3
Fabric structures and production methods

3.1 Introduction, fibres and yarn types

The use of textile products for the trim areas of vehicles has a relatively recent history when compared with other more established sectors of the decorative textiles industry.

The high technical requirements that the automotive industry places on all items which go into vehicles has ensured that many of the old-established methods of producing fibres, yarns and fabrics proved to be at best extremely difficult and at worst virtually impossible for many reasons, among the most important of these are;

Abrasion,	Fastness to light and UV degradation,
Tensile strength,	Pilling,
Flammability,	Seam strength.

Although many tests are required by OEMs before a fabric is signed off as acceptable, it was the reaction to these tests which proved instrumental, almost by a process of natural selection, in identifying the most suitable fabric technologies, and in quantifying polyester as the most universally acceptable fibre for automotive trim fabric. In selective tests other fibres, particularly nylon for strength and elasticity, acrylic for lightfastness, and polypropylene for strength for minimum weight, can each outperform polyester but none can perform as consistently well across all the tests.

The fact that polyester has become a world fibre in the truest sense means that it is now virtually universally available no matter where the fabric manufacturing takes place. Intense research into new variants of polyester to achieve specific results such as stretch, variable dyeing, different lustres, and colour extrusion of the polyester filaments, has contributed to consolidate its position as the dominant fibre for automotive decorative trim fabrics. In 1997 polyester gained the distinction of achieving a 94% world market share of automotive textile trim fabrics and as at the time of writing, there seems to be little in the way of serious competition to radically change that situation in the foreseeable future. However the choice of polyester is but the first link in the chain, yarn production systems, and fabric technologies play an equally important part.

3.1.1 Fibres

The use of natural fibres in the production of textile materials for automotive interiors is limited in the main to wool, due to minimum performance requirements for lightfastness, abrasion etc but also due to the comfort and added value which wool is perceived as imparting to the product. It has been the introduction of synthetic fibres which led to the growth in products which found their way into automotive end uses for reasons mainly to do with performance, cost and versatility.

Synthetic fibres are always produced in a continuous filament form which can be retained as continuous filament in producing textured yarns or cut into short lengths, known as 'staple', for blending with natural fibres such as wool and spinning on the conventional systems such as ring or open end which we shall describe later. Most synthetic fibres and yarns and certainly the ones used in automotive fabrics are thermoplastic in nature. This is an important property of synthetic fibres particularly when texturized yarns and fabrics are being produced. Essentially it is the ability of the fibre, yarn and eventually the fabric, to be set without causing a chemical change, in various conditions by the application of heat on a time/temperature basis. In very broad terms what has been set into the fibre during manufacture will be permanent unless the time and temperature is exceeded in subsequent processing at which point a new overriding 'set' is introduced. [This process is fundamentally different from the crease-resist processes which are applied to cellulosic fibres and fabrics where a chemical cross-linking of the fibre molecules takes place.] This property is often referred to as the 'heat memory' of the fibre.

3.1.2 Partially orientated yarn

When synthetic fibres are being manufactured the molten polymer solution is extruded through a spinneret which is a series of fine holes in a plate, the size, shape and number of the holes determining the decitex, fibre cross-section and number of filaments in the yarn being produced. The filaments are gathered together, dried in an airflow and wound onto a producer bobbin for the next stage. It is necessary during some stage in the process to 'draw' the fibres. This process refers to the stretching of the individual filaments to orientate the molecules, which in turn strengthens the fibres and reduces to acceptable levels the further tendency to stretch.

It has been found that part of this drawing process can be carried out during downstream operations such as texturizing [air or false twist known as draw texturing] or warping [known as draw warping]; this speeds up the production of the original fibres and is commercially attractive for this reason.

It also has technical advantages since yarns can be produced with specific amounts of residual stretch left in by adjusting the draw ratios during texturing and for automotive use, particularly in fairly rigid flat-woven cloths, partially orientated yarns can produce cloths which are capable of being moulded under pressure to three-dimensional shapes such as door panels or head shells.

3.1.3 Heat history

During the manufacturing processes from fibre through yarn, fabric and finally into a finished product a ‘heat history’ is acquired and a close study of this can often provide useful information, for instance in the designing of suitable downstream processes, or in developing characteristics for specific end uses, or even in finding the cause of quality problems such as dimensional changes in the fabric after manufacture, which could be either subsequent shrinkage or the opposite one of extension or ‘bagging’ in use. A rule to remember is that any synthetic thermoplastic fibre, yarn, or fabric will always strive to return to the form of its most permanent set [time × temperature] wherever that occurred during the process.

Heat history of synthetic textile products can either be an extremely useful or a very dangerous property depending upon how much attention it receives during the whole manufacturing process and should never be ignored during the development processes. We have earlier referred to the dominance of polyester as a fibre for automotive textiles. This is a synthetic and has thermoplastic properties and is capable of being produced in continuous filament textured form, blended or produced as 100% in staple-spun yarns.

3.1.4 Yarn types

In order to produce a good-quality, well-designed, aesthetically pleasing fabric it is essential to pay particular attention to the basic building blocks of the structure and they start with the yarn. Many yarn types are used in the production of automotive fabrics and, although continuous filament false twist and continuous filament air-textured predominate, we need to have an appreciation of other possible methods to obtain a rounded view of the situation in order to make informed decisions about designing fabric structures and also appreciate the possible problems associated with selecting the wrong route for particular fabric technologies.

3.1.5 Staple spinning

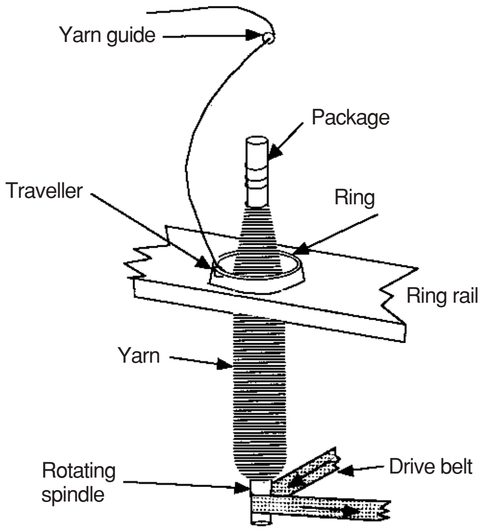
This is probably the oldest method of yarn production. It started as the method to consolidate discontinuous variable-length fibres, known collectively as staple, of natural products such as cotton, wool, flax, etc. into continuous lengths of yarn of known and controllable thickness designated by the 'count' or ' number' of the yarn (i.e. weight per unit length).

The method used was one of drawing out the fibres into ever more parallel sheets or strands called 'rovings'. These were then made more parallel by a process known as carding and in the case of the better quality yarns, usually produced from fibres with longer staple lengths. A further 'combing' process was included. Eventually the roving of parallel fibres was drawn out or 'drafted' to reduce the number of fibres in the cross-section and when the desired number had been achieved twist was inserted to bind all the fibres together and produce a yarn. The strength of such a yarn was highly dependent upon the amount of friction between the individual fibres – known as 'inter-fibre friction'. Up to certain points this was increased or decreased by adding or reducing the amount of twist applied at the spinning stage.

For thousands of years the whole process was done by hand until the Industrial Revolution in the mid-eighteenth century saw the introduction of mechanical means of reproducing the process, which is now referred to as 'ring spinning' on account of the ring which carries the yarn round the package as twist is inserted [see Fig. 3.1]. Other methods such as 'open-end' spinning and 'wrap spinning' are all based on forming fibres into yarns and each have their own particular characteristics. All these methods tend to reduce the amount of twist required to form a yarn, thus increasing production and reducing costs but in almost all cases also reducing the surface abrasion characteristics of the yarn. An exception to this would be the air-jet spinning technique – not to be confused with air-jet texturizing – where twist is inserted into the fibres by application of multiple air jets, and wraps fibres in opposing directions round a central core of fibres.

For automotive applications any system which reduces surface abrasion should be avoided so wrap-spun or open-end-spun yarns should be treated with caution. Ring spinning is the system which has the longest history and is tried and trusted, plus it has the advantage that abrasion properties can be improved by simply increasing the twist in the yarn at the spinning stage.

The method of forming fibres into yarns known as ring spinning started with natural fibres but now encompasses the full gamut of synthetic fibres including polyester where the continuous filaments are cut into suitable



3.1 Basic elements of ring spinning.

lengths prior to the spinning process and are either spun as pure fibre or as blends with natural fibres, with polyester and wool being a favourite blend for automotive applications.

The staple length of the fibres and also the thickness and variability decide which of various systems are used – cotton system, worsted system, woollen system etc. – each creates yarns with their own characteristics and properties. There is not enough room in this book to go into detail but blended polyester and wool ring-spun yarns are used extensively in woven velvet and flat-woven automotive structures where the strength and abrasion resistance of the polyester complements the comfort and moisture-absorbing properties of the wool in a yarn which adds to the aesthetic appearance and handle of the trim fabric.

3.1.6 Continuous filament yarns

The advent of synthetic fibres in the middle of the twentieth century saw an explosion of new applications for textile products – replacing silk in hosiery, strengthening vehicle tyres, assisting in civil engineering projects, etc. etc. Despite these new markets however no sooner had the new synthetics started to become known in their own right than ways were investigated to make them more 'natural' in handle and appearance. We have described how this could be done by cutting the filaments into suitable lengths to spin and also to blend with natural fibres such as cotton and wool but how could bundles of continuous filaments be made to rival natural products?

Investigations eventually led to the creation of what we now know as 'texturizing' processes. Over the years these have become extremely versatile and effective in engineering yarns to meet specific purposes and have had a huge effect upon the development of textiles for automotive use particularly in the trim areas. Over the years many methods of texturizing yarns have been developed and most have concentrated on curling or deforming the individual filaments within the yarn and increasing the air space between the filaments to create such properties as soft handle, high bulk, warm touch, etc. Methods such as 'gear crimping', 'stuffer box crimping', 'knit de knit crimping' have all gained a place in specialized end uses. However, in automotive applications the need to meet strict performance requirements, such as abrasion and strength, has ensured that the two main methods which have survived and which are worth studying due to their success in penetrating the automotive fabric business are 'false-twist-textured' and 'air-jet-textured'

3.1.6.1 False-twist texturizing

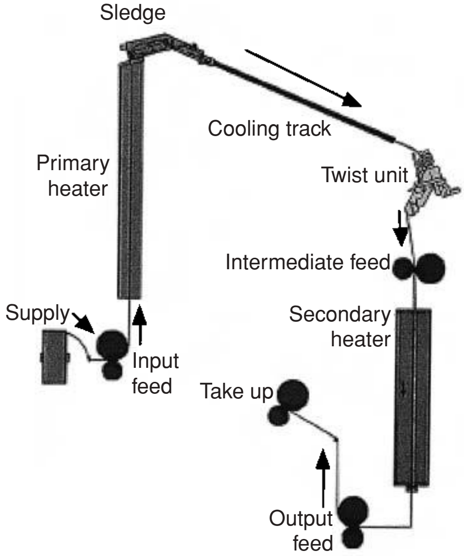
This method uses the principle of twisting the filaments in a continuous multifilament thermoplastic yarn, thermal fixing of this twisted yarn and then untwisting at a lower temperature.

The twist which had been set into the yarn is 'false' in the sense that at no time during the texturing process is either the supply package or take-up package rotated but the individual filaments due to their heat memory try to assume the twisted dimension. This creates a bulking of the yarn as the filaments try unsuccessfully to spiral round each other.

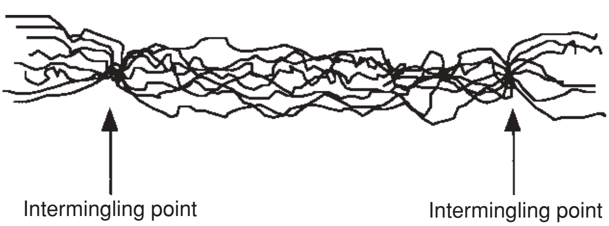
The method of twist-insertion, heat-setting and twist-removal is a continuous process as illustrated in Fig. 3.2 reproduced by kind permission of Rieter-Scragg Ltd.

The yarn which results from this method of texturizing is characterized by high bulk where the filaments retract and distort under conditions of zero load and are pulled virtually parallel when load is applied. This lends an element of stretch or extensibility to the yarn which can, in certain circumstances, be very useful for automotive applications. In order to give some cohesion to the yarn the filaments are 'intermingled' at points along the length of the yarn by introducing jets of air during manufacture. These intermingling points, sometimes referred to as 'knots' or 'nodes', can be at almost any predetermined frequency although 100 knots or points per metre, or one every centimetre, is a fairly common standard which is applied.

The axis of the yarn in close up is shown in Fig. 3.3 and from this it can be seen that despite the intermingling points the individual filaments are highly visible and this can cause abrasion problems when the yarn is used in woven products where the filaments are easily worn away in use. Careful



3.2 False twist texturizing. (Reproduced by kind permission of Rieter-Scragg Ltd.)



3.3 False-twist yarn in relaxed condition showing crimp developed in the individual filaments. Note that the filaments are not bound into the body of the yarn except at the intermingling points – this can cause abrasion problems if the axis of the yarn is exposed during use.

attention to fabric design and combination with other yarns, such as air-textured or staple-spun, can reduce this effect and still allow the advantages of false-twist yarns such as production efficiency, stretch and cost effectiveness to benefit the end product.

False-twist yarns however have made major contributions in automotive fabrics as the pile yarn in cut pile fabrics such as woven plush, double-needle bar, circular knit. In these cases the bulking effect is shown to best advantage when translated into pile coverage or density, and the abrasion issue is much less of a problem since it is taking place on the cross-section rather than the axis of the yarn. This invariably yields a better result even though the test method used can have some unfortunate effects – the Martindale abrasion method for instance can show up some harsh results on cut pile fabrics unless it is subject to very careful assessment, and reliance on this method alone could lead to over-engineering the product and the cost.

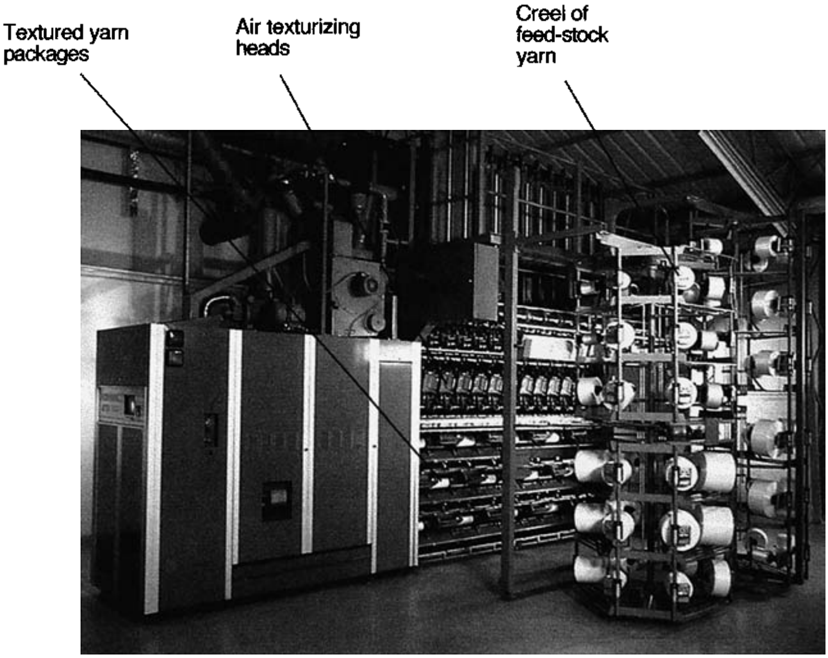
False-twist yarns are produced primarily from nylon and polyester but can theoretically be produced from any strong synthetic fibre which is thermoplastic and can display heat memory. The dominance of polyester for the reasons explained at the start of this chapter continue to ensure that the majority of false-twist yarns used in automotive trim fabrics are produced from this fibre.

3.1.6.2 Air texturizing

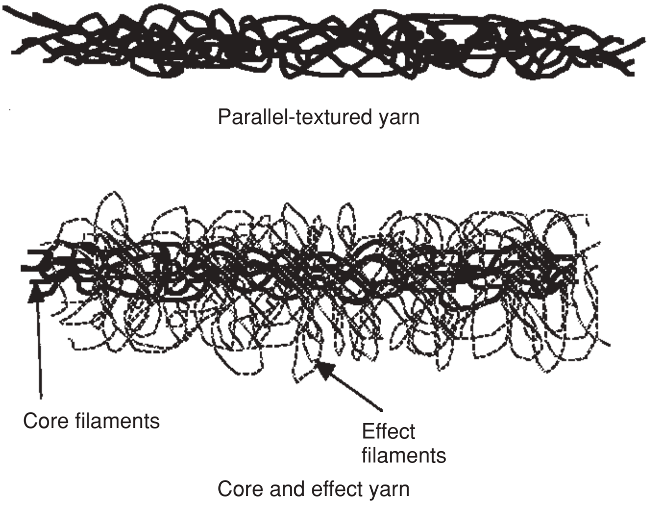
The development of the air-texturing process for continuous filament yarns was probably one the most significant textile processes contributing to the vastly increased use of textile fabrics in the trim area of cars. The use of polyester soon became prominent for the reasons discussed earlier but the technique of air texturing added a new technical dimension which increased the durability and quality of the fabrics, particularly flat-woven fabrics using textured yarn, and provided answers to many of the early problems of consistent quality and durability encountered with other yarn technologies.

Several flat (i.e. parallel-filament, un-textured) individual continuous filament yarns known as 'feed stock' yarns (which are likely to be partially orientated yarns as described earlier) are arranged in a creel and run together into the path of an air jet which distorts and intermingles the filaments so that, unlike false-twist yarns, they are effectively locked in position to create a composite yarn which has strength, a high degree of levelness and uniformity, and which, due to the integration of the filaments, possesses greater resistance to surface abrasion than almost any other yarn technology. The individual feed stock yarns can be introduced into the air jet at the same rate to create what is known as a parallel-textured yarn where all the feed stock yarns are textured to the same level, or they can be introduced at different rates to create what are known as core and effect yarns, which possess a higher degree of texture on the effect creating a raised surface and warmer touch in the fabric. A typical air-texturizing line is illustrated in Fig. 3.4. The differences between a parallel textured yarn and a core and effect yarn is shown in Fig. 3.5.

There are many other possible variations in the design of specific properties in air-textured yarns. These include using feed-stock yarns with different filament thickness (decitex) or lustre (bright, dull, etc.) or filaments with different cross-sections (round, tri-lobal, etc.). Another technique for automotive use is to design stretch into the yarn by using a feed-stock yarn



3.4 Air-jet texturizing line. (Reproduced by kind permission of Rieter-Scragg Ltd.)



3.5 Comparison of parallel and core and effect air-jet textured yarns.

made from a special polyester polymer which has a certain amount of stretch and recovery 'built in'. These special polymers known as polybutylterephthalate or PBT have made major contributions in recent years in the design of woven fabrics with enough flexibility to allow the automotive interior designer greater freedom in the application of the fabrics to more adventurous three-dimensional shapes.

3.1.7 Speciality yarns

Although numerous novelty and speciality yarns have been developed, only a fraction of these have found their way into automotive uses, mainly due to the high specification requirements particularly abrasion, pilling, snagging, etc. However, at least two yarn types are worth discussing since they have been quite successful in automotive fabrics.

3.1.7.1 Chenille yarns

Chenille yarns are constructed from at least two fine-core yarns woven in leno fashion or twisted together during this process. Pile yarns are inserted at right angles and cut to within 1 or 2 mm of the core yarn surface to create a surface in which the fibres contained in the pile yarns burst and form a soft pile surface to the yarn. There are two main features of this technique which cause problems for automotive use; one is the fact that due to the construction technique the pile tends to twist and flatten in different directions causing variable light reflection and the other is the tendency for the pile yarns to pull out of the core during use.

Developments of the method of construction have largely eliminated these problems; low-melt fibres have been inserted in the core which fuse with the pile under subsequent heat processes to help increase pile adhesion and clever methods of pile yarn insertion have created a more rounded yarn effect yet still retained the somewhat unique character of the chenille.

3.1.7.2 Flock yarns

Flock yarns must not be confused with chenille since they are totally different yarns although they still present a pile surface. They have been used extensively in automotive applications due to their high abrasion resistance and versatility. They are constructed from pre-cut pile fibres which are only 1 or 2 mm in length and which are electrically charged and deposited upon a core yarn which has been pre-coated with an adhesive. Opposite electric charges ensure that the fibres are attracted to the core in a vertical position and are fixed in this position by the adhesive. This method means that when the pile is deformed in use the fibres have to bend easily or they will break causing uneven wear and it is this feature which has led to the use of nylon as the pile fibre rather than polyester which has a much more brittle and less flexible character than nylon. Viscose has been used successfully as a core due to the affinity with the adhesive to give good adhesion to the pile.

Loss of pile in extended use with flock yarns is much less likely than with the chenille yarns in similar fabric constructions although the fabrics tend to be harsher and less flexible.

The differences in yarn profiles can be clearly seen in Fig. 3.6.

3.1.8 Yarn thickness or 'count'

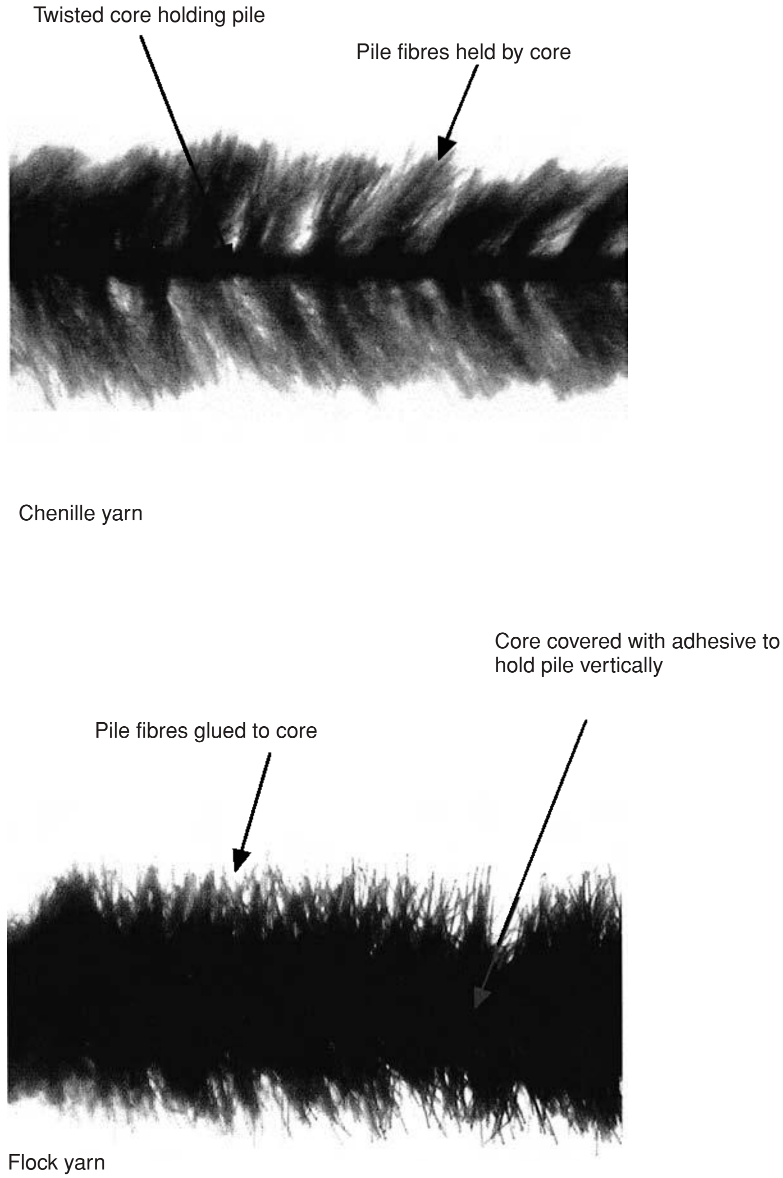
The thickness or weight of yarns is measured by calculating the weight per unit length. There are dozens of different methods of doing this but generally all continuous filament textured yarns are designated by their 'Decitex' which is a direct system of measurement – the higher the number of the Decitex the thicker the yarn. The Decitex is the weight in grams of 10000 m of the yarn, 10000 m of an 830 decitex yarn weighs 830 g. (Incidentally the forerunner of Decitex was Denier most often associated with nylon hose. Denier was and still is the weight in grams of 9000 m of yarn.)

Staple-spun yarns use an indirect system in that the greater the number of the count and the thinner or lighter the yarn, the count is calculated according to the spinning system used (i.e. cotton-spun – cotton count or cc or Ne; worsted system used for wool uses the worsted count or wc. Linen system linen count or lea). In Europe attempts at standardizing the situation has led to a metric count to cover all systems. Whatever system is stated, it always is based on the weight in pounds or kilograms of a certain stated length of yarn.

The table in Fig. 3.7 gives a clearer understanding of what can be a confusing situation. Proper consideration of the count of the yarn is vital in designing suitable fabrics for automotive and, in fact, any other use since it is the building block on which all subsequent properties are based.

3.2 Fabric structures – wovens

Automotive textile manufacture is somewhat unique in that it requires the producer to be competent, if not expert, in several textile fabric technologies all at the same time. Traditionally this has not been the way in which most textile companies have developed. Usually it has been a case of concentrating investment and expertise in maybe one technology and concentrating effort in locating different markets for essentially the same product technology. Where possible, additional investment would be channelled into upstream or downstream activities which would support this original technology. Even large multinational companies which had acquired many



3.6 Comparison of surface profile of chenille and flock yarns.

fabric manufacturing technologies would effectively differentiate between them by placing them in different divisions with separate profit centres.

The requirements of the automotive companies turned this well-established concept on its head. Their need was for one company serving one end use with as many technologies as could meet the demanding

		Direct count systems [The higher the count number the thicker/heavier the yarn]
TEX	[Tex]	Weight in grams of 1000 m of yarn
DECITEX [Dtx]		Weight in grams of 10 000 m of yarn
DENIER	[Den]	Weight in grams of 9000 m of yarn

		Indirect count systems [The higher the number the thinner/lighter the yarn]
METRIC [Nm]		Number of 1000 m hanks of yarn per 1 kilogram
COTTON [Ne_c]		Number of 840 yard hanks per 1 pound weight
WORSTED	[Ne_w]	Number of 560 yard hanks per 1 pound weight
WOOLLEN [Yorkshire]	[Ny]	Number of 256 yard hanks per 1 pound weight
WOOLLEN [American]	[Nar]	Number of 1600 yard hanks per 1 pound weight
LINEN	[Ne_L]	Number of 300 yard hanks per 1 pound weight

3.7 The major direct and indirect yarn count numbering systems in use.

technical requirements. This led over a period of several years to the establishment of single companies dedicated to serving the automotive producer with flat wovens, warp knits, circular knits, prints, non-wovens, each in a variety of effects achieved through the finishing processes. The technical strains this placed upon management have been considerable and in many cases led to the creation of joint ventures or technical agreements between manufacturers although the strong textile producers in the field nowadays have faced up to the responsibility of coming to terms with all these various fabric production technologies and their up- and downstream requirements in terms of raw material and finishing. During the course of this chapter we shall be looking at the main fabrics in use in the automotive industry but before that, it is important to have an appreciation of the fibre types and yarn production methods which have developed and the reason why they have developed to support the successful fabric technologies.

The three main fabric-forming structures which have a place in automotive manufacturing are woven, knitted and non-woven. Each of these can be divided into a multitude of additional classifications each with its own particular technology or technique; broadly speaking woven structures have a base of two sets of interlacing threads at right angles to each other; knitted structures have a base of many individual interlacing threads at a variety of angles to each other and non-woven structures are based on textile structures produced directly from fibres rather than yarn and utilize some bonding or needling process. They are dealt with separately in Section 3.6.

In both the woven and knitted sections true pile fabrics are included which utilize the same base but have an additional dimension of pile which stands out vertically or semi-vertically from the two-dimensional base and these are discussed under woven velvet and weft knitting.

3.2.1 Woven structures

The woven fabric is the original textile structure and is formed by the interlacing of two sets of yarns.

The properties of woven structures are determined by three main elements:

1 Yarn properties in terms of thickness, surface characteristics, fibre content, strength, extensibility etc.
2 Fabric setting or the density in which the yarns are woven, usually referred to as the threads per inch or per centimetre
3 The method of interlacing of the yarns known as the weave of the fabric

By varying the above three elements an infinite number of fabric variations can be created in terms of physical, chemical or aesthetic properties as well as an equally vast range of surface design and colour options. It is this huge potential in terms of design and physical possibilities which has been instrumental in making woven structures a dominant force in automotive trim over the past 20 years or so. In more recent times however one of the features of woven structures – their tendency to be rigid in both directions – has mitigated against their use in the more adventurous trim and seating designs where the ability to stretch round corners has been an increasing requirement. The use of stretch yarns and special finishing techniques has helped but not totally solved this problem.

Woven fabrics can be further subdivided into flat woven and pile woven. Flat-woven structures are essentially two-dimensional whereas pile woven use the two-dimensional flat woven as a base upon which vertical pile yarns are incorporated to create a more three-dimensional velvet or plush effect.

3.2.1.1 Flat woven

Flat-woven structures are composed of two sets of individual threads interlaced at right angles to each other. The vertical threads are collectively referred to as 'warp' or individually as 'ends' and the horizontal threads are collectively referred to as 'weft' or individually as 'picks'. In the USA weft is referred to as 'filling'.

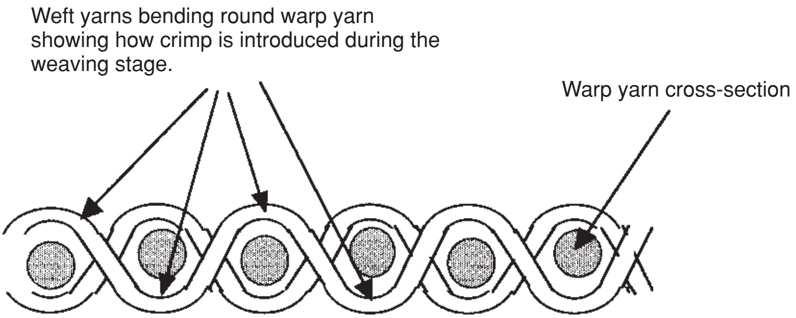
The interlacing of warp and weft is done by separating the individual warp threads across the full width of the fabric to create an opening or 'shed' through which the weft thread is inserted. This shed is then closed and the weft thread compacted or 'beaten up' to the preceding weft thread before another shed is formed separating different combinations of warp threads – and so the process is repeated at up to 1000 times a minute or more in the fast air-jet weaving machines. The method used to control the individual warp threads to create the shed determines the potential of the process to create simple or complex weaves and surface patterns.

