CHAPTER 4

Carpet and yarn printing

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4.1 HISTORICAL DEVELOPMENT OF CARPET PRINTING

The initial development of the printing of carpet piece goods took place in the UK shortly after the introduction of tufted carpet production, which followed the lead given by the USA from the early 1950s onwards. The manufacture of broadloom tufting machinery expanded rapidly in the period 1956–64, with continuous improvements in sophistication and productivity following the establishment of such firms as British Tufting Machinery, Cobble Bros (subsequently Singer Cobble), Ellison Tufting Machinery and Edgar Pickering of Blackburn. By 1980 tufted carpets constituted 80% by area of all soft floor coverings made in the UK, and half of these were printed. The desire to print tufted carpets arose because of the then very limited patterning potential of tufting machines; even today, despite the advent of the Hydrashift and Graphics machines, with which it is possible to produce patterns comparable with those seen in two- or three-frame woven Wilton carpets, tufters cannot imitate the more complex multicolour designs of printed carpets. Some improvement in design appeal became available with the introduction of space-dyed and differential-dyeing nylon yarns and with variable-pile-height tufting mechanisms using the 'buried end' pattern effect. The UK market was, however, accustomed to traditional Axminster designs and it was therefore opportune to look to printing techniques to achieve greater flexibility.

Three prototype machines were designed during 1957–60, of which two involved surface roller printing (a principle that had long been used for some types of textiles and for wallpaper printing) and the third a novel dip printing process. The two surface roller printing machines (developed independently by BTM and Stalwart Dyeing Co) incorporated wooden printing rollers carrying raised designs covered with rubber. Each roller rotated in a trough of dye liquor placed below it, and the pile of the carpet was pressed against the patterned surface by a counter-pressure roller. The BTM machine was not developed further but the Stalwart machine went on to prove popular, particularly in the USA.

During the same period Deep Dye Industries, USA, patented a novel machine in which each colour area of the design to be printed was defined by flat-bottomed, shallow troughs fed with dye liquor. The carpet was pressed, face downwards, on to this printing 'plate'. Thus all the colours of the design were printed simultaneously, which obviated the registration problems of all other methods. The process was particularly good for long-pile carpets, but never achieved widespread usage. The initial preparation of patterns for both these early systems was slow and labour-intensive and required considerable craftmanship, being comparable to the making of hand-printing blocks.

Early attempts to use conventional flat-screen textile-printing machines for carpets quickly showed that a completely new design would be necessary to obtain satisfactory penetration of the print paste into the carpet pile. This was first achieved by Carpet Printers Ltd (Bradford Dyers' Association), who produced a machine that utilised a vacuum slot beneath the carpet surface to achieve penetration of the paste into the pile. The machine, which enjoyed modest success in the UK and America, was very ruggedly constructed for, in contrast to a textile printer, extremely heavy engineering is required for the intermittent transport of the carpet (which may weigh as much as 4 kg m^{-2} when wet) and also to raise and lower the large screens (up to 5×1.2 m in size). During these early days printed carpets carried a definite stigma, as did tufted carpets in general, since they sold at the low-quality end of the market and had poor wear performance, viscose rayon being the main fibre used. Indeed, manufacturers tended to hide the fact that the carpets had been printed by using such phrases as 'design dyed' and 'pattern dyed'!

The situation improved, however, with the increasing introduction of nylon carpets and a trend towards finer tufting gauges and low-level loop carpet constructions, which were well suited to carpet printing using the newer flat-screen and later rotary-screen printing machines. From the mid-1960s onwards, following the introduction of the Peter Zimmer machine, carpet printing expanded rapidly, especially in the USA, the UK and, to a lesser extent, Germany. Fashion is cyclical, however, and the carpet trade seems to favour a slow swing between plain shades (or very muted patterned effects) and multicolour Axminster-type designs. This trend, together with increasing competition from Europe and in particular from Belgium, has affected the share of printing in the UK, and the present-day industry is much smaller than it was 10–15 years ago (Table 4.1).

Printing carpets in piece form is the most logical approach to achieve minimum stockholding and the fastest reaction to customer demand. For a time, however, certain forms of yarn printing were used for the production of tufted carpets. The production of

Table 4.1 Estimated size of printed carpet market

	Production of tufted carpets /$m^2 \times 10^6$		Proportion of tufted carpets printed as yarn or in piece form/%			
			As piece		As yarn	
	1980	1990	1980	1990	1980	1990
USA	920	1028	25	10	10	4
Germany	120	129	15	19	27	1
UK	125	113	50	33	10	1
Belgium	120	222	15	43	30	3
Japan	100	141	0	3	0	0

tapestry yarns for patterned woven carpets was practised over 150 years ago, the main process using a large drum round which a warp of yarns was wound and printed in a complex, preset design. After the dye was fixed and excess dye and chemicals washed off, the yarns were beamed and then woven into a fully patterned carpet on a single-frame Wilton loom. With the advent of tufted carpets, similar techniques were examined with the aim of overcoming the lack of patterning potential of the early tufting machines. It soon became clear that differences in tension, shrinkage and so on between individual yarns comprising the warp were too great, and pattern fit was easily lost during printing, steaming, washing and drying. Two warp-printing processes were, however, devised independently in the USA by Westpoint Pepperell and Crawford/Mohasco (the latter's product being subsequently commercialised as the Crawford Pickering machine).

Of much greater importance was the warp printing of yarns with random bands of colour to yield attractive, random speckled designs on the tufted carpet, an effect which became fashionable from the 1960s onwards and still remains popular, particularly in Europe. A completely different approach, the knit–deknit method, was also devised in America and is usually ascribed to Fred Whitaker, who claimed to have originated the term 'space dyeing'. This technique involved pad dyeing of the yarn in tubular knit form, followed by overprinting with multicoloured stripes using surface or engraved printing rollers. Many other space-dyeing systems have since been devised, but somewhat similar effects can now be achieved more economically using producer-intermingled, differential-dyeing nylon yarns.

None of these approaches to the production of patterned carpets represents the end of the road, however. The use of computer-aided design (CAD) systems for the preparation of textile patterns, which can then be stored as digital information on floppy discs, is now commonplace. This information can then be used to produce negatives for colour separations or, more directly, for the laser engraving of lacquer screens. The next logical step is to use the digital data more directly still, i.e. to drive the printing mechanism, and this has been achieved in various ink-jet printing machines. This type of advanced printing system is typified by Milliken's Millitron and Zimmer's Chromojet machines. These systems still use conventional dyes which require fixing and washing off, but there is no basic reason why colour application should not be the very last process applied to the carpet. This is the case with the printing of carpet tiles and rugs using the transfer printing techniques described in Chapter 3.

The historical development of carpet printing has been reviewed by a number of authors [1–3].

4.2 YARN PRINTING (SPACE DYEING)

Although the printing of yarns for true patterned effects proved very difficult to control, the random space-dyed effects that can be more readily attained by a variety of yarn-printing methods have continued to be popular. The patent literature abounds with systems for producing coloured flecked effects on yarns but the two most successful methods entail either warp printing or colour application to a tubular knitted 'sock'. The essential process sequence begins with dye liquor application, followed by steam fixation, washing-off and drying

Various warp-printing methods have been used over the years. In most present-day systems several ends of carpet yarn are taken from wound packages on a creel and colour is applied, either by lick rollers or by some form of spray or spinning disc applicator, to the yarns. The yarns are carried past the print heads in warp form or lying on a brattice on which they have been laid down in a continuous circular or elliptical coil. Warp printing tends to give the so-called 'long spacing' designs in the tufted carpet produced from them.

Knit–deknit applications, on the other hand, tend to give characteristically speckled 'microspaced' designs, because of the limited degree of penetration of dye liquor achieved by the duplex printing rollers into the yarn sock.

Although the end-effects produced by the two methods are basically different, the processes can be modified so that their results are more closely comparable. Thus the long spacing effects of warp printing can be imitated by overall application of a ground colour followed by colour spotting with segmented lick rollers or oscillating jets of dye liquor. Similarly oscillating jets of liquor can be applied to knitted sock and excess liquor squeezed out before steaming. This leaves large coloured areas with good liquor penetration and, when tufted, the long spacing effect is achieved. Some examples of machines used for space dyeing are listed in Table 4.2.

Table 4.2 Space dyeing systems

Yarn application	Knit–deknit application
Martin Processing	Fleissner
Callebaut de Blicquy	Ilma
Superba[a]	Whitaker
Hoerauf[a]	Murphy

a In these machines dye fixation and heat setting of the yarns is achieved simultaneously

In contrast, the Crawford Pickering warp-printing system was designed to produce fully patterned tufted carpets with up to eight colours. The warp of yarns was passed between a pair of cylinders, around the surface of which were mounted rows of small dye applicator pads (about 20 mm square). The lower cylinder dipped into a trough of dye liquor (in a similar manner to the Stalwart printer described in section 4.3.1) and dye was thus picked up on the surface of the pads. These pads could be actuated mechanically so that when opposing pairs were in the raised position the yarn passing between them was printed. With a typical 5 mm pile height carpet, a 20 mm printed length of yarn was equivalent to two tufts of the final carpet. With longer pile carpets of the Saxony or shag pile type single tuft definition was possible, and it was on such carpet constructions that the best results were ultimately obtained. In the original machine the pattern control mechanism was a movable notched bar, the positions of the notches determining the raising or lowering of the print pads. Preparation of pattern bars was therefore rather tedious; later, one company introduced electropneumatic actuation of the individual print pads with pattern data provided from a microprocessor. Ultimately, however, the full patterning potential of this machine was not realised, mainly because of the problem of keeping a warp of printed yarns in register. There is now only one machine left in operation.

