.15.

The next method of forming a durable treatment for cellulose is by the use of Pyrovatex. This material is closely related to the crosslinked resins used in textile finishing and is in fact always applied with a crosslinked resin to form a chemical bond to the cellulose. The application scheme is given in Fig. 7.16.

The Pyrovatex process may be summarised as follows:

1. Pad the Pyrovatex mixture.
2. Dry at 120°C.



7.16 Chemistry of the Pyrovatex process.

3. Cure at 160°C for 3 min.
4. Wash in dilute sodium carbonate.
5. Wash in water.
6. Dry and stenter to width.

As the reaction is with the cellulose, the flame-retardant substance is chemically bound to the fibre and is therefore durable. However, because the flame-retardant substance has to be applied with a crosslink resin, then the finished fabric has good dimensional stability and also excellent crease-recovery properties making this finish the one preferred for curtains. Unfortunately these desirable properties are not without disadvantages, the main one in the case of Pyrovatex being the loss in tear strength, which occurs with this and all crosslinking systems.

7.5.2 Synthetic fibres with inherent flame-retardant properties

The Furniture and Furnishing (Fire) (Safety) Regulations¹² made it mandatory that all upholstery materials should withstand the cigarette and match test as specified in BS 5852:1979: Pt1. This produced an enormous amount of work in the industry on possible routes which could be used to meet this legislation. These ranged from the use of materials that would not support combustion to chemical treatments and backcoating techniques. It is now clear, however, that backcoating is the main means by which these regulations are being met. Currently, some 5000 tonnes of backcoating formulations are being used in the UK for upholstery covers.

The majority of backcoating formulations are based on the well-known flame-retardant effect of the combination of antimony(III) oxide and a halogen, which is usually bromine, although chlorine is also used to a lesser degree. The synergistic mixture for this is one part of antimony(III) oxide to two parts of bromine containing organic compound. A typical formulation which describes the application level per square metre, is shown in Table 7.1.

To this basic formulation are often added softeners, which modify the fabric handle and antifungal compounds. In addition, foaming agents are used which enable the use of foam application techniques, so that a minimum amount of penetration of the backcoating compound onto the face of the fabric is achieved. The use of foam application also enables higher precision in the weights applied and shorter drying times to be achieved.¹⁵

Thus Proban, Pyrovatex and backcoating with antimony/bromine compounds represent the major flame-retardant treatments for cellulose.

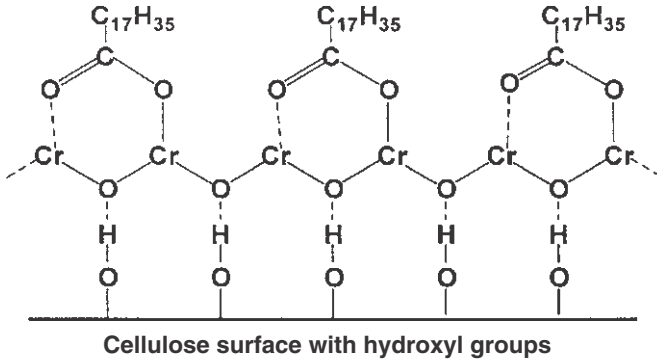
7.5.3 Water-repellent finishes

The early water-repellent finishes were all based on the application of a mixture of waxes, which were pliable at normal temperatures, applied to tightly woven cotton fabrics. These were, of course, well suited to sail cloth and protective clothing, but problems were encountered when the garments were cleaned. Therefore, the search was on for water-repellent treatments that were simple to apply but would also allow the treated fabrics to be cleaned.

It was noted early on that the heavy metal soaps did have water-repellent properties and therefore the first attempt at the production of a durable treatment was

Table 7.1 Typical backcoating formulation

	Application level (gm ⁻²)
Antimony(III) oxide	40
Decabromodiphenyl oxide	80
Acrylic binder	120

**7.17** Reaction of the chromium salt of a fatty acid with cellulose.

to use the chromium salt of a fatty acid, which was applied to cotton and then baked. This gave a certain durability to the fabric thus treated and the mechanism is illustrated in Fig. 7.17.

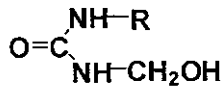
Some of the later treatments involved the use of other fatty acid derivatives and some of these are shown in Fig. 7.18.

The most recent treatments involve the use of the fluorocarbons which are basically esters of polyacrylic acid and a perfluorinated hexanol, as illustrated in Fig. 7.19. A list of finishes is given in Table 7.2.⁶

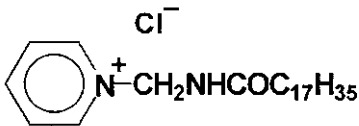
7.5.4 Antistatic finishes

Static electricity is formed when two dissimilar materials are rubbed together. It cannot be formed if identical materials are rubbed together. Thus when dissimilar materials are rubbed together a separation of charges occurs and one of the materials becomes positively charged and the other negatively charged. The actual sign of the charge depends on the nature of the two materials that are taking part and this may be deduced from the triboelectric series, shown in Table 7.3. The materials at the top of the table will derive a positive charge when rubbed with any of the materials below them.¹⁷