The two main classifications of weaving machines are 'dobby looms' and 'jacquard looms' both use exactly the same principle of interlacing vertical warp threads with horizontal weft threads but the control mechanism for the process is totally different and accounts for the greater versatility of jacquard looms in the production of figured fabrics and designs. Dobby looms use individual 'shafts' which have the limitation of controlling warp threads in groups whereas jacquard looms have much greater versatility in that they control a far greater number of threads individually by the use of a 'harness' arrangement.

The weaving process is carried out on a loom which requires a pre-prepared sheet of individual warp threads or ends to be entered into either a set of shafts in the case of the dobby looms or into the harness in the case of the jacquard looms. In both cases the shafts or the harness control the individual warp threads or ends and allow the weft threads or filling to be inserted to create the weave and thereby the woven structure.

Figure 3.8 shows the basic woven structure and how the warp and weft threads interlace, it also shows how yarn crimp is introduced due to this process. The control and manipulation of this physical characteristic of woven cloths is an often misunderstood and overlooked element which can add or subtract from the required cloth performance.

Many different manufacturers produce machinery for the production of woven cloths and there are several different ways in which the weft threads can be inserted – by the traditional shuttle or by the more recent rapier



3.8 Cross-section of a plain-weave structure showing how the yarns interlace and 'crimp up'.

principle which can be either rigid or flexible, by individual 'bullets' as in projectile weaving, by compressed air as in air-jet weaving and also by jets of water in water-jet looms. The speed with which the insertion of the weft threads can be carried out determines the fabric production speed and thereby the production costs.

Each method has advantages and disadvantages and usually is suited to a particular range of yarns and fabric types.

The main essential processes involved in the production of woven fabrics, either flat or pile, are: yarn preparation; warping; production of the warp beam for the loom; entering the warp into the loom; weaving; checking all elements against approved masters; doffing the woven pieces; finishing (to include coating laminating etc.).

3.2.1.2 Warping

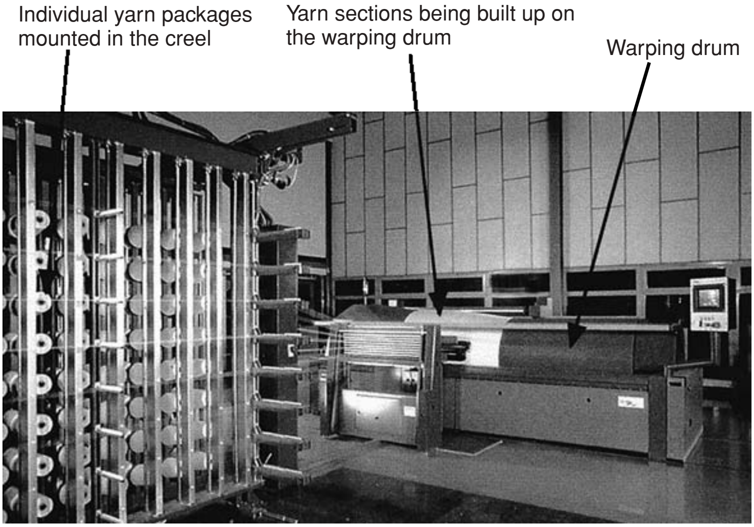
As in all things careful attention to the preparation of the raw material is a prerequisite to producing a good quality product and this is never more true than the preparation of the warp prior to the weaving process. This requires a creel in which all the individual yarn packages are mounted and drawn together as a section to be wound on to the drum.

The warp contains all the individual threads or ends which are used in the full width of the fabric, these threads are wound side by side onto a beam as a continuous sheet which can be up to 3000 m or more long dependent upon the count and density in ends per cm of the yarn being processed. Various methods are employed to do this but the one which best combines quality, production efficiency and pattern versatility is the section-warping system in which the warp sheet is built up in sections across the width of a large diameter drum until the full length and number of ends is completed. This is then transferred from the drum onto the weaver's beam used in the loom. One of the leading producers of section-warping machinery is the Benninger company of Switzerland and the process is illustrated in Fig. 3.9 and 3.10.

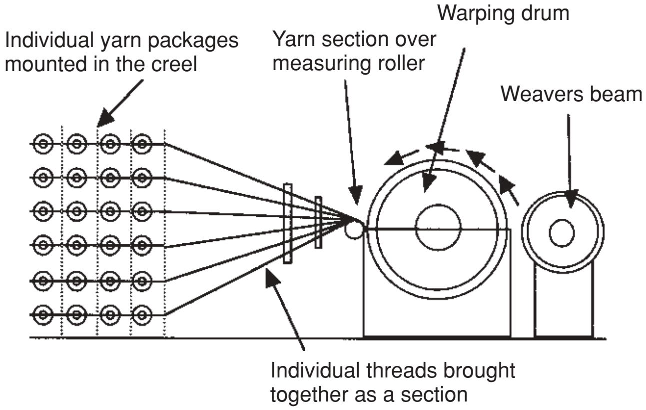
The modern section-warping machine is effectively under computer control with continuous control of yarn tension during all production phases, and the all important control of the correct build-up of the individual yarn sections across the width of the large drum which is so vital to the production of high quality warps which form one of the building blocks for successful fabric production.

3.2.2 Weaving – flat fabrics

The process of creating fabric from the warp is carried out on a loom which mechanically interlaces the individual vertical warp threads with the hori-

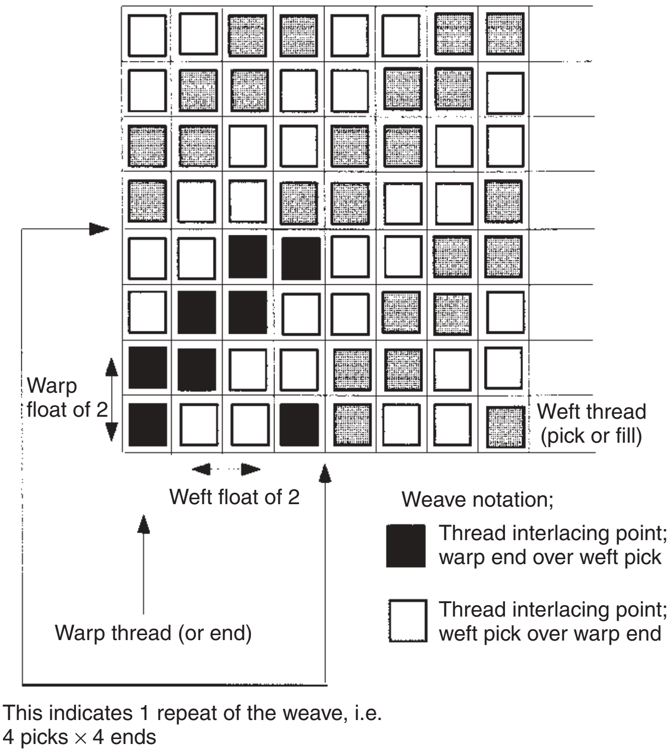


3.9 Section-warping machine. (Reproduced by kind permission of Benninger Co Ltd. Switzerland.)



3.10 Diagram of section warping machine. (Reproduced by kind permission of Benninger & Co Ltd. Switzerland.)

zontal weft yarn. The way in which this interlacing is done determines the weave and surface design of the fabric. An individual warp end can only be in one of two positions in relation to the weft thread – it can either be over the weft or under and it is this 'over' and 'under' position of each of the ends across the full width and length of the fabric that determines the weave of the cloth and also the surface design or pattern. This weave can be illustrated on squared paper known universally as 'point paper' where a square



3.11 Point paper notation of 2 × 2 twill weave.

filled in represents a warp thread (end) over a weft thread (pick or filling) and a blank represents a weft thread over a warp thread. Where a thread goes over another thread the result is known as a 'float' so that if a warp end goes over two adjacent weft picks it is referred to as a warp float of two and where the reverse applies it would be known as a weft float of two. Where this is done however it is important to define whether the float is on the face or the back of the fabric.

All weaves have a repeat, in other words the interlacing pattern starts repeating after a certain number of ends and picks. Figure 3.11 illustrates a very common weave known as 2 × 2 twill since it is formed by ends floating over a group of two picks and vice versa. Twill weaves such as this create diagonal lines in the fabric, the angle of the twill is determined by the relationship of the number of ends per inch to the number of picks per inch. In a 'square set' fabric these are equal and the angle would be 45°.

A weaving machine performs three main elements mechanically:

1 It controls the way in which the warp ends interlace with the picks, this determines the weave and surface pattern of the fabric.

2 It controls the amount of warp that is advanced or 'let off' after each weft thread has been inserted, this is a major contributor to the fabric density by controlling the picks per cm (or inch) in the cloth. The lower the advance after each pick the higher will be the picks per inch, the higher the fabric density, the lower the production rate of the cloth and the higher the overall cost to produce each metre or yard of fabric.
3 It controls the insertion of the weft yarn into the fabric and the speed at which this is carried out directly determines the production rate of the cloth and is therefore responsible for one of the main production cost elements of the fabric.

There are two main methods of controlling the individual warp ends – by shafts in dobby-woven fabrics and by harness cords in jacquard-woven cloths. Jacquard-woven fabrics have a far greater potential for surface pattern creation than dobby which tend to be limited to plain, semi-plain weave effects or geometric-style patterns. The visual effect of both can be increased by the use of coloured yarns in stripe and check formation and it is the combination of yarn selection, colour selection, weave creation and design or pattern production which is the preserve of the highly skilled woven textile designer.

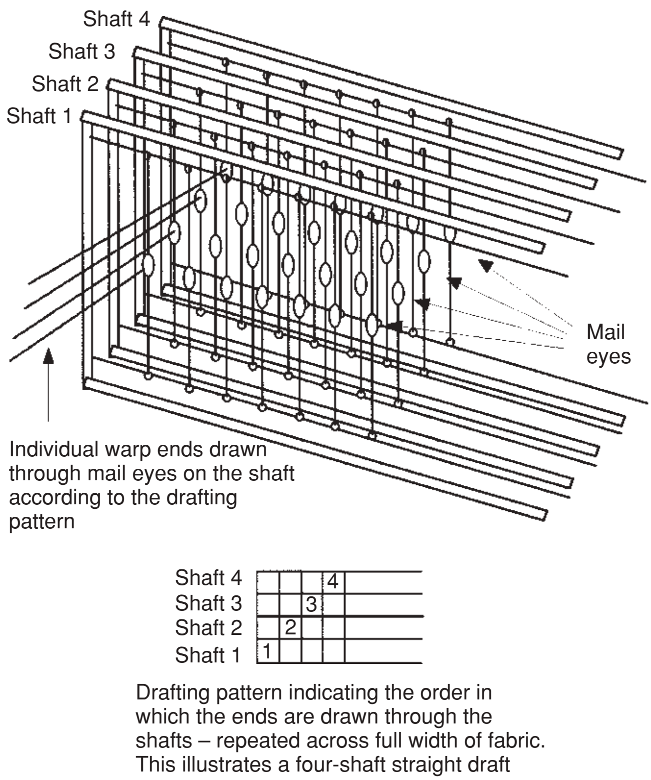
3.2.2.1 Dobby weaving

In dobby production the individual ends of the warp are entered through mail eyes which are mounted on frameworks or shafts which traverse the full width of the cloth. Each shaft can lift or lower all the ends it controls over or under each pick as they are inserted but since the number of individual shafts which can be accommodated in a loom is limited (16 is common but above 20 is more difficult and can reduce weaving speeds and efficiencies) it follows that the possible combinations of thread interlacing are also limited so that the figuring capacity to produce complex patterns is much less than with a jacquard machine. The figuring capability can be increased by carefully deciding the order in which the ends are arranged through the mails and on the shafts – this is known as 'drafting' and is yet another skilled operation worked out by the textile designer when creating the fabric and design.

Figure 3.12 illustrates the arrangement for a simple four-shaft style which could be used to produce the 2×2 twill weave. The drafting arrangement or 'draft' is noted on point paper in a similar way to the weave.

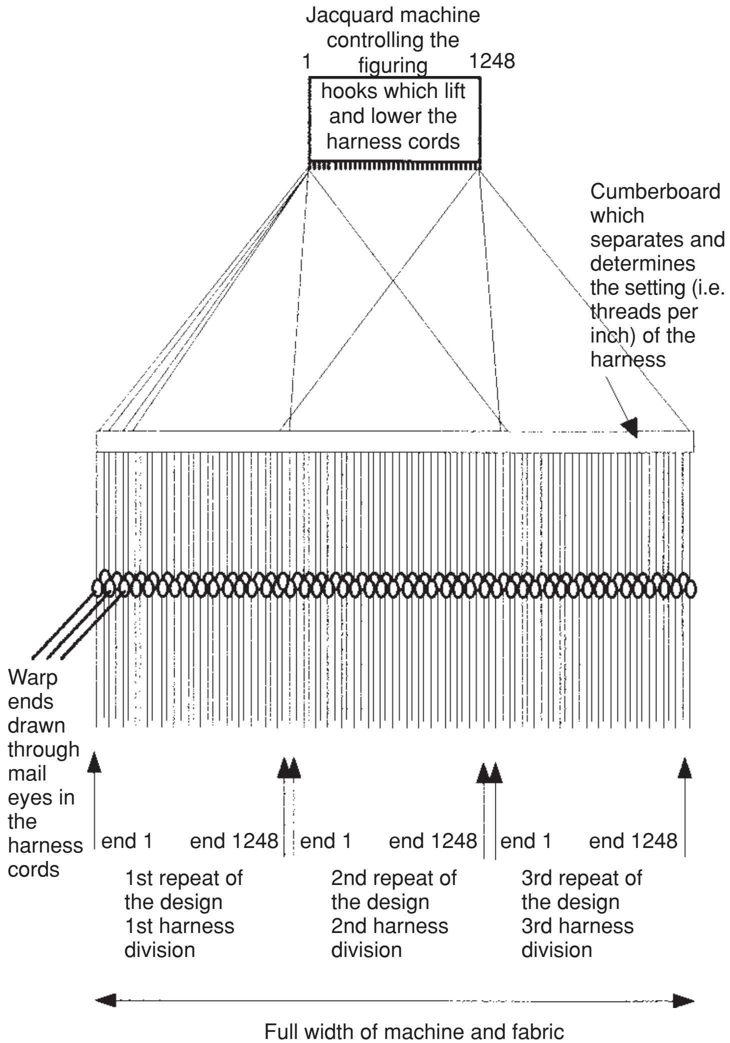
3.2.2.2 Jacquard weaving

In jacquard-woven cloths each individual end in the repeat of the design is controlled separately by a harness cord which is in turn controlled by the



3.12 Set up for a four-shaft Dobby style fabric.

jacquard mechanism mounted above the loom. A typical harness would have in each division 1248 individually controlled ends to create one repeat of the design so if the warp were set at say 48 ends per inch the design repeat capable of being produced by such a harness would be 1248/48 or 26 inches. If the cloth width required was say 78 inches or 198 cms this would require 78/26 or three repeats of the harness division across the full width of the loom creating three full repeats of the design across the full width of the cloth. This would in fact be the harness design for that particular loom and although it has great flexibility in terms of design in that any weave combination or pattern figure can be created within the repeat of the 1248 ends, it is less flexible when it comes to requiring different warp settings (i.e. ends per inch). Settings which are less than that for which the harness has been designed (in our example 48 ends per inch) can be accommodated by 'casting out' the harness – this simply means not using all the harness cords which are available – but it is impossible to produce fabrics which require a higher set than the harness – in these cases the only answer is to purchase another harness.



In 'cast out designs' ends are drawn through only some of the harness cords thus reducing the effective set or ends per inch in the fabric. This system enables a variety of different fabric structures to be woven in the same harness.

3.13 Typical jacquard harness arrangement.

The harness cords are controlled by the jacquard mechanism which has the ability to lift and lower each cord individually within the repeat to create the pattern. Nowadays almost all of the mechanisms are controlled electronically and designs can be programmed onto floppy disks which slot into a controller on the loom and create the lifting pattern of the ends which in turn creates different weaves to produce the design.

Figure 3.13 provides a schematic of the main elements of a jacquard and harness arrangement mounted over a loom.

Although the jacquard mechanism was invented in 1790 by Joseph-Marie Jacquard from Lyon, France, it was not until the latter part of this century that the original mechanical arrangement invented by Jacquard was supplanted, almost world-wide now, by the electronically controlled machine. The leading developer of this has been the Bonas Machine Company, Gateshead, England.

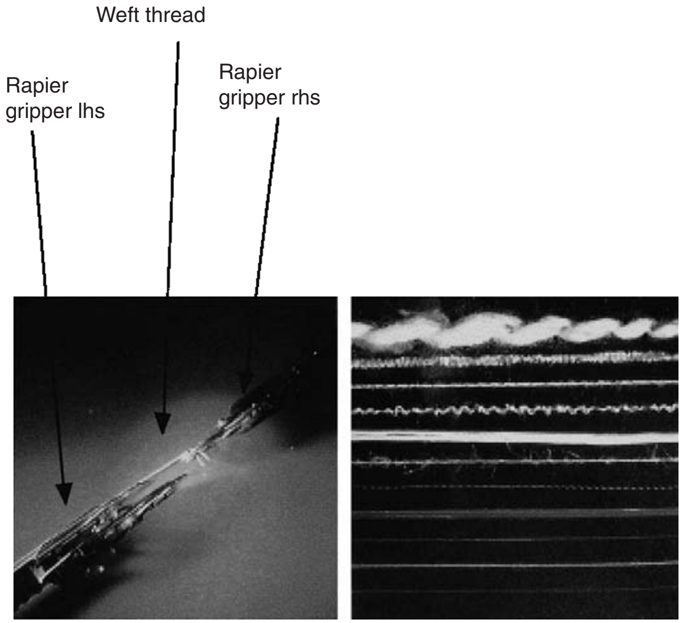
3.2.3 The weaving machine (or loom)

The weaving machine which produces the fabric can operate, with certain modifications, either a dobby or a jacquard – in effect the dobby or jacquard provides the figuring capacity and the loom provides the mechanics for actually weaving the fabric. There are many methods used for propelling the weft yarn across the warp. The original way was with a shuttle loaded with a bobbin of yarn but nowadays, this has largely been superseded by water jets, air jets, rigid rapier, flexible rapiers, projectiles or 'bullets' etc.

The weaving of automotive fabrics demands a system which can efficiently handle a wide variety of yarn types and counts in both warp and weft, can insert from a variety of packages and select many different colours as required by the design. One machine which has been particularly successful at this is the Dornier rigid rapier system. In this method the weft thread is propelled across the width of the fabric by two rigid rapiers each carrying a gripper which grips the thread on the entry side of the fabric, takes it half way across the cloth and transfers it positively to another gripper propelled by the rapier on the other side which completes the journey. This positive method of transfer is unique to the Dornier system and is an important feature when weaving high-quality fabrics particularly for the automotive industry. The individual weft threads are presented to the grippers by selectors and the versatility of the machine means that 12 or more different yarns or colours can be used in the same fabric of widely differing thickness and type as illustrated in Fig. 3.14.

The Dornier type P weaving machine and its various parts including the VDU control station are illustrated in Fig. 3.15 which shows a dobby mechanism for controlling the warp ends whereas Fig. 3.16 shows a similar machine but mounted under a jacquard head with a harness controlling the warp.

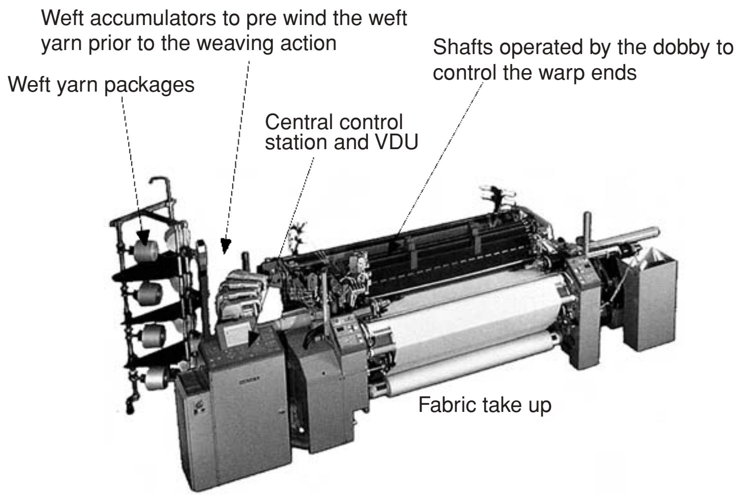
Computer control of the jacquard pattern is, nowadays, complemented by similar computer-driven, programmable controls of such things as dobby shafts, warp yarn let-off and fabric take-up, weft selection and control and



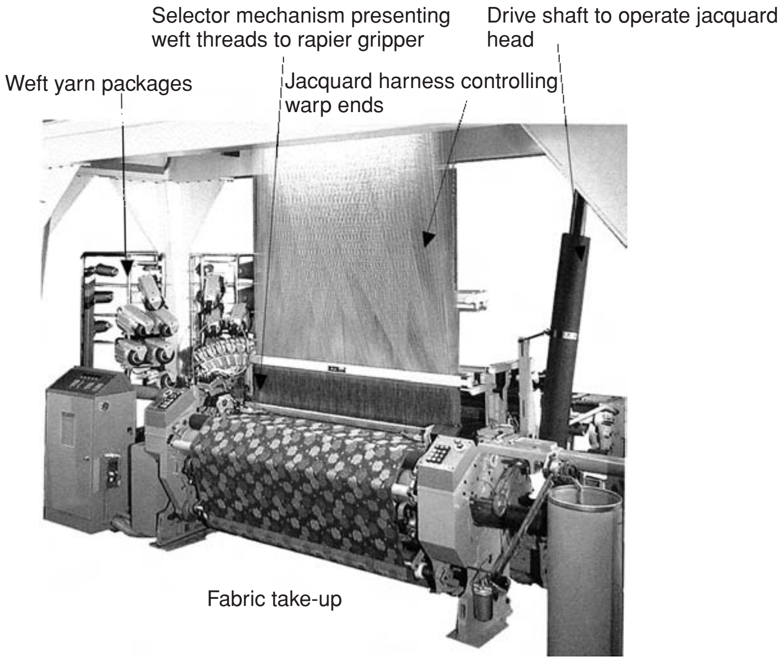
As weft in transferred from left-hand to right-hand of fabricy

Typical range of weft varns which can be woven on the Rapier loom – app 8 Decitex to 33 000 Decitex

3.14 Dornier rapier gripper arrangement and typical weft which can be efficiently handled. (Reproduced by kind permission of Lindauer Dornier Gesellschaft mbH.)



3.15 Dornier model P weaving machine with warp ends controlled by a dobby mechanism. (Reproduced by kind permission of Lindauer Dornier Gesellschaft mbH.)



3.16 Dornier model HTV 12/J Rapier weaving machine mounted beneath electronic jacquard. (Reproduced by kind permission of Lindauer Dornier Gesellschaft mbH.)

an increasing number of other features such as variable pick rate which ensure that the fabric designer and technologist are presented with possibilities not dreamt about only a few years ago.

3.2.3.1 Fabric constructions

The construction of any flat-woven fabric is determined by the nature and type of the warp and weft yarns, the weave or interlacing pattern and the setting of the fabric in terms of ends per inch or cm and picks per inch or cm.

There is a general requirement to go lighter in weight for reasons of fuel economy etc but this is tempered by the requirement to meet physical tests and also by the possible design requirement to create design detail and colour content by 'cramming' the warp or weft yarns (cramming is a weaving technique used to increase end or pick rates beyond what would normally be considered adequate specifically to produce dense colour or design details).

The result of this is that the 'normal' range of weights for flat-woven fabrics is usually between 250 and 350 g per m^2 (7.4 to 10.4 oz per yd^2) with occasional 'crammed' fabrics reaching up to 450 g (13 oz/yd^2). These weights are based on the 'singles' fabric – i.e. before coating or lamination.

In order to achieve this sort of weight range many different combinations of yarns and settings can and are used, Dobby fabrics can be produced using almost any combination of end, pick and yarn, but jacquard fabrics are usually standardized within a particular manufacturing plant due to the expense and difficulty of changing the harnesses which determine to a certain extent the ends per inch.

Some possible combinations are listed below with counts shown in both Decitex and English cotton count – approximate weights which include an estimate of yarn crimp are shown:

Warp	Ends cm (inch)	Weft	picks cm (inch)	Singles g/m^2 (oz/yd^2)
420 dtx (14 cc or 2/28 cc)	20 (51)	830 dtx (7 cc or 2/14 cc)	17 (43)	236 (7.0)
540 dtx (11 cc or 2/22 cc)	20 (51)	830 dtx (7 cc or 2/14 cc)	16 (41)	254 (7.5)
420 dtx (14 cc or 2/28 cc)	40 (101)	540 dtx (11 cc or 2/22 cc)	20 (51)	289 (8.5)
540 dtx (11 cc or 2/22 cc)	25 (64)	830 dtx (7 cc or 2/14 cc)	18 (46)	298 (8.8)
420 dtx (14 cc or 2/28 cc)	30 (76)	830 dtx (7 cc or 2/14 cc)	20 (51)	307 (9.0)
830 dtx (7 cc or 2/14 cc)	20 (51)	830 dtx (7 cc or 2/14 cc)	16 (41)	315 (9.3)
1300 dtx (4.5 cc or 2/9 cc)	15 (38)	1300 dtx (4.5 cc or 2/9 cc)	12 (30.5)	368 (10.8)
830 dtx (7 cc or 2/14 cc)	25 (64)	830 dtx (7 cc or 2/14 cc)	18 (46)	375 (11)
600 dtx (10 cc or 2/20 cc)	40 (101)	600 dtx (10 cc or 2/20 cc)	30 (76)	441 (13)

It may be useful at this stage to consider the calculation for fabric production which is directly related to the picks per inch [or cm.]

3.2.3.2 Production rates

The production rate of both flat- and pile-woven structures is dependent upon three primary elements: picks per inch (or cm); weaving speed in picks per minute; weaving efficiency.

Once these three factors are known the calculation is straightforward according to the formula.

$$\text{Production in metres per hour} = \frac{\text{picks per minute of the weaving machine} \times 60}{\text{picks per cm} \times 100} \times \text{efficiency }\%$$

Example: 20 picks per cm weaving at 400 picks per minute at 80% weaving efficiency.

$$\text{Production} = \frac{400 \times 60}{20 \times 100} \times \frac{80}{100} = 9.6 \text{ metres per hour}$$

3.2.3.3 Design and fabric development

The designing and development of the yarns and fabric structures still rely on the tried and trusted methods of weaving and finishing samples. Certain yarns have become almost standards, such as 830 decitex parallel textured for warp yarn and textured with overfeed effect on parallel core for weft. Such yarns are capable of producing a wide range of fabric weights in a variety of structures which have met the testing requirements of most OEM's world-wide.

Development is now centred upon devising new yarn effects and weave structures to allow innovative fabrics to be produced. In this context the importance of weave development (i.e. the specific order of interlacing of warp and weft yarns) cannot be overemphasized since clever designing and innovation in this area can enhance visual design effects and mean the difference between fabrics passing and failing tests.

Finishing processes have also been important particularly with the increasing importance of flexibility in fabrics. In its simplest form a woven cloth simply needs a stenter finish to set the yarn and structure before it is laminated but by adding wet processes it is possible to better relax and consolidate the fabric, which can improve both handle and abrasion performance. Finishing agents such as softeners, anti-static agents etc can also be applied.

By including surface actions such as brushing, sueding etc. new fabrics can be developed which have different physical and aesthetic properties.

3.2.4 Weaving – pile fabrics

The basic principle of weaving pile fabrics is very much the same as flat-woven fabrics in that the ground structure of the fabric is composed of vertical warp ends and horizontal weft threads. However the pile takes the form of additional warp threads controlled either by pile shafts in a dobby-woven cloth or by a jacquard harness in a figured-jacquard structure. In both cases the design of the fabric is created by the vertical pile ends which form the surface of the cloth.

Many systems have been developed to manufacture this type of fabric including wire looms for the production of cut and uncut moquette but the one which has dominated particularly the automotive sector is the 'double plush' or 'face to face' system. One of the main reasons for this is the fact that two fabrics are effectively woven at the same time one above the other joined together by the pile warp ends which cross from top cloth to bottom cloth according to the design and during this weaving process a knife situated between the two cloths continuously traverses the width of the fabric cutting the pile warp threads to create two cloths each with a cut warp pile surface. It is important to appreciate that a surface pile tuft is formed only when a pile end crosses from the top cloth into the bottom cloth and is cut on the loom by the traversing knife, and it is in this way that the surface pile design and colour are created. When it is not required on the surface of the fabric the pile is woven or 'incorporated' into the ground structure either in the top or bottom cloth.

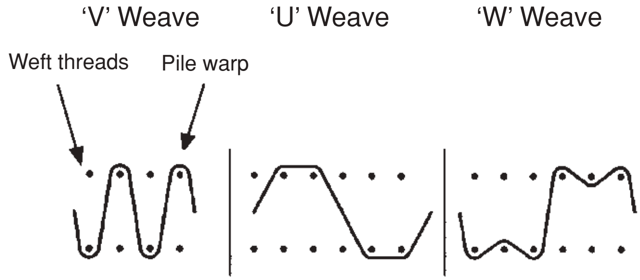
Some of the more complex structures also utilize a 'reflect' warp principle where there are areas of no pile which reveal the ground structure as part of the design. This is a principle that is widely used in the domestic upholstery business but has to be used with care in automotive due to issues with the uneven surface causing abrasion and other performance problems. The two obvious results of this system are that the production costs are reduced due to the simultaneous production of two cloths and also that the design on the top cloth is a mirror image of the design on the bottom cloth – a feature of particular importance when planning fabrics and seats to be made from jacquard-woven designs.

The main function of the ground yarn is to support the structure and create a base which meets tensile and seam fatigue requirements. However, any stretch requirements would be a function of ground yarn and structure and would have to be approached in the way described for flat wovens although there would be much less opportunity to influence yarn crimp.

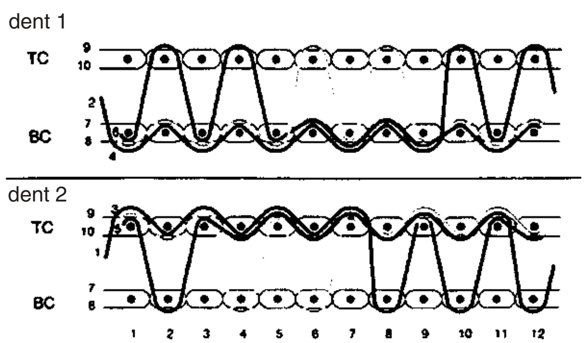
The pile yarn is the main feature and must meet aesthetic design, colour and the main technical requirements such as lightfastness, abrasion, crush resistance, tuft adhesion.