4.3 CARPET PRINTING

4.3.1 The Stalwart machine

The print head of the Stalwart machine consists of up to four print rollers, which run in troughs containing a thin print paste, with the carpet pile to be printed being pressed against the upper surface of the print roller from behind. The print rollers are arranged at 45° to the vertical, one above the other (Figures 4.1 and 4.2). Maximum running speed is about 6 m min^{-1}. The individual print rollers consist of a steel-centred wooden bowl on the surface of which is mounted the design. The design is cut from thick rubber sheet covered with a nylon or polyester fibre pile. The relative simplicity of this machine ensured its success at a time when two- or three-colour blotch designs on plain ground shades were popular. Fitting patterns with 100% coverage cannot be printed, so the ground shades are obtained either by printing on predyed carpet or by wet-on-wet printing on to a prepadded or cover-printed ground. There is also limitation in line definition, as the narrowest rubber strip that can be mounted on the roller is about 4 mm wide. The machine has, however, proved ideal for the production of the so-called shadow-printed effects on long-pile carpets, which have remained in fashion for many years.

4.3.2 Flat-screen printing machines

Initially there were two types of flat-screen printing machines for carpets, namely the BDA machine (manufactured for a time by Singer Cobble) and that produced by Peter Zimmer.

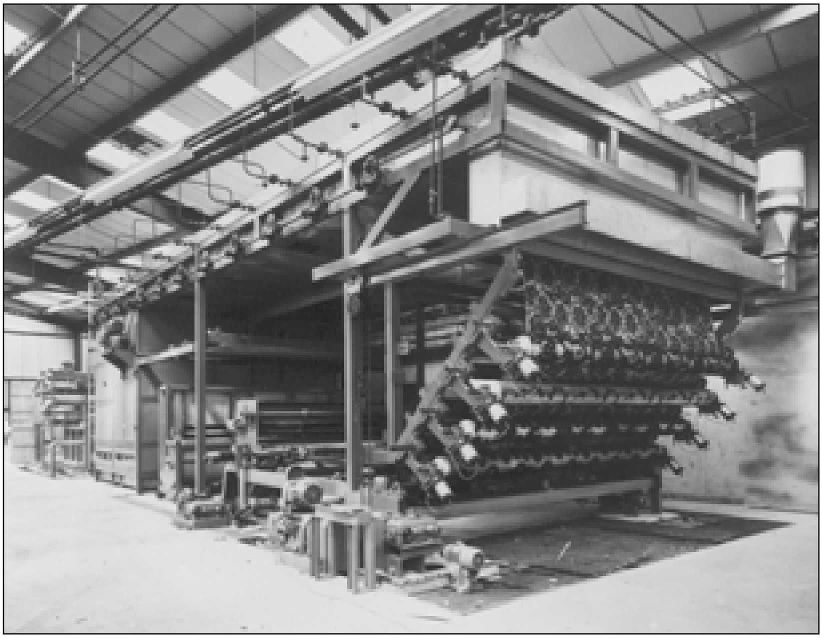

Figure 4.1 General view of the Stalwart printer

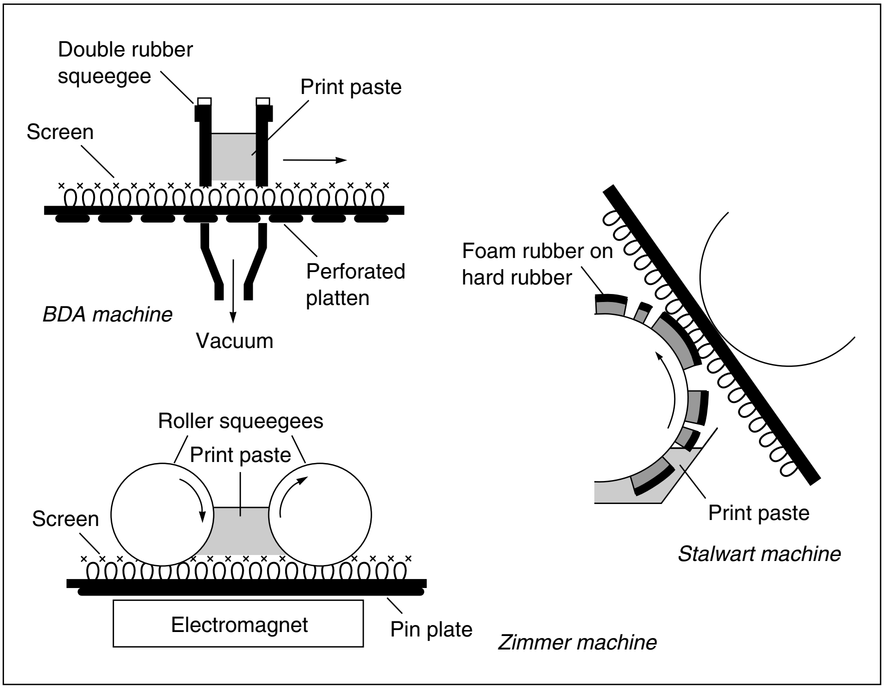

Figure 4.2 Principles of the Stalwart, BDA and Zimmer machines

BDA machines remained in operation until 1990 but none is still in use, although this machine is of some interest from a historical point of view (section 4.1). In this machine a reservoir of dye was confined between the blades of a double squeegee, and good pile penetration was obtained by applying a vacuum beneath the strip of carpet over which the squeegee passed (Figure 4.2). To achieve this the conventional rubber transport blanket was replaced by an endless belt of perforated metal platens, which carried the carpet forward when the screens were lifted after each printing cycle. Despite the relatively low vacuum used (about 75 mm water gauge) it was possible to obtain good penetration on fairly long-pile carpets. The maximum running speed of the BDA machine was about 5 m min^{-1}.

The Peter Zimmer machine operates on the principle of the electromagnetic double-roller squeegee, the print paste being confined between the two rollers which are of a considerably larger diameter (80 mm) than those used on the similar Zimmer flat-screen printer for textile fabrics. Pile penetration by the print paste is achieved by the 'pressure wedge' of paste trapped in front of the second roller as it moves forward over the screen (Figures 4.2 and 4.3). As in the BDA machine, the screens are covered with 60–70 mesh polyester screen fabric. The downward pressure and reciprocating motion of the squeegee rollers (more than one stroke is usually necessary to achieve good pile penetration) is achieved by a bank of electromagnets moving beneath the endless rubber belt that carries the carpet. Maximum running speed is usually 2–4 m min^{-1}, depending on carpet quality.

As in the textile-printing field, rotary-screen printing has become the dominant method used to print carpets, but there is still a market niche for flat-screen printing where short runs to a pattern or colourway are required (for example, in the custom design field of architect/specifier contracts for prestige buildings).

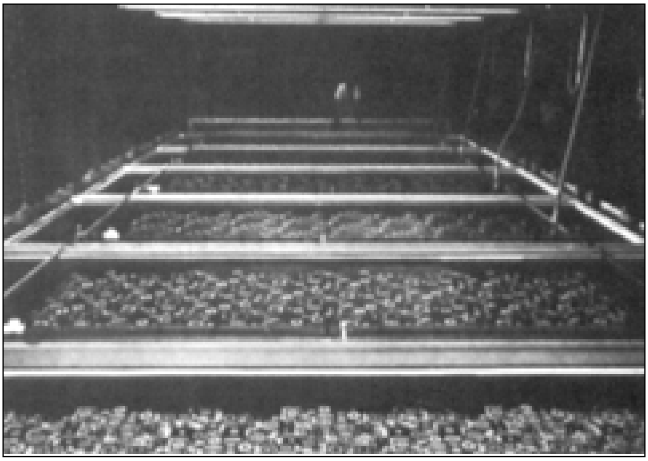

Figure 4.3 View of the Zimmer flat-screen printer from the feeding end

4.3.3 Rotary-screen printing machines

The main difference between rotary-screen printing machines for carpets and those used for textiles lies in the type of squeegee used. All carpet squeegees are considerably larger, and end-rings with wider openings are therefore used. The standard print width is usually 4 m, so considerable storage space is necessary for the many screens and designs used by a typical carpet factory. The screens themselves are galvano nickel of a fairly heavy gauge (0.3–0.5 mm thick), with a much coarser mesh (20–30 mesh) than that used for flat screens (lacquer screens are not used for carpet printing). Standard rotary screens give a pattern repeat of 1 m but larger screens to give repeat sizes up to 3 m can be provided for particular purposes such as printing oriental carpet designs.