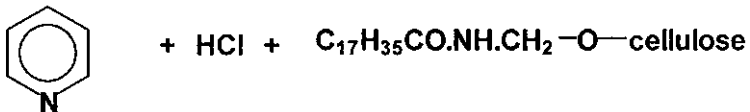
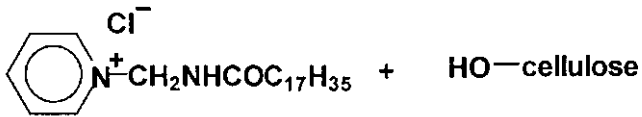
Cotton is a fibre that has very good antistatic properties on its own and presents few problems. This is because the natural water content of cotton is high (moisture contents of around 8% are commonly quoted), which provides the fibre with sufficient conductivity to dissipate any charge that might accumulate. However, with the advent of synthetic fibres, which had a low water content and were sufficiently non-conductive to hold a static charge on the surface, severe static problems began to arise. Thus some synthetics, particularly polyesters, can sustain such a high charge density on the surface that it can actually ionise the air in the vicinity giving rise to

Methylol derivatives of fatty acid amides


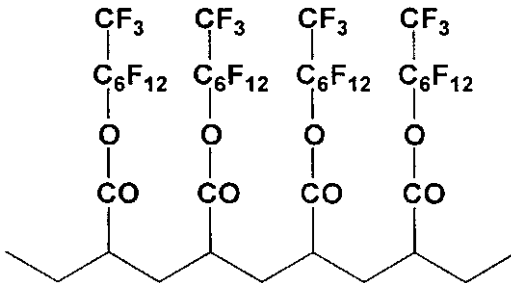
where R is a fatty acid, e.g. $\text{C}_{17}\text{H}_{35}\text{CO}$

Pyridinium salts of fatty acids, for example


will react with cellulose



7.18 Reactions of some permanent repellents.



7.19 Fluorocarbon showing polyacrylate backbone and perfluoro side chain.

a spark, which discharges the static that has been built up. In most cases this results in a mild shock to the person experiencing this static discharge, but where explosive gases might be present it can result in disaster.

Antistatic treatments, therefore, are based on the principle of making the fibre conductive so that high charge densities are dissipated before sparks can form. This

Table 7.2 Common water repellent finishes

Finish	Application method	Trade names
Paraffin wax emulsion	Spray	Mystoline, Ramasit
Paraffin wax plus Al or Cr salt	As above but lower amounts	Mystoline
Metal soap plus fatty acid	Pad, dry, bake	Persistol
Methylol stearamide	Reactive resin, pad, dry, bake	Phobotex
Pyridinium compounds	Pad, dry, bake	Velan (ICI), Zelan (Du Pont)
Reactive silicone resins	Pad, dry, bake	Silicone Finish (ICI)
Fluorocarbon emulsion	Pad, dry, bake	Zepel (Du Pont), Scotchgard (3M)

Table 7.3 The Triboelectric Series

<i>Positive end</i>
Polyurethane
Nylon
Wool
Silk
Rayon and cotton
Acetate
Polypropylene
Polyester
Acrylic
PVC (polyvinylchloride)
PTFE (polytetrafluoroethylene)
<i>Negative end</i>

is done by the application of both anionic and cationic agents to the fibre. Typical structures of these materials are similar to the softening agents used for cotton, which contain a long chain hydrocarbon with an ionic group at the end. One of the most interesting advances in the field of antistatic treatments has been the development of the permanent antistatic finishes, one of which was the Permose finish developed by ICI. These are actually a series of finishes that consist of block copolymers of ethylene oxide and a polyester. When polyester fibres are treated with Permose, the polyester block of the copolymer is adsorbed by the polyester fibre but the polyethylene oxide portion is incompatible with the polyester fibre and thus remains on the surface, where it attracts water and forms a conductive surface on the polyester fibre.

7.5.5 Antimicrobial and antifungal finishes

Problems of hygiene are coming more and more to the fore in textile finishing¹⁸ and it is now generally realised that a microbiocidal finish is very valuable in certain textiles for two reasons: as a prophylactic measure to avoid reinfections and as a deodorant.

Perhaps at this stage it might be useful to define some of these terms:

- *Bacteriostatic*: a chemical that inhibits the growth of bacteria. Fabric that has been impregnated with a bacteriostat will stop the growth of germs, which eventually die in time.
- *Fungistatic*: a chemical that inhibits the growth of fungi.

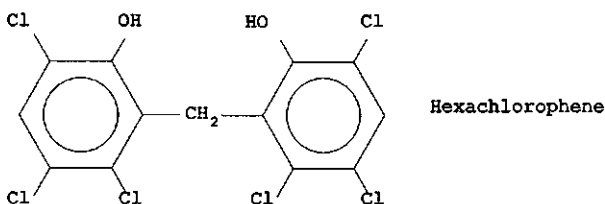
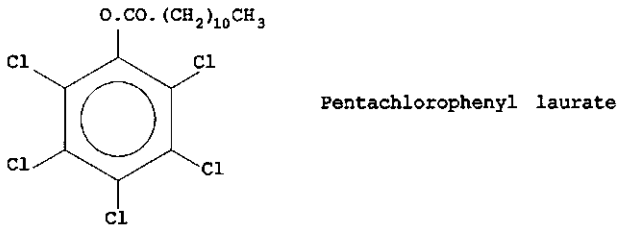
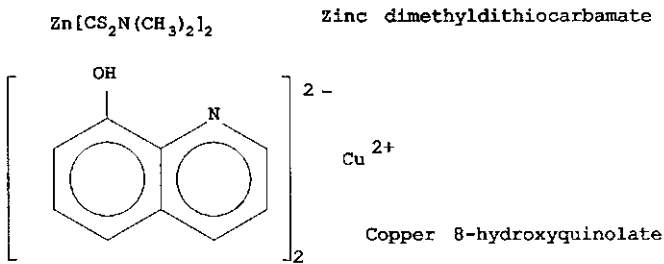
Bactericidal, *fungicidal* and *microbicidal* all mean that the chemical will kill these three types of microorganism.