Special looms are used to weave face to face velvets. These insert two picks at a time, one top cloth, one bottom cloth, but use conventional shaft arrangements controlled by a dobby or alternatively a jacquard harness to control the pile ends. The looms are quite complex and since variable take-up of threads is part of the weaving process, complex warp yarn let off and tension-compensating devices are required. The situation in jacquard is complicated by the fact that each of the several thousand individual pile warp ends is incorporated into the cloth at a different rate which means that all the ends come from a separate package all mounted in a creel utilizing a negative system of yarn feed controlled by friction tension devices.

There are many different weave structures associated with velvet particularly in relation to the interlacing of the pile yarns and often velvets are referred to as 'V', 'U', or 'W' weave. This refers to the individual tuft formation and is illustrated in Fig. 3.17. It is immediately apparent from this that the densest pile will be formed from the 'V' weave but it will also have the lowest tuft adhesion since each tuft is only anchored by one thread. 'U' weave has a lower pile density, and 'W' weave has a low density but a high tuft adhesion since it is anchored by three threads. For automotive uses the



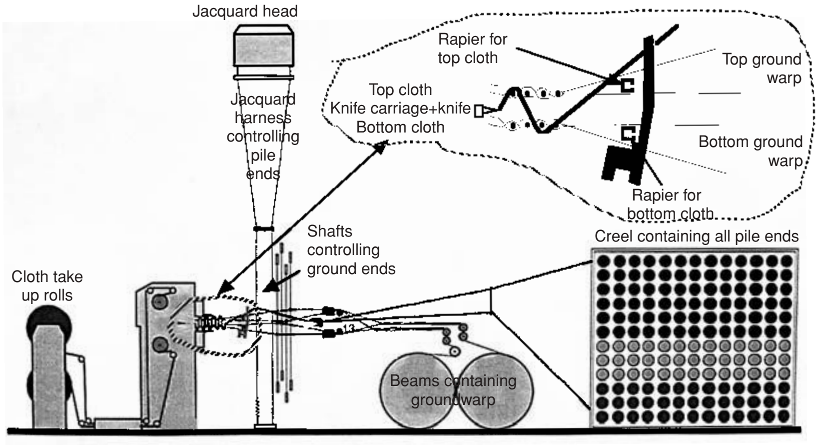
3.17 Illustrating the three main pile warp interlacing techniques used in face to face woven velvet structures. 'V' weave is popular due to high pile density for any given ground structure but has low pile adhesion properties. This is improved by back coating the fabric. (For purposes of clarity the ground warp interlacing is omitted from above diagram.) (Reproduced by kind permission of Michel Van De Wiele NV.)



3.18 Section through a jacquard structure showing two adjacent lines of the design – dent 1 and dent 2, each one containing three differently coloured pile ends which can be crossed from top to bottom to create a design of three distinct colours plus combinations of these. When not in use the pile ends are incorporated in both top and bottom cloth to equalize fabric weight. This would be known as a 'three-frame' jacquard design and utilizes the 'V' pile principle shown in Fig 3.17 as the basis for the pile interlacing. (Reproduced by kind permission of Michel Van De Wiele NV.)

'V' pile is very popular since it produces high pile density, and tuft adhesion is improved to acceptable levels by back-coating the fabric.

Figure 3.18 shows a cross-section through a jacquard-woven structure where for every two ground ends in top and bottom cloth, there are three pile ends crossing between. It can be seen that where a tuft is formed the 'V' weave is used and where the pile end is not required on the surface it is incorporated into the ground either on the top or bottom cloth. The dents



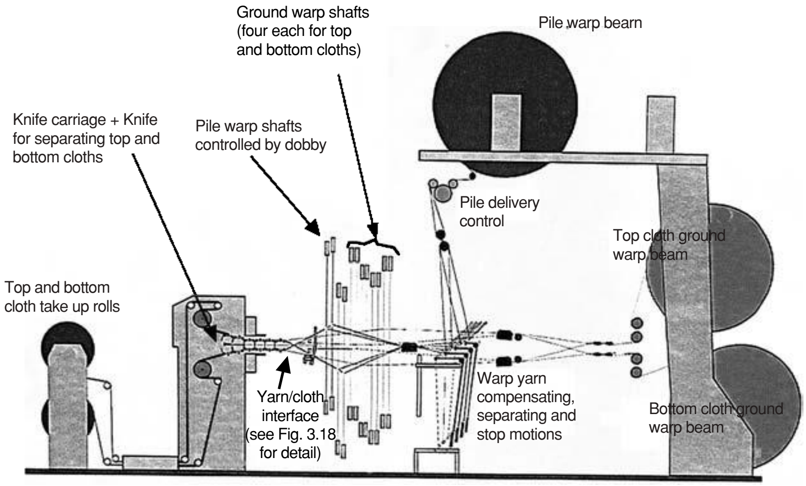
3.19 Face to face velvet jacquard weaving machine with detail inset of yarn/fabric interface. (Reproduced by kind permission of Michel Van De Wiele NV.)

refer to each vertical line of figuring, and in this structure it is possible to select any one of the three different colours of pile to create the design. Each alternate line (i.e. dent 1, dent 2) would tend to incorporate the pile into opposite cloths in order to create a balanced weight structure between the top and bottom cloths, and the weave selection to do this is part of the highly skilled job of the velvet design technician.

The looms for weaving face to face velvet cloths are, in principle at least, similar to those used for weaving flat fabrics but have many additional features to accommodate the pile ends and also the ability to weave two cloths simultaneously one above the other. The looms can be built to either use a jacquard machine to control the pile ends as illustrated in Fig. 3.19 or they can utilize a dobby mechanism for this as illustrated in Fig. 3.20. In both cases the weaving of the ground structure is very similar.

Designing for velvet fabrics is a highly skilled operation requiring specialist knowledge of the weaves, yarns, fabric structures etc. Since the ground cloth is rarely seen, it is usual to try to minimize weight and cost of ground yarns consistent with tensile and tear strength requirements. However, they do have an effect on the adhesion of the pile yarns so ground yarns which present high surface friction will help tuft retention (air-textured yarns for instance).

Pile yarns on the other hand form the fabric surface and depend upon the individual filaments 'bursting' to create a full dense surface. Attention should be paid here to filament denier and cross-section and spinning systems which allow filaments to burst – it is well known that the air texturizing system employed for yarns in flat-woven automotive cloths (and which are quite good as ground yarns) does not lend itself to creating good



3.20 Face to face velvet dobby weaving machine. (Reproduced by kind permission of Michel Van De Wiele NV.)

pile yarns due to the high degree of entanglement of the filaments. The staple-spun or false-twist method is better in this regard.

Finishing is a vital part of velvet cloth development. After weaving the cloth is cropped to even out the pile surface and 'tigered' or vigorously brushed on the pile surface to burst the yarn filaments, cropped again to create a standard 'pile height' specification and maybe heated and brushed again to thermally set the pile at a specific angle. Totally vertical pile looks good but is not favoured since in use it does not present a uniform appearance when individual filaments crush in different directions. A slight angle to the pile causes the filaments to crush in a similar direction presenting a more even light reflection and appearance in use.

Woven velvet structures have been, and still are, highly regarded as an up-market product for automotive trim, particularly in Japan where they compete with leather in the higher trim levels and in excess of 20% of the textile trim market has been accounted for by woven velvet fabrics mainly of 'V' weave structures. In America the 'V' weave predominates and has in recent years accounted for around one-third of the trim market. However this tendency has been less pronounced in Europe where the market share has been somewhat less than 10% with 'W' weave featuring in better qualities with wool or wool-blend pile yarns. The reason for this low market share is unclear but could be associated with the high cost and also because velvets are even more difficult than flat-woven cloths to produce with stretch to match modern seat and interior design. They have also faced intense competition in Europe from innovations in jacquard circular-knitted structures which have inherent stretch characteristics and, despite their more limited capability to exploit novel yarn characteristics, have in recent years taken a large share of the pile fabric market.

3.2.4.1 Design and development

The designing of velvet fabrics requires the same attention to CAD, yarn development and finishing as flat-woven cloths. Efficient CAD packages are now available to design and simulate velvet fabrics in printouts.

Yarn development concentrates on developing standard ground yarns which are cheap, which meet the strength requirements and are at the correct count level to give the correct density and weight. They should also display a high surface friction in order to form an efficient anchor for the pile yarns to maximize tuft retention, and it is this property which tends to favour staple-spun yarns or air-textured filament yarns as ground yarns for automotive velvets rather than flat- or false-twist filament which are cheaper. However, there is a trade off in terms of cost since tuft retention can be increased by the application of a back coating and it may be cheaper in the final analysis to use a cheap flat-filament ground yarn and apply a heavy back coating. Development trials and testing are the way to verify the suitability. Once this has been decided the effort should be diverted to the pile yarns which form the aesthetic surface of the fabric as these can be of an infinite variety with a much greater choice available than for say, the circular-knitted pile cloths. However the performance requirements tend again to limit the choice to fibres which can display light and UV resistance and good abrasion performance. Since woven velvets tend to be expensive and have an up-market image just under that of leather in Europe and Japan (less so in the USA), the trend has been to use wool or wool blended with polyester as pile yarn for automotive in counts ranging from 2/17s metric to 2/28s metric in 70/30 polyester wool-blend fibre dyed and worsted spun. Wool blended with nylon has for a long time been prominent for public transport.

3.2.5 Woven cloth characteristics

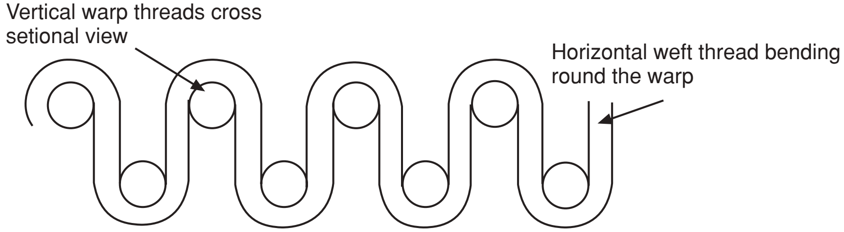
By their very nature, woven structures are rigid or semi-rigid in the vertical and horizontal directions with only slightly more flexibility in the bias direction. Over recent years this has become a handicap due to the increasing requirement for stretch substrates to allow greater flexibility in the design and manufacture of both seats and door panels. This situation has affected both flat- and pile-woven cloths and has been addressed by the weavers in two main ways.

Special yarn is designed to incorporate stretch by the use of stretch polymers for limited stretch requirement. This would include the use of polybutylterephthalate-type yarns where recoverable stretch was wanted or part-oriented yarn (using a feedstock which had not been fully stretched during the manufacturing extrusion process described earlier under fibres) where stretch was needed but recovery was not important (e.g. bonded door panel manufacture) or incorporating an elastomeric fibre (e.g. Lycra®) into the yarn during manufacture where much greater stretch and recovery properties are needed. These methods have met with some success in meeting a lot of the requirements and in competing with the knitted structure but have presented problems of cost and also the constant difficulty of making the same design colour in both stretch and cheaper non-stretch versions in matching fabrics.

The other solution, where only minimum amounts of flexibility are needed to overcome specific problems, requires special weaving and finishing techniques using standard yarns – this method is almost entirely dependent upon introducing yarn crimp into the fabric during weaving and/or finishing. An exaggerated view of yarn crimp is illustrated in Fig. 3.21 and it can be appreciated from this that, once developed into the fabric, it is, by the application of tension, capable of being pulled or extended thus creating a limited amount of stretch.

This crimp is influenced by such things as yarn thickness (i.e. count), yarn type, order of thread interlacing (i.e. weave) and weaving tensions. Once the fabric is woven these parameters are fixed in the fabric but can be altered by finishing techniques applied to the fabric after weaving, particularly where the fabric is wet out or scoured, relaxed and dried under various tension controls on the stenter. These techniques can, to a limited extent 'interchange' warp crimp to weft crimp and vice versa. When applied at the finishing stage under the influence of heat to thermoplastic fabrics such as polyester, it is possible to set the crimp in the fabric, thus making it permanent and recoverable unless the setting temperature is exceeded.

Close attention to this aspect of fabric geometry can be extremely useful in addressing such problems as surface abrasion, fabric handle, fine tuning



3.21 Illustration of yarn crimp which can contribute to fabric stretch in woven structures.

	Weaving tension	Greige stretch	Finishing tension	Finished stretch	Effect
Warp A	High	Low	High	Lowest	Lowest warp stretch (Length gain)
B	High	Low	Low (or overfeed)	High	Crimp interchange (Length loss)
C	Low	High	High	Low	Crimp interchange (Length gain)
D	Low	High	Low (or overfeed)	Highest	Highest warp stretch (Length loss)
Weft E	High	Low	High	Lowest	Lowest weft stretch (Width gain)
F	High	Low	Low	High	Crimp interchange (Width loss)
G	Low	High	High	Low	Crimp interchange (Width gain)
H	Low	High	Low	Highest	Highest weft stretch (Width loss)

3.22 Table showing how weaving and finishing parameters can influence rigidity and stretch characteristics of woven structures.

a cloth for specific applications, maybe in special seat or door panel shapes etc.

The theoretical effects of combining these parameters from weaving through finishing is shown in the table in Fig. 3.22 but since actual results are dependent upon many factors the development of crimp and crimp interchange should form part of the initial fabric development process.

3.3 Fabric structures – warp knitted

In the three major car producing areas of USA, Western Europe and Japan significant differences are apparent in the usage of the various fabric-producing technologies.

Taking an average percentage figure for all three markets, the technology which has the largest overall share is the warp knit technology which claims approximately 36% of all trim material used. This compares with a figure of around 25% for flat woven where by far the largest share is in Europe and 21% for woven velvet where the largest share is in the USA.

The reason for this can be traced to the highly efficient production methods which realize low cost with high fabric performance at relatively low fabric weights, and the traditional view that the limiting factor to sales is the lack of an efficient, productive and versatile method of creating surface pattern has been partially addressed by the development of jacquard Raschel machines and the new and innovative fabric printing methods including ink jet which are being applied to warp knit structures and which are described in Section 4.3.

There are two main warp knit technologies which have had a major influence in the automotive textiles market and those are Tricot knit (including pile sinker styles) and double needle bar Raschel.

The main feature which Tricot knit fabrics share with woven cloths is that they are produced from a warp, but unlike woven cloths there is no weft yarn since the structure is formed by creating loops using needles which interlace the individual warp threads around themselves and their neighbours to create a line of vertical stitches known as 'wales'. Each needle produces a wale and the number of needles per inch is known as the gauge of the machine.

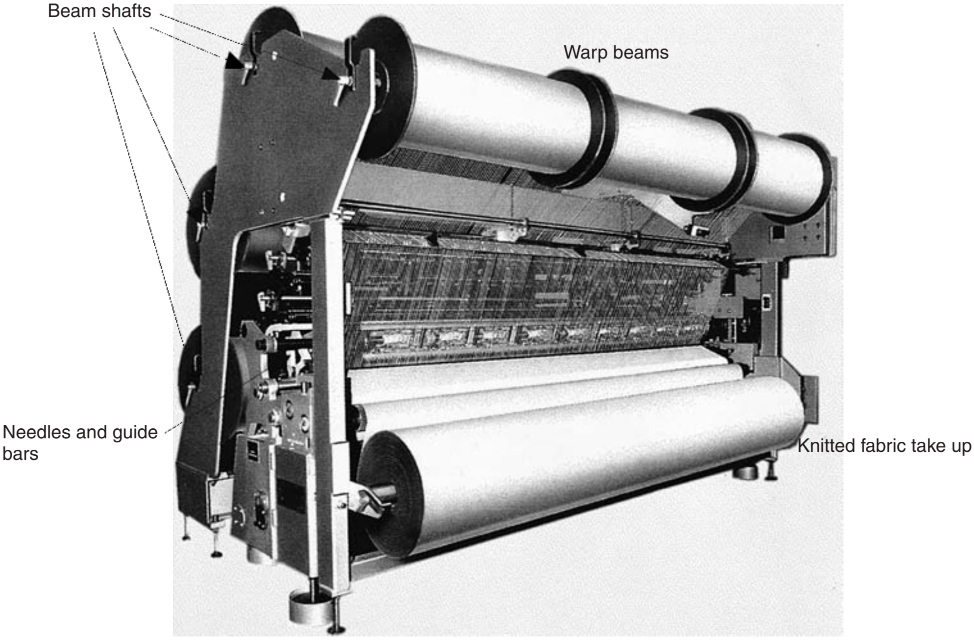
The length of the loop or stitch is visible on the back of the fabric as a horizontal line of stitches and is known as a 'course'. The number of wales and courses in a knitted fabric defines the construction along with the yarns used and the stitch formation.

The movement of the yarn is controlled by guide bars which work horizontally by moving the yarn from side to side around the needles which operate vertically in the formation of the stitches. It is common for Tricot machines to have from one to four guide bars – the greater the number the greater the potential for creating stitch variations and thereby surface effects or patterns.

Figures 3.23 and 3.24 show the Karl Mayer four bar Tricot machine front and side view. These machines are, like circular-weft knitting machines, available in various gauges (i.e. needles per inch) such as 18, 20, 22, 24, 28, 32 and also various widths from around 136 to 210 inches, however, these widths must not be confused with ultimate fabric widths since high reductions in width occur during the finishing operations particularly if the fabric is brushed or raised. This is an advantage over circular knitting technology since, when a machine width has been specified it is – unlike circular knits – possible to knit at narrower widths than the machine width; this is a feature warp knitting shares with weaving.

It can be seen from the illustrations that the beams are contained on beam shafts mounted above and around the machine. It is possible to have one wide beam per shaft or several narrower ones as shown. For ease of handling, the latter arrangement is often preferred. However, once mounted on a common shaft all beams operate as one, and it is this shaft which controls the let off or warp feed.

The warp ends are presented in the form of a sheet to the guide bars (in weaving the equivalent would be the shafts in a dobby loom) which control



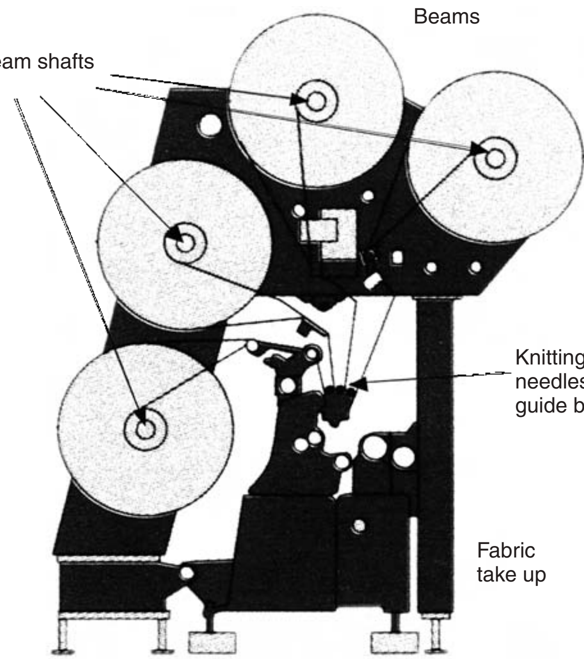
3.23 Karl Mayer HKS4 – four-bar Tricot warp knitting machine. (Reproduced by kind permission of Karl Mayer Textilmaschinenfabrik GmbH.)

the underlapping or sideways shogging movement of the bars to form the stitch pattern. The normal arrangement would be to have one shaft containing a set of beams for each guide bar of the machine, hence in the illustration there are four beam shafts for a four-guide bar machine, which is regarded as the maximum for efficient production.

The reason for this is to ensure that the warp let off of each shaft can be precisely matched to the requirement of the guide bar it feeds, each of which takes up warp at a rate determined by the design, which in turn defines the amount of sideways lapping the guide bars perform during the knitting process.

3.3.1 Stitch formation and patterning

These could almost be regarded as two separate operations with the stitches which create the knitted structure being formed by the operation of the needles and the pattern being created by the operation of the guide bars. This is not strictly true, of course, since the different stitch formations possible are frequently regarded as part of the design and could roughly be

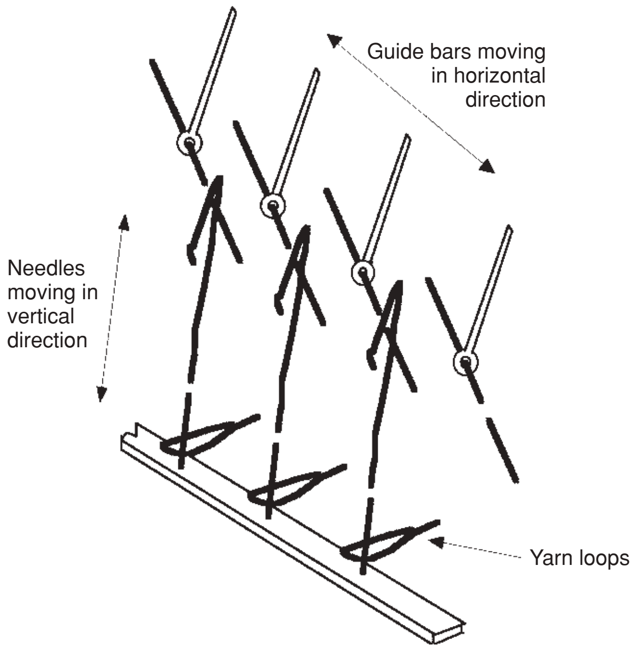


3.24 Karl Mayer HKS 4 – four-bar Tricot warp knitting machine. (Reproduced by kind permission of Karl Mayer Textilmaschinenfabrik GmbH.)

compared to the actual weave structure of a woven cloth. The guide bars however govern the location of the various warp yarns in the fabric by controlling the sideways lapping which has no theoretical limits and is governed only by what is mechanically possible. By introducing different types of yarn and yarn colours, surface design and effect are added to and the more guide bars available for patterning the greater the potential for creating surface design, but this comes with the penalty of complexity and reductions in knitting speed.

Figure 3.25 illustrates the basic principle showing how the guide bars move the warp threads laterally across the needles which move vertically to interlace the structure.

By the addition of sinkers, it is possible as with circular knit structures to create surface loops during the knitting process which can be subsequently cropped leaving a dense pile surface. However the patterning possibilities with these methods of manufacture are restricted due to the physical limitations of movement of the guide bars resulting in designs and effects of relatively small repeats when compared to jacquard weaving and weft knitting.



3.25 Illustrating the relative movements of guide bars and needles to create the stitches in warp knit structures.

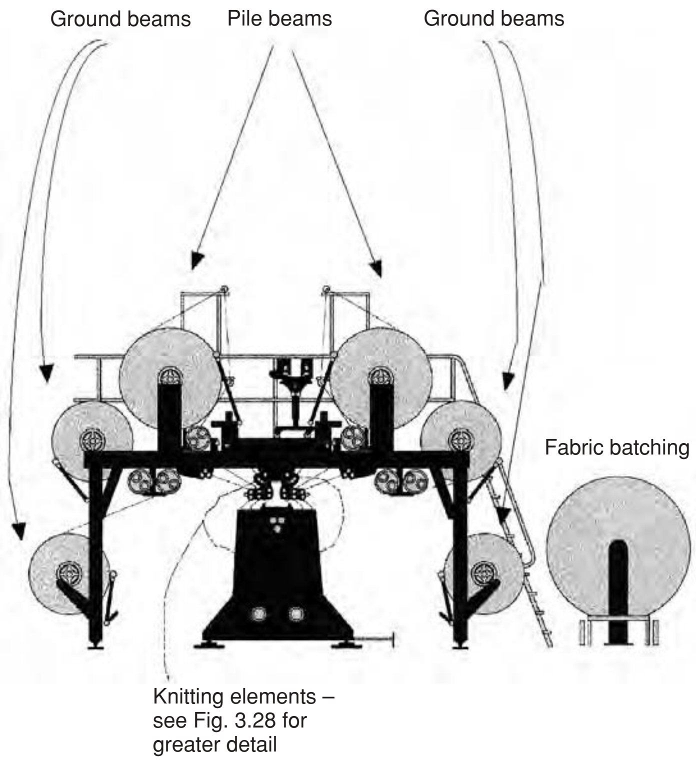
3.3.2 Raschel structures

These are knitted structures which utilize up to forty-eight guide bars that transfer yarn across rows of vertically knitted loops or wales and create a structure which can closely resemble a woven cloth or be used to create design effects as in jacquard lace structures where the guide bars are controlled by a jacquard arrangement. In automotive fabrics, the use of Raschel has been extensive due to the development of double-needle-bar techniques which are frequently referred to as double needle bar Raschel or DNBR for short.

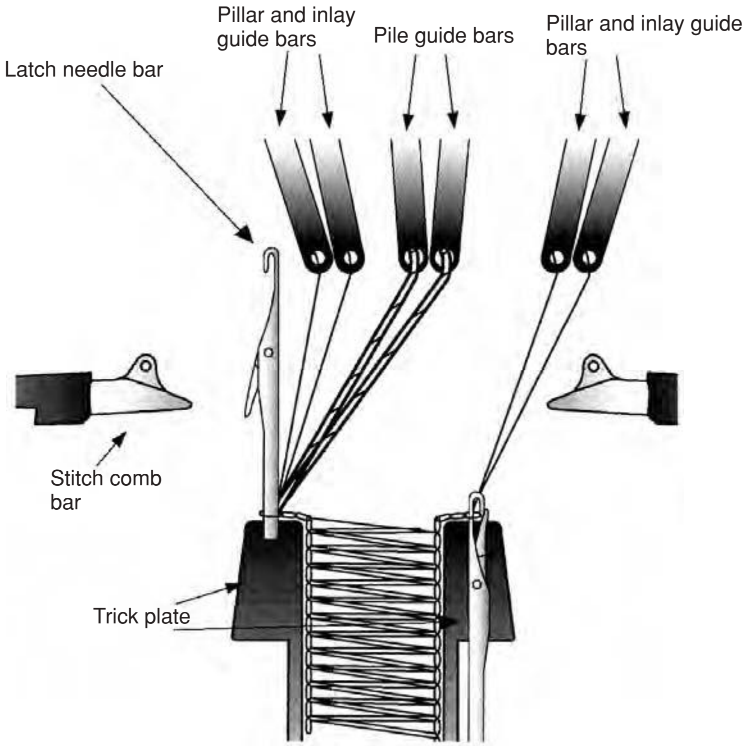
The technique follows the double plush woven model in that two fabrics are knitted at the same time but in this case one behind the other. One is on the front needle bar and one on the back needle bar and they are joined by warp moving between the two and controlled by the guide bars, thus creating a double cloth comprising two single cloths with the centre composed of yarn floating between the two cloths.

Figure 3.26 shows the front and Fig. 3.27 shows the schematic view of the Karl Mayer RD6 DPLM double needle bar machine illustrating the arrangements of pile and ground beams with Fig. 3.28 illustrating the knitting action of the needles in creating the double structure.

3.26 Karl Mayer double-needle-bar knitting machine RD6 DPLM – front view. (Reproduced by kind permission of Karl Mayer Textilmaschinenfabrik GmbH.)



3.27 Karl Mayer double-needle-bar knitting machine RD6 DPLM – schematic showing main elements to produce double fabric. (Reproduced by kind permission of Karl Mayer Textilmaschinenfabrik GmbH.)



3.28 Needle action during double-needle-bar knitting process. (Reproduced by kind permission of Karl Mayer Textilmaschinenfabrik GmbH.)

When this double-knitted cloth has come off the machine it goes through a separating and cutting process (unlike woven double plush which is cut on the machine). This produces two single fabrics, each with a pile surface which requires final cropping and tigering in a similar way to that of woven and weft knitted pile cloths.

Methods have been developed to create complex jacquard patterns by controlling the operation of the guide bars individually with jacquard mechanisms. Unfortunately due to the different yarn take up according to the way it is interlaced into the structure and depending upon the design in which warp yarn creels have to be employed instead of beams, (again similar in concept to woven double plush) this has led to complex machine technologies which have not proved effective in competing with the circular-knit methods of production.

In plain, semi-plain and modest small repeat geometric type designs DNBR has proved to be a formidable force to be reckoned with in terms of cost, production speed and fabric structures, which meet the needs of seat and interior trim engineers.

DNBR is also an ideal and competitive pile structure to use as a print ground and as printed fabrics increase their share of the automotive market it could well take an increasing share particularly if ink-jet printing becomes a major force in applying design to fabric for automotive fabrics since DNBR is an idea substrate for this technology.

3.3.3 Machine gauges, speeds and fabric development

The main elements which determine the characteristics of warp knitted structures are; gauge; courses per inch; yarn type; stitch type and guide bar movements; and dyeing and finishing techniques.

The gauges of warp knitting machines largely depend upon the end use of the fabric and machines are developed to cater for this.

However, common gauges for the types of cloth produced for automotive end uses would be between 20 and 28 gauge (i.e. wales/needles per inch). They could be finer or coarser if required but, unlike weaving where it is relatively easy and inexpensive to change gauge, (referred to as EPI or ends per inch in weaving) it is a fairly expensive procedure to change gauges of warp-knit machines once they have been constructed and so it is necessary to spend more time deciding this aspect before specifying the machine.

In double-needle-bar structures it is possible to refer to the gauge of each needle bar separately or together. For instance a 44 gauge DNBR cloth would be produced from two needle bars each of 22 gauge so it would be quite correct to refer to the fabric as a 22-gauge structure but having been produced on a 44-gauge DNBR machine.

Warp knitting machines are a highly productive method of producing fabric, and speeds which are only now being realized in weaving of 800 to 1000 picks per minute for complex fabric structures have been around for many years in warp knitting, which now talks in terms of 2000 to 3000 courses per minute even in the more complex pile structures. With this sort of fabric production, it is important to carefully select raw materials for suitability, to optimize yarn quality to minimize down time and also to carefully consider other possible causes of lost production such as down time lost when changing coloured yarns on short runs.

It is factors such as these which have tended to influence the type of products which are developed and the designing of downstream activities to maximize the production potential, which is why fabric dyeing and finishing have become an essential part of warp-knit fabric production, and also why colour knitting does not feature widely. This contrasts with weaving technology where colour weaving forms probably the major part of the sector devoted to automotive fabrics.

The development of fabrics for warp knitting, therefore, has become an integral combination of yarn development to ensure aesthetic values are considered along with production viability, and of dyeing and finishing treatments. It is almost impossible to develop each in isolation when considering new products particularly for automotive end uses.

Both filament and staple-spun yarns are used but filament takes a very large share, with most of that being in either flat-filament or false-twist texturized products. Air texturizing figures only as a minor part of the business. 78 dtx, 167 dtx through to 200/300 dtx yarns are used. Different texturizing methods and also the mixing of different dye polymers such as disperse and cationic dyeable polyester are all ways of introducing subtle variations into the product.

3.3.4 Finishing

The finishing techniques are complex and jealously guarded by individual manufacturers but generally consist of piece dyeing, brushing, raising, cropping, stentering in various combinations and to different levels and, as previously mentioned, are closely related to the yarn and fabric structure in the realization of the final result.