The carpet is transported by means of an endless rubber blanket or rubber strips; these sometimes carry small pins on the surface to grip the carpet backing and prevent progressive distortion as the carpet passes under each print head.

Four types of rotary-screen printer for carpets have been produced, namely:

- the Peter Zimmer machine (now made by Johannes Zimmer, Klagenfurt) with a magnetic-roller squeegee, friction driven with variable magnetic pressure, as in the flat-screen printer; larger screens are possible to give up to 3 m repeats
- the Peter Zimmer Hydroslot system, which relies on hydrostatic pressure to force the paste through a slot in the special squeegee box and into the carpet pile; screen sizes are as above
- the Mitter positively driven roller squeegee, which combines the use of a large squeegee diameter and high paste levels behind the roller to achieve good colour penetration into the carpet pile; special flexible screens of triangular cross-section can give repeats up to 4 m
- the Johannes Zimmer Magnojet and Variojet machines, which are a further development of the Hydroslot system.

The principles of the above machines are illustrated diagrammatically in Figure 4.4, and a general view of a production Zimmer machine is shown in Figure 4.5.

Rotary-screen printers are considerably more productive than the older flat-screen machines. Print speed is 15–30 m min^{-1}, the machine occupies much less space and labour costs are lower. With special screens or actuating mechanisms it is even possible to print pattern repeats of 2–3 m for bordered oriental square designs. The disadvantages include the higher cost of galvano screens and longer screen-changing times (although recent developments in screen-handling equipment have greatly

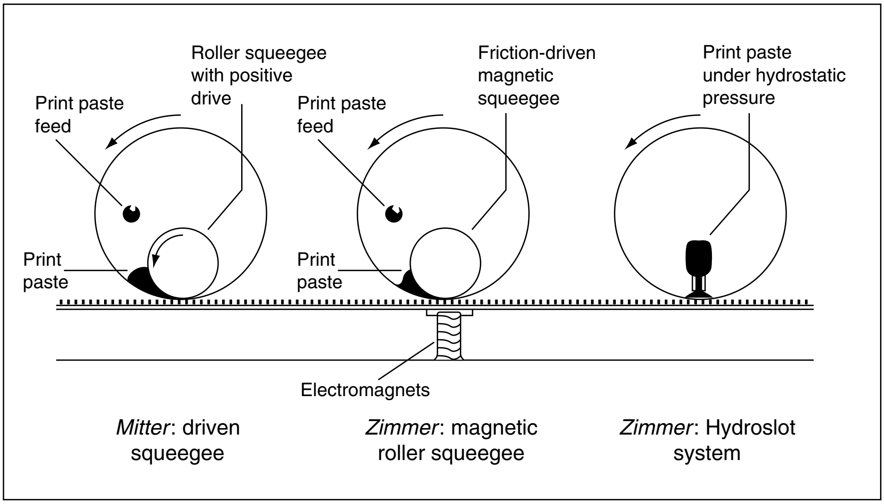

Figure 4.4 Principles of rotary-screen printing

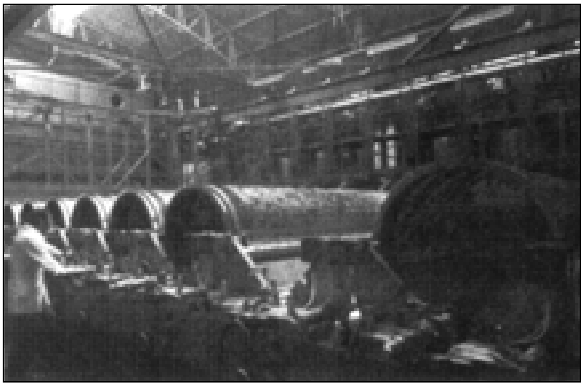

Figure 4.5 Large rotary-screen printer for carpet squares (Zimmer)

improved the situation). There is also a tendency for carpet to spoil during stoppages, because the paste tends to flow fairly easily through the coarse mesh screen whilst it is stationary. The use of thickeners with 'short' flow properties (section 7.7.3) can help to prevent leakage from the screens when stopped.

The rotary screens of the Zimmer machines carry driving gears and bearings which are attached to the end-rings. These are in turn supported on adjustable open bearings arranged in a V-configuration. When the screens require changing, each screen is simply lifted out of the open bearing, together with the associated squeegee and colour feed pipe. In contrast the Mitter machine screens run in closed bearings and, to avoid having to remove the squeegee and colour feed pipe before lifting the screen, the whole print head (including the bearings and main support beam) is lifted from the table. In the original production machines the roller squeegee was driven at a slightly faster surface speed than the screen so that a shearing effect was created. This was supposed to increase the flow of print paste through the screen and achieve better pile penetration. It was subsequently shown that this was not the case (section 4.6.2), and as the shearing action produced unnecessary wear of the screen the squeegee and screen speeds were equalised in later models.

The roller squeegees used are of large diameter (80–160 mm) which allows space for the relatively large wedge of print paste necessary to apply sufficient colour to carpets, particularly to dense high-pile constructions. With roller squeegees, there is a tendency for the carpet pile to be crushed as it passes under successive print heads. This is of little importance when printing low-pile carpets, but does lead to inferior print definition in longer-pile constructions. By contrast, the two Zimmer slot squeegee systems exert minimal pressure on the carpet surface and the penetration of the paste (driven by the pressure head behind the paste) can be precisely controlled. In the original Hydroslot system the print paste was fed into the slot from tall glass columns at the side of the machine and the pressure head was therefore generated statically using level controls. In the more recent Magnetjet system the paste is pumped from a stock tank at atmospheric pressure into a delivery tank which is dynamically controlled at a precise pressure. With this latter system there is much less wastage of paste at the end of the production run.

4.3.4 Spray and jet printing machines

Various machines have been used to produce multicolour patterned effects on carpets over the last 25 years, the effects produced varying from spotted, blotch or streaked effects of a somewhat random nature right through to geometric patterns with regular repeats. Typical examples of such systems that have been exploited during this period are quoted in Table 4.3.

Table 4.3 Multicoloration systems

Maker	System	Description
Küsters	Multi-TAK	Oscillating inclined plane dye applicator
	Küstercolor	
	Foamcolor	Overflowing foam layer, deflected by air jets
Mitter	Multicolor	Divided slot squeegee
Various	ICI Polychromatic	Oscillating dye streams with mangle squeeze
Otting	Jet-Flo	Jets or air-spray jets with on/off control
	Jetfoam	
Gaston County	ColorBurst	Fan-spray jets with on/off control

In the USA the Küsters systems became very popular for the production of a generic carpet design style, which became known technically as Gum-TAK and popularly as ‘shadow printing’ or ‘the American look’, and eventually captured more than half the market. This fashion later spread to the UK, where similar effects were produced using a combination of plain colour applicators and conventional carpet-printing machines. The aim of the original Küsters system was to imitate, at lower cost, the pattern effects seen in carpets tufted from space-dyed yarns. Dye liquor picked up on the surface of a lick roller was divided into individual streams by an oscillating doctor blade, and these were further broken up into a random shower of droplets by a chain and oscillating comb system running between the applicator and the carpet surface. The droplets were applied to carpet which had previously been padded with a ground shade liquor. By varying the viscosity of the dye liquor, the composition and pick-up of the pad liquor and the steaming conditions, sharply defined or more diffuse patterns were obtained.

The pattern potential of the TAK machine was further enhanced by the use of doctor blades with cutaway sections which could be opened and closed by a reciprocating drive to produce larger areas of colour. This machine was used to apply patterns to long-pile carpets, particularly cut/loop pile constructions, followed by an overall coating of a plain paste containing only thickening agent. This had the effect of displacing dye from the tips of the cut pile while leaving the shorter loops unaffected, hence the name Gum-TAK. In more recent times the American market has favoured the effects produced by spray jet systems, particularly because these machines are cheaper and can be run at higher production speeds than the TAK system and can also give good results at lower liquor pick-up values.

All the foregoing methods are limited in the type of design effect they produce and, more significantly, cannot be controlled to produce a prespecified design. Thus the equipment must first be employed to produce a wide range of effects, by altering the colours and the mechanical variables, and only then can selections be made from these by, for example, design or marketing personnel. This is one of the fundamental differences between the earlier jet coloration methods and the second-generation jet printing systems, quite apart from the great increase in sophistication of the control mechanisms, all of which are high-speed electromechanical systems.

The first commercial carpet-printing machine based on selective deflection of individual dye jets was the Elektrocolor, made by Textima, of the former DDR. The American Millitron machine was based on the same concept (that of deflecting continuous streams of dye liquor), but the deflection was achieved more precisely with air jets. The later Chromotronic (Zimmer) and Titan (Tybar Engineering) machines were based on the so-called ‘drop on demand’ principle, namely the use of switchable electromagnetic valves placed in the dye liquor feed tubes to allow the jetting of discrete drops of dye liquor in a sequence predetermined according to the pattern to be printed.