Here are just a few of the many microorganisms with the infections they cause:

- *Staphylococcus aureus*: found in mucus membranes, causes boils and abscesses
- *Pseudomonas pyocyanea*: causes spots and boils
- *Trichophyton menagrophytes*: fungus, which causes dermatomycosis of the feet
- *Candida albicans*: yeast-like mould which is the main cause of thrush and foot rot.

7.5.5.1 Areas of use

Microbicidal finishes are mainly used in textiles that are being handled continuously by a large number of people. Locations where these are used include, hotels, hospitals, asylums and student hostels, where mattress ticking, blankets and pillows,



carpets and upholstery all come into contact with a large number of different individuals. The following companies all manufacture microbicide:

- Bayer: Movin
- Thomson Research Associates: Ultra-Fresh
- British Sanitised: Actifresh
- Sandoz: Antimucin
- Protex: Microcide
- Ciba-Geigy: Fungicide G.

Any one of the following methods can apply all these products:

- exhaust
- pad batch
- continuous
- spray.

The normal add on depends on the efficiency of the particular product, but add-on weights of 1–4% are commonly quoted. Some of these are shown in Fig. 7.20.

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8

Coating of technical textiles

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8.1 Introduction

This chapter will deal with the chemistry of coatings and their application to various coated technical textiles that are in use. It will leave the reader to make use of the many excellent reviews, which are referenced in this article, for details of individual items.

8.2 Chemistry of coated textiles

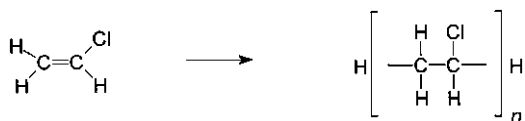
Coatings used in the production of technical textiles are largely limited to those products that can be produced in the form of a viscous liquid, which can be spread on the surface of a substrate. This process is followed by a drying or curing process, which hardens the coating so that a non-blocking product is produced. Thus the coatings for these products are limited to linear polymers, which can be coated as a polymer melt or solution and on cooling form a solid film or form a solid film by evaporation of the solvent. There are some types of coatings that can be applied in the liquid form and then chemically crosslinked to form a solid film.

The coatings used in technical textiles are all thermoplastic polymers, which are long chain linear molecules, some of which have the ability to crosslink. The properties of these polymeric materials directly influence the durability and performance of the end product. Therefore, some description of these materials is necessary.

8.2.1 Polyvinyl chloride (PVC)

This polymer is manufactured from the free radical polymerisation of vinyl chloride as shown in Fig. 8.1.

The polymer is a hard rigid solid, which if it is to be used as a coating material for technical textiles needs to be changed to a soft flexible film.¹ This is possible



8.1 Polyvinyl chloride.

because of a remarkable property of PVC, the ability of the powdered polymer to absorb large quantities of non-volatile organic liquids. These liquids are known as plasticisers and a typical plasticiser for PVC is cyclohexylisooctylphthalate. The polymer can absorb its own weight of this plasticiser. However, when the powdered polymer and plasticiser are first mixed, a stable paste is formed which is easily spreadable onto a textile surface. The paste of PVC and plasticiser, known as a plastisol, consists of the partially swollen particles of PVC suspended in plasticiser. When this mixture is heated to 120°C complete solution of the plasticiser and polymer occurs, which on cooling gives a tough non-blocking film. The flexibility of this film can be varied by the amount of plasticiser added. However, for most uses plasticiser contents of up to 50% are most common. Plasticised PVC forms a clear film, which shows good abrasion resistance and low permeability. The film may be pigmented or filled with flame-retardant chemicals to produce coloured products of low flammability. The coatings are resistant to acids and alkalis but organic solvents can extract the plasticiser, making the coatings more rigid and prone to cracking.

One great advantage of a polymer with an asymmetric chlorine atom is its large dipole and high dielectric strength. This means that the coated product may be joined together by both radiofrequency and dielectric weldings techniques. This factor combined with its low price make it ideal for protective sheetings such as tarpaulins, where the low permeability and good weathering properties make it a very cost effective product.

8.2.2 Polyvinylidene chloride (PVDC)

PVDC is very similar to PVC. As in the case of PVC it is made by the emulsion polymerisation of vinylidene chloride, as illustrated in Fig. 8.2.

The resulting polymer forms a film of low gas permeability to gases, however, the polymer is more expensive than PVC and therefore only tends to be used where flame resistance is required.² As may be seen from the formula, PVDC contains twice the amount of chlorine as PVC and this extra chlorine is used in flame-resistant coatings. When a flame heats these materials the polymer produces chlorine radicals which act as free radical traps, thus helping to snuff out the flame.