A possible process for a typical two-bar 28-gauge loop-raised 100% filament polyester structure which could be used for automotive seating would be to knit at around double the required finished width and follow a knit–brush–pre-set–jet dye–stenter process route with the possibility of several passes through the brushing process to achieve the desired result. Pre-setting prior to dyeing would be necessary to avoid dramatic changes in fabric geometry during the dyeing process, so if dyeing is done at say 130–140 °C the pre-set would have to be higher than this at maybe 175 to 185 °C.

In the case of DNBR fabrics the addition of a slitting process carried out on a specialized slitting machine is an essential part of the finishing process together with greater attention at cropping stages.

Tricot-type structures have been developed with yarns traversing the surface to create relatively long floats, which are subsequently dyed and brushed heavily to produce a raised structure in which the individual yarns and filaments are brushed up but not broken to any significant degree creating a surface of raised loops, described, not surprisingly, as 'loop-raised' structures. These have enjoyed great success due to their competitive cost, pleasing handle and ease of engineering into the final product; properties which can all be influenced by careful attention to specifications at the foam-laminating stage.

One stage further than the loop-raised structure is to create an even denser ground cloth and subject to many very heavy raising procedures.

This has the effect of greatly consolidating the structure with great width reductions but creates a surface structure with the filaments broken and which is extremely dense and has all the attributes of a pile fabric. It is known as a 'full rip' structure which refers to the technique of fully ripping the individual filaments of the surface yarns. It is a highly specialized finishing technique but has been used extensively for automotive materials particularly in Japan.

The availability of plain-warp knitted structures which can be piece dyed, finished and raised to consistent shades and good quality at reasonable cost have created a market for seat backs and side bolster fabric which are embellished with seat centres, and door panels created from other more suitable fabric patterning technologies such as weft knitting or jacquard weaving. This has proved and is still proving to be an enduring combination in the production of automotive interior textiles.

3.3.5 Fabric characteristics

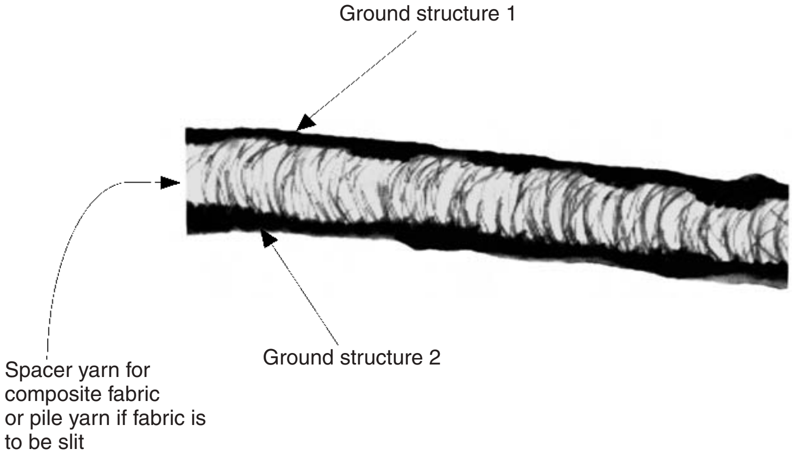
The extremely clever technology available to the warp knitter, particularly Raschel production, enables them to closely reproduce other types of fabric such as flat-wovens, double-plush and weft-knit pile cloths, while at the same time creating unique products such as loop-raised Tricot and full-rip cloths. The restrictions placed upon the structures due to the requirements of the automotive industry has meant that a lot of the potential of the technology has been difficult to realize especially with regard to the surface patterning and so developments have taken more of a technical rather than an aesthetic or highly visual route.

This has in fact led to the development of very interesting structures illustrated by a range of cloths known as 'Spacer Fabrics' originating from the double needle bar technology. DNBR fabrics have been developed in which the centre pile yarn is a monofilament nylon, creating a thick double structure with the monofilament at right angles to the top and bottom ground fabrics.

If this double structure is left unslit it can be used as a replacement for foam. It is known as a 'spacer fabric' – although it has never been possible to reproduce the quick recovery from deformation or crushing which is displayed by foam-backed products (see Chapter 6 for further reference).

It also has to be attached to the back of the face fabric by some form of adhesive lamination rather than the cheaper flame lamination process used for attaching foam to face fabric.

Face fabrics themselves have in fact been produced using the spacer technique, with the design effect obtained by ink-jet printing this is an ingenious way of making use of an inherent structural characteristic to create an aesthetic effect. A cross-sectional view of such a fabric is illustrated in Fig. 3.29.



3.29 Cross-section of fabric produced by double needle bar technique prior to slitting.

3.4 Fabric structures – weft knitted

Weft-knitted fabrics use the same principle as warp knits in the use of interlocking loops of yarn to form the textile structure. However, unlike warp knits where the loops are formed in a vertical direction with each warp thread creating a vertical row of loops (wales), weft knits are produced by a series of horizontal loops (courses) and they can be created either on a flat-bed machine or on a circular machine in which the needles are arranged around a cylinder and are raised and lowered by cams to create the stitches as the cylinder revolves. This produces a tube of fabric which is folded flat and rolled up as part of the take down process on the machine. It has then to be slit to open out into a flat fabric.

This slitting can, on the more recent machines, be carried out as part of the knitting process but due to the extra dimensions involved, takes up valuable space around each machine and is frequently done as a separate operation. Weft-knitted fabrics exhibit what is known as 'spirality', which is a tendency for the vertical wales of the structure to spiral around the vertical axis of the tube of knitted fabric, and it is caused mainly by the use of yarn with twist which tries to deform or untwist in the same direction. This is complicated by the inherent spiral of the structure in which the courses are inserted in a natural coil. This complicates the slitting process and demands special machinery to ensure the exact location of the knife as the fabric is cut.

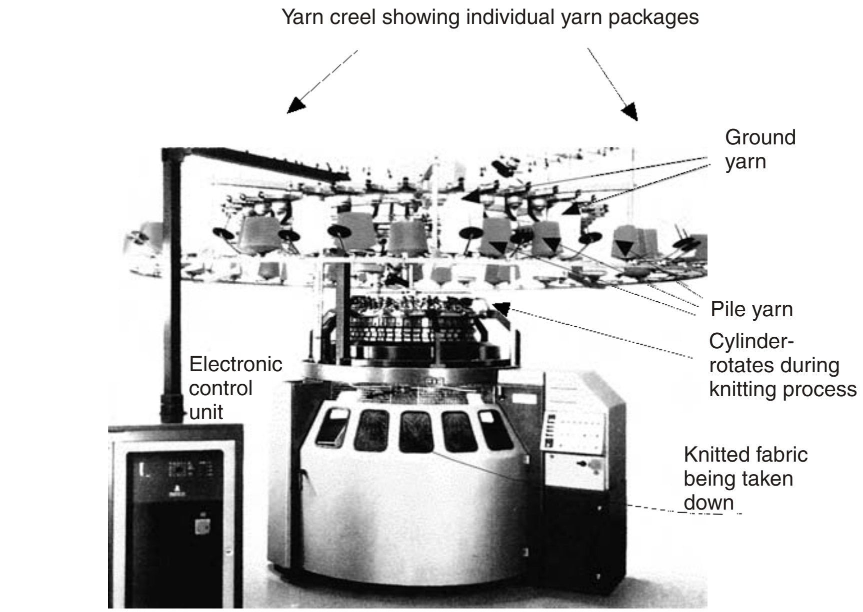
Although the concept of circular knitting has been around for almost 200 years the advent of circular-weft knitted structures into volume production for automotive seating is, compared with wovens and warp knits, a relatively recent development and one which has progressed faster in the European manufacturing sector than either Japan or USA. The exact reasons for this are debatable but among the more significant ones must be:

1 The rapid development of jacquard patterning machines for the production of pile structures at a time when jacquard patterns had been pioneered via the flat-woven route and found a definite niche in the market.
2 The ease with which designs and colours could be changed during the critical development phase coincided with an increasing market requirement to differentiate product by surface design on an increasingly short time scale.
3 The stretchability of the structure enabling complex shapes to be easily designed for.

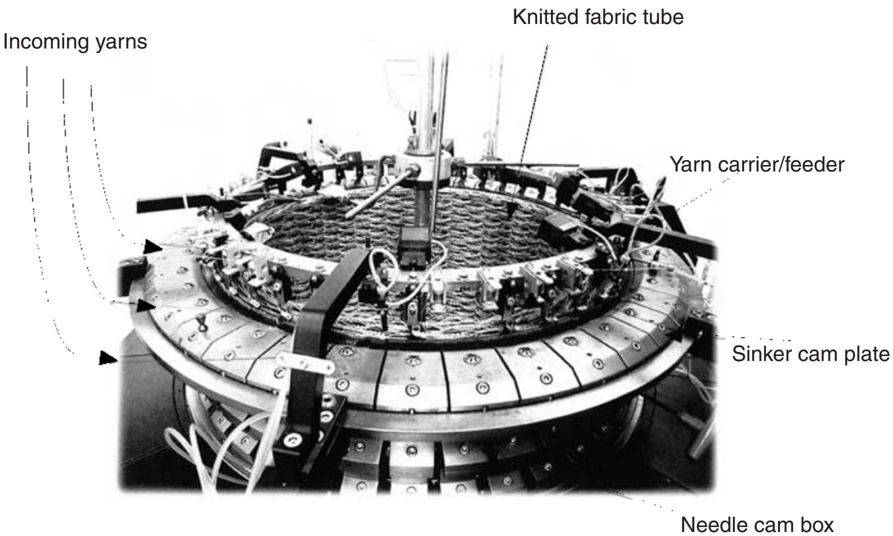
One company that has been active in the development of circular knitting machines to service this growing market in Europe and the rest of the world is Mayer & Cie, Albstadt, Germany, and the technique they have employed is to develop a single jersey machine with electronically controlled individual needle selection featuring ground and plush or pile threads. Each ground thread has several pile threads working in the same row and they are individually controlled by needles and a hold-down sinker, which tensions the ground yarn, and a plush sinker, which holds and controls the pile yarn and also determines the size of the loop, and therefore, the ultimate pile depth. When a needle is selected, a pile thread is pulled over the plush sinker and interlaces with the ground structure to form a loop. Where no needle is selected the pile thread floats over the loops of those that have been selected. The ground threads work to form the ground structure and since each has pile loops formed within the same feeder assembly a high density of pile and good definition of jacquard pattern results.

Figure 3.30 is a front view of the Mayer MCPE Jacquard circular knitting machine showing yarn creels and control panel.

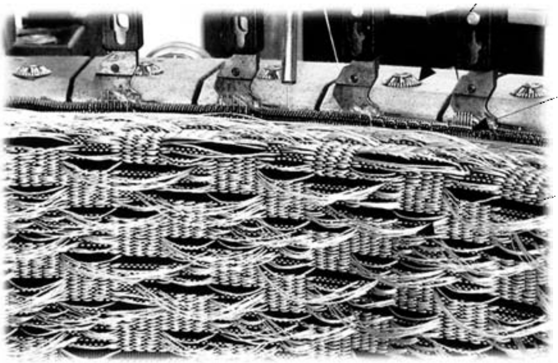
The top view of the machine is illustrated at Fig. 3.31 showing the cylinder needles and yarn feeds with a close-up of the knitted structure shown in Fig. 3.32. Here, the needle formation of the pile loops and the long floats of the pile yarn over the surface of the structure can be clearly seen. Figure 3.33 shows a diagram of the cylinder with the spaces or 'tricks' cut in to hold the needles and also the sinker arrangement to create the pile loops. The pile loops are controlled by the use of sinkers and where a needle has selected a thread the loop is formed by pulling the thread around the sinker which controls the height of the loop, and eventually of course the depth of the pile. The activity of thread and sinker selection is performed electronically according to the pre-programmed design and by linking this to



3.30 Mayer MCPE Circular jacquard knitting machine. (Reproduced by kind permission of Mayer & Cie Rundstrickmaschinen GmbH. Albstadt, Germany.)



3.31 Mayer MCPE Jacquard sinker circular knitting machine for the production of figured circular-knitted pile cloths for automotive trim. Illustration shows top view looking down the cylinder. (Reproduced by kind permission of Mayer & Cie Rundstrickmaschinen GmbH. Albstadt, Germany.)



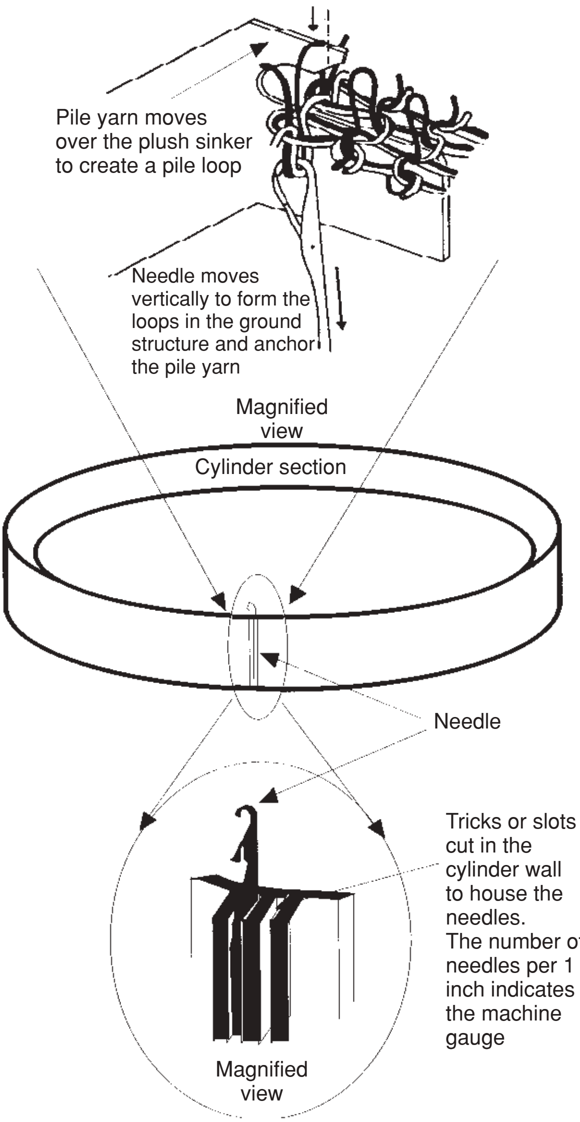
3.32 Close-up of jacquard circular-knitted fabric clearly showing the yarn floating over the surface where not required for the design. (Reproduced by kind permission of Mayer & Cie Rundstrickmaschinen GmbH. Albstadt, Germany.)

the various colours of pile threads. Intricate multi-coloured designs can be produced at high pile densities and, since all the threads in the fabric are individually controlled, patterns which repeat across the full width of the fabric are possible, although for aesthetic reasons this feature is not used to any great extent, except maybe in the production of special graphic images or logos which are required to extend across the full width of the seats in the car.

3.4.1 Machine gauge and diameter

The cylinder of a circular knitting machine has to be manufactured at a specific diameter with a number of spaces engineered for the needles so the gauge and capability of the machine is set when the cylinder is made and the machine is built around this. Once these parameters are decided they are difficult and expensive to change.

The diameter of the machine is critical to the final width of the fabric based on fabric contraction figures once it comes off the machine and goes through the finishing processes. The figures can vary according to yarn type and stentered widths, which in turn will affect the amount of residual shrinkage and stretch in the final fabric, so it can be appreciated that determining the correct diameter and gauge of machine is a complex process. Hence the fact that certain standards have emerged with regard to these parameters.



3.33 Diagram of the needle and sinker arrangement within the cylinder.

This contrasts with woven cloths where gauge (ends per inch) and fabric width are relatively easily changed without any machine modifications and indeed form part of the fabric development process. Two common diameters are 26 and 30 inches and common gauges would be 18, 20 and 22 needles per inch, although many others have been produced. By calculation 26 and 30 inch machines would give a circumference available for knitting of approx 81 and 94 inches and if these figures are then multiplied by the gauge (needles per inch) they would indicate the total number of needles in the machine. It is not that simple however, and such a calculation would only give a very approximate idea since there are other variables at work and each manufacturer would state the number of needles in the machine of any specific diameter. Mayer quote a 26 inch 20-gauge machine at 1612 needles and if this figure is divided by the gauge an idea of the exact knitted width is obtained. Yarn, knitting tensions, structures, stitch length and downstream finishing operations all affect the final finished width of the fabric.

3.4.2 Design, yarn and fabric development

The density and width of circular-knitted structures are determined by the following main parameters: machine gauge expressed as needles per imperial inch in the cylinder; knitted courses per imperial inch; pile and ground yarn counts; finishing processes.

In circular pile fabrics the depth of pile also gives the impression of contributing to density.

Due to the high cost of changing the machine parameters of gauge and diameter, once the machine has been decided upon, the major part of circular-knit fabric development, apart from design and colour, centres around yarn development and finishing technique.

Where a coloured tuft is required in the design a loop is formed of that particular yarn at the knitting stage, where no tuft is required the pile yarn floats over the top of the structure.

When the cloth is subsequently cropped the ends of the loops are cut to form tufts and the floats are cut away completely and contribute to the high cropping waste. It is the formation of these tufts which, by combination of colour and yarn, form the surface design effect.

There are two main rules to bear in mind when considering yarns selection: ground yarns have a large influence upon fabric stretch, strength and density; and pile yarns have a large influence upon design, colour, abrasion and handle.

From a development point of view, therefore, ground yarns should be relatively cheap and strong whereas pile yarns should be soft to handle, easily coloured, with filaments which burst easily to give good pile density on the surface. They can also be developed to have variable lustre to create optical differences and maybe different shrinkage potentials to produce dual-height surface pile effects.

Other effects such as twists of different components or blending of predyed filaments to produce melange effects on the surface are all possible.

It is worth noting that whereas woven structures utilize air-textured yarns due to their high resistance to abrasion along the yarn axis the use of these yarns in pile fabrics where they form the pile must be made with caution since the locked intermingling points of the filaments can show up as disturbances on the pile surface after cropping and are totally uncontrollable. This is one of the reasons why false-twist textured yarns are preferred as pile.

Although polyester is used in the production of weft-knit pile structures it is far from an ideal fibre for pile due to the brittleness and poor resistance to deformation showing up as pile crush in use (this is one of the reasons polyester pile carpets are not often seen). Nylon would be a far better fibre to use in almost all respects except that of lightfastness and long-term UV degradation, the key properties which have ensured the overall supremacy of polyester in most automotive fabric structures.

The yarn features and properties are very important to the ultimate effect of the fabric and this is where a lot of time is spent, but due to the delicate nature of the knitting process the tolerances of yarn counts and profiles are quite tight and good quality yarn is essential to efficient knitting. Ground yarn counts would mainly be in the 70 to 200 dtx range whereas pile yarns would probably start at 167 dtx through to 300 dtx dependent upon the design effect envisaged and test performance which the cloth would be required to pass. Fine slub yarns are about the most extreme examples of the variable surface profiles which could be accommodated, with the more extreme yarn characteristics such as boucle, loops, knops etc. excluded due to their poor performance through the machine yarn paths and loop-forming process.

3.4.3 Finishing

The correct finishing of weft-knit pile cloths is an absolutely key process to the production of acceptable fabric and can be regarded almost as more important than the knitting process in the effect it can have upon the ultimate fabric.

The main processes involved vary according to the expertise developed by individual manufacturers. Very often the details are a closely guarded secret but all producers have to slit the fabric to make a single sheet, crop away the tips of the loops and the unwanted pile yarn floats, and have some technique for bursting the pile filaments which could involve both washing and brushing the pile surface, possibly recropping to ensure an absolutely even surface, and finally stentering to width to arrive at the final fabric prior to lamination etc. The finishing plant required to make a success of this part of the production process is both expensive in capital cost as well as space and could involve four or more different types of machine, for example: slitter, cropper, wash range, stenter.

The finishing ranges take up a lot of floor space and could involve separate machines to carry out the processes of slit – relax – repeated shear (i.e. cropping the loops) – heat set and stenter. The machinery could be arranged in line or in some form which would reduce any requirement to batch the fabric during the process, since until finishing is completed the fabric surface is easily disturbed and vulnerable to marking.

It can be seen that, due to the production technique where unwanted pile yarn floats over the surface and is disposed of at the cropping stage, the yarn wastage in weft-knitted pile cloths is very high. It is also very design sensitive. The more colours that are used and remain unused for large parts of the design the greater the waste and the slower the knitting process, and it may be necessary to knit a cloth at 350 g/m^2 to arrive at a finished weight of say 250 g/m^2, a yarn waste of around 28%. Even though this may be an extreme example the figures usually do not fall lower than 20/22%, compared with zero on woven cloths and maybe 3% cropping waste on woven velvets. Although techniques of incorporating unwanted pile yarn into the ground structure have been developed they rarely come without some deterioration in pile density or the need to use heavier pile yarns to improve pile coverage, thereby negating the theoretical savings. In this environment, it is arguably better to crop the yarn away and create a lighter resultant fabric in keeping with most OEM policies of reducing vehicle weight than to keep the yarn there unseen but adding to the weight.

The resultant fabric then has to meet the demanding requirements of passing the physical testing schedules.

3.4.4 Production rates

The production rate is dependent upon the courses per cm or inch, the machine speed in revolutions per minute, the number of yarn feeders, the number of feeders per row (four for a three-colour jacquard, three for a two colour) and the machine efficiency.

The calculation for metres per hour is:

$$\frac{\text{RPM} \times 60 \times \text{Number of feeders}}{\text{Feeders per row} \times \text{courses per cm} \times 100}.$$

For a three-colour design at 16 courses per cm on a 42 feed machine running at 20 revs per minute at 90% efficiency (= 18RPM working speed) the production rate would be as follows:

$$\frac{18 \times 60 \times 42}{4 \times 16 \times 100} = 7.09\,\text{m per hour}$$

3.4.5 Fabric characteristics

Circular-knitted structures due to their method of manufacture display high stretch and relatively low resistance to deformation in all directions. This feature has proved to be extremely useful to automotive trim engineers when designing and manufacturing seats and door panels with high three-dimensional shapes. However, too much stretch in use can result in other problems particularly if the stretch is not fully recoverable, and ways of controlling the stretch have been developed by modifying ground structures and also by carefully controlling the lamination process particularly trilamination where foam and scrim are applied to the back of the fabric.

By carefully selecting the scrim and foam, various combinations of stretch can be engineered into the ultimate trilaminate to prevent 'bagging' or deformation during use. This characteristic of weft-knitted fabrics when combined with the endless possibilities with regard to surface pattern, design and general aesthetic properties of appearance and handle, have contributed to carve a significant niche for these structures in automotive interiors.

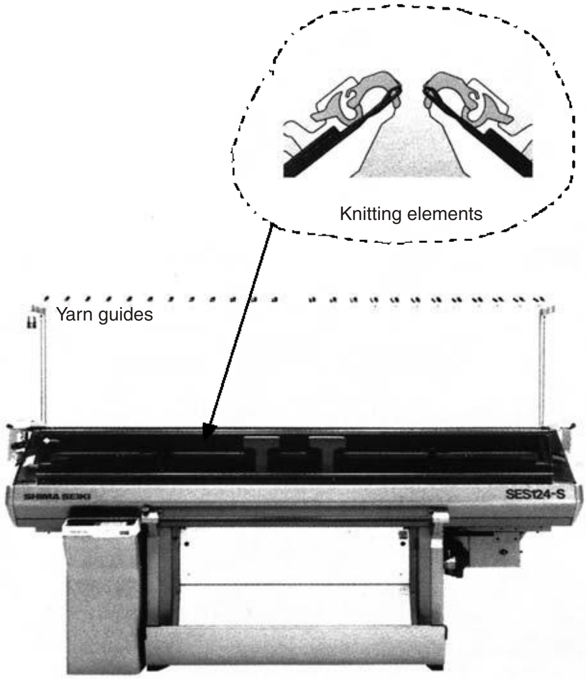
3.5 Fabric structures – flat-bed knitting

This is a little-used technology in automotive trim despite the fact that in jacquard form it can rival flat woven in terms of surface design and yarn exploitation and the ability to realize designers' creative thoughts. The technology has the ability to produce surface patterns which can coincide with 3D specially knitted fabric shapes.

The original concept was developed in the 1960s, aimed mainly at the garment trade and owes a lot to the presser-foot technology which Frank Robinson of Courtaulds played a major part in developing and refining.

The fabric is produced on the flat-bed knitting machine used for fully fashioned garments. Two rows of needles are inclined at an angle to each other forming an upturned 'V' hence the term 'V' bed which is also used to describe such machines that are manufactured by, among others, Dubied, Shima Seiki, Stoll. Figure 3.34 shows such a machine manufactured by Shima Seiki which could be used for knitting automotive-type trim fabrics provided suitable yarns were used to meet the technical requirements.

Developments by Courtaulds in conjunction with the General Motors Corporation in America in the late 1980s and early 1990s resulted in the ability to knit jacquard patterns into three-dimensional shapes, which could coincide with the shaped requirements of the seat and door panel manufacturer, opening up the possibility of knitting fully shaped seat covers with hook and tie down points actually knitted into the cloth thus



3.34 Shima Seiki SES124-S Flat-bed knitting machine. (Reproduced by kind permission of Shima Seiki Europe Ltd.)

demanding a different approach towards the manufacture of the automobile seat.

It has found its way into vehicle interior trim and also onto office furniture and is in current production on car models. Despite the enormous potential it offers in terms of design and production cost savings related to the production of automotive seats, the technology has not yet made the inroads first expected into the automobile market.

For further reading on the subject please refer to Chapter 6.

3.6. Non-woven and compound fabrics

3.6.1 Introduction

'Non-woven' is a term used to describe a type of material made from textile fibres which are not produced on conventional looms or knitting machines but are held together by some other mechanical, chemical or thermal bonding method. They combine features from the textile, paper and plastic industries and an early description was 'web textiles' because this term reflects the essential nature of many of these products. A definition of non-woven is provided by ISO 9092:1988 which details the fibrous content and other conditions. However, felts, needled fabrics, tufted and stitch-bonded materials are usually grouped under this general heading for convenience, even though they may not strictly be described by the definition – hence the title of this section.

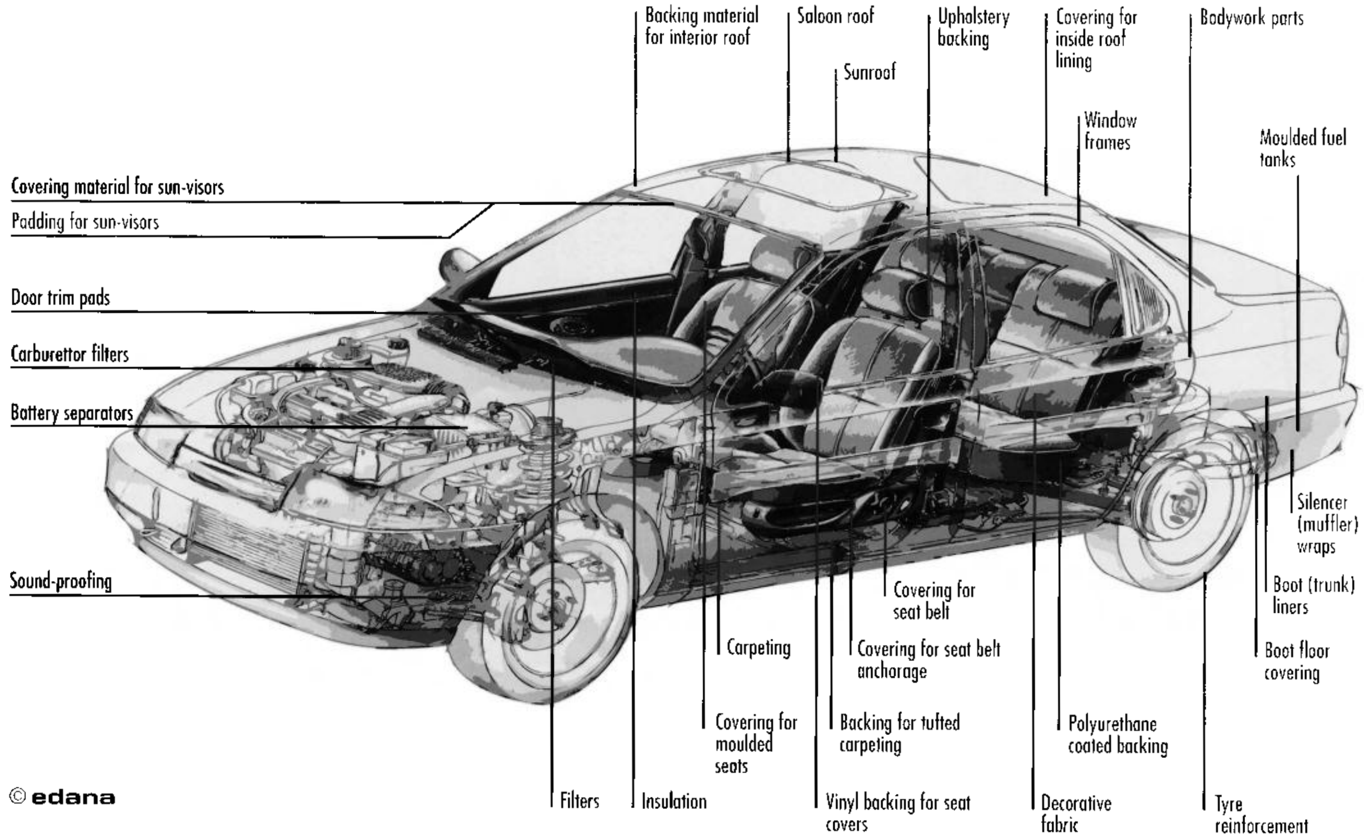
They are made from all types of fibre, natural, regenerated man-made or synthetic or from fibre blends. One of their most significant features is their speed of manufacture, which is usually much faster than all other forms of fabric production, for example, spunbonding can be 2000 times faster than weaving. Non-wovens are therefore very economical but also very versatile materials, which offer the opportunity to blend different fibres or fibre types with different binders in a variety of different physical forms, to produce a wide range of different properties. They thus have many applications; the main automotive uses are shown in Fig. 3.35. A summary of methods of manufacture appears in Fig. 3.36.

All non-wovens are manufactured by two general steps, which sometimes can even be combined into one. The first is actual web formation, and the second is some method of bonding the web fibres together. Sometimes, but not always a finishing process is required to provide the specific needs of a particular end use, in a similar way to woven or knitted fabrics.