Printing by jet techniques offers several advantages over conventional carpet printing:

– digital pattern data from CAD systems (suitably edited) can be used immediately to drive the printer, hence allowing quick customer response
– there are no screens to handle, and there is instantaneous (electronic) change of pattern and hence much improved machine occupation, making short runs economically viable; for comparison, changing screens on an eight-colour rotary-screen carpet-printing machine takes about 1 h
– no screen replacement or storage space is required
– no physical pressure is exerted on the carpet pile, therefore optimum surface appearance results
– large repeats are possible without resorting to special techniques.

The Millitron machine can be compared with a rotary-screen printer in that the carpet is carried continuously by an endless blanket under a series of jet bars, each of which provides one colour to the overall pattern. Unlike the horizontal arrangement in screen-printing machines, however, the carpet moves up an incline under the print heads (Figure 4.6). Each jet bar carries a series of orifices, 50–100 μm in diameter, spaced at 4 per cm (recently, up to 8 per cm), and under nonprinting conditions the streams of liquor are deflected by opposing jets of air into a collecting gutter, from whence the liquor is recycled. Each air jet has an electromagnetic valve which can be switched, according to the signals received from the processor reading the pattern data, so that the air either deflects the dye stream or escapes to the atmosphere, when it allows a spurt of dye liquor to fall on to the carpet surface. In order to control the quantity of liquor applied to the carpet, which may vary from a lightweight low-level loop type to a heavy-quality shag carpet, it is necessary to vary not only the 'firing time' (the time interval during which the jet is allowed to fall on to the carpet) but also the pumping pressure of the dye liquor in the system.

The Chromotronic machine (Figure 4.7), which was later named the Chromojet, resembles a flat-screen printing mechanism in that the carpet is moved intermittently and printing is carried out by a print head traversing the carpet from side to side whilst it is held stationary on the transport belt. During the traverse, a bank of needle valve jets in the print head are made to open individually in turn at the correct instant to place 'shots' of dye liquor in appropriate positions, so as to build up one colour of the pattern. The print head is relatively large, as the special needle jet valves are about 5 cm in diameter. In the original full-width carpet-printing machine each successive colour was applied by another traversing print head, in a manner analogous to the successive screens in a flat-screen printer. In this process the dye liquor flow is

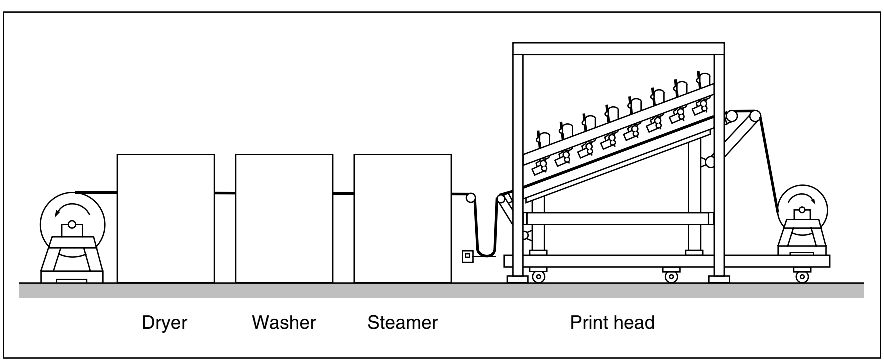

Figure 4.6 Layout of jet printing machine (Millitron)

Figure 4.7 Chromojet printing machine (Zimmer)

intermittent, controlled by means of the high-speed valves which are operated from digital data on magnetic storage discs. Good pattern definition is achieved by having a matrix of as many as 500 jets, each one being slightly offset from the next, in a print head which traverses a 63 cm band of carpet, thus giving a resolution equivalent to around 8 jets per cm. The same definition as that from the Millitron machine (i.e. 4 jets per cm) could be achieved from a Chromojet machine with a print head 1 m wide with 400 jets per head. For the linear carpet production speed to be the same (say 10 m min^{-1}), however, the needle valves have to operate four to five times faster to achieve the same definition in the direction in which the jets traverse the carpet. One type of machine at present on offer can print carpet from 2 to 5 m wide in eight colours from a single print head with 512 jets (64 per colour). The valve opening time ('firing time') is 5–15 ms on the Millitron machine and the liquor pressure relatively low (70 kPa or 10 lbf in^{-2}). The frequency of firing is determined by the speed of printing, but at 10 m min^{-1} would be 69 Hz. The Chromojet machine uses shorter firing times and higher liquor pressures and the valves can operate at up to 400 Hz. The quantity of liquor which needs to be applied to the carpet depends on the carpet quality (particularly the pile height and weight) and is controlled mainly by the selection of the appropriate firing time. Both machines, which were originally designed to print full-width carpets, have been produced in versions designed to print carpet tiles at a definition equivalent to 10–20 mesh.

One type of ink-jet printing technology normally associated with paper printing utilises tiny charged drops of dye liquor which are deflected by passing between electrically charged plates. This principle has been used by Stork as the basis of a sample printing machine. The volume of liquor which the jets can deliver is too small for the system to be used for printing carpet substrates, however, although printing of fabric samples can be carried out satisfactorily.

Much simpler, monochrome ink-jet printing machines have also been used to print the backing side of carpets with motifs such as batch numbers or company logos whilst the carpet is passing down a production line or inspection table. This is possible because data can be instantly updated by the control system and transmitted to the print head, a flexibility that is unavailable with the flexographic roller printing systems more generally used to mark the backs of carpets and particularly carpet tiles.

4.3.5 Foam printing

Mainly as a result of the oil crisis in the mid-1970s the textile industry looked at various possible methods of reducing energy costs. The dyeing and printing of carpets requires considerable energy input, usually in the form of steam, and this is largely due to the substantial amount of liquor applied to the substrate (liquor pick-up may be 300–400%) which must then be heated to 100 °C. Attention was therefore turned to ways of reducing the water content of the carpet prior to steaming.

One approach to this problem, which has also been applied to textile dyeing and finishing, is to use foam as the fluid medium for dye and chemical application. A typical foam for carpet coloration may consist of 10–20 volumes of air to one of water, and it has the flow properties of a viscous liquid. The first successful use of foam to colour carpets was for continuous dyeing, followed by multicolour foam printing. In 1980 Stork introduced a modified rotary-screen printer for textiles using foamed print pastes, and both Mitter and Zimmer produced machines for foam-printing carpet.

In the Mitter printer the print liquor, containing special surfactants, is passed through a microprocessor-controlled foam generator (either a so-called marshmallow pump or a static mixer unit) and the foam is fed through the rotary screen from a slot applicator, not unlike the Zimmer Hydroslot squeegee. The Zimmer system utilises the Variopress squeegee placed inside the rotary screen and the foam is fed continuously by the gear pump system through the applicator slot.

Foam printing has not been without its problems and, in the USA at least, foam applicators have been largely replaced by the simpler spray jet application systems. Both foam and spray systems allow the liquor pick-up on the carpet to be reduced to about 150%, which not only reduces steam consumption but also allows faster running speeds (up to 30 m min^{-1}). In Europe, however, following persistent problems with respect to levelness, reproducibility and the attainment of heavy shades, the foam printing of carpets has become obsolete. Foam application is still used, however, for less critical carpet-finishing systems such as the application of stain-blocking chemicals.

4.4 PRINTING OF CARPET TILES

Carpet tiles are now being used extensively as an alternative to broadloom carpet, both domestically and increasingly in contract locations such as offices and public buildings. There is a rising demand for patterned effects, ranging from random stipples to multicolour geometric designs or company logos. Tiles are normally machine-cut from a finished dyed or printed carpet which has been given a heavy-quality backing (usually PVC- or bitumen-based). It was soon found, however, that the dimensional stability of preprinted broadloom carpet during drying and subsequent backing operations was insufficient to allow the pattern register to be maintained when the tiles were cut and laid on the floor. The printing of tiles with such patterns, therefore, must be carried out on individual tiles. Attempts were made to use both flat- and rotary-screen printing, but the sublimation transfer printing process (section 4.4.2) proved a simpler solution. More recently Mitter have offered a flat-screen tile printer with a wide variety of squeegee options, a double roller squeegee being recommended for long-pile carpet tiles. If large-volume printing of tiles is required the relatively large investment needed for a jet printing unit is more appropriate.

4.4.1 Jet printing

The Chromotronic machines, now called the Chromojet M and MS, have been particularly successful for tile printing, and a typical machine can print eight colours from a single traversing print head in which are arranged 512 jets (64 jets per colour). Printing speed depends on the definition (usually 10 or 20 mesh) and the number of colours to be printed (commonly four for most tile designs); a typical machine runs at 2–4 m min^{-1} with a print width of 2 m – that is, four tiles side by side. The tiles may be placed precisely on the transport belt to keep them in register; alternatively, several tile designs, slightly larger than the finished tile size, may be printed on a larger piece of carpet which is subsequently cut into tiles. This avoids a problem that can occur when individual tiles are printed, namely that the very edge of the tile may remain unprinted owing to the tufts being distorted either prior to, or during, passage under the print head. This defect is particularly noticeable if a white-base carpet material is being used. It is more common, particularly when printing logos, to use a predyed carpet as the base material because tiles can then be laid on the floor with the printed ones alongside plain ones of the identical ground shade.