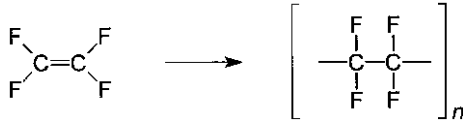
8.2.3 Polytetrafluoroethylene (PTFE)

PTFE is perhaps the most exotic of the polymers which occur in coated textiles. It is manufactured by the addition polymerisation of tetrafluoroethylene (Fig. 8.3).

Since its discovery by Du Pont in 1941, PTFE has found many uses in coating particularly in the protection of fabrics from the harmful effects of sunlight.³



8.2 Polyvinylidene chloride.



8.3 Polytetrafluoroethylene.

One remarkable feature of the polymer is its very low surface energy, which means that the surface cannot be wetted by either water or oil. Textile surfaces treated with this polymer are both water repellent and oil repellent. Hence PTFE is found on diverse substrates which range from conveyer belts used in food manufacture to carpets where stain resistance is required. In addition the polymer shows excellent thermal stability and may be used up to a temperature of 250°C. It is resistant to most solvents and chemicals, although it may be etched by the use of strong oxidising acids; this latter fact may be used to promote adhesion. In many ways PTFE could be regarded as an ideal polymer, the main drawback to its use being its very high cost compared to the other coating materials.

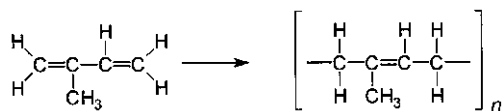
In order to reduce the cost of fluoropolymers several less expensive compounds have been produced, such as polyvinyl fluoride (PVF) and polyvinylidene fluoride (PVDF), which are analogous to the corresponding PVC and PVDC. However, while these materials are similar to PTFE they are slightly inferior in terms of resistance to weathering.

8.2.4 Rubber

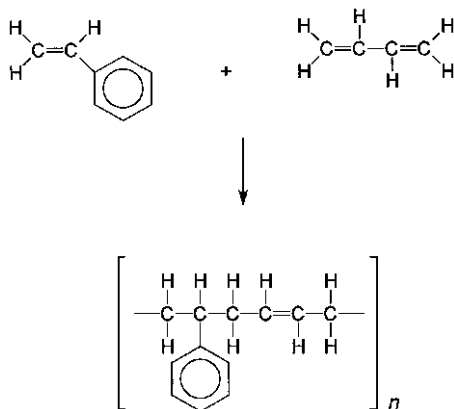
Natural rubber is a linear polymer of polyisoprene, found in the sap of many plants, although the main source is the tree *Hevea brasiliensis*. Rubber occurs as an emulsion, which may be used directly for coating, or the polymer may be coagulated and mixed at moderate temperatures with appropriate fillers.⁴ The formula, see Fig. 8.4, shows that the natural polymer contains unsaturated double bonds along the polymer chain.

The double bonds may be crosslinked with sulphur, a process known as vulcanisation, which can give tough abrasion-resistant films or hard ebony-like structures. The flexibility of the rubber may be adjusted by the amount of crosslinking which takes place. However, one great advantage of this process is that the rubber can be mixed at high rates of shear with the appropriate compounding ingredients and spread onto a textile, after which the coated textile is heated to vulcanise the rubber compound. These principles are used in the production of tyres and belting, where the excellent abrasion resistance of natural rubber makes it the material of choice.

Unfortunately, the presence of a double bond makes the polymer susceptible to



8.4 Polyisoprene (rubber).



8.5 Styrene-butadiene rubber (SBR).

oxidation. In addition, the polymer swells in organic solvents although it is unaffected by water and dilute acids and alkalis. Natural rubber is far more sensitive to both oxygen and ozone attack than the other synthetic materials which are described in the next section.

8.2.5 Styrene-Butadiene Rubber (SBR)

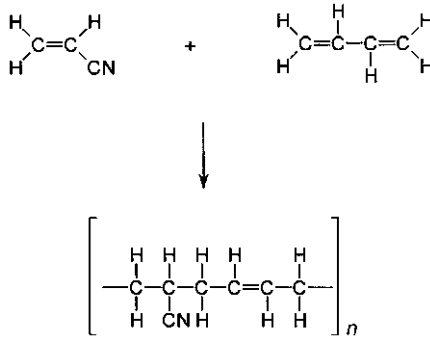
SBR is made by the emulsion polymerisation of styrene and butadiene as illustrated in Fig. 8.5.

The formula illustrated implies a regular copolymer but this is not the case and SBR is a random copolymer. The compounding and application techniques are very similar to those for natural rubber although the material is not as resilient as natural rubber and also has a greater heat build-up, which make SBR inferior to natural rubber in tyres. In the case of coated fabrics, the superior weatherability and ozone resistance of SBR, combined with the ease of processing, make this the product of choice. It is estimated that 50% of all rubber used is SBR.⁵

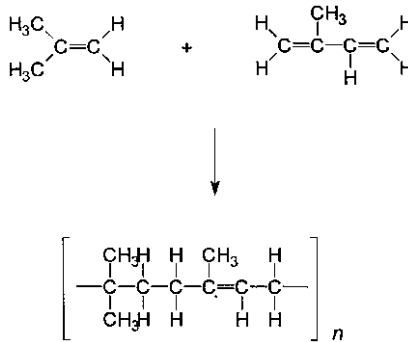
8.2.6 Nitrile rubber

Nitrile rubbers are copolymers of acrylonitrile and butadiene shown in Fig. 8.6.