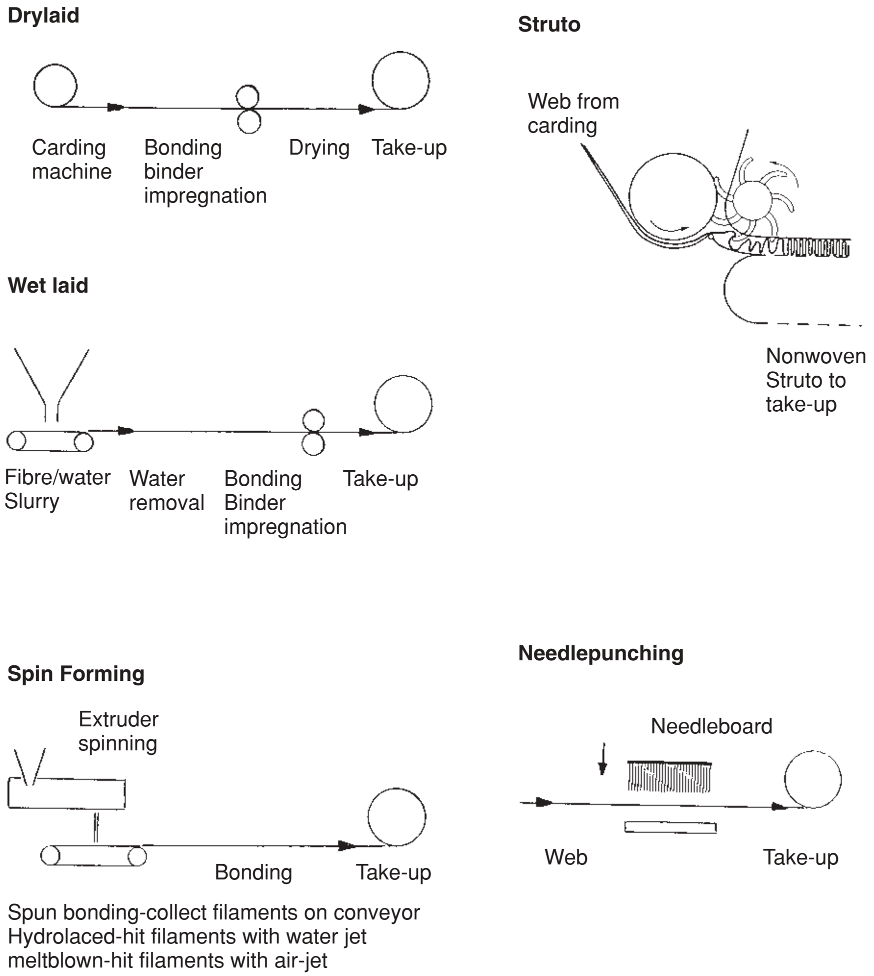
3.6.2 Web formation

Webs can be formed by drylaying staple fibres directly from a carding machine on to a conveyor which produces fibres parallel laid in the machine direction. This produces webs with good tensile strength and low elongation but poor tear strength in the machine direction. A cross-laid web would produce the same properties but across the width. By a process known as 'cross-lapping', in which a parallel-laid web, is laid across another parallel-laid web at an angle, it is possible to obtain a composite web with fibres laid in more than one direction. The properties of this web will depend on the degree of randomness achieved by the cross-lapping process. An alternative dry-laid method is used for shorter fibres; the short fibres are fed into an air stream which deposits them on to a moving belt or a perforated drum to produce a randomly oriented web. This second method yields a softer web of lower density and provides more scope for blending of fibres. Airlaid webs can sometimes be identified by the absence of a layered structure.

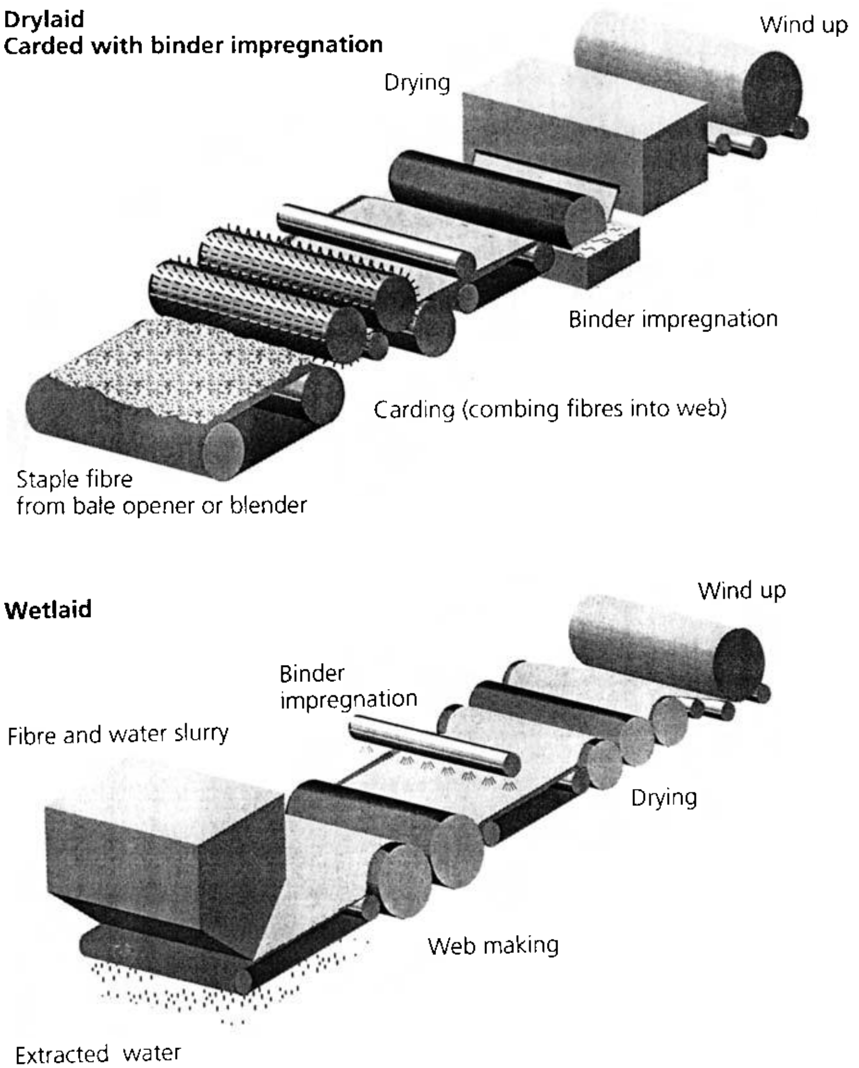
A related method to dry laying is wet laying in which the fibres are deposited on to a wire screen from a slurry with water to form the web. This web is consolidated by pressing between rollers and is then dried. The wet laying process can be adjusted to produce a range of different fibre orientations from nearly random to nearly parallel and a variety of fibres and



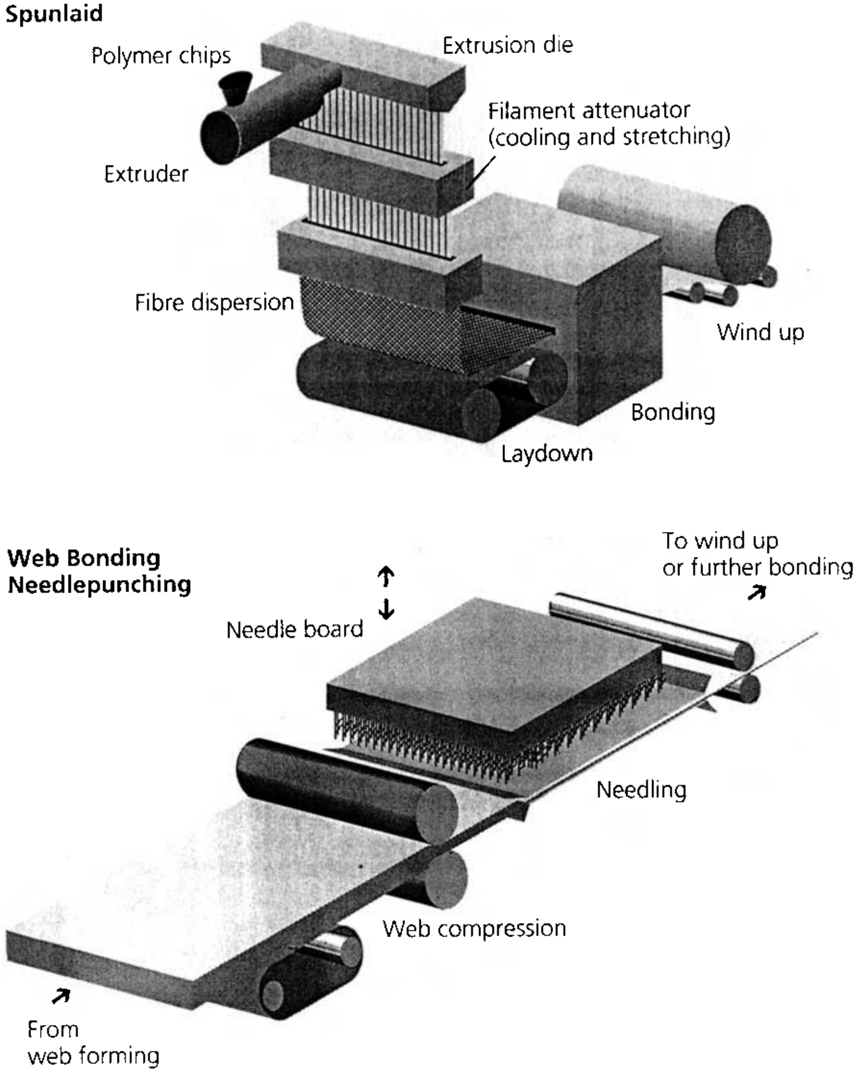
3.35 The 'Non-woven Car'. This shows some of the very many applications of non-woven fabrics in automobile production. Copyright held by EDANA and reproduced with kind permission.



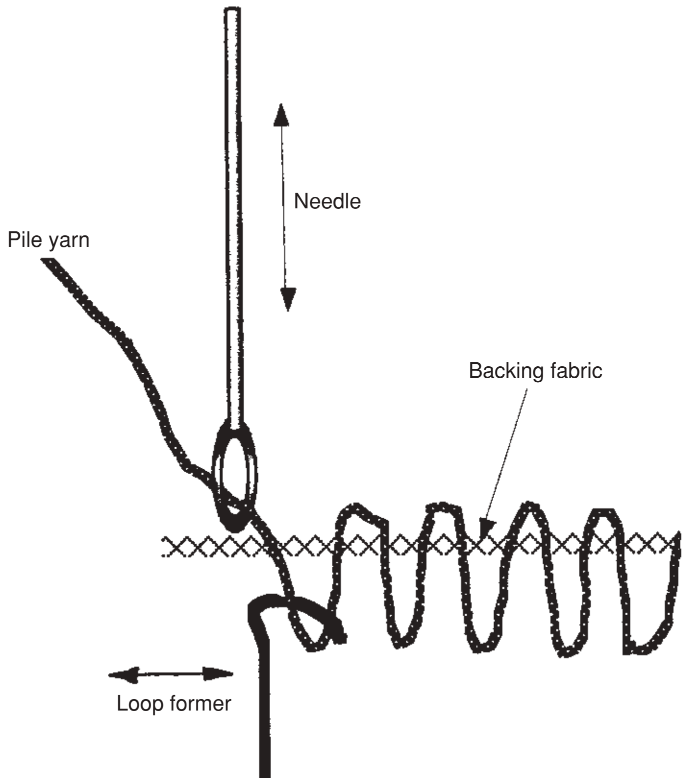
3.36 Non-woven fabric production. Schematic summary of some of the techniques used. Graphics reproduced with kind permission of EDANA.


Drylaid
Carded with binder impregnation
Wind up
Drying
Binder impregnation
Carding (combing fibres into web)
Staple fibre
from bale opener or blender
Wetlaid
Wind up
Binder
impregnation
Fibre and water slurry
Drying
Web making
Extracted water

3.36 (cont.)


Spunlaid
Polymer chips
Extrusion die
Filament attenuator
(cooling and stretching)
Extruder
Fibre dispersion
Wind up
Bonding
Laydown
Web Bonding
Needlepunching
To wind up
or further bonding
Needle board
Needling
Web compression
From
web forming

3.36 (cont.)



Tufting

As the needle is lowered through the backing fabric the loop former moves forward and the loop is formed around it. When the needle is raised, the former withdraws, ready for the next depression of the needle. For cut piles, a knife advances to the loop, as the needle is depressed and the former begins to advance at the start of another cycle.

3.36 (cont.)

fibre lengths can be used. Both dry- and wet-laid webs require bonding together to produce the actual fabric. A third method of web formation – spun techniques are carried out immediately after filament extrusion – see below.

3.6.3 Bonding

There are three general ways of bonding webs together; chemical methods – using adhesive binders, thermal hot-melt methods or some form of mechanical treatment such as needling or stitching. The method chosen depends on the actual properties required in the end-product, the price structure and the equipment available. Chemical bonding is usually carried out by treating the web with a binder applied by aqueous impregnation, foam processing, coating, printing, powder adhesive scattering or by a solvent- or water-based spraying method. The binders are selected depending on the end-use, durability requirements, cost or downstream processing considerations. All the common chemical types are used, acrylic, acrylic copolymer, SBR, vinyl acetate ethylene copolymer etc., and application of the binder is followed by drying, and curing, if the resin is a cross-linking type. Thermal bonding makes use of the thermoplastic nature of the web fibre itself, or an external hot-melt adhesive is sometimes introduced. Quite often a lower melting point bi-component fibre is made and co-spun and this bi-component fibre acts as the binder. Bonding is achieved using a calender process, by controlled hot air, infra-red heaters or by high frequency or ultrasonic welding.

Needlepunching is extensively used as a means of mechanically bonding webs together. Barbed needles are inserted into the web which force some of the fibres downward causing them to be entangled with fibres in lower layers of the web. Further entanglement occurs on the upward movement of the needles. A wide variety of properties can be obtained using specially designed needles and by joining together webs of different characteristics. Non-woven fabrics with the characteristics of both weaving and knitting and the appearance and properties of fleece and velours can be produced by needlepunching.

Webs can also be consolidated by stitching both with a thread or without a thread. In the latter case the needles are designed to pull small loops of fibre out of the web and these are then used as the stitch material holding the web together. Stitch bonded fabrics have considerably stronger tensile strength in the direction of stitching than across the width.

Hydro-entanglement by the use of high-pressure jets of water is another means of mechanically bonding webs together and a wide range of novel effects can be obtained.

3.6.4 Extrusion or spun methods

Webs can be produced directly from the fibre extrusion spinning process.[1] As the continuous filaments are extruded, they are cooled and deposited on to a conveyor to produce a uniform web. Some bonding together will take place as the still hot filaments touch each other, but this cannot be relied upon as a bonding manufacturing process and secondary components are sometimes co-extruded to provide better bonding capability in a subsequent separate process. The spinnerette may be rotated to deposit filaments in different patterns and jets of air can be used to cause filament tangling to produce different web assemblies. The web then moves on to bonding via a hot melt or chemical method to produce the spunbonded fabric.

So called hydro-entangled fabrics are made by hitting the filaments after extrusion with high velocity jets of water, causing entanglement and this holds them together mechanically. These fabrics are lightweight and very soft and flexible.

Melt-blown fabrics are made by breaking the freshly extruded filaments into short lengths with a high-velocity air jet. The short fibres are entangled and deposited on to a conveyor to form the web, which is consolidated by thermal bonding.

3.6.5 Stitch-bonded fabrics

There is a whole family of fabrics made on machines, which can be described as stitchbonding or sewing–knitting machines.[2,3] An array of yarns or the base fibre web is held together by stitching with a thread in different ways to produce fabrics with the appearance of a raised finish. The rate of production is many times faster than both knitting or weaving – up to 250 m per hour for the simpler fabrics. The first material of this type to be produced commercially was the Malimo fabric in which a set of warp-direction yarns and a set of weft-direction yarns are sewn together by needles and threads. A modification of this process starts with only the weft yarns; during the process the stitching threads themselves become the warp.

Maliwatt fabrics are made by stitching a web with a sewing yarn to produce a fabric with a fleece appearance, which can be made quite thick and heavy, and some can even resemble needlepunched fabrics. Malipol fabrics have a pile made by stitching pile loops onto a backing fabric to give a material which resembles terry and imitation fur. The Malivlies process does not start with an actual sewing thread but the thread is formed by the production of loops of fibre from the web itself, with which the fabric is stitched together. The resultant fabric looks like a standard knitted fabric, which has good mechanical properties. In another material from the same family, the Voltex process, fibres from the backing material are intermeshed and stitch-bonded to form a voluminous pile fabric. Variations of these fabrics, especially those with a fleece or pile have been evaluated as polyurethane foam replacements. An example is Kunit, a voluminous material produced from a length orientated fleece by stitching the fibre structure into pile loops. A development based on Kunit is Multinit where Kunit itself is used as the starting material and the top of the loops are stitched together to form a fabric with two plain surfaces with a voluminous fleece in between the two.

3.6.6 Felts

This term arises from the ability of wool to compact and join together because of the scale structure of wool fibres. However if other fibres are mixed with wool and put through a felting process, the wool fibres will lock together and also hold the other fibres.

3.6.7 Tufting and needlepunching

Tufting is a relatively new technique commercialized in the 1950s for making upholstery, blankets and domestic carpets. It is now used for automotive carpets especially in the United States. The process is carried out by inserting loops of fibre into a backing carrier fabric in such a way that the ends are perpendicular to the carrier to form a pile of loops which can be cut or left uncut. The tufts are held in place by the yarn's own bulk and untwisting and by coating with latex or hot-melt binder. Although tufting is many times faster than weaving and thus more economical, costs are such in the automotive industry that only upmarket cars have a tufted carpet. Needlepunching is more economical than even tufting; production speeds are of the order of 3 to 4 m/min for tufting but over 20 m/min for needlepunching. Consequently needlepunching is gradually expanding at the expense of tufting, especially since developments in recent years have made certain needlepuched carpets as attractive, some say more attractive, than tufted ones. This has been made possible only relatively recently by the development of the random velour machine. An advanced model is the DI-LOUR machine by DILO AG which allows a much higher fibre content in the pile of the fabric than has been achievable before which improves all-round properties including abrasion resistance. Tufting puts 90% of the total fibre content in the pile, which produces the high abrasion resistance. The best achievable with a non-woven was 60% before the DI-LOUR development.[4] In addition improvements in Fehrer needle looms allow carpets to cover sharp contours without exposing the backing material. There has been a recent surge in use of needlepunched fabrics for carpets, especially in Japanese cars. Needlepunched products are also being used more and more for headliners, boot liners, parcel trays, seat backs and the lower parts of door panels; the coarsest yarns are used in carpets, the finer ones in the more decorative articles.

3.6.8 Finishing

The final processes produce the properties specifically required by the final customer and non-wovens can be dyed, printed, embossed, raised or flocked when used as face covering material. They can be made flame retardant, coated or laminated to other materials or used as a base for synthetic suede or leather.

3.6.9 Non-wovens in the car

The numerous applications of non-wovens in cars can be classified as functional (sometimes referred to as 'hidden') or aesthetic but there is a third category – that of substitutes for other materials. Non-wovens can be made in a wide range of densities and different forms, which offer sound insulation, heat insulation and soft-touch properties.[5–16]

Much development work has been directed towards the use of non-wovens for sound and vibration insulation applications and the versatility allows densities and other fibre parameters to be optimized to produce the best performance. At the present time, efforts are being made to exploit the properties of non-wovens to replace not only polyurethane foam but also fibreglass, and the area of composite technology presents many exciting possibilities in replacing metal. Recently there seems to be renewed interest in non-wovens produced from natural fibres, which are not based on oil or coal and are therefore a renewable resource. New possibilities are presented by the area of safety, which is driven by legislation in many countries of the world.

More details of the major uses of non-wovens are presented later under the appropriate product headings. The use of non-wovens is increasing because of their cost-to-performance ratio as substitutes for more expensive materials and their versatility. In addition they are easy to work with, retain their shape when moulded and are easily recycled, polypropylene being regarded as being easier to recycle than polyester. Most automotive non-wovens are either polyester or polypropylene and each has its own advantages and disadvantages. Polyester has a higher melting point, which allows it to be used in situations where the lower melting point of polypropylene would be a disadvantage. Higher moulding temperatures and therefore higher production rates are possible with polyester. Polypropylene is generally cheaper than polyester and, especially relevant to transportation applications, it has the advantage of being significantly lighter. As well as being used actually in the car, non-wovens are used extensively for car paint shop disposable wipes, for work area air filters and for protective clothing. Any materials used in paint shops must be completely lint free.

Non-woven development continues with improvements in appearance, methods of production and physical properties appearing all the time. One of the latest innovations is the 'Struto' method of vertical laying of the fibre web to produce more resilient bulk.[16,17] Manufacturers in their continuing efforts to reduce costs and to recycle interior components are now examining the possibilities presented by non-wovens more closely.

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4
Yarn and fabric processing

4.1 Introduction

Most car seat fabric is made from polyester fibre but there are still relatively small amounts of nylon, wool and acrylic used. Acrylic fibre is used in the roof of convertible cars because of its excellent resistance to weathering and UV degradation. Wool is, and will continue to be, used in luxury and up-market cars. The processing methods, machines and materials used for each fibre vary according to the fibre type and fabric construction. Colour lightfastness must be of a very high standard and the number of dyes available for each of the four fibre types, is relatively small compared to other applications such as domestic furniture. Automotive upholstery is fixed in place for the life of the car and cleaning in a washing machine is not possible. The only methods of cleaning are brushing, vacuuming and shampooing. This factor has contributed to restricting interior colours to generally dark shades, although this is now changing.

Fabric finishing is important, because if not carried out properly to give fabric with uniform properties, serious problems can arise in downstream processing as well as giving rise to complaints by the car buyer. An essential requirement is that the fabric has consistent stretch, dimensional stability as well as a good uniform appearance, because as will be seen, difficulties could arise in seat making. The synthetic fibres, polyester, nylon and acrylic are thermoplastic, which means that they will melt if heated to a sufficiently high temperature. Fabrics made from them will shrink readily with heat unless they have been heat set.

Yarns are normally lubricated at various stages of processing to reduce static electricity and to help improve the efficiency of winding, texturizing, warping and weaving. In addition, residual dyebath chemicals can still be present on the yarn. These lubricants and processing chemicals, loosely referred to as 'oil', are best scoured off before the fabric is dressed flat on the stenter. Scouring provides a number of benefits including reducing the phenomenon of fogging, which can be caused by the 'oils' vaporizing off under the action of hot sunlight and condensing on the car windscreen thus reducing visibility.

Very few actual fabric finishes are applied to automotive fabrics compared to say apparel materials. Some OEMs request a soil-release finish or an anti-static finish, but they have to be carefully chosen, for reasons which will become clear later. A back coating is sometimes applied to woven fabrics to improve abrasion resistance, and in some cases, to impart a measure of flame resistance. A coating to help lock in the pile is important for woven velvet fabrics.

After finishing, the fabric is laminated to polyurethane foam, and a scrim is laminated on to the back of the foam to produce a triple laminate. As already noted the scrim acts as a slide aid, but it also helps seam strength and seam fatigue. With knitted fabrics, the scrim helps control stretch and scrims of different construction and properties are required for different knitted-face fabrics. Flame lamination is widely used as the method of producing the triple laminate. This process is economical and produces a laminate with the required handle and drape, such as the ability to bend around concave and convex curves without 'cracking'. The lamination process can be accomplished with a single pass but it burns off a layer of polyurethane foam producing potentially toxic fumes which have to be treated before release to atmosphere. Several alternative lamination methods have been developed and proposed to replace it. This aspect is discussed later in this chapter and in Chapter 8.

The processing sequence for the production of both woven and knitted car seat fabrics can be summarized:

Parent yarn
texturize (if applicable)

yarn package dye	warp/beam	yarn package dye	yarn package dye
warp/beam	**warp knit**	wind on to cone	wind on to cone
weave	brush/crop	**weft knit**	**3D knit**
scour	stenter preset	shear	heat stabilise
stenter/finish	scour/dye	scour	fit to seat
foam laminate	stenter	stenter/finish	
cut/sew	brush	foam laminate	
fit to seat	stenter finish	cut/sew	
	foam laminate	fit to seat	
	cut/sew		
	fit to seat		

Sometimes it is necessary to vary the processing sequence and to add to it, for particular yarns or to optimize certain properties. Printing is carried out on prepared fabric; the significant advantage is that many of the constraints of weaving and knitting are absent, and the design decision, can be made closer to the launch date of the car. This enables the design to be right up-to-date, and there are also possible cost savings, because the new printed fabric may not have to be put through the full testing and acceptance procedure if a different print design is put on to an existing and already approved base fabric.

4.2 Dyeing and finishing

4.2.1 General principles of dyeing

Dyeing is a very complex operation; the following is a simplified account of the theory and principles, but deals only with processes relevant to automotive fabrics. Dyeing has been described as essentially putting material into a pot of water and stirring. In reality the water is either pumped through the material or the material is drawn through the water. Either way the objective is to provide good liquor circulation by stirring or agitation to obtain a level uniform dyeing. Heat is also applied to make the process go faster. For economic and commercial reasons, the dyeing must take place as fast as possible, using the least amount of water, but it must also be level, on shade, and make full use of the dyes. Dyes are expensive chemicals and so as much as possible should go on the yarn or fabric, and not remain in the water at the end of the dyeing process. Thus dyeing machines are designed to accomplish a quality dyeing quickly, using the minimum amount of water, but they must also preserve the properties, texture and other aesthetics of the substrate, i.e. the yarn or fabric. Economical use of water and full use of the dye also minimizes effluent problems as will be made clear in Chapter 8.

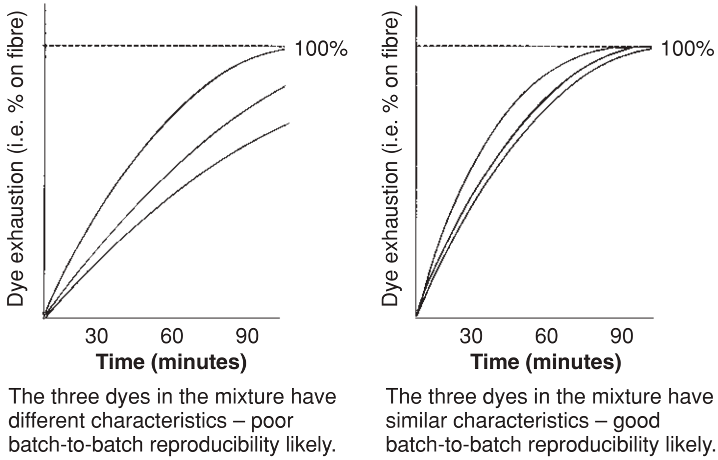
Dyes are organic molecules consisting in general of two parts; one part is synthesized to produce the colour, the other part is designed to have affinity for a particular fibre. Different fibres have different positions or sites on the polymer molecules, which attract particular classes of dye. Nylon and wool are dyed with acid (anionic) dyes, acrylic fibres are dyed with basic (cationic) dyes. Polyester with no specific chemical sites for dyes, is dyed with dyes called disperse dyes which occupy spaces within the polyester polymer network.

Fibres, especially synthetic fibres, are made up from long polymer chains which in some areas of the polymer network can be closely packed and relatively parallel to each other (called crystalline regions), or more tangled and more loosely packed areas (called amorphous regions). The amorphous regions are more accessible for dye penetration because they are more open. When heat is applied above the glass transition temperature (T_g), the polymer chains are able to move about more freely and to swell, to allow the entry of dye into the more crystalline regions in addition to the amorphous regions. Thus the higher the temperature, the faster the dye uptake and this factor is especially important for polyester fibres, which have no specific dye sites, nor any special affinity for dyes. This is the reason why polyester must be dyed at high temperatures, above the boiling point of water and in pressurized dyeing machines. It is possible to swell polyester using 'dye carriers' and dye at lower temperatures, but this is seldom done because the 'carriers' are environmentally unfriendly chemicals. The disperse dyes, once inside the polymer chain network are trapped, cannot escape easily and therefore have good fastness.

Dyes must go on the fibre quickly, but they must also go on uniformly to produce a level appearance. Rate of dyeing and levelness are controlled by temperature increase, and by the use of chemical dyeing auxiliaries. Polyester dyeing auxiliaries help to dissolve and disperse the dye uniformly in the water. In the case of acid dyes for nylon or wool, auxiliaries can control the rate of dyeing by forming temporary complexes with the dye, thus holding it off the fibre or by blocking the dye off the fibre by temporary occupying dye sites on the fibre.

At the molecular scale, dyeing takes place by three fundamental steps, dissolution of the dye in water, movement of the dye to the fibre and adsorption on to the fibre surface, and finally penetration and diffusion of the dye inside the polymer network. This last step is very important for dye-fastness. If the dyeing cycle is too short, or water circulation not effective, the dye will be concentrated on the outside of the fibre, and will be easily removed in a fastness test such as wet perspiration, rubbing or crocking. The lightfastness is also likely to be lower than expected. This condition is referred to as 'ring dyed'.

Shades are usually produced by mixtures of dyes and the trichromatic mixture of a red, blue and yellow dye is usually the most versatile. However, because each dye has its own special character and rate of dyeing, the best results are obtained by mixtures of dyes with similar characteristics, and which are compatible with each other. Incompatible dyes can block each other off, and mixtures of dyes with different dyeing rates can produce uneven dyeings, and batch-to-batch variation, see Fig. 4.1. The dye and dyeing auxiliary chemical makers, compete with each other by providing advice and technical service. They recommend dyes, recipes and dyeing methods suitable for the end use as well as those best suited for a particular dyeing method. Many dyes produced by different manufactures are identical chemically, and share the same Colour Index Number, (e.g. Acid Red 80), assigned by the Society of Dyers and Colourists (UK) and the American Association of Textile Chemists and Colorists. Several articles have appeared in the technical press specific to the dyeing and finishing of automotive textiles.[1–5]

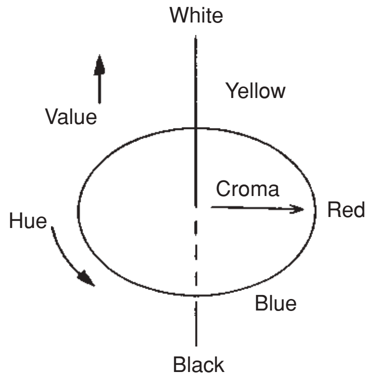


4.1 Dye mixture compatibility. Dyeing with dye mixtures, e.g. trichromatic mixtures. For batch to batch reproducibility, all the dyes in the mixture should have similar dyeing characteristics. Ideally, dyes in the same mixture should have similar dyeing rates and final exhaustion values for reproducible results. Dyers sometimes struggle to obtain this ideal with the small number of dyes available which have the high performance requirements necessary for automotive use.