4.4.2 Transfer printing

Of the various transfer-printing methods so far devised for printing textiles only the heat-transfer (sublimation) printing method is suitable for carpet substrates. For best results, however, it is necessary to use specially selected disperse dyes to print the transfer paper. The penetration of the dye into the pile of the carpet can be greatly improved, either by carrying out the transfer process under vacuum conditions or by producing a flow of hot air through both the transfer paper and the carpet pile. Continuous rotary-drum transfer-printing machines, of the type used to print textiles, have been used for carpet printing, but there is a tendency for the pile to be crushed and colour penetration is poor. For printing rugs and carpet tiles, on the other hand, better results are obtained using special vacuum transfer printing presses.

Sublimation transfer-printing techniques can only be used on synthetic fibres – nylon, polyester and acrylic. Polyester gives the best results in terms of the fastness properties achieved, but it is difficult to attain good dye penetration into the carpet pile on this fibre. The use of nylon 6.6 represents the best compromise between the attainment of good print quality with moderately good fastness properties. The main limitations in fastness are light fastness in pale shades and shampoo fastness in heavy shades. As a result of all these limitations transfer printing of carpet substrates has remained relatively unimportant.

4.5 TREATMENTS BEFORE AND AFTER PRINTING

4.5.1 Pretreatment of carpet

In front of the printing machine there are the conventional carpet take-off rolls, a space for butt sewing, a J-box or compensation roller storage unit, followed by a back-beater and a lint-extraction system.

It is not usual to give wet pretreatments to the carpet before printing, because the materials that may still be on the fibre, such as spin finishes, do not in general interfere with the absorption of the print paste or the fixation of the dyes. An exception arises with some carpet qualities, such as fine-gauge velours, the surface appearance of which is greatly improved if they are prewashed at about 60 °C before printing. This prewashing produces a bulking effect on the fibres which cannot be achieved by steaming alone, although presteaming is sometimes used in place of hot water treatment.

In some cases superior print penetration is obtained on prewetted carpet; one example is the printing of longer-pile carpets such as Saxonies using the Millitron jet printing machine. This also allows the application of a background tint to the carpet, which renders any lack of dye penetration or misfitting less noticeable. After wet pretreatment the carpet is passed over powerful extraction slots to reduce the residual moisture to between 50 and 80% pick-up, depending on carpet quality. Carpets may also be prepadded with a ground shade for certain resist, displacement and discharge processes (section 4.7.4).

4.5.2 Steam fixation of prints

However well the printing stage is carried out, the ultimate results may be spoiled by imperfect steam fixation conditions.

Unlike textile steaming, dye fixation on printed carpets is carried out without intermediate drying, partly because very considerable energy would have to be expended to dry the carpet (having about 250% pick-up of print paste) and partly because the steaming time is much reduced when the process is carried out on wet carpet. The first requirement of the steamer is that it must be capable of transporting the material through its interior without affecting the quality of the goods (by loss of yarn bulk or by pile deformation, for instance) and without allowing unfixed dye to ‘mark off’ on to other parts of the print. The second requirement is that the steam quality must be such that dyes are fixed as rapidly as possible, without any tendency to ‘bleeding’ or any loss of clarity of print. To meet these criteria a range of steamers has been produced, the most successful of which are described below.

Yarn steamers

Most yarn steamers employ the brattice principle, the yarn (as a warp, as hanks, in helical coils or as knitted sock) being carried through the steamer held between two opposed endless wire mesh belts or a series of chain-driven slats. The tubular knitted sock used for space dyeing may be treated in single-brattice steamers, whose capacity is greatly increased by overfeeding the material so that it plaits down on to the brattice in a series of overlapping folds.

All yarn steamers are of the horizontal type, as roller or festoon types exert tensions that would lead to a lean yarn with unsatisfactory coverage properties when tufted into carpet. Manufacturers include Ilma and Fleissner for tubular-knit types, and Superba and Hoerauf for coiler types. The coiler steamers are often used for heat setting the yarns and for this purpose operate either at atmospheric pressure with superheated steam or, when constructed with entry and exit seals, with saturated steam under pressure.

Carpet steamers

At the production rates and steaming times (say 10–20 m min^{-1} and 3–6 min respectively) that may normally be used, a carpet steamer requires a capacity of 20–80 m. Space is often at a premium and festoon steamers were used in most of the earlier installations, as is still the case for the continuous dyeing of carpets. Experience showed, however, that better print clarity could be obtained if all the steam treatment, or at least the initial stages of dye fixation, could be carried out with the carpet horizontal. Two-pass horizontal steamers were also tried, but these gave problems of marking-off in heavy shades when the carpet ran with the pile side downwards on the second pass. Present-day practice is therefore to use a completely horizontal steamer, if space allows, or a steamer with a horizontal entry leg followed by a festoon section, so that the internal rollers contact the back of the carpet only. Multipurpose steamers are also available; these may be used in either horizontal or vertical festoon mode depending on the particular print style that is being produced.

For optimum dye fixation, air-free saturated steam at 98–100 °C is required. Air is inevitably brought into the steamer by the incoming carpet, and its effect is to decrease not only the moisture content of the steam but also the rate at which the liquor on the carpet is heated up by steam condensing on its surface. Freedom from air is best assured by good steamer design. If the carpet enters the steamer at the top then the entry leg should have a good purging supply of steam and an extract vent should be sited near the entry to the main steamer. Recent practice has been to have both entry and exit at the base of the steamer and to use so-called 'cloud control', that is, to maintain a clear air/steam boundary in the base of the steamer by feeding the steam in through the roof of the steamer and to rely on the lower-density steam to displace air from the main body of the steamer. This results in a considerable saving in steam consumption. Even so, ideal steaming conditions are rarely achieved; although the dry-bulb thermometer may read 100 °C or slightly above, the wet-bulb temperature may be only 95 °C, or sometimes even lower. Such conditions lead to inferior dye fixation, particularly if milling acid or metal-complex dyes are being used. Where the steaming conditions vary during a run or from one batch to another, problems of lack of reproducibility of colour yield will result.

Once the liquor on the carpet has reached 100 °C, it is undesirable to surround it with an atmosphere of superheated steam; this may induce a tendency to dry out, which reduces the rate of fixation of some dyes as well as tending to increase 'frostiness'. In steamers of the wet-sump type superheating is unlikely, but it can occur with dry-sump steamers if the closed steam circuit (used for anticondensation pipes) is run at too high a pressure or if the incoming live steam carries superheat from the boiler. In such cases the closed steam should be run at relatively low pressure and the live steam fed through a pressure-reducing valve and saturator.

A particular problem with dye-fixation conditions may arise with carpet tiles if these are backed with a material that is not stable at 100 °C. PVC-backed tiles may be processed without problems, but bitumen backings soften and distort if treated at elevated temperatures (70–90 °C depending on the particular bitumen composition used). With careful choice of carpet fibre, dyes and print paste additives (section 4.7), satisfactory dye fixation can be achieved using a saturated 'steam' atmosphere at lower temperatures.

4.5.3 Washing-off equipment

No dyes can be completely fixed on carpet fibres, so that residual dye, as well as the chemicals and thickening agents, must be removed at the washing-off stage. For economy cold water alone is used, in contrast to textile-printing practice. Only in the case of polyester and acrylic carpets are heated wash tanks considered. Two or three baths, preferably with countercurrent water flow, are used. Nevertheless a typical carpet-printing range requires a wash-water flow of $20–40 \times 10^3$ $l\,h^{-1}$. To accelerate the interchange between the liquor on the carpet and the wash water, various agitator systems have been used; in addition, each exit path from the liquor should have a spray pipe and mangle squeeze or, better, an extraction slot. A particularly good effect can be achieved using perforated-drum wash units in which the liquor actually passes through both the pile and the backing of the carpet.

Occasionally, where very heavy shades are being produced, cross-staining of washed-off dye on to pale or white ground shades may occur. This can be avoided by passing the carpet through a mildly alkaline bath as it leaves the steamer. This also improves the wet fastness of the prints, as the alkali aids the removal of unfixed dye.

In yarn-printing operations, heated wash-off tanks are more commonly used, followed by spray pipes and mangle squeezing.

4.6 PHYSICAL FACTORS AFFECTING THE QUALITY OF PRINTED CARPETS

The basic mechanism of screen printing is the application of a shearing force and pressure (in a pressure wedge formed by the angle between the advancing squeegee and the screen surface) to the print paste, thus forcing it through the screen mesh and on to the carpet surface. When printing carpet, however, a further requirement is to force this paste to penetrate well down into the carpet pile, whilst maintaining an adequate degree of pattern clarity, and this poses considerable problems.