These materials are used primarily for their excellent oil resistance, which varies with the percentage acrylonitrile present in the copolymer and show good tensile strength and abrasion resistance after immersion in oil or petrol. They are not suitable for car tyres but are extensively used in the construction of flexible fuel tanks and fuel hose.⁶



8.6 Nitrile rubber.



8.7 Butyl rubber.

8.2.7 Butyl rubber

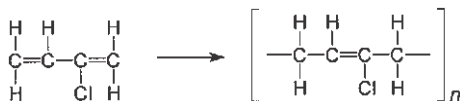
Butyl rubbers are copolymers of isobutylene with a small amount of isoprene to make the copolymer vulcanisable or crosslinked as illustrated in Fig. 8.7.

Because of the low amount of isoprene in the structure, the vulcanised structure contains little unsaturation in the backbone and consequently the rate of oxidation or oxygen absorption is less than that of other elastomers except for the silicones and fluorocarbons. When an elastomer contains double bonds, oxidation leads to crosslinking and embrittlement, whereas in butyl rubbers oxidation occurs at the tertiary carbon atom which leads to chain scission and softening. Further, the close packing of the hydrocarbon chains leads to a structure which is impermeable to gases and its main use is in tyre tubes and inflatable boats.⁷

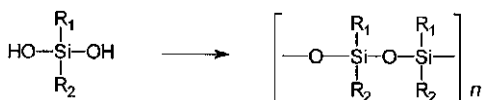
8.2.8 Polychloroprene (neoprene)

Neoprene rubber was first developed in the United States as a substitute for natural rubber, which it can replace for most applications. It is made during the emulsion polymerisation of 2-chlorobutadiene as illustrated in Fig. 8.8.

Neoprene rubbers can be vulcanised and show tensile properties similar to natural rubber, however, they are perhaps most widely used for their excellent oil resistance.⁸ Weathering and ozone resistance is good and the polymer finds its main



8.8 Polychloroprene (neoprene).

8.9 Silicone rubbers. R_1 and R_2 are unreactive alkyl or aryl groups.

end-uses in the production of belts and hoses. The neoprene latex can also be used in dipping and coating.

8.2.9 Chlorosulphonated polyethylene (Hypalon)

Treatment of polyethylene with a mixture of chlorine and sulphur dioxide in solution yields a product in which some of the hydrogen atoms in the polyethylene are replaced by chlorine and some by the sulphonyl chloride groups ($-\text{SO}_2\text{Cl}$). The resulting polymer can be crosslinked via the sulphonyl chloride by the use of metal oxides. Typically the polymer will contain about one sulphur atom for every 90 carbon atoms in the polyethylene chain and about 25% by weight of chlorine.⁹

These products show good resistance to weathering and have excellent ozone resistance, but they do have low elongation. Their main uses in coating are where flame resistance is required; here the synergism between sulphur and chlorine promotes flame retardancy.

8.2.10 Silicone rubbers

Silicone rubbers are polymers which contain the siloxane link $\text{Si}-\text{O}-\text{Si}$ and are formed by the condensation of the appropriate silanol which is formed from the halide or alkoxy intermediate; the final condensation then takes place by the elimination shown in Fig. 8.9.

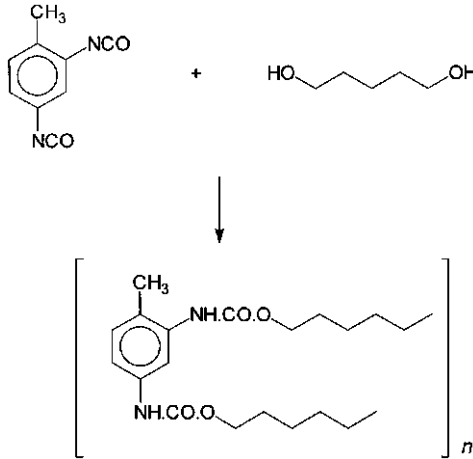
The groups R_1 and R_2 are normally inert groups such as methyl, but they may include a vinyl group and therefore are capable of crosslinking. It is also normal to fill these polymers with finely divided silica, which acts as a reinforcing filler.¹⁰

These polymers show outstanding low temperature flexibility and can be used at temperatures as low as -80°C , while they retain their properties up to 250°C . They also show good resistance to weathering and oxidation. Unfortunately their price is high.

8.2.11 Polyurethanes

Polyurethanes are made by the reaction of a diisocyanate with a diol as shown in Fig. 8.10.¹¹

The particular diisocyanate shown is 2,4-toluene diisocyanate and the diol is



8.10 Polyurethane.

pentane diol but any of the analogues may be used. Polyurethanes used for coating textiles are not quite as simple as the one illustrated and the materials are frequently supplied as an isocyanate-tipped prepolymer and a low molecular weight hydroxyl-tipped polyester, polyether or polyamide. The two materials will react at room temperature although this is often accelerated by raising the temperature. The only drawback to this system is that once the components are mixed, crosslinking starts immediately and so the pot life of the system is limited. Stable prepolymers which contain a blocked diisocyanate usually as a bisulphite adduct are now available. These blocked isocyanates will not react at room temperature, but will react at elevated temperatures in the presence of organotin catalysts.