4.2.2 Laboratory recipe preparation

Everyone working with colour should first be tested for colour-defective vision, using standard 'colour confusion' test patterns such as Ishihara. Any colour can be specified by the use of three quantities termed, hue, value and chroma. These qualities can be represented in a three-dimensional diagram, the 'colour solid', see Fig. 4.2. Hue refers to how it appears as red, blue, yellow, etc. Value, also termed saturation, is the white/black content, i.e. whether the colour is a strong or deep shade or a pastel shade. Croma expresses the 'grey' content or vividness or brightness. There is a fourth quantity termed 'metallic brilliance' in SAE J361, (recommended procedure for visual evaluation of vehicle interior and exterior automotive trim), which refers to the metallized or opalescent appearance, but this fourth quantity is more associated with plastics and metal than fabric. The Munsell Book of Colour contains a large number of standard colour samples arranged according to the colour solid. Any shade can be described by matching it to a standard sample in the book, which are specified using Munsell notation representing the hue, value and chroma.

Every colour can also be specified in numerical terms based on information obtained by an instrument known as the spectrophotometer, which measures the reflectance of light in each part of the spectrum. An



4.2 The Colour Solid. Hue refers to appearance, yellow, red, blue, etc. Value (saturation), is the 'white/black' content. Croma expresses the 'grey' content or 'brightness'

alternative instrument is the tristimulus colorimeter, which measures the reflectance for each of three colours. The information in both cases can be expressed as the 'chromaticity co-ordinates which represent the lightness/darkness (L), the redness/greeness (a), and the blueness/yellowness (b), as seen by a standard observer. This information is then fed into a colour computer, which has been programmed with a data bank of information of colours and shades obtainable by a range of dyestuffs both individually or in combination with each other. These dyestuffs will have been specially selected for automotive use on particular fibres. From the input information, the computer is able produce a dye recipe to give any shade on the specified fabric. This recipe and a suitable dyeing procedure can then be evaluated in the dye laboratory and if necessary, adjustments can be made to produce a closer matching. Matching of shades by computer techniques has been available for many years and is being continuously improved. It is possible mathematically to convert chromaticity co-ordinates to Munsell notation and vice versa.

The shade must be viewed under agreed lighting conditions, preferably using a standard source of illumination, see also colour approval, Chapter 5. This is especially important in automotives when not only the same fabric processed in different factories, but also leather, plastics and other materials all produced to the same colour may come together in the same car interior. If precautions are not taken they could all appear slightly different when viewed in different lighting conditions. This phenomenon is known as 'metamerism' and arises because the different shades or individual dyes in the shades, may have the same spectral absorption curves in daylight, but are different under say tungsten or some other artificial light. To avoid metamerism, careful dye selection is important; the individual spectral curves on each substrate should be the same at all wavelengths, and under lighting conditions specified by the customer. For this reason, use of a spectrophotometer is preferred to use of a tri-stimulus colorimeter.

In order to accurately reproduce the laboratory shade in bulk commercial dyeings, it is essential that the same dyeing method (rate of temperature rise and time), dyeing recipe, dyes, liquor-to-goods ratio, chemicals and even water are used in both the laboratory and the actual dyehouse. Extremely careful weighing and dispensing of dyes and chemical are essential for on shade dyeings, which must be right first time if the dyeworks is to operate economically. In a modern dyeworks, operative error and human variation are much reduced by automated dispensing systems both in the laboratory and main works, which provide accurate and consistent weighing and dispensing of dye and chemical.[6,7] Shade additions add significantly to time and cost, and 'blind dyeing' techniques – i.e. when the shade is not examined until the dye cycle has ended and the goods taken out of the dyeing machine, are now the order of the day for profitability especially where automotive fabrics are involved. Figure 4.3 shows the action in some dyeing machines and Fig. 4.4 shows a laboratory sample dyeing machine.

4.2.3 Yarn package dyeing

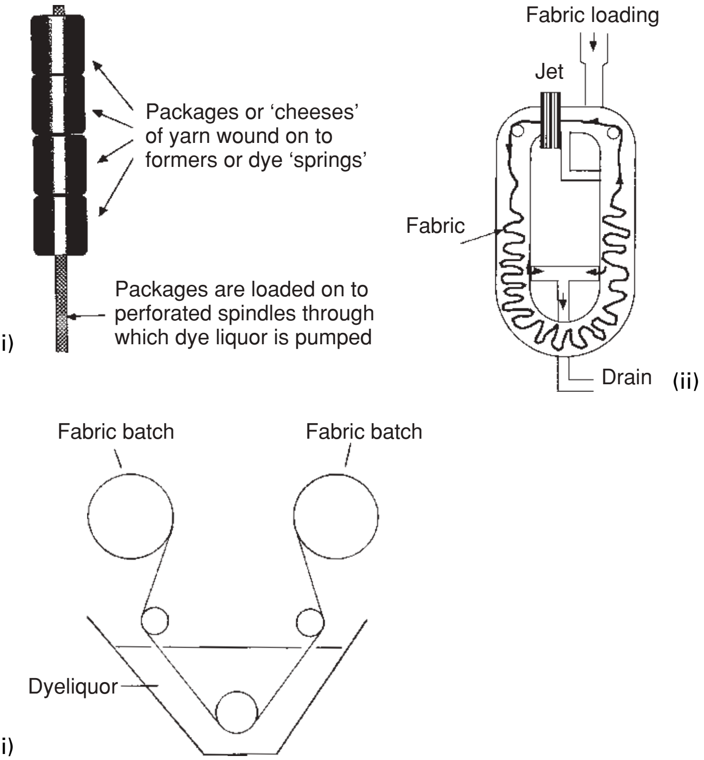
Yarn is first wound on to a former or 'dye spring' to prepare a package of yarn usually weighing about 1–2 kg. Skill is needed in this operation to produce a package of uniform density, which is essential to obtain a level dyed package. Also the correct tension is necessary to allow for any shrinkage which could occur, causing layers of yarn to crush those layers underneath and thus damage texture. In extreme cases the textured yarn can be flattened into a tape-like appearance. Also high yarn shrinkage could produce hard areas within the package thus restricting liquor flow causing dye unlevelness.[8,9] When the yarn is woven or knitted into fabric these factors could produce an irregular appearance such as unlevel dyeing or lustre stripes.

Packages of yarn are placed on top of each other on a perforated spindle; each dyeing machine containing several spindles, see Figs. 4.3 and 4.5. Most modern package dyeing machines are pressurised and operate at temperatures above the boiling point of water, where maximum penetration and maximum efficiency of the pumps is obtained. Dye liquor is pumped through the packages via the spindle – this process being termed inside to outside flow. The liquor can also be reversed and pumped into the perforated spindle via the yarn packages – this process is termed outside to inside flow. The whole dyeing procedure, including rate of temperature rise is computer controlled for batch-to-batch consistency. Package dye levelness can

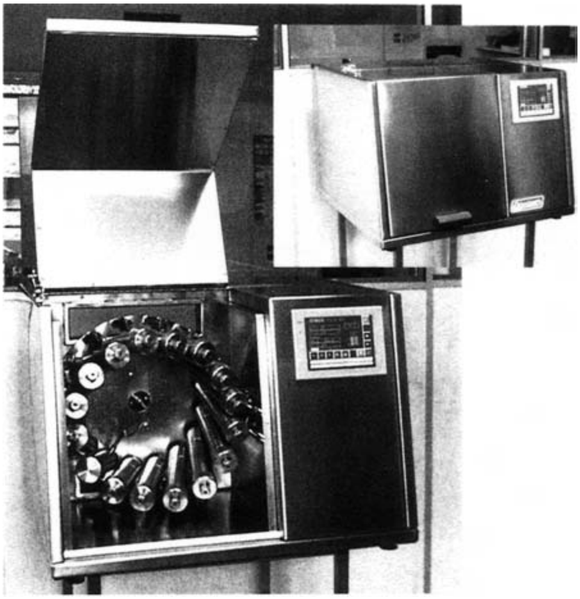
(i)

(ii)

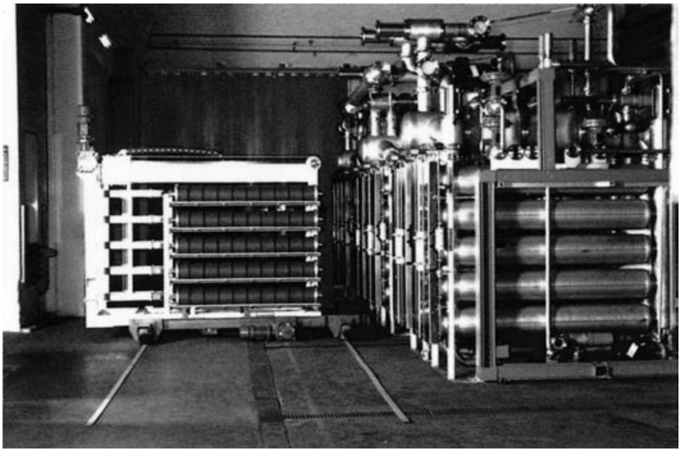
(iii)



4.3 The action of some dyeing machines used in automotive fabric production. (i) Package dyeing/beam dyeing, the dye liquor is pumped through each package of yarn, which must be wound with uniform tension for a level dyeing. However yarn shrinks under the conditions inside a dyeing machine and package winding and preparation are skilled and complex operations. **Beam dyeing of fabric** uses similar principles; the dye liquor is pumped through layers of fabric wound on to a perforated spindle called the beam. Fabric shrinks during dyeing and must be heat set to stabilize it beforehand. (ii) Jet dyeing, fully immersed fabric is drawn through the dyeliquor by the jet. The machine is pressurized and the liquor is above the boiling point of water. The size and design of the jet are regulated to suit the fabric being dyed. (iii) Jig dyeing, the fabric passes open width from one roller to the other through the dye liquor. Thus the fabric is kept flat the entire time during dyeing and creases are prevented.



4.4 Laboratory sample dyeing machine with infra-red heating. Reproduced with kind permission of Roaches International Ltd.



4.5 Commercial yarn package dyeing machine. Each horizontal spindle has its own individual dyeing tube for maximum efficiency and dye evenness. Courtesy of Obem Dyeing Machinery/Border Textiles (UK) Ltd. and reproduced with kind permission.

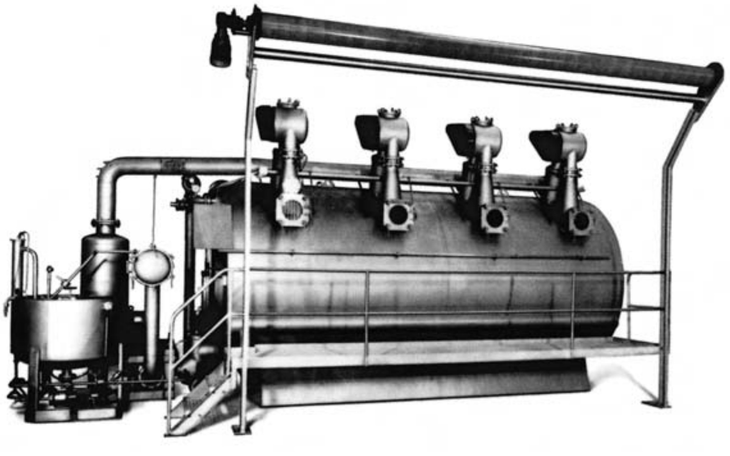
be assessed by taking a sample of yarn from the outside of the package and knitting it adjacent to a sample taken from the inside of the package and then viewing them side-by-side in a light cabinet. Yarns of high dtex such as carpet yarns or very high bulk can be dyed in muffs, i.e. softly wound packages without a former or in hank form. After the completion of dyeing an antistatic agent or lubricant is applied to facilitate yarn winding.

4.2.4 Fabric (piece) dyeing

Knitted polyester is invariably dyed in a fully enclosed pressurized jet-dyeing machine, where the fabric is forced through the machine by vigorously moving dye liquor. In addition it passes through the jet or nozzle, the action of which adds to the agitation and turbulence inside the machine, see Figs. 4.3 and 4.6. There are a number of jet machines of various configurations, each designed to optimize a particular dyeing or fabric-handling aspect, and each is considered best suited for a particular construction of fabric. All jets are operated above the boiling point of water, about 130 °C.

Knitted nylon fabric can be dyed on a beam which is a perforated spindle on to which preheat-set fabric is wound, and liquor pumped through it, in a similar way to the package dyeing machine. It is essential to heat-set the fabric first to stabilize it, otherwise it could shrink on the beam during dyeing causing watermarks, loss of texture, creasing and in extreme cases 'telescope' off the beam, or even cause the beam to collapse.

Rigid-woven fabric that is woven from non-textured yarn, such as taffetas which are prone to creasing, are dyed open width on a jig machine



4.6 HT eco-soft general purpose jet dyeing machine for both heavy and lightweight knitted and woven fabrics. Courtesy of Thies (UK) Ltd. and reproduced with kind permission.

(Fig. 4.6). The dye process consists of winding and rewinding the fabric from one large roller to another through the heated dyebath. In this way the fabric is never folded or creased. For polyester the machine is enclosed and pressurized to obtain temperatures above the boil.

4.2.5 Polyester dyeing

Polyester requires high temperature above the boil to achieve build up of dye.[10] Disperse dyes are sensitive to alkali and so polyester is generally dyed under acidic conditions – a new technique of *alkali dyeing* is described later in this section. An example of a dyeing procedure and recipe using Clariant chemicals is: x% disperse dye; 2–4% Fadex F liquid; 1–2 g/l Sandacid PB liquid (to give pH 4.5–5); and 0.5–1 g/l Lyocol RDN liquid.

Sandacid PB liquid is a blend of organic acids, salts and anionic dispersing agents for disperse dyes. Lyocol RDN liquid, is an additional dispersing agent for disperse dyes. The inclusion of a UV-absorbing agent such as Fadex F can improve the lightfastness further by up to 1–2 points, as well as reducing fibre damage by photochemical degradation. Dye recipes must be accurately prepared first in the laboratory, and then trialled with small pilot quantities of yarn or fabric, preferably using a small model of the type of commercial machine which will be used to dye in bulk. Disperse dyes recommended by Clariant are their Foron range prefixed with the letter A – for automotive, e.g. Foron Brilliant Red AS-5GL. Ciba recommend their Teratop selection of disperse dyes for automotive fabrics.

In fact there are only about 15 disperse dyes in existence which meet the very high lightfastness standards required for automotive fabrics. A dye mixture comprising dyes compatible with each other is more likely to produce good batch-to-batch reproducibility than a mixture containing dyes not compatible with each other, see Fig. 4.1. Sometimes however it may be necessary to use dyes together which are not ideal in terms of compatibility – because there are no alternatives to obtain the required shade. After the dyeing of polyester is complete, a thorough rinsing procedure termed 'reduction clearing' is usually carried out to remove all dye on the surface of the fibre which has not penetrated inside the polymer network. This process is essential to ensure that dyefastness, i.e. light, wet and rubbing is optimum.

4.2.6 Oligomer reduction – alkali dyeing of polyester

A major problem associated with polyester dyeing is the presence of oligomer, which is a low molecular weight by-product of the polymerization reaction. Oligomer is believed to be mainly trimer and is present in polyester yarn at levels up to approximately 3% or more by weight.[11] It appears as a white powder during dyeing and can contaminate dyed yarn or fabric and also leave deposits in the dyeing machine. Oligimer has been described as the single biggest problem in the dyeing of polyester. Regular thorough cleaning of dyeing machines is necessary to minimize the risk of oligomer contamination, which can arise in downstream processing such as weaving and fabric scouring.

Oligomer is more soluble in hot water than cold, and more soluble in alkali liquor, say pH 10 to 11 than lower acid values of pH. Thus draining the dye liquor at high temperature and at high pH values helps to remove it from the dyed goods. Special plant is normally required to do this however, as water authorities may not allow hot water and water at these high values of pH to enter drains. A novel method of reducing oligomer was pioneered in Japan, the concept of *alkali dyeing*. Oligomer is significantly more soluble in alkali liquors compared to acid, but the shade and other properties of disperse dyes can be influenced by alkali conditions. The Japanese were the first to develop a method of actually dyeing under alkali conditions to reduce the nuisance of oligomer. At the present time several dyestuff manufacturers now have products and recommended methods for alkali dyeing of polyester,[12–14] but care is needed as reduced abrasion resistance of polyester yarn can result. Also each dye must be individually screened for suitability for use in this method.

4.2.7 Nylon dyeing

Nylon is dyed in a different way to polyester. Dyeing above the boil is not essential and acid dyes are used instead of disperse dyes. Only a certain class of acid dyes, metal complex – also called premetallized dyes – have the necessary high standard of lightfastness. As with polyester dyeing, dye mixtures are best made up from dyes which are compatible with each other. Recommended acid dyes for automotive fabric include selections from the Lanasyn (Clariant), Lancron (Ciba) and Neutrilan (Crompton and Knowles) ranges. There are more dyes to choose from compared to polyester dyeing but the premetallized dyes generally tend to be duller and darker shades.

The rate of dyeing of nylon is pH-sensitive, the rate being much faster under acid conditions. In order to obtain level dyeings, it is usual to start the dyeing under slightly alkali conditions and raise the temperature of the dyebath to the boil at a controlled rate. When most of the dye had gone on to the fibre it was usual to add acetic acid to lower the pH to exhaust the remainder of the dye. Nowadays there are now 'acid donor' chemicals which are alkaline, at the start of the dyeing, but break down as dyeing proceeds at about 80 to 100 °C and release acid to lower the pH.

4.2.8 Acrylic dyeing

Acrylic is a synthetic fibre which is dyed with basic (cationic) dyes such as the Astrazone range produced by Dystar. Much acrylic fibre (made by Acordis, using the Neochrome process developed by Courtaulds) is spun dyed during yarn manufacture which produces dyeings of higher light fastness than those produced in an aqueous dyebath.

4.2.9 Wool dyeing

Wool can be dyed using the same premetallized dyes recommended for nylon. Wool processing especially needs environmental monitoring because of the amounts of oils or greases which may be present in raw wool. Wool, being a natural product, is more variable in its properties than synthetic fibres and cannot generally be 'blind dyed'.

4.2.10 Fabric scouring

For fabrics woven from dyed yarn, the scouring process not only removes residual lubricant and dirt from the fabric, but it is also an opportunity to relax the material and to develop bulk and texture. There are specialist machines available for processing delicate fabrics with very high levels of stretch but they can be very expensive. Woven fabrics are generally scoured full width on continuous scouring ranges to prevent creasing. Care and the correct apparatus are needed if the material is to relax according to specification, without stretching and destroying texture and residual stretch, which could be needed in a later process. The washing process is essentially controlled by four factors; mechanical aspects determined by machine design, chemical aspects, which means choice of the correct scouring agent and auxiliary chemical (e.g. to treat hard water), temperature of the water baths and time of treatment. In continuous scouring, time is determined by fabric speed. The chemical nature of the scouring agent is important because residual amounts may react adversely with finishing agents. For example a residual strongly cationic scouring agent may form white deposits with an anionic anti-static agent applied later to the fabric. Nonionics or weak anionics are probably the safest scouring agents. Ideally the scouring agent must first enable rapid wetting of the fabric, followed by removal of soiling. The scouring agent should then hold the soiling in suspension and prevent redeposition back on to the fabric. Fabric drying on cans requires considerable care because the fabric can be stretched affecting dimensional stability and in extreme cases can cause glazing or loss of texture. Knitted fabrics are generally scoured in the dyeing machine before dyeing.

4.2.11 Final stentering of fabric

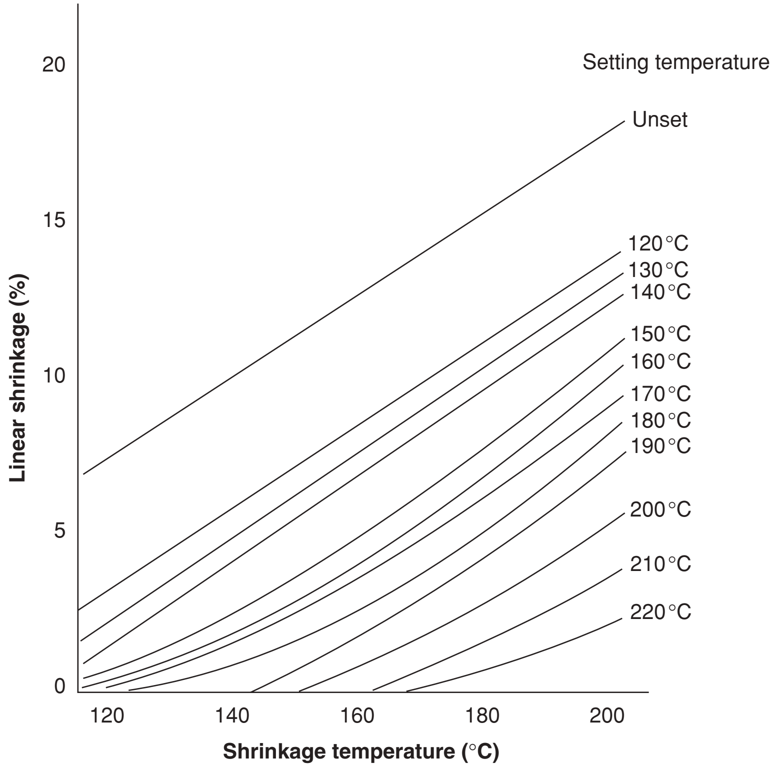
This is a very important operation requiring much attention, and its importance is sometimes not fully appreciated. It is not simply an operation to dry off water and to put the material into convenient-sized rolls for handling. Final stentering is to produce fabric with the correct width, appearance and dimensional stability and must be carried out according to a carefully formulated standard operating procedure which takes into consideration all the processes the fabric will undergo after it leaves the finishing works. Final stentering imparts to the fabric the important properties of dimensional stability and the correct degree of stretch. These properties are developed by the amount of overfeed put into the fabric. However allowance must be made for the width and vice versa. Fabric pulled out widthways will tend to lose length, fabric stentered with excessive overfeed may be slack in the width. Dimensionally stable fabric with the correct properties are essential for efficient fabricating into panels for seats or other components as will be seen later in Chapter 6. The higher the setting temperature, the more dimensionally stable will the fabric be, see Fig. 4.7. Some automotive fabrics are not stentered at especially high temperatures because of the risk of shade change.

During the stentering process the fabric aesthetics, texture and pattern should be preserved. This is not easy when fabrics with checked designs or with lines down the length or across the width are being processed. The pattern is carefully examined at the take-up end of the stenter and any necessary adjustments to correct any 'bow and skew' should be made immediately. Distorted pattern is the reason for much rejected fabric, which can sometimes be corrected by restentering. Occasionally distorted patterns are noticed on laminated fabric during final examination; these cannot usually be corrected and so it is important to detect faults as early as possible and before further processing value has been added to the material. Very occasionally distorted patterns are noticed by the customer when the fabric has been made up into a seat cover – which is a disaster!

The stenter must be equipped with the appropriate equipment for controlling fabric especially when processing lightweight knitted material, which needs effective edge uncurlers and gum applicators. Clear instructions for simple operations such as stentering to the correct width must be made, whether the stated width is between the pins (usable width) or overall width including or excluding the 'fringe'.

4.2.12 Fabric finishing

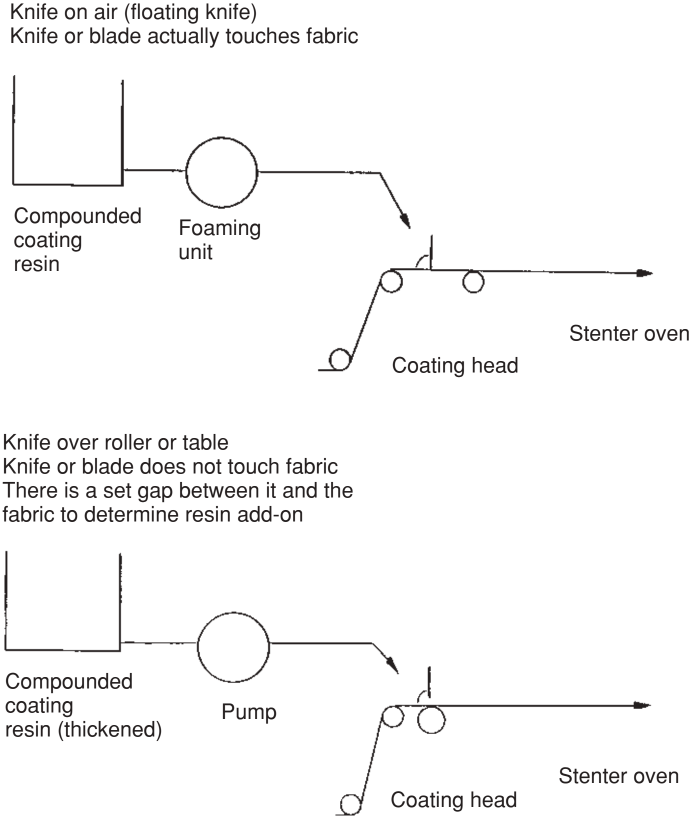
There are very many fabric finishes available for textiles but very few are actually applied to automotive textiles. Some finishes have the side effect



4.7 The effect of setting temperature on the dimensional stability of DuPont polyester fabric. Technical information from DuPont (UK) Ltd. (April 1999) and reproduced with kind permission. The higher the setting temperature the more thermally stable the fabric, i.e. the less shrinkage on reheating.

of reducing abrasion whereas others would cause fogging problems, give rise to white deposits, reduce lightfastness properties or otherwise affect colour. Many automotive fabrics have no finish at all applied. Some OEMs specify an anti-static finish, which is applied by dipping or full immersion on a pad mangle – a process usually described as padding or impregnation. Finishes can also be applied by a foam-finishing route which is more economical than padding, because less heat is required to dry off a reduced amount of water. Thus faster stentering speeds are possible and in addition there is no wasted residual chemical in a pad bath and therefore less effluent. Another important advantage is that the finish is applied to only one side of the fabric, the face side, because some finishes, notably soil release agents and especially silicones, reduce adhesion on lamination.

The foam-finishing process entails adding a small amount of foaming agent to an aqueous bath of the finish to be applied, at the concentration



4.8 Fabric coating on stenter.

calculated for the required add on. The mixture is then put through a mechanical foaming machine and the foam is applied to the face of the fabric by a knife coating process. When foam processing is being carried out, the knife or blade normally touches the fabric surface, see Fig. 4.8. This procedure is termed ‘knife over air’ or ‘floating knife’, see fabric coating below. The foam density is such that it sits on the fabric surface without sinking into the fabric. The chemical add-on to the fabric is controlled by concentration of the chemical in the liquor, i.e. solids content and foam density (sometimes called blow ratio or cup weight). Blade profile, fabric speed and fabric surface condition and geometry will also influence add-on.

Anti-soil finishes with branded names, such as Scotchguard (3-M) or Teflon (DuPont), are sometimes specified by the OEM and these can be applied by the same methods of padding or by foaming. Soft finishes or flame-retardant finishes are hardly ever applied to automotive interior fabrics because of fogging or other problems already mentioned, which could develop on the fabric over a period of time in the car. Flame-retardant chemicals are applied to automotive fabrics via a back coating, see below. Care is needed in formulating foam recipes otherwise frothing may occur during wet crocking and 'tide marks' may appears after drying. Also the amount applied needs to be optimized carefully. Too much can affect the shade of the fabric or cause stiffening, cracking or 'chalk marking'. There are fabric finishes developed to improve the abrasion resistance of fabrics which can be applied by padding or foam processing.

Foam processing should not be confused with the process of fabric coating, which is a similar process. The difference between 'foam coating', (also called foam finishing or foam processing) and 'fabric coating' is that the actual 'solids' applied to the fabric is, in the former case, the same as that added by a pad or impregnation route, i.e. 0.5 to 2% or less. Fabric coating applies considerably more, say 10 g/m^2 and much higher, usually as a visible layer to the back of the fabric. Foam processing is an alternative to padding or impregnation and where the finish cannot be seen. Only woven fabrics and some heavier weight knitted fabrics can be foam processed by this coating technique. Knitted fabrics, especially lighter-weight qualities intended for, say headliners are usually too stretchy and require more specialized apparatus such as a curved blade applicator.

4.3 Printing

The printing of textile substrates has been around almost for as long as textile fabrics, with evidence dating back 2000 BC. Printing of textile fabrics for automotive trim usage is, needless to say, somewhat more recent! Before describing the processes primarily used for automotive fabrics it would be useful to quickly review, and briefly describe, some of the many techniques used for applying a printed image to a textile fabric.

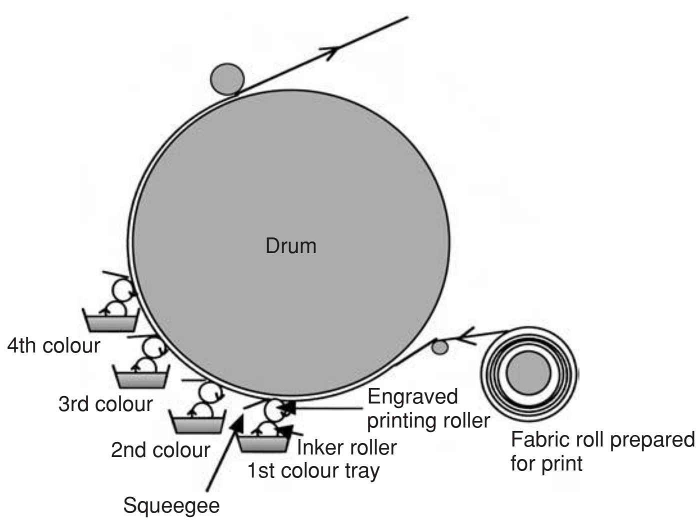
One of the earliest was block or hand printing where the flat surface of a block of wood was engraved with the design required to appear on the fabric left as a raised surface with the parts not required carved away. Upon completion the engraved part of the block was dipped in a colourant and applied under pressure to the fabric leaving an imprint of the design. By carefully applying the block print to line up with its neighbour top, bottom and side to side a complete coverage of the material is obtained and careful designing ensured that the pattern repeat could be disguised to appear much larger than it actually was.

Resist printing employed a similar technique of applying a printed image but instead of a dye or colourant a dye resistant substance was used (wax, clay, etc.) and the fabric was subsequently dyed with the dye failing to register where the wax appeared. This was then washed out leaving clear areas of design on a dyed background. Clever developments of this technique allowed the process to be repeated several times to achieve multicoloured effects and have been successfully employed for centuries in such places as Indonesia where the process has become known as 'Batik' printing.

A further development of the Batik technique is 'Ikat' where the warp yarns are treated in a similar way and after dyeing and removal of the resist substance the warp is woven to create a very indistinct and it has to be said somewhat unrepeatable impression of the design. This Ikat principle is used today by printing the full design in all colours on the warp and then weaving. Very attractive effects are obtained in this way but the somewhat random and uncontrolled nature of the end result preclude it from becoming a serious process for automotive and in fact is yet another example of where the control and requirement for accurate repeatability, so much a feature of automotive production, preclude so many of the more creative and traditional textile processes being utilized.