Two practical solutions to this problem involve use of a pressure differential between the surface of the applied paste and the reverse side of the carpet (using vacuum in the BDA machine, hydrostatic pressure in the Zimmer Hydroslot and Magnetjet systems). An alternative approach is to use a double roller squeegee of relatively large diameter in place of the single rubber squeegee commonly used by textile printers. This, in effect, produces fairly wide and acute-angled colour wedges, factors which have been shown to lead to increased delivery of paste per squeegee stroke and to improved pile penetration. At the same time there is a loss of sharpness of the print, but this is quite acceptable in the context of carpet printing, where a spread of up to 3 mm is not unusual except in the finest designs. Dowds has studied the above factors in the field of textile printing [4]; in carpet printing, allowing for slower running speeds of the squeegees, coarser screen mesh and the lower paste viscosities used, it can be calculated that the shear stress is lower by a factor of about 100.

4.6.1 Flat-screen printing

Few quantitative studies of flat-screen carpet printing appear to have been undertaken but, using small-scale laboratory equipment, Dawson showed the beneficial effect of increased pressure loading on roller squeegees (simulating the magnetic rollers of the Zimmer machine) in improving pile penetration (Figure 4.8) [5]. The effect was comparable to that obtained by increasing the degree of vacuum in the BDA process (Figure 4.9) or the nip pressure in the Stalwart printing technique (Figure 4.10). Similar curves to these were obtained over a range of paste viscosities, but the sensitivity of the results to varying viscosity was not very marked in the flat-screen printing applications. Clearly, however, there is a considerable lack of detailed knowledge in this field.

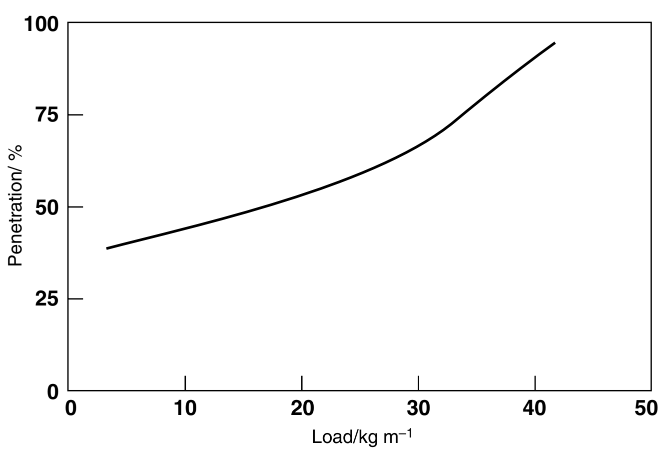

Figure 4.8 Zimmer flat-screen printing process; effect of roller squeegee pressure

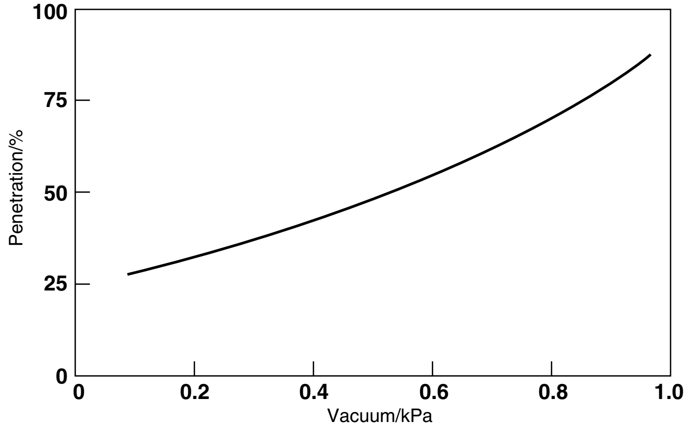

Figure 4.9 BDA flat-screen printing process; effect of vacuum applied

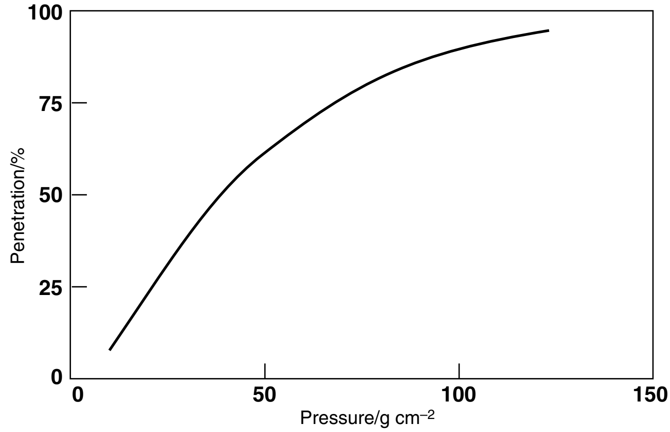

Figure 4.10 Stalwart printing process; effect of nip pressure

4.6.2 Rotary-screen printing

An extensive comparative study of the variables in the various rotary-screen printing techniques has been reported by Dunkerley and Hughes [6]. Rather than trying to relate the results obtained on bulk-scale machines, where truly comparative results cannot be attained, a laboratory machine was used on which the mechanical arrangements corresponding to each of the present rotary printing techniques could be simulated. Thus, for example, all the mechanical variables indicated in Figure 4.11 for a rotary-screen printing machine were investigated, using thickeners that differed in

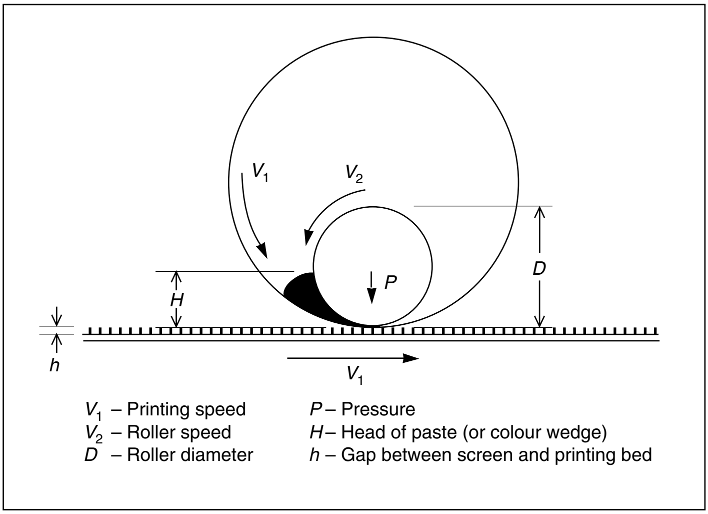

Figure 4.11 Mechanical variables of rotary-screen printing (roller squeegee)

both viscosity and rheological type. In the case of the Hydroslot squeegee system, the main variable examined was that of hydrostatic head of print paste.

The practical printer is mainly interested in attaining penetration of dye down to the base of the carpet pile without serious loss in pattern definition, but these goals are generally mutually exclusive. It is found, for example, that the most effective method of increasing pile penetration with a roller squeegee system is to increase the head of print paste behind the squeegee; however, increasing this so-called 'colour wedge' leads to paste being expressed through the screen mesh before it comes into contact with the carpet. The paste can therefore flow outside the edges of the pattern on the screen, and definition is lost. This tendency is less pronounced with the Hydroslot squeegee system (Figure 4.12), since preflooding of the screen is effectively prevented by the narrow slot in the squeegee. There is some loss of definition, however, when the hydrostatic head is increased, as there is some lateral spread of paste within the carpet pile.

In the case of roller squeegees, somewhat surprisingly, the paste viscosity has only a limited influence on pile penetration. On the other hand, print definition is improved by increasing viscosity, as might be expected. When the Hydroslot system is used, on the other hand, paste viscosity requires close control since pile penetration, definition and the amount of paste applied to the carpet (i.e. wet pick-up) are all markedly affected by this factor (Figure 4.13). The Hydroslot system is a particularly flexible one, since the desired end-results can largely be achieved by adjusting the interrelated variables of static head and viscosity. For example, similar results can be achieved by using a small static head with a high-viscosity paste, and vice versa.