Polyurethane coatings show outstanding resistance to abrasion combined with good resistance to water and solvents, in addition they offer good flexibility. The chemistry of the diol can be varied considerably so as to convey water vapour permeability to the coating. Coatings made from polyurethanes do have a tendency to yellow on exposure to sunlight and they are therefore normally pigmented in use.

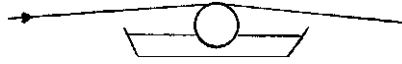
8.3 Coating techniques¹²

The original methods of coating were largely based on various impregnating techniques based on an impregnating trough followed by a pair of squeeze rollers to ensure a constant pick-up. The material was then air dried at constant width, usually on a stenter, and rolled. However, when the coating was required on one side of the fabric then total immersion of the fabric in the coating liquor was not possible and other techniques had to be developed.

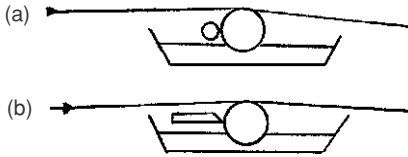
8.3.1 Lick roll

In this method the fabric was passed over the coating roll which was rotated in a trough of the coating liquor as shown in Fig. 8.11.

There were several variations on this theme, which were developed to ensure a



8.11 A lick roll.



8.12 Other lick roll methods. (a) A metering roll and (b) a knife doctor.

more even application of the coating by metering the coating onto the fabric. This was done by two main approaches, the first of which was to use a second roll on the primary coating roll, which picked up a fixed amount. The second was to use a doctor blade on the primary roll, so that again only a fixed amount of liquor was transferred to the fabric. These are also illustrated above in Fig. 8.12.

The main disadvantage of these systems was that the amount of coating on the fabric was dependent on the surface tension and viscosity of the coating fluid and also the surface condition of the fabric. To overcome this problem knife coating was developed, which functions in basically the same way that butter is spread on toast.

8.3.2 Knife coating

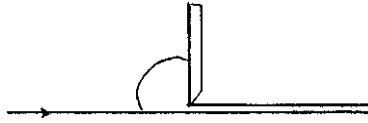
In this method the coating fluid is applied directly to the textile fabric and spread in a uniform manner by means of a fixed knife. The thickness of the coating is controlled by the gap between the bottom of the knife and the top of the fabric. The way in which this gap is controlled determines the type of machinery used. The following are the main techniques used:

- knife on air
- knife over table
- knife over roller
- knife over rubber blanket.

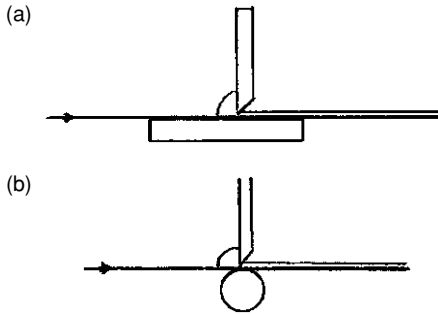
In the first of these the spreading blade is placed in direct contact with the fabric under tension and the coating compound is thus forced into the fabric. This is shown in Fig. 8.13.

The main advantage of this technique is that any irregularities in the fabric do not affect the running of the machine. However, this is not the case with the knife over table or knife over roll methods (Fig. 8.14), for although the coating thickness can be accurately controlled, any fabric faults or joints in the fabric are likely to jam under the blade causing fabric breakage.

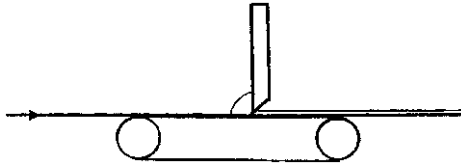
The problem of metering an accurate amount of coating onto the substrate was finally solved by the use of a flexible rubber blanket, which gives a controlled gap for the coating compound and yet is sufficiently flexible to allow cloth imperfections or sewing to pass underneath the blade without getting trapped and causing break-outs. This is shown in Fig. 8.15.



8.13 Knife on air.



8.14 Coating methods using (a) knife over table and (b) knife over roller.



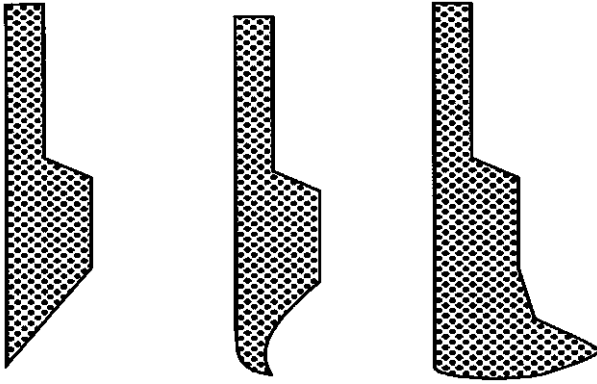
8.15 Knife over blanket.