Roller printing could be regarded almost as a development of block printing where the block is formed into a cylinder with the design being engraved on the outer circumference of the cylinder, producing a roller which is charged with dye liquor and rolled across the fabric surface leaving behind an impression of the design. This is shown in a simplified form in Fig. 4.9.

Roller printing is expensive due to the high cost of the metal rollers (usually plated copper etched with acid), delicate and slow engraving



4.9 Simplified digram of roller printing by engraved copper roller, showing set up for a 4 colour printed design.

process and high set-up costs demanding very high print runs for economy. However, it has a place in the production of very high quality and fine detail prints where large volumes are required per design and colour. The four main commercial printing processes which are relevant to automotive textile substrates are: flatbed screen, rotary screen, heat transfer, and the latest, and the one with possibly the greatest potential, digital ink jet.

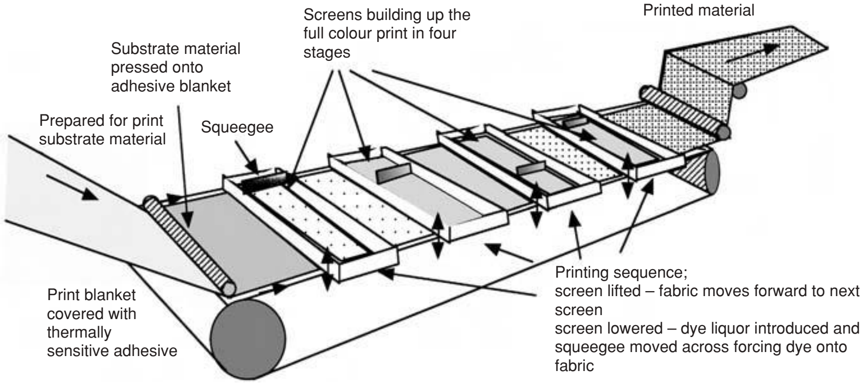
4.3.1 Flatbed screen

In this technique the final design as perceived by the designer is separated into the constituent colours and each of these prepared as an individual design – this initial process is referred to as 'separation' and for a design composed of six colours would result in six individual designs being separated out prior to the next process. This used to be a highly skilled manual process but now the design is scanned into a computer and the colours automatically separated out and prepared as individual designs in exact register with each other so that if they were printed onto transparent film and laid exactly one on top of the other an exact reproduction of the original artwork would be seen.

Each of these separated designs is prepared on a flat screen which originally used to be of a fine silk material – hence the term 'silk screen printing', which is still used today, although nowadays the screen is likely to be of a synthetic material or fine metal mesh. The design is transferred to the screen by coating it with photosensitive material and exposing to light those areas which represent the colour to be printed. This degrades the coating and allows the exposed part to be washed out in the next process. One screen for each of the colours in the design is prepared in this way.

The screen covers the full width of the fabric and can be of varying length. Each screen is mounted in a frame locked into position above the printing bed, and the frames are arranged along the printing bed in the order in which the colours are going to be applied to the fabric. The fabric to be printed is temporarily stuck down to a printing blanket by thermally sensitive adhesive and transported by this blanket under the screens stopping for the screens to be lowered and the design printed.

The printing is done by introducing a viscous print paste containing the ink or dye of the desired colour onto the top of the screen and traversing the full width of the screen with a squeegee to force the dye paste through the screen areas, and onto the fabric. The fabric is then moved on and the next colour printed on top of the previous one, etc. until all the colours have been applied and a full colour-printed fabric reaches the end of the print bed and is peeled off the printing blanket to go through a dryer ready for the next process. A diagram of the process can be seen in Fig. 4.10.



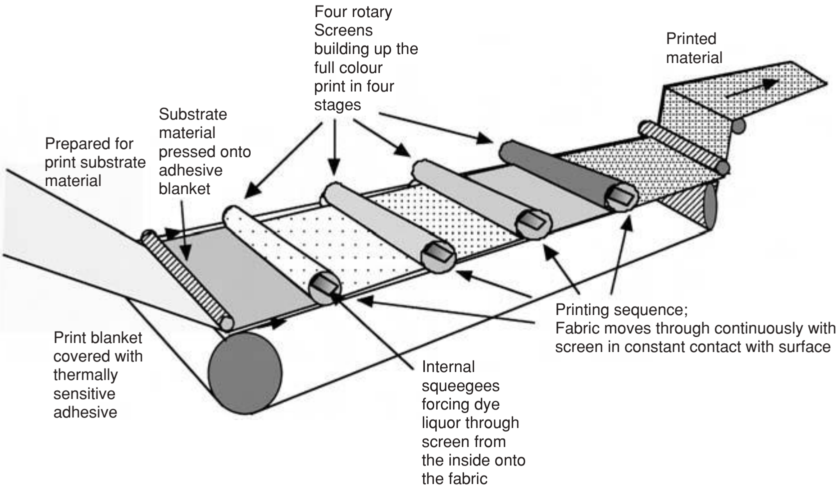
4.10 **Simple diagram of flat-bed printing, showing main elements and sequence of the process.**

Flatbed screen printing is a relatively slow but precise process which allows for fine detail in the design similar to an engraved roller but it has become expensive and rather uneconomic when compared with rotary screen printing. The problem of course is the fact that no matter how mechanized the process becomes, the fabric always has to stop to be printed.

4.3.2 Rotary screen printing

In principle this is a development of flatbed. The flat screens have been replaced by hollow cylinders, the screen forming the outside perimeter of the cylinder and the dye liquor introduced into the centre of the cylinder and 'squeegeed' through the screen to the outside and onto the fabric. Like the flatbed screens the cylinders are arranged down the printing bed and the fabric is stuck down and transported down the bed but this time it is allowed to travel continuously and the cylinders or rotary screens revolve continuously, printing the individual colours in stages down the fabric until the full colour design has been built up. Figure 4.11 shows a simplified view of this. The speed of printing is vastly greater than for flatbed screen and the cost is of course lower for this reason, however the detail which can be obtained and the variety of substrates which can be printed is more limited so flatbed still holds an increasingly niche market in the printing of textile products.

The consistency of the dye paste for rotary screen is much thinner since it has to penetrate the screen much faster. With both systems it is essential for the individual screens to be in perfect register down the print bed so that the different colours are printed in exactly the right place on the fabric with no overlap of colour except where this is required as a specific part of the design.



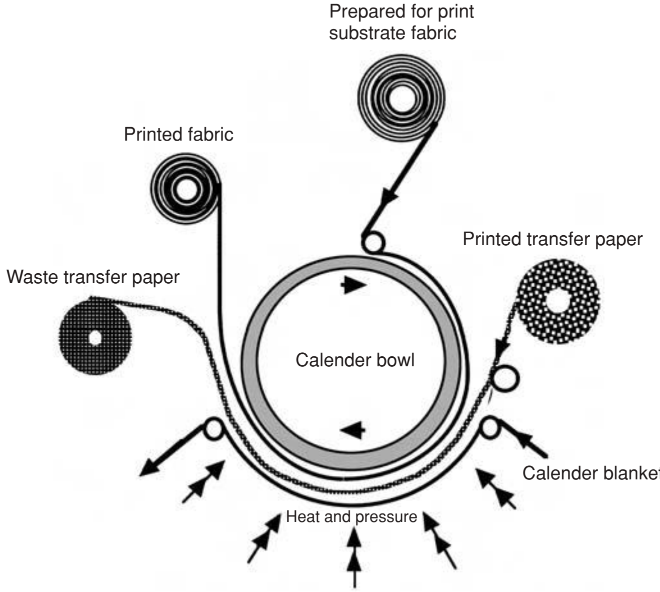
4.11 Simple diagram of rotary screen printing showing main elements and sequence of the process for a four-colour screen print design.

The overall principle of printing either by flat or rotary screen is the same and the formulation of the basic dye recipe is similar as are the additional processes after printing. This is of particular importance for the printing of automotive cloths, which are likely to be based on polyester fibres.

In order to achieve the required fastness to light on polyester, it is necessary to carefully select the dye stuffs used and also to fix these into the fabric at around 130 °C. When package dyeing the yarn or fabric, this is done by processing under pressure in an enclosed cylinder. Of course, this is not possible when printing so the fixation has to be a separate process after the fabric has been printed. It is usual to wash off loose dyestuff immediately after the print process then transfer the fabric through a cabinet of superheated steam raising the temperature of the fabric to above 130 °C for several minutes. This has the effect of driving the dye molecules into the fibres and developing optimum light fastness. Additional fastness is frequently obtained by mixing the dyes with a UV absorber of which there are several propriety brands available. The final process would be to stenter out the fabric to the required width and roll up.

4.3.3 Heat-transfer printing

This method came to prominence mainly due to its ability to print fabrics cheaply and easily on inexpensive equipment – only a simple calender arrangement is needed – plus the added advantage that the heat generated



4.12 Diagram of a transfer printing machine used for polyester fabrics.

during the process made it very suitable for polyester fabrics which needed the heat to thermally fix the dyes into the fabric.

In transfer printing, the original design is printed in mirror image using disperse dyes selected for their ease of sublimation (i.e. ability to move from fixed to vapour form from one substrate to another under application of heat) onto special heat-resistant paper.

The paper and fabric are then pressed together in a rotary calender or press and the dyes sublime from the paper onto the fabric under the influence of heat at between 170 and 220 °C. This produces a mirror image of the paper design on the fabric in great clarity and detail since no liquid phase is involved; furthermore, due to the heat the dyes are firmly fixed and display maximum lightfastness. The process is economic with short runs and is also able to print dimensionally unstable fabrics such as knits. The process of printing the papers prior to printing the fabric is the preserve of specialist transfer-paper printers.

With all these advantages particularly for printing polyester fabrics – the staple diet of automotive trim – it is a valid question to ask why it has not been massively exploited in this area. There are, as you may expect, a few key disadvantages – colour repeatability to the fine tolerances required in automotive materials is difficult – the pressure means that any fabric with any sort of surface pile or nap will be flattened and almost all fabrics will change appearance and handle. This aspect has proved to be a great limitation with regard to the number of fabric types which can be processed successfully for trim, although the process has been and still is used particularly for applying colour and design to headlining fabric and other areas where there is some wider tolerance in terms of aesthetics and handle. A simplified diagram of the process is shown at Fig. 4.12.

4.3.4 Ink-jet printing

Flatbed and rotary screen printing are basically fairly old technologies which are still used to print automotive fabric and both these methods are usually carried out by specialist printing companies who have invested the considerable amounts of money required in the capital-intensive print machines and after-processing equipment. However a lot of development effort is now invested in a process which has the potential to totally reverse this situation and that is digital ink-jet printing.

Ink-jet printing itself has been around for many years but has been largely confined to the graphics industry and to a limited degree carpet printing (Millitron® process is an example of this) where fine definition of design is not vital to the product.

The printing of textile substrates by ink jet has been carried out for several years in the production of single one-off panels for approval of design and colour prior to the engraving of screens but with recent developments of wide-width, ink-jet printers and the massive advances in computing power and speed, fine detail printing at 360 dots per inch and more can be carried out on a continuous basis albeit very slowly in comparison with rotary screen printing.

An ink jet printer is essentially composed of an ink supply, print head, a drive mechanism which propels the print head horizontally across the fabric width somewhat reminiscent of the shuttle, a continuous cloth feed arrangement and of course a CAD system which not only allows the design to be created but also drives and controls the print heads and colour mixing. Many such wide-width printers are available, some developed by the traditional screen printing machine manufacturers and totally dedicated to printing textile substrates, and some developed by the graphic printer manufacturers such as Epson, Hewlett Packard, Encad, Innotech etc. which have been modified to take textile instead of paper substrate.

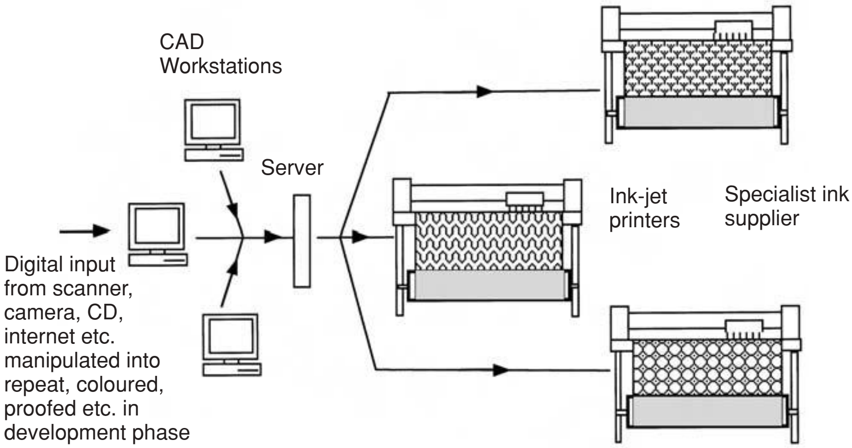
There is a fundamental difference between ink jet and conventional printing in that ink jet uses what is known as 'process colour' to create the effect on cloth where each colour is a combination in varying proportions of cyan, magenta, yellow and black (CMYK) which are only mixed to create the required colour effect when they actually hit the substrate from the ink jets.

Conventional printing on the other hand uses what has become known as ‘spot colour’ where the actual final colour required is premixed in a colour kitchen before printing. This means that the range of colours available as ‘spot colours’ is almost limitless and when they are printed they are effectively ‘pure’ colour with great clarity. ‘Process colours’ on the other hand are much more limited both in their range and also the sharpness and clarity when printed out. Developments are in hand to improve this by increasing the standard four CMYK inks to intermediate shades up to eight or more each with its own jet and combining blocks of jets to operate as one, this is known as ‘super pixel’ technology and it produces greater freedom to match colour requirements since colours can be premixed in a similar manner to ‘spot colours’ to better match design colour needs. It currently has problems with small jet nozzles and is not an ideal solution for the graphics application where very high resolutions are needed but has possibilities for textiles where print resolutions can be much lower to match existing screen print.

Development is ongoing and the approach taken for textiles has varied from company to company. The traditional manufacturers of such machines, coming from a graphics background where high print resolution has been the driving force, have tended to assume that this would also be a key requirement for textile substrates and have adapted existing machines to take textile fabrics. This has sometimes meant that fabrics have to be coated or laminated to create an even surface – not an ideal situation and much more relevant products will have to be developed for this end use.

Other manufacturers, such as Stork and Zimmer, coming from a background in textile printing have realized that machines have to accept many different fabric substrates and that high printing speed to keep production costs down would be an important factor. Since this is more easily obtained at lower print resolutions (not as many jets to feed with ink and information from the computer) development effort now is considering more closely matching the ink jet with the existing resolution of screen print and, in fact, possibly varying the print head according to the resolution and substrate to be processed – a very fine silk chiffon is likely to require far different treatment from a coarse velvet coach fabric in terms of design definition or resolution.

The basic hardware requirements and possible configuration for an ink-jet printing set up are illustrated in Fig. 4.13. However, irrespective of the origins of the printer the key element is the print head and this is usually of three main types as illustrated in Fig. 4.14. They are: continuous drop deflection where a continuous flow of droplets (over half a million per second) from each jet is directed at the fabric and when not required, is deflected away; drop on demand thermal (e.g. thermal ink jet as produced by Canon and Hewlett Packard) where the ink is heated up to 300 to



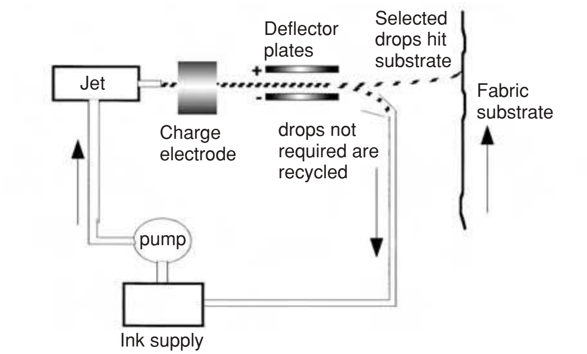
4.13 A possible configuration for the digital printing of textile substrates.

400 °C to form a bubble which explodes and propels the ink onto the surface of the fabric; and drop on demand Piezo electric (e.g. Epson printers) which applies an electric charge to a piezo crystal which expands a diaphragm in the ink well causing a mini explosion that forces ink drops from a jet. The sort of wide-width printer which would house the print heads is illustrated in Fig. 4.15.

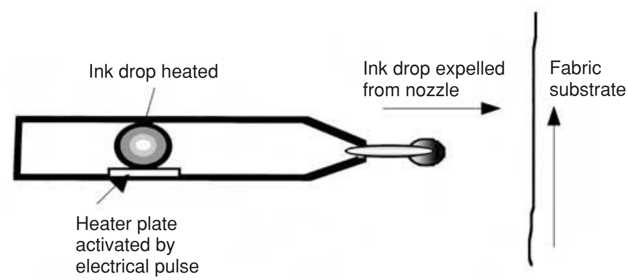
Whichever system is used the method of building up the design and colour is essentially different from the traditional methods in that the different colours on the fabric are built up by mixing dots of pure CMYK colour on the surface of the fabric. This has been referred to earlier as 'process colour' compared with the 'spot colour' of traditional screen printing where the individual colours are mixed to the correct shade *before* applying to the fabric.

There are many issues to address using ink-jet systems, one being the development of suitable inks and colourant dyes which do not clog the jets – particularly important for polyester where disperse dyes comprising fairly large dye particles are concerned. Another and fundamental issue is the development of the CAD software package to produce the design to control the jets and to mix the colours to fine limits to realize and control the exact colour required for each element of the design. In other words to decide how many dots from each of the jets will be required to create the final colour on the cloth.

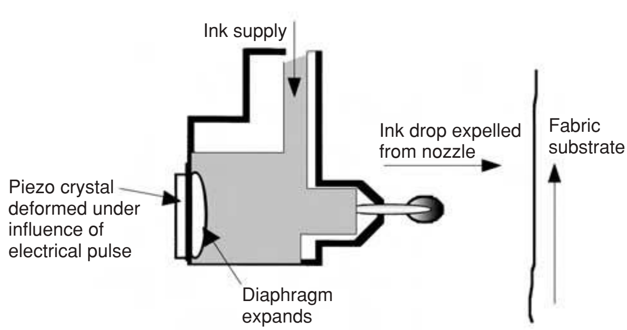
Both these issues have received a lot of attention from such companies as Du Pont, CIBA, BASF etc. who manufacture the inks and dyes and Sophis Systems, who are headquartered at Wevelgem Belgium, and have



Continuous inkjet drop deflection technique.
A continuous stream of drops is fired at the substrate and given ± charge by electrode. Drops not required are deflected by ± plates and recycled

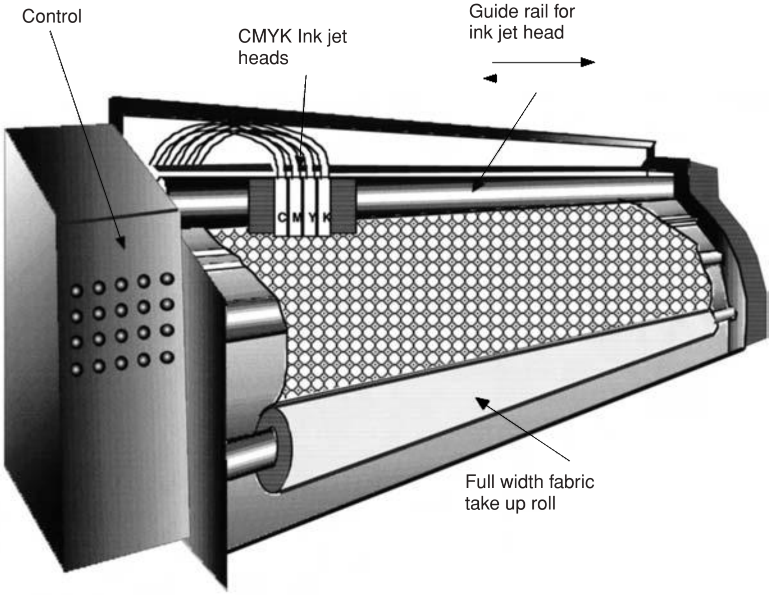


Drop on demand – thermal
Ink drop heated to 400 °C in millisecond and expands to form vapour bubble.
It is expelled through nozzles and hits fabric as a droplet



Drop on demand – piezoelectric crystal
Diaphragm expanded under influence of piezo crystal and displaces ink out through the nozzle as as droplets which deposit onto the fabric

4.14 The three main types of ink-jet printing heads, illustrating the principles involved in propelling the ink drops onto the substrate material.



4.15 Diagram of wide-width ink-jet printing machine adapted for the continuous printing of textile substrates.

spent many years perfecting the CAD systems necessary to drive the design elements of the process.

Following the printing process it is necessary to wash off and, in the case of polyester, fix the dyes into the fabric to obtain the necessary lightfastness. This is done in ways similar to those employed following rotary or flatbed screen printing. It has to be borne in mind, however, that the continuous ink-jet printing of textile products, particularly automotive materials with its preference for polyester, is, on a world scale, in its infancy but companies such as Seiren in Japan have currently taken a lead in the application of the technology to automotive substrates.

A lot of attention is being focused on the process mainly due to the advantages it offers in terms of ease of design and colour change with minimum down time, and responsiveness to what has become known as 'agile manufacturing'. This is the ability of a process to respond quickly and efficiently to short-term demand based on sales patterns and volume requirements and is particularly relevant to the automotive scene where design and production and the need to differentiate models is becoming increasingly short term and complex.

These advantages however are balanced by the slow production and the totally new organization required to make a success of this form of printing. No longer is it necessary to involve commission printers to print large volumes from a few hugely expensive machines installed in a central print works. Rather it offers the possibility of installing many ink-jet printers controlled, via a CAD system, by the fabric producer and similar in concept and production rates to the manufacture of jacquard-woven fabrics.

Ink-jet is the only true noncontact method of applying surface pattern to substrates and this fact alone offers many advantages for textile producers, particularly those involved with pile products or any fabric which has a sensitive surface such as artificial suede, etc. Since the print heads never actually come into contact with the fabric surface no disturbance can take place due to the actual printing process and the ink can be made to penetrate into the pile surface without any necessity to apply pressure and flatten any specific surface effect.

Further development of control systems of the fabric relative to the print heads offers the potential to locate colour on specific parts of the fabric to within fine tolerances which could mean that jacquard woven or knitted designs in ecru fabric could be printed with colour located on the actual design area imitating colour weaving or knitting but without the large yarn inventory and the extended lead times this involves.

Ink-jet is an emerging technology which is largely computer driven, where development is traditionally very fast and which has huge potential in the production of figured automotive trim fabrics and transportation fabrics generally. It also offers the possibility for existing fabric producers to become involved in a small way and grow as experience and knowledge are obtained. One company, The Seiren Co Ltd., Fukui, Japan, have done just that with their Viscotecs® system.

Whether this potential will be fully realized world-wide will depend on many factors, of which mastering the technology and optimizing production speeds, print resolution, physical properties, colour consistency, range and repeatability, are but a few.

4.4 Coating and lamination

4.4.1 Fabric coating

This section is concerned only with the coating of automotive fabrics, more general information is presented in Chapter 9. The definition of fabric coating is usually accepted as the application of a polymer or resin to one side of a piece of fabric. A simple analogy is spreading butter onto toast. The modern coating industry dates from the early nineteenth century, when Charles Macintosh made the first rubber-coated fabric. His name became synonymous with the raincoat. Automotive fabrics are coated for a number of reasons, the two most important being to improve abrasion resistance and secondly to confer some flame-retardancy (FR) properties. Early heavy knitted automotive fabrics were coated to control fabric stretch. Other properties, which can be imparted by coating include high frequency (HF) weldability, by application of a PVC latex, and barrier properties to liquids. The higher the amount of coating applied the better the barrier properties. However, fabric handle can be stiffened significantly by coating especially if the coating resin applied is not chosen carefully. Fabrics are also sometimes coated to modify stretch and to control porosity. In general only woven fabrics can be easily coated by the usual methods – knitted fabrics are generally too stretchy and dimensionally unstable. Having stated this, it is believed some heavy-duty knitted fabrics are sometimes back-coated to reduce excessive stretch. Woven velvet fabrics must be coated to lock in the pile.

Polymers applied are generally water-based acrylic, polyurethane or PVC lattices. Acrylics are probably the most versatile and are used the most. Polyurethanes are a little more expensive but generally have better stretch properties. The polymers are mixed with water and other ingredients such as thickening agents, foaming agents, fillers for economy and when necessary, FR chemicals. The whole mixture is referred to as a compounded resin. Sometimes extra cross-linking agents, wetting agents and other specialist additives are also included. The compound is mechanically foamed by high speed agitation and air pumped in to give a foam of a predetermined density usually about $0.2\,g/cm^3$. This compound is pumped on top of the fabric reverse side up, in front of a doctor blade in front of a stenter. This particular method of fabric coating is referred to as the 'direct method' and there are a number of variations. When the doctor blade or 'knife' actually touches the unsupported fabric, see Fig. 4.8 it is referred to as a 'floating' knife and the method 'knife on air'. When higher levels of polymer are applied, the fabric is supported by a table or roller and a finite gap between the blade and the supported fabric is set using a feeler gauge. The size of the gap is another factor which determines add-on. This method is referred to as 'knife over roller' or 'knife over table'.

The same factors that already have been mentioned in foam processing control compound add-on. Motion of the fabric forwards into the stenter oven spreads the foamed coating evenly onto the surface of the fabric. On drying under the action of the stenter the foam collapses and an even coating is obtained on the back of the fabric. Foaming is necessary to prevent the compound wetting and sinking into the fabric and penetrating to the face side. This method is excellent for applying relatively low addons of resin, say up to about $30–40\,g/m^2$. When much heavier weights need to be applied, the compound is not foamed but thickened with a thickening agent. This has the same effect as foaming, allowing the resin to sit on the surface of the fabric without sinking in, and penetrating to the face side. Resin penetration can lead to fabric stiffening and chalkmarking or other appearance problems. Both foam processing and foam coating can also be carried out using rotary-screen techniques, which have certain benefits such as allowing certain knitted fabrics to be coated by the direct method, but which entail more expensive plant.

4.4.2 Introduction to lamination

Lamination is the joining together of two materials, and is one of the fundamental processes in the production of car interior trim. Usually a third material is used as the adhesive, but sometimes one of the materials being joined can itself act as the adhesive as in flame lamination. There are four main groups of mechanisms by which adhesion is believed to take place.[15] These are: mechanical interlocking, diffusion of polymer molecules across the interface, electrostatic forces and finally interatomic and intermolecular attractions between the atoms and molecules of the materials being joined, i.e. the adhesive and one of the substrates. The adhesive acts as a 'go between' between the two substrates being joined together. The last-named group includes chemical bonding, which generally produces a strong and durable bond. All types of bond require clean surfaces that are free from dirt, grease and other contaminants especially silicones. Increasing the surface roughness generally improves the bond strength. When bonding problems with films and plastics are experienced, surface treatment of the film or plastic with corona discharge or a plasma process sometimes help. Chemical cleaning or pretreatments with flame are also reported to be helpful.

Mechanical interlocking, especially with rough, natural, short-filament fibres such as cotton, is an important means of adhesion. Much development has been necessary to improve the bonding of rubbers and plastics to smooth continuous filament synthetic fibres. In automotive applications, high production rates are the norm and material handling considerations are just as important as the actual joining process. Feed systems for fabrics, foams, films and other materials to be laminated at high speeds present logistic problems and other limitations, which are common to all methods of joining. The lamination process must not affect the appearance, colour or surface texture of the fabric being joined and should have minimum effect on the handle of materials especially those that are to be used for further processing. Thus adhesive must be controlled: it should first 'wet' and flow on the surfaces of the materials being joined, penetrate to a certain extent but not such that it will cause stiffening or penetrate through to the fabric or material face.

4.4.3 Types of adhesives

Adhesives are available as solutions, as dispersions in water or solvent or as solids, which melt under the action of heat. All adhesives must have some affinity for both the materials being joined. As just mentioned above, they must first of all 'wet', cover and penetrate the surfaces to be joined and then solidify by evaporation of the carrier liquid to form the permanent bond by the mechanisms already mentioned. In the case of a 'hot-melt' adhesive, the bond is formed on cooling. Hot-melt adhesives are available in several forms; as a 'web' (resembles a net curtain), as a continuous film, or in powder or granular form. Some adhesives are also available as a liquid or jelly which are 100% (or nearly) active material and do not contain any solvents or water.

4.4.3.1 Solvent- and water-based

Solvent-based adhesives are generally environmentally unfriendly, and safety precautions must be take because many are flammable and their fumes can be harmful to health. In addition solvents are more expensive than water but in general, solvent adhesives 'wet' the surfaces to be joined better than water-based adhesives, have more 'grab' and they also dry off faster. Shelf life is reported to be generally better than water-based, because the organic ingredients disperse better in a solvent, compared to water. Water-based adhesives are safer to use and pose less of a problem to the environment, but drying of water can be expensive both in terms of energy and time.

4.4.3.2 Hot-melt adhesives

Because of the factors stated above, hot-melt adhesives are gaining in popularity but they need to be carefully selected. For good durability their softening and melting point must be well above the temperature to which they will be exposed inside the car. Other performance factors, which must be considered in common with all types of adhesive are, bond strength, resistance to moisture, humidity, heat ageing, light and UV degradation, and any effect on fabric colour. The nature of the materials to be joined, where they will be used within the car, and their physical form, all need to be taken into consideration when deciding which adhesive, and which lamination machine to use.