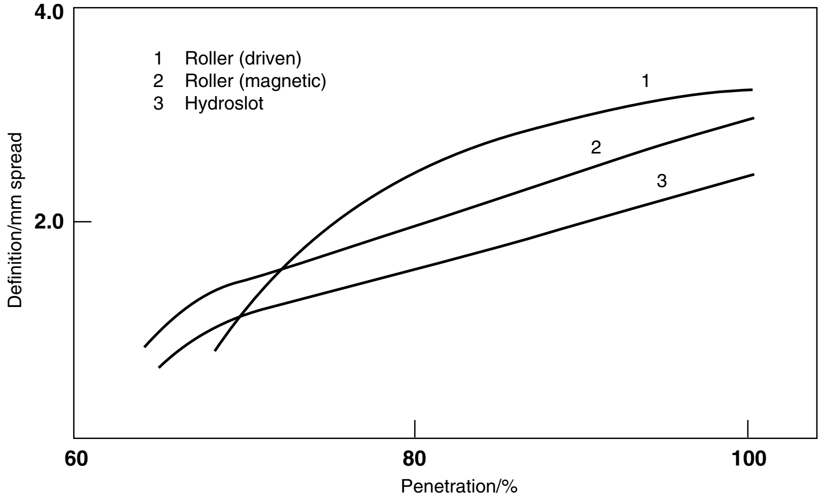

Figure 4.12 Relationship between pile penetration and definition

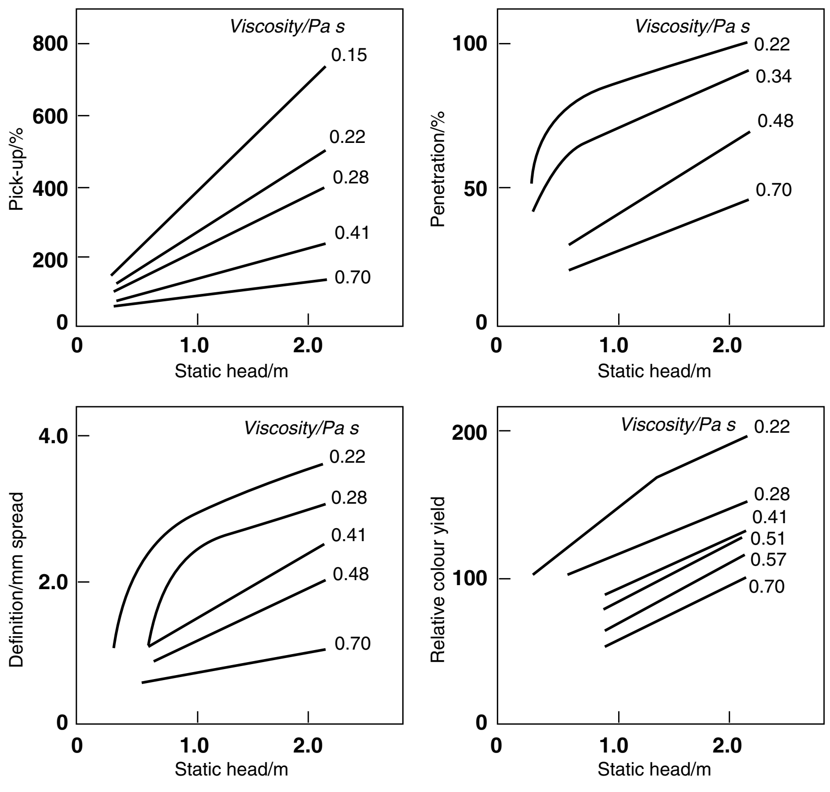

Figure 4.13 Hydroslot system; effect of viscosity

With roller squeegee systems paste viscosity has only a limited effect on the results achieved, and therefore to achieve the desired end-results other control variables must be sought. Foremost among these is that of the size of the colour wedge behind the roller squeegee. Clearly, however, the maximum size of colour wedge that can be employed will depend on the diameter of the roller squeegee. This probably explains the trend towards larger-diameter roller squeegees (up to ca. 150 mm) as the mechanics of both magnetic and driven roller systems were refined over the years. The loss in definition that normally results from the use of both large-diameter rollers and large colour wedges can fortunately be countered by the simple expedient of increasing the running speed of the machine. Higher running speeds are indeed desirable from a productivity point of view, but are limited to lightweight carpet constructions (such as low-level loop 'kitchen' carpet qualities), since insufficient paste may be delivered to the carpet surface – that is, pick-up values become undesirably low (Table 4.4). Table 4.4 also illustrates the similarity in the results with both friction and positively driven roller squeegees.

Table 4.4 Effect of increased size of roller squeegee

Roller diameter /mm	Driven (D) or magnetic (M)	Head of printing paste /mm	Printing speed /m min^{-1}	Pick-up /%	Pile penetration /%	Definition (spread/mm)
80	M	30	7.5	120	70	3.0
80	M	40	7.5	150	80	3.0
80	M	30	15.0	120	50	2.0
80	D	30	7.5	140	70	3.0
80	D	30	15.0	120	50	1.5
160	M	30	7.5	220	95	3.5
160	M	40	7.5	210	100	4.0
160	M	30	15.0	160	85	3.0

Thus, despite the 10% circumferential speed difference between the driven roller and the screen in the case illustrated, no marked increase in pick-up or pile penetration was observed. In practice, the main advantage of positively driven roller squeegees lies in the fact that they can be so adjusted that only a slight crushing effect is exerted on the carpet pile. Little pile deformation therefore occurs during the printing process. With the magnetic squeegee system, by contrast, a minimum magnetic 'pull' on the squeegee is required to obtain a friction drive and to maintain the squeegee in position. Moreover, the greater this downward pressure the greater is the pile penetration, although this effect is not marked. Experience shows that, depending on the quality of the carpet being printed, the pressure exerted by a series of magnetic printing rollers can adversely affect the handle and aesthetic appearance of the final carpet. The repeated 'crushing' effect is, however, beneficial in terms of improved colour penetration into the carpet pile, which may increase by as much as 40%.

Although not commonly resorted to in practice, a further method of improving print definition is that of using a finer screen mesh. Carpet-printing machines of the roller squeegee type normally employ a raster of 7–10 holes per centimetre (18–25 mesh). For fine line work (such as outlines on low-level-loop carpet), however, it is possible to use a 16 raster screen as the loss in penetration and pick-up which results from this change is acceptable for 'fall-on' effects. With the Hydroslot squeegee system, by contrast, pile penetration and print definition is less affected by changes in mesh (Table 4.5), so that finer-mesh screens could be used even for blotch prints.

Table 4.5 Effect of screen mesh

Squeegee system	Screen raster/cm^{-1}	Pick-up /%	Pile penetration /%	Definition (spread/mm)
Roller (magnetic)	7	200	100	3.5
	16	50	30	<1.0
Roller (driven)	7	220	100	3.0
	16	50	20	<1.0
Hydroslot	7	375	100	2.5
	16	200	90	2.0

4.6.3 Jet printing

Unlike flat- and rotary-screen printing methods, jet printing is a noncontact application system and the only mechanical force that can be regulated (in order to increase pile penetration by the colour, for example) is that controlled by the volume and the pressure/velocity with which the drops of liquor can be ejected from the jet on to the carpet. In general, increasing the drop velocity improves pile penetration; but the liquor pressures that can be used in practice are limited by the desired minimum drop size (which affects print definition) and the need to avoid splashing by the drops as they impinge on the carpet surface. Further penetration of the dye into the carpet pile is then dependent on capillary action and fibre surface wetting forces.

The target definition of the jet printer (usually 10 or 20 mesh) determines the minimum size of drop that can be used (or rather the diameter of the spot produced when the drop lands on the substrate). Thus at 10 mesh the diameter of the spot produced should be about 2.5 mm. If the drop size is now increased, the liquor penetrates into the carpet pile by capillary forces but there is a gradual lateral spread. Thus for any quality of carpet there is an optimum firing time which produces drops of such a size that they give acceptable print definition with the maximum degree of pile penetration.

Figure 4.14 gives a general indication of the relationship between firing time and liquor pressure on the pick-up values that would be obtained on carpets of different pile weights. Table 4.6 shows the effect of firing time and the liquor pressure on the degree

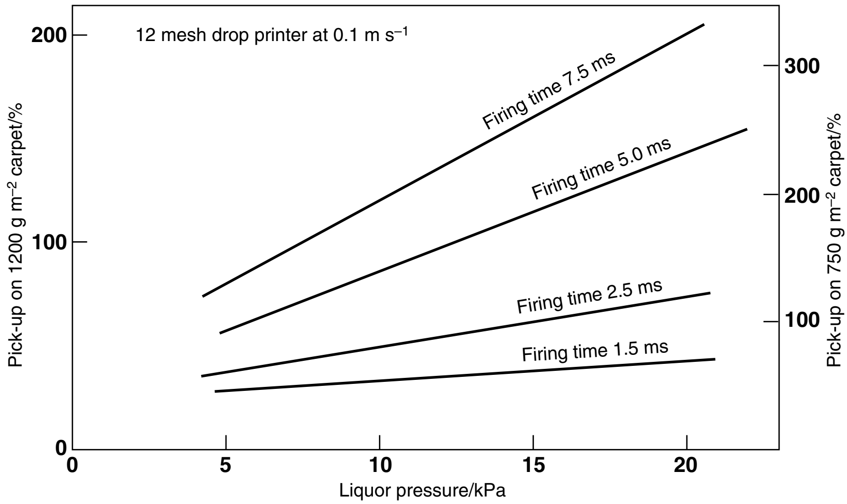

Figure 4.14 Jet printing; control of pick-up

Table 4.6 Effect of liquor pressure and firing time on print definition and pile penetration

Liquor pressure /kPa (lbf in^{-2})	Firing time /ms	Pile penetration /%	Definition (spread/mm)
Low-pressure machine			
7 (10)	1.5	25	0.6
7 (10)	3.0	80	1.2
7 (10)	5.0	100	2.5
10.5 (15)	1.5	50	1.2
High-pressure machine			
14 (20)	0.7	30	0.5
21 (30)	0.7	60	1.0
31 (45)	0.7	80	1.5
41 (60)	0.7	100	2.0

of pile penetration by the colour compared with the increasing loss of definition by lateral spread for jet printers operating at low pressure (such as a Millitron machine) and at high pressure (such as a Chromojet machine).