8.3.2.1 Knife geometry

The geometry of the coating knife and the angle of application also have an important role to play in the effectiveness and penetration of the coating. Obviously if uniform coatings are to be obtained over the width of the fabric then an accurately machined flat blade is mandatory. In addition the profile of the knife can have a marked influence on the coating weights and penetration of the coating. There are three main types of knife profile, illustrated in Fig. 8.16 with many variations in between these three:

- **Pointed blade:** the sharper the blade the more of the coating compound is scraped off and consequently the lower the coating weight.
- **Round blade:** this gives a relatively higher coating weight than a sharp point.
- **Shoe blade:** this gives the highest coating of all the blade profiles; the longer the length of the shoe the higher the coating weight.

In general knife coating fills in any irregularities in the fabric surface giving a smooth finish to the coated surface. The machines which use knife coating are in general simple to operate and can be used for a wide variety of thicknesses from about $1\mu\text{m}$ up to $30\mu\text{m}$.



8.16 Three blade profiles.

8.3.2.2 Air knife coating

In discussing knife coating, mention must also be made of the air knife as a method of removal of the excess coating fluid. In this technique a blast of air is used to blow off the excess coating fluid. The viscosity of the fluid is much lower than in the case of conventional knife doctoring and the coating applied follows the profile of the substrate to which it is being applied. The technique is more frequently used in the paper industry, where it is used to coat photographic paper, rather than in the textile industry.

8.3.3 Gravure coating

The use of a gravure roller in coating was developed from the printing industry, where it was used to print designs. The technique involves the use of a solid roller, the surface of which has been engraved with a closely packed series of small hemispherical depressions. These act as metering devices for the coating fluid, which fills the hemispheres with coating fluid from reservoirs of the fluid. The excess fluid is scraped from the roll with a doctor blade, leaving the depressions with an exact amount of fluid in each. This is then transferred to the substrate to be coated. The quantity of fluid transferred depends on the volume of the engraved depressions and the packing on the surface of the roll. However this technique is perhaps the most accurate, in terms of the applied coating weight, of all the techniques discussed. The greatest drawback to this technique is that for a fixed depth of engraving a fixed coating weight is obtained. Thus if a different coating weight is required then a new engraved roll has to be produced. Further, unless the viscosity characteristics of the coating fluid are controlled, the pattern of the printed dot can be seen on the coated substrate. What is required is a printing fluid that will flow and form a flat surface in the drying process. This formation of a flat coating can be greatly improved by the use of offset gravure printing. Here the fluid is printed onto a rubber roller before being transferred onto the substrate.

8.3.4 Rotary screen coating

This technique is similar to the rotary screen printing process that is used to apply coloured patterns to fabric. The applicator is a cylindrical nickel screen, which has

a large number of perforated holes. The coating compound is fed into the centre of the screen, from whence it is forced through the holes by either a doctor blade or a circular metal rod. The coating weight can be controlled by the number of holes per unit area and the coating weights are very precise. However, the coatings have a dot configuration and to obtain a continuous coating a wiper blade that spreads the dots into a continuous coat must be used. The two companies associated with this type of coating are Stork Brabant BV, whose system uses a metal doctor blade, and Zimmer, whose system uses the circular metal rod.

8.3.5 Hot-melt coating

In this technique the coating materials must be thermoplastic, so that they melt when heated and in this condition are capable of being spread onto a textile substrate. Thus, in some respects they are similar to paste coating. However, the big difference from paste coating is that the thermoplastic coating has no solvents to evaporate and no water that has to be evaporated, giving the process both economic and ecological advantages. The molten polymer is usually calendered directly onto the textile or in some cases extruded directly from a slotted die. This is followed by contact with a polished chill roller, if a smooth surface is required on the coating or a patterned roll if a patterned effect is required.

One further process, the use of powdered polymers as a coating medium, needs to be mentioned in the area of hot-melt coating. In this technique the powdered polymer is sprinkled onto the substrate, followed by heating with radiant heaters to melt the thermoplastic. The coating is then compacted and rendered continuous by a compaction calender. The main materials used in this are polyethylenes and nylon and these are now being applied in the production of carpets for car interiors, where because of the mouldability of the thermoplastic, a complete car carpet may be pressed out in one operation.

8.3.6 Transfer coating

The final coating technique to be described in this section is transfer coating. In this the coating material is preformed into a continuous sheet which is laminated to the substrate either by the application of heat or by the use of an adhesive known as a tie coat. The great advantage of this technique over all the others is that the coating film may be made completely free of holes and defects before it is applied to the fabric. In general, transfer coating will give the softest coating of all coating techniques in terms of fabric handle and furthermore there is no possibility of the coating bleeding through onto the face of the coated fabric.

8.4 Fusible interlinings

8.4.1 Introduction

Fusible interlinings¹³ represent an important field in technical textiles and as such deserve a special mention. A fusible interlining is a fabric that has been coated with

an adhesive coating, which under the influence of heat and pressure will melt and form a bond with any other fabric that is pressed against it.

The basic function of a fusible interlining is to control and reinforce the fabric to which it is fused. It does this by giving a degree of stiffness to the fabric by increasing the apparent thickness of the fabric, causing the flexural modulus of the fabric to increase proportionally to the cube power of that thickness. Thus a relatively small increase in thickness will produce a relatively large increase in the stiffness of the laminate.