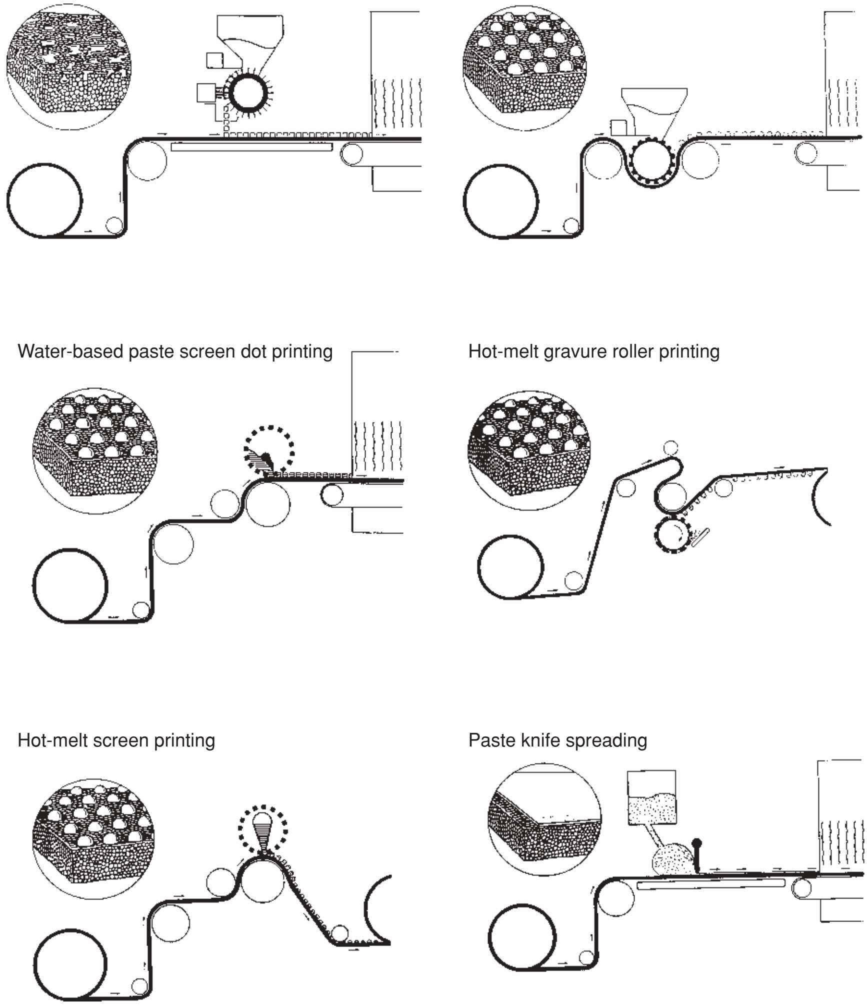
Choice of hot-melt adhesive affects the handle because of two reasons. The first is the physical property of the adhesive material itself, i.e. if it is hard or soft, and secondly the degree to which it sinks into the fabric. The melting characteristics, flow properties and viscosity of hot-melt adhesives are important considerations. If too much heat is applied they can flow away from the surfaces to be joined and hence produce a poor bond. This excessive flow may also cause stiffening of the laminate and penetration to the face of the fabric being laminated. The adhesive manufacturers offer advice on which chemical class of adhesive to use, and the best particular one for the job in hand. They should also have information on adhesive properties including recommended temperature of bonding, heat resistance, resistance to water, and solvents, etc. Manufacturers should also be able to advise on resistance to PVC plasticizer migration, when PVC is being joined, and have information on adhesive viscosity at the recommended bonding temperature. Of course it is always sensible to get at least a second opinion, and to carry out impartial trials. The manufacturer being consulted may not actually sell the best product or even the best chemical type for the job. They may judge that it is not in their best interest to recommend a competitor's product!

Chemical types include polyethylene, polypropylene, (the two chemical types merge and are often referred to as polyolefin), polyamide, polyester and polyurethane. There are copolymer varieties of each chemical type allowing a wide range of properties including melting points and heat resistance to be obtained. Polyolefins tend to be the most economical but tend to have lower durability. The polyurethanes tend to be the most expensive but they are capable of giving softer, more flexible and stretchy laminates.

Adhesives in film or web form are generally significantly more expensive than corresponding adhesive powders. Continuous film adhesives cause stiffening which may not be a problem in the case of say headliners. Slit films, which reticulate on the application of heat, are available, e.g. Sarna Xiro films. These allow a more flexible handle as do adhesive webs or powder. Adhesive powders are available in all the chemical types and also in particle sizes ranging from very small, up to about 500 microns or so in diameter. The choice of size depends on a number of factors including the machinery available, the surface nature of the substrates and the handle and properties required. There are a number of processes by which hot melts can be applied, each with its own merits, see Fig. 4.16.

4.4.4 Materials to be joined

The largest volume material in the car interior is the car seat cover which is a triple laminate made up of polyester fabric joined to polyurethane foam with a thickness of anything between 1 and 10 mm, with a scrim fabric on the back. Door casing and headliner fabric is also laminated to polyurethane foam to provide a soft touch, but a scrim fabric is not generally needed. A variety of methods is used in door panel assembly with textiles being used in combination with plastic foils in polyurethane, PVC,



4.16 Hot melt adhesive application methods. Diagrams reproduced with kind permission of EMS-Chemie AG Switzerland. The hot-melt screen printing and hot-melt roller printing methods require a screw extruder to melt the powder and deliver the melt adhesive to the coating head. Diagrams reproduced with kind permission of EMS-Chemie AG (Switzerland).

PVC/ABS and polypropylene; textile/leather combinations appear in up-market models. Solvent spray adhesives are still widely used with 100% solids hot melt coming into use. Some manufacturers make use of pressure-sensitive adhesives, which are clean and require no heating or drying and no special safety apparatus such as extraction units or spray booths. The nature and texture of the materials being joined, the performance required plus the plant available, all have an influence on which adhesive and which adhesive type to use.

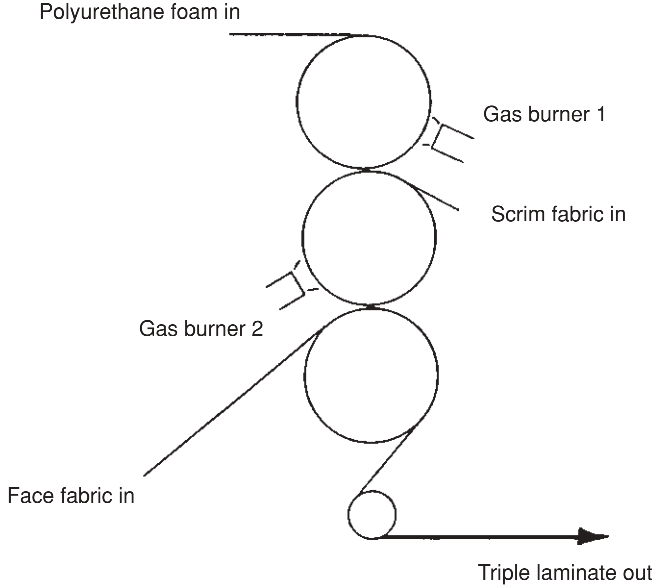
The following factors must be taken into consideration:

Chemical nature of substrates to be joined i.e. polyester, PVC etc.
Physical condition i.e. texture, pile and surface nature – will it be damaged, especially by hot-melt processes?
Fabric construction, open or relatively closed – will adhesive penetrate?
Fabric stability – how it will affect handling – is stretching or shrinkage likely to occur?
Presence of fabric finish or residual lubricant and possible effect on adhesion.
Temperature resistance required of the resultant laminate.
Initial bond strength specified.
Bond durability, i.e. resistance to water, high relative humidity etc.
Plasticizer migration (of PVC components).
UV and light resistance (if applicable).
Possible effect on appearance, e.g. discoloration of face fabric.

4.4.5 Flame lamination

The process in widespread use throughout the world is flame lamination, which was actually invented in the 1950s and extensively developed commercially in the 1970s. This lamination method makes use of the polyurethane foam itself as the adhesive and is a quick, economical process. All three components, face fabric, polyurethane foam and scrim fabric are fed into the laminator and the three materials, joined together, emerge at speeds between 25 to 40 m (or more) per minute. A gas flame licks and melts the surface of the moving foam, which then acts as the adhesive to the fabric, which is laid over it. This happens twice in a double head machine as shown in Fig. 4.17. To compensate for the foam burnt off, input foam slightly thicker than that specified must be used. Headliner and door casing face fabric is generally produced in the same way but without a scrim – a bilaminate. It is possible to flame laminate polyester face fabric to a polyester non-woven material (polyurethane foam substitute), using 'mini' foam, i.e. polyurethane foam about 0.5 to 1 mm thick. The foam adhesive is virtually all burned off, but some readers may hold the view that this practice is not satisfactory because one of the objectives of using non-woven fabric is to replace polyurethane foam and remove the need to flame laminate!

Machine settings controlling flame temperature (gas/air ratio), burner distance, gap separation of the rollers and speed must be optimized for each quality of foam and fabric being laminated. Flame-retardant grades may



4.17 Flame lamination. The gas flame from burner 1 melts the surface of the foam, which then acts as the adhesive for the scrim fabric. On the other side, burner 2 melts the other surface of the foam, which then acts as the adhesive for the face fabric. Thus three separate materials are fed in and a single triple laminate emerges.

need more burn off to produce a satisfactory bond. Originally polyether polyurethane foam could not be bonded well by the flame lamination process but the foam manufactures have modified it and it can now be bonded just as well as polyester polyurethane foam, although different machine settings may be needed. The two types of foam, which are both polyurethanes, have slightly different properties, the main one being that polyether polyurethane foam has better hydrolysis resistance than polyester polyurethane foam. The former variety is better suited to more tropical regions of the world and is specified by some OEMs. The two terms sometimes cause confusion, especially when for brevity they are referred to as simply 'ether foam' and 'ester foam'. They are both polyurethane foams.

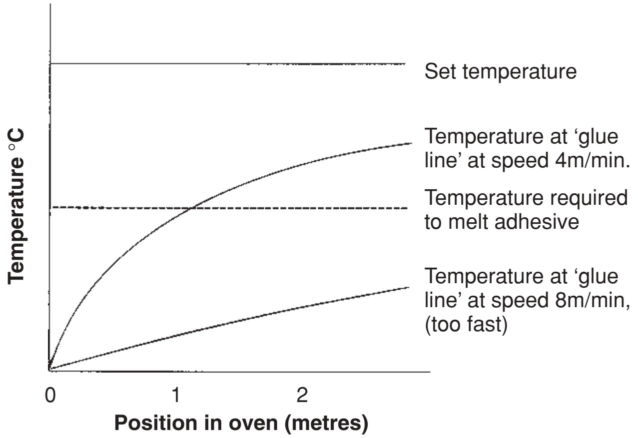
The flame lamination process has come under environmental scrutiny in recent years,[16,17] because it produces potentially toxic fumes by the burning of polyurethane and alternative methods have been developed using hot melt adhesives.[18–21] However the cost of controlling the emissions is, in many cases covered by the economies of the process and certain large volume operators have chosen to continue to operate flame laminators.[22,23] They have installed effective fume control equipment such as carbon adsorption which has satisfied the environmental authorities. Flame lamination produces a flexible laminate with high bond strength and without affecting the aesthetics of the fabric in any way. A particular requirement of laminated fabric for car seats is the ability to form both concave and convex curves without 'cracking'. In-put tension control needs to be controlled very carefully for the laminate to be uniformly dimensionally stable and to have the ability to lie flat on the cutting table. Panels cut from the laminate must keep their shape and not distort under differential tensions within the material itself because of the substrates, foam in particular, being joined in a stretched state.

4.4.6 Flatbed laminators – calenders

When the issue of flame lamination being an environmentally unfriendly process arose, thoughts first turned to calenders and the hot-melt adhesives, which had been used in the garment industry for many years. The calender principle is that a sandwich is made of the two materials being joined with a hot-melt adhesive film, web or powder in the centre. This is then fed into the calender which heats the materials and melts the adhesive to produce a laminate. Webs or films are only available at fixed weights and widths but if volumes are sufficiently large, the suppliers will normally supply any width required. Much higher volumes are required for webs or films to be specially made at a particular weight. The advantage of powder is that it can be conveniently applied at any weight, and at any width for both short and long production runs of fabric.

Calenders are usually heated electrically and transfer of heat by conduction is not as rapid as say in a textile stenter. The goods being processed take heat out of the machine and heat is being lost all the time to the surroundings. Because of this bond strength should be checked frequently in a production run. The important temperature is the 'glue line temperature', i.e. the actual temperature in between the two substrates where the adhesive actually is, and not the temperature on the machine control panel. Depending on the thickness of the substrates and machine speed, this temperature could be 20–30 °C higher than the glue line temperature and the adhesive not being melted, see Fig. 4.18. Heat-sensitive paper is available to determine the actual temperature at the glue line.

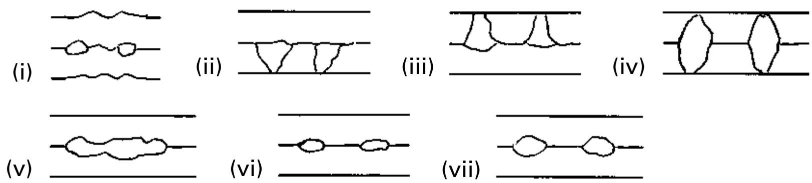
Optimum heater temperature, height adjustment, pressure and speed settings, must be established by thorough trials to determine the best conditions for producing laminates of the right quality at the maximum speed for commercial production. Modern machines accurately record all processing conditions and can be computer controlled. Conditions that are too mild will not effectively melt the adhesive and produce the required bond



4.18 Calender/flat bed lamination. Contact heat. At speed of 8 m/min bonding does not take place because the adhesive never reaches its melting temperature. The correct balance of time and speed determines the 'dwell time', i.e. the time actually in the heating zone. This must be optimized. The set temperature may be hot enough to damage the goods if the machine stopped or is operated too slowly. Heat-sensitive indicator paper is necessary to determine the actual temperatures attained at the 'glue line' and at the surface of the goods.

strength, whereas conditions that are too severe could damage the fabric appearance by glazing or by flattening pile or texture. Viscosity of the molten hot-melt adhesive is important because at the bonding temperature, it must flow to cover a certain amount of substrate area and 'key' into the substrates being joined.[24] If it flows too much it will strike through the substrates causing stiffening and in extreme cases flow away from the surface, hence resulting in a poor bond, see Fig. 4.19.

Calenders are available from several manufacturers with different designs, e.g. different layout of heater zones and heater arrangement, some with cooling inside the machine, others with the cooling unit outside. Much thought has gone into the design to enable them to produce quality laminates at commercial speeds. The main drawback of the calender method is that the heat is supplied to the hot melt adhesive *via the substrates themselves*, which could be prone to damage by heat, especially fabrics with textured yarns or with a pile. This is aggravated by the fact that when the two substrates are nipped together to form the bond, they are both hot. Moreover, the materials most often being joined in the automotive textile industry, textured polyester fabric, non-woven materials and polyurethane foams are also good *insulators* of heat and so the process is quite slow. The 'open' lamination method shown in Fig. 4.20, being used for substrate S3, is best

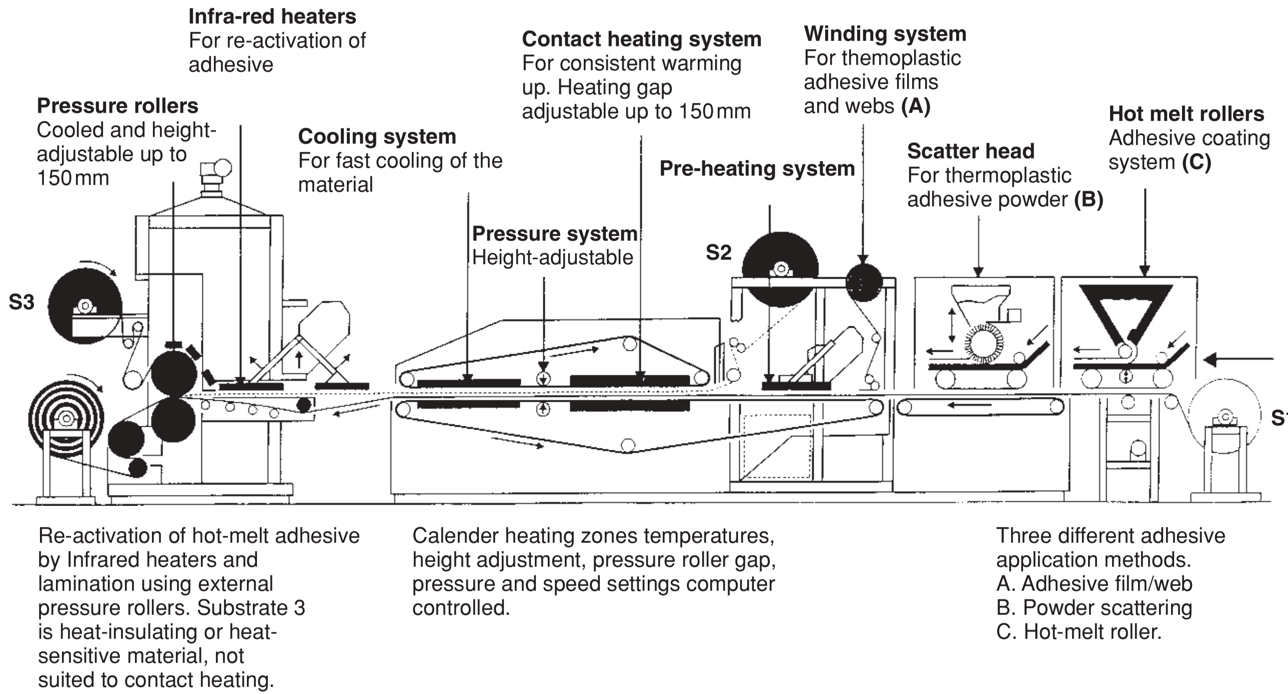


4.19 Fusing problems associated with powder hot-melt adhesives. (i) Substrate distortion, shrinking. (ii) Strike through base substrate, sticking to belt or roller. (iii) Strike through top substrate, sticking to top belt or roller. (iv) Strike through both top and bottom. (v) Powder joining together causing stiffening. (vi) Insufficient penetration and melting – poor bond. (vii) Correct bonding. Reproduced with kind permission from EMS-Chemie AG Switzerland.

for especially thick materials – if the equipment is available. Infra-red heaters are used to heat the adhesive but they should emit radiation of the optimum wavelength so heat is absorbed irrespective of the colour of the substrate.

To minimize damage to the texture or raised surface of pile fabrics, the top belt on some calenders can be set to a precise distance from the bottom belt. This facility of being able to set a gap between the belts is also useful to reduce loss of thickness by crushing which can occur especially when pressure is combined with heat. However, having said this, both polyurethane foam and thick non-woven fabric materials, (as has already been noted), are good insulators of heat and some compression is necessary, for rapid heat transfer. Polyurethane foam is likely to recover, but non-woven fabric may not – depending on the temperature and pressure applied and this must be checked beforehand, see Table 6.1. Any number of layers of material can be joined simultaneously provided a multiple feed system is available, but the limiting factor is likely to be speed, because heat has to penetrate through all the layers to reach the glue line to activate the hot-melt adhesive. Generally the choice is low-temperature machine settings to preserve material properties and low production speeds – or higher temperature settings for higher production speeds with the risk of thermal damage to the fabric or other substrate. High temperatures may also produce unsatisfactory results because of thermal shock, shrinkage of the goods and strike through of adhesive.[24,25] Long heating zones such as those on the newer Reliant calenders allow lower temperatures to be used for more gradual and gentler heating overcoming these problems and, also allowing reasonable production speeds.

Calenders, also referred to as flatbed laminators, are used extensively for headliners and other textile automotive components because several layers of materials, each with an adhesive layer in between can be joined with one



4.20 Schematic representation of lamination of three substrates in a single continuous process using three different hot melt adhesive types. Reproduced with kind permission of Machinenfabrik Herbert Meyer GmbH.

pass. The use of calenders is not an alternative to high volume flame lamination for seat covers or other fabric/foam joining operations because of the relatively slow speed. Calenders can be used for laminating non-roll goods, such as leather hides to foam and for small scale production lamination. They are especially useful for development and preparation of samples, when anything from A4 size pieces to thousands of metres can be conveniently produced. Belt joins may produce a mark on the goods, which can sometimes be overcome by balancing the conditions of temperature and pressure. Belts with very flat joins are available but the most satisfactory remedy is use of continuous belts which have no join but these are considerably more expensive than joined belts.

4.4.7 Powder scattering

Powder adhesive lamination is the most versatile, and probably the most economical method of hot-melt lamination, because powder can be applied at any optimized weight and width, and also because powder is not as costly as the corresponding web or film. Careful thought and pre-trials are needed to determine on which of the substrates to scatter the powder. The usual procedure when laminating automotive fabrics to foam is to scatter the powder on to the face fabric first because the unsupported foam on some machines is not capable of being self-supporting. When the scrim is laminated the powder must be put on to the foam because in most cases the scrim construction is too open to scatter powder on it. In this situation however, powder may sink into the foam and be wasted and therefore the choice of particle size needs careful consideration. Smaller particles are not only wasted, they can cause the foam to lose resiliency and reduce porosity. The machine consists of a hopper containing the powder with a gravure roller at the bottom, the effective length of which can be controlled by the use of blanking off plates. The roller rotates and picks up powder, which is scrapped off by a wire brush outside the hopper. The powder then falls onto the moving substrate below, see Fig. 4.16.

The amount of powder applied is controlled by the speed of rotation of the gravure roller and the speed of the moving substrate. The substrate, with powder on it, then passes under infra-red heaters which melt the adhesive. The speed must not be excessive or the powder adhesive will not be melted sufficiently. The second substrate to which it is being joined, is then placed over the molten adhesive and the two materials are then joined by bringing them together at a pair of nip rollers, or alternatively the substrates pass into a calender. When infra-red heaters and nip rollers are used, the same factors, relating to hot-melt adhesives, that were mentioned in connection with calenders, apply. The molten adhesive must have the correct viscosity at the temperature of bonding for satisfactory results. In addition the correct balance of time (speed), temperature and pressure must be established for the actual substrates being joined and the powder adhesive being applied. As for calenders, too much pressure and time could cause the adhesive to strike through the substrates causing problems of appearance and stiffening.[24,25] Too low a temperature, too fast a speed and too low a pressure could result in a poor bond. Careful cooling may also be necessary to avoid curl in the completed laminate – commercial apparatus is available for this. Any powder which does not fall on to the substrate, can be collected in a tray underneath the machine and reintroduced into the hopper thus minimizing waste.

4.4.8 Powder printing – dry and paste

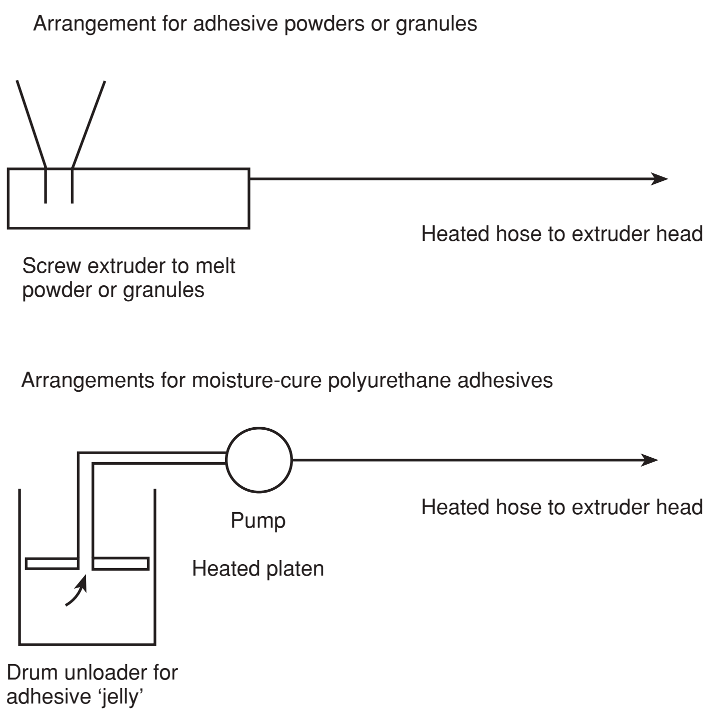
Powder can be applied directly to the fabric by a dry printing technique using a gravure roller. This method is also termed 'powder point', see Fig. 4.16. Powder can also be compounded into a paste for dot printing through a rotary screen, e.g. Stork apparatus or for spreading with a doctor knife, i.e. by direct coating. With the paste process the fabric can if necessary, be rolled up after drying for reactivation at a later date by another unit or customer and this technique is widely used in the non-wovens industry. Preparation of the paste is a skilled compounding process because it is necessary to produce a paste with the correct viscosity, stability and flow properties as well as giving the adhesion required. The finest particle-size powder is normally used and in the case of screen printing, mesh size must be predecided to obtain a laminate with the required handle and bond strength.

4.4.9 Melt print – roller and screen

In this process hot-melt powder or granules are melted into a trough. A gravure roller with indentations of the appropriate size for the materials being processed, picks up the adhesive in these indentations and transfers it by a print process on to one of the substrates. The material is then joined to the other substrate by nipping together. A variation of this method makes use of mesh screens, see Fig. 4.16. Indentation size and mesh size, are critical in producing a laminate with the required bond strength and handle and it is likely that more than one or two rollers or screens will be necessary to cover the range of adhesive add-on required for a range of different substrates. The same considerations of molten adhesive viscosity, time, temperature and pressure already discussed above apply, to produce a laminate with the correct qualities. One drawback to these processes, is the amount of down time necessary to clean the machinery, especially when the adhesive, roller or screen is being changed. Hot-melt moisture-cure polyurethane adhesives are applicable by this technique, and apparatus to prevent premature cross-linking by making use of an inert gas such as nitrogen may be necessary.

4.4.10 Slot die extruder

The machinery includes pumps capable of delivering liquid molten adhesives, jacketed or heated hoses and a coating head capable of delivering adhesive uniformly across the width of the goods. A drum unloader with a heated platen is required for adhesive in jelly form and a screw extruder for adhesive in powder or granule form. To produce a flexible laminate, the adhesive is extruded in a discontinuous array of dots or small streaks. Again the same balance of time, temperature and pressure apply to obtain just the correct bond strength without laminate stiffening or adhesive strike through and again the adhesive must have the correct viscosity. The molten adhesive is applied to one of the substrates just in front of a pair of nip rollers and just before the second material is introduced, see Figs. 4.21 and



4.21 Slot Die Extruder Adhesive Applicator. Adhesive delivery methods.

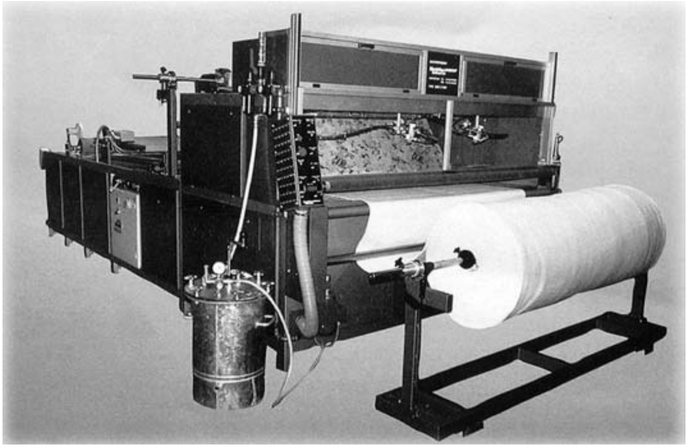
4.22 Slot Die Adhesive coating and lamination head. Courtesy of Nordson (UK) Ltd and reproduced with kind permission.

4.22. An important advantage of this method is that the substrates being joined are not themselves exposed to heat during the lamination process and so there is minimal risk of damage to fabric aesthetics of texture and pile.

Because the hot-melt adhesive is enclosed right up to the moment before use, this allows the use of moisture-curing polyurethane adhesives. These adhesives are activated by moisture from the atmosphere and in the substrates themselves. The chemical cross-linking allows high bond strengths at low levels of add on, and because they are also 100% active material with no solvents present, they are environmentally friendly. Machine downtime in this process is believed to be a minimum because the adhesive is mainly totally enclosed within the system and all parts are heated. A blanket of an inert gas such as nitrogen is sometimes necessary to prevent premature cross-linking of the adhesive during down periods.

4.4.11 Spray application

The problems usually associated with spray applications are uniformity and precision of application, occasional blocking of a spray nozzle, control of the liquid being sprayed – usually a solvent and continuous drying of the liquid. In theory, all types of liquid adhesives can be sprayed, hot-melt, solvent-based, water-based and high-solids versions. In practice however, hot melts need expensive apparatus to ensure they do not solidify prema-



4.23 Machtex Multi-purpose spray adhesive laminating and coating machine, Type CMW-3. Reproduced with kind permission of Mach Tex Holland BV.

turely or char, solvents present problems of flammability and water-based adhesives may not dry at commercial speeds. In recent years, reactive polyurethane adhesives have been developed which allow high bond strengths with low levels of add-on. Moisture-cure polyurethane adhesives do not need a high temperature to initiate cross-linking and are available as a jelly with virtually 100% solids content.

Machtex of Holland have specialized in spray lamination machines over many years and their machines can be used to process materials such as raised velvets or velours which would be damaged by high temperatures and pressure. Figure 4.23 shows their CMW-3 Machine is a multi-purpose model suitable for several adhesive types.

4.4.12 Discussion of the various methods

In common with all lamination methods, the substrates must be delivered to the lamination head, where they are actually joined together in a flat tension-free condition, if a quality dimensionally stable laminate is to be produced. This is not easy with polyurethane foam and lightweight knitted scrim fabric, both of which stretch easily, especially at the lamination speeds necessary for a commercially viable process. Lamination is a critical process and must be carried out with precise control for consistent stretch and set properties, consistent thickness, consistent bond strength and the ability to lie perfectly flat for accurate panel cutting. The machine feed and take up units are just as important as the lamination unit itself. They need careful design and set up if lamination is to continue at commercial speeds when fresh rolls of face fabric, foam and scrim are joined on without stopping the process. These material-handling logistics are common to all methods of lamination. Fabric surface geometry, handling considerations, volumes being processed, plant and personnel skills available all contribute to the hot-melt application method. A schematic multi-purpose lamination range is shown in Fig. 4.20. In all hot-melt processes one of the main problems is rapid cooling and premature loss of stickiness, ('tack') of the hot-melt adhesive in air before the second material can be introduced. This is particularly relevant of powder adhesive containing small individual particles which lose heat to the surroundings very quickly. The time the adhesive remains molten and tacky is referred to as 'open time'. Sometimes small secondary heaters, an infra-red bar or even a small ceramic heated bar, are used to provide extra heat just before the joining nip to prolong the open time.

When the various methods are costed, *all* factors must be taken into consideration, i.e. cost of adhesives, energy consumption, speed of process, time spent on cleaning and maintenance, time spent when adjustments are made to produce different qualities of product, manning levels, 'burn off' of foam or reduction in thickness. Fume abatement – both initial installation and running costs, and cost of second quality material produced must also not be overlooked. Other ancillary items which may also be required should be noted and included, e.g. drum un-loader apparatus, hot-melt extruder and pumps in the case of hot-melt adhesives. For high production levels involving polyurethane foam, flame lamination appears to be still the most economical method for most producers despite the increasing cost of emissions control.

4.4.13 Welding

Welding of textiles and plastics is essentially a hot-melt process and only thermoplastic materials can be welded directly. There are two types commonly used in textile and plastic processing, i.e. ultrasonic welding where localized heat is produced by vibrational mechanical energy and HF (high frequency) and RF (radio frequency welding).[26,27] In the latter two cases – which are similar processes – the localized heat is produced by molecules of the substrates vibrating rapidly in an applied electrostatic field. The thermoplastic materials must first melt and then flow and form a bond. Materials which weld well by one method do not necessarily weld well by the other methods. PVC is by far the best material for HF welding but produces only acceptable results with ultrasonic welding. Hot-melt adhesives can also be activated by welding techniques and used to join materials which cannot be satisfactorily joined together directly. To be suitable for RF welding the material must be thermoplastic with a high 'dielectric loss factor' and must have the correct melt flow properties.

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