4.7 SELECTION OF DYES AND CHEMICALS FOR PRINTING NYLON CARPETS

The main components of a print paste which may be used on nylon carpets include dye, acid-producing agent, solubilising agent, sequestering agent, antifrosting agent, antifoaming agent, swelling agent and thickening agent. Some agents fulfil more than one of these functions, whilst the action of others may be somewhat obscure, even though they may be described as wetting agents, lubricants, penetrating agents and so forth. Examination of practical print formulations often shows that they contain a wide variety of agents which at some time have been considered to improve some factor (possibly fortuitously) and which, as a result, have become established in use. Since all contribute to the cost, it is clearly desirable to discard any agent which shows no demonstrable beneficial action, and to use multipurpose agents wherever possible, thereby operating with the simplest possible formulation.

The selection and application of dyes, auxiliary products and thickening agents will now be considered in more detail. With the exception of thickening agents, the printing technique employed does not affect the selection of the various print paste components unless they have a deleterious effect on the materials of construction (for example, solvents used as fibre-swelling agents may attack screen lacquers).

4.7.1 Thickening agents

Owing to the very high consumption of paste in carpet printing (the average machine requires 2500 $l\,h^{-1}$), thickeners must be relatively cheap and possess rapid dispersion and dissolving properties in cold water. As in other printing applications, they must be stable to the other components of the paste (such as acids, dyes and auxiliary products) but, since carpet prints are steamed without intermediate drying, the thickened paste must maintain a reasonable viscosity at 100 °C to prevent flushing. Furthermore, as only a continuous cold-water rinse is used to wash the carpet after steaming, the thickener must be readily removable under these conditions. These criteria are met by modified locust bean or guar gums, while starch types and xanthan gums are also used to some extent. Low-solids, high-viscosity products are preferred and, for purely economic reasons, modified guar gums are particularly popular. The rheological properties of these thickeners vary somewhat, particularly with regard to their property of so-called pseudoplastic flow, that is, a tendency to decrease in viscosity with increasing applied shearing forces (section 7.7.3). This effect can have an effect on print quality (pile penetration, pattern definition and so on).

Figure 4.15 illustrates the behaviour of three types of thickener: a 'long' thickener Indalca PA1 (hydroxyethylated locust bean gum), a 'medium' thickener Prisulon E3 (depolymerised guar gum) and a 'short' thickener Kelzan (xanthan gum). These curves emphasise the practical importance of quoting viscosity values at a particular shear rate. Commercial viscometers give reliable values over only limited shear rates, and care must be taken in comparing results from different instruments. The range of viscosities required in the various print applications for carpets is very wide, ranging from about 50 mPa s (centipoise) at a shear rate of 50 s^{-1} for warp-printing to some 5 Pa s (5000 centipoise) for certain rotary printing techniques. The short thickenings tend to be favoured for space-dyeing and jet-printing applications, whilst those of intermediate flow properties are now widely accepted for screen-printing applications.

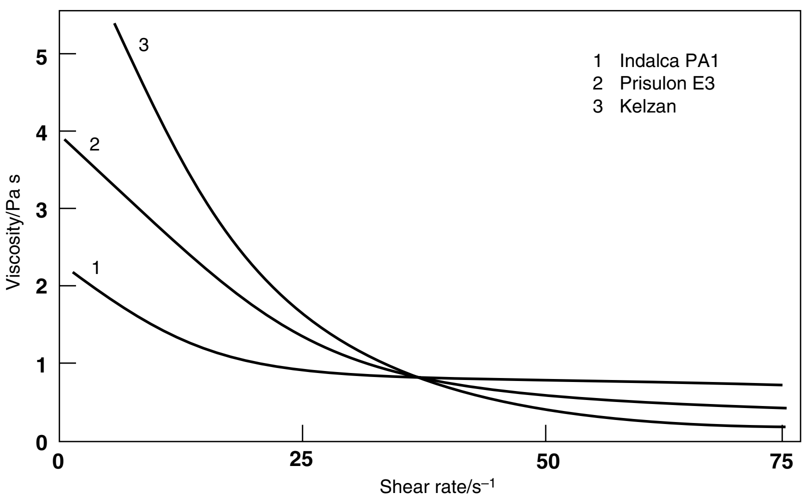

Figure 4.15 Relationship between viscosity and shear rate

4.7.2 Chemicals and auxiliary products

The rate of fixation of dyes on nylon is controlled by the pH during steaming: the lower the pH, the more rapid is the fixation. A wide variety of acid-producing agents has been suggested from time to time ranging from acid-producing salts (such as ammonium sulphate, ammonium dihydrogenphosphate and ammonium tartrate) to organic acids of varying strength (such as acetic, glycollic, formic and citric acids, which increase in strength in this order). Not all of these acids produce constant pH during the steam fixation stage, however, owing to their steam volatility. This is especially the case when acetic or formic acid is used. Table 4.7 shows the effect of steaming a series of prints on the pH of extracts and, from this data, the variable conditions (depending on the steaming conditions) which are likely to result from the use of volatile acids are evident. Such variations can lead to end-to-end or side-to-side variations in dye yield, particularly when applying the slower-fixing dyes, the fixation of which is pH-sensitive. The use of volatile acids also leads to increased corrosion problems within the steamer. Thus the potential advantages of using the nonvolatile acids outweigh their higher cost; the most economical are usually citric acid or the by-product acid from nylon 6.6 manufacture (a mixture of adipic acid homologues). Even stronger acids, such as oxalic or sulphamic acids, are used occasionally.

Table 4.7 Stability of print paste pH during steaming[a]

	pH of aqueous extract	
Agent used (10 g l^{-1})	Before steaming	After steaming
None	6.7–6.9	6.7–6.9
Ammonium sulphate	6.9	4.8–6.3
Ammonium tartrate	7.0	4.7–5.1
Acetic acid (80%)	4.0	6.3–6.5
Formic acid (90%)	3.6	3.9–5.6
Tartaric acid	2.9	3.0–3.4
Citric acid	2.6	2.8–3.1
Sulphamic acid	1.8	2.2–2.5

a Steaming for 10 min at 105 °C

The necessity for maintaining a constant low pH throughout the steaming process is illustrated in Figure 4.16, which shows the effect of pH on the fixation of four different types of dye within the pH range 3–7. Monosulphonated equalising acid dyes are much less sensitive to pH variations than are disulphonates, but rather surprisingly, mono- and di-sulphonated metal-complex and milling acid dyes also show the effect. Thus using an acid which gives a constant low pH enables the carpet printer to select dyes from a wider range of products than if a weaker acid or acid-producing salt were used. (The weaker acids and acid salts are, of course, used by the conventional textile printer, who dries the goods and afterwards steams them for 30 min or more.)

The addition of the acids necessary to attain rapid dye fixation tends to reduce the solubility of the dyes, and a solubilising agent may be required. This may also be the

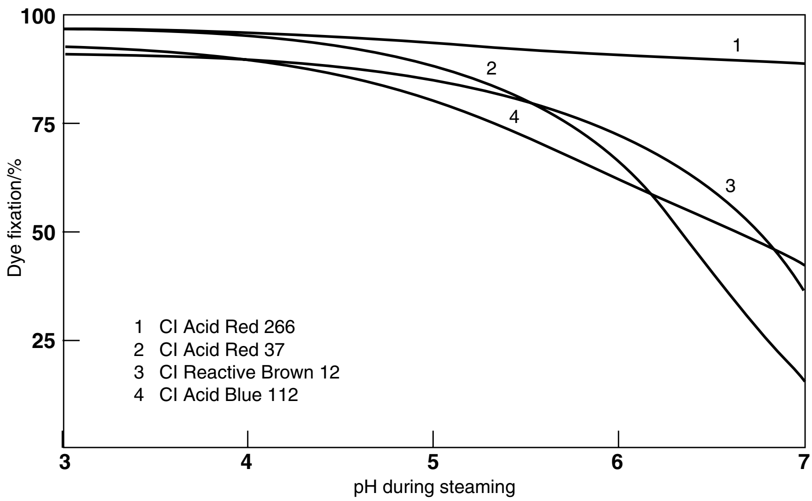

Figure 4.16 Effect of pH during steaming on dye fixation

case where a particular depth or fastness criterion is to be met. In practice, however, solubilising agents are not commonly used. This is because the dyes selected have high solubility in cold water, and the antifrosting agents often added to the print paste (discussed below) also act as solubilising or dispersing agents. Moreover, there is less need for such products in carpet printing than in textile printing, since prints are steamed without predrying. Where it is necessary to use solubilising assistants, thiodiglycol is the one most commonly chosen. Other, less water-soluble, organic solvents, such as benzyl alcohol or chlorphenoxyethanol, are sometimes used; their precise mode of action is not clear, but they appear to assist the rate of dye fixation by swelling the nylon and/or by forming a more highly concentrated dye solution on the fibre surface. As in all dyeing processes, the time required for fixation increases with increasing dye concentration, and it is therefore in heavy depths where the effect of the addition of solvents to the print paste is most marked (Table 4.8).

There is a general tendency in an impregnate–steam dyeing process on nylon carpets to obtain an effect called 'frostiness', whereby