8.4.2 History

The use of stiffening materials in clothing has been known for many thousands of years. From the tomb drawings in Egypt, for example, we can see how these materials were used to accentuate the rank or social status of the wearer. The Elizabethans used both linen and woven animal hair to reinforce and stiffen the elaborate clothing of the court ladies and gentlemen. This material had to be laboriously sewn into the garments by hand but as long as labour was cheap and servants in plentiful supply, it did not present any problem to the upper classes of the time. The cost of producing these 'hand made' garments was, of course, beyond the reach of any but the moneyed classes and it was not until the development of mechanised methods of garment production and the use of fusible interlinings that it became possible for the man or woman in the street to be able to afford a suit, which carried both elegance and style. Thus it became no longer possible to tell a gentleman by the cut of his jacket.

8.4.3 Development of adhesives

The first synthetic resin to be developed for clothing applications is usually attributed to Alexander Parkes, who at the Great Exhibition of 1862 introduced a nitro-cellulose plasticised with camphor, which he called, with all due modesty, Parkesine. This material was a thermoplastic and could thus be moulded by heat and pressure. It was also found that the material was unaffected by water and it was used in the Victorian era for the manufacture of cheap collars and cuffs. Eventually it was given the name 'celluloid' and its use was extended into many areas. It was, for example, the original material on which the early moving pictures were shot. Unfortunately, celluloid had one major disadvantage, it was highly flammable and burned with an almost explosive violence. This prompted the search for a less flammable alternative to celluloid.

The beginning of the 20th century saw the development of another thermoplastic resin from cellulose, cellulose acetate. Benjamin Liebowitz in the USA developed the use of this material in fusible interlinings. He developed a fabric that consisted of both cotton and cellulose acetate woven together. It could be softened in acetone, which produced a very sticky fabric that was used to reinforce the collar of a man's shirt. The Trubenised Process Corporation exploited this invention producing the Trubenised semi-stiff collar, which was washable. Because the cellulose acetate adhesive did not form a continuous glue line in the collar, the collar remained permeable and hence very comfortable to wear. The result was that many millions of men's shirts with Trubenised collars were made in the thirty years from 1930 onwards.

Table 8.1 Typical coating resins

	Dryclean performance	Wash performance
Low density polyethylene	Poor	Very good
High density polyethylene	Very good	Very good
PVA/Novolac	Fair	Fair
PVC/plasticised	Good	Good
Polyamide	Very good	Good
Polyester	Very good	Very good
Reactive	Very good	Very good

8.4.4 Modern adhesive development

In the early 1950s a search began for a fusible adhesive resin which could be coated onto the base fabric and fused by the action of heat and pressure alone, thus avoiding the use of flammable and toxic solvents. The first of these was obtained by the plasticisation of polyvinyl acetate, which was applied to the fabric in the form of a knife coating by an emulsion of plasticised PVA. After the material was dried the coated fabric was wrapped in a release paper for use. The fused products were stiff and were used in the preparation of fabric belts for ladies dresses and suits; this is still their main use.

However, the continuously coated fabrics used as fusibles produced laminates that were rather too stiff for normal clothing use. The use of these materials would have remained in the special belting product, had it not been for the development of the powdered adhesive, for when this was used as a fusible interlining, the resultant stiffness of the laminate could be controlled by the particle size of the adhesive powder and by the amount of powder in the glue line of the laminate. The powder had to be applied to the interlining in an even manner and much thought went into development of machinery to ensure that this was so. The main resins used for these coatings are shown in Table 8.1. However, the most recent development has been the introduction of a reactive adhesive resin. This material melts when heated and then undergoes crosslinking, thus producing a very stable bond.

The initial coatings produced were known as sinter or scatter coatings. New coating techniques were then developed and refined by more precise positioning of the adhesive dot, so that the handle of the fused product could be more accurately controlled. This led to the printing of the adhesive in dot form which can be done either by a paste print through a mesh screen, or by the use of a gravure roller.

All these interlinings are fused by the application of heat and pressure in an electrically heated press, which has developed from the original flat bed system of heated platens to the continuous roller bed presses of the present day.

8.5 Laminating

No discussion on interlinings would be complete without mention of laminating, as this is the ultimate use of these materials. In general, textile laminates are produced by the combination of two or more fabrics using an adhesive. The hot-melt adhe-

sive is environmentally friendly, requires less heat and is now preferred over the more conventional solvent-based adhesives.¹⁴ Flame bonding using a thin layer of polyurethane foam is still being used in some applications, where the bulky appearance of the final product is required by the market. However, strict legislation concerning the gaseous effluent from this process has most manufacturers searching for alternatives that are more environmentally acceptable. It seems likely that hot-melt adhesives will replace most of the other adhesive techniques, either on energy grounds, or environmental grounds. The other driving force behind this change is the continued development of the hot-melt adhesives that are available to the manufacturer, which produce laminates at a higher speed, or more permanently bonded laminates.

An interesting development in the improved efficiency of the process, for example, was the development of Xironet.¹⁵ This is a lightweight net of fusible adhesive, which when sandwiched between two fabrics can effectively laminate the fabrics together by the application of heat and pressure from a heated calender.

To improve the permanence of the adhesive bond, and as mentioned above, a hot-melt adhesive has been developed that will crosslink after the adhesive bond has been formed.¹⁶ These materials will melt at 130°C and form an adhesive bond and on further heating will crosslink to give an adhesive that is relatively inert.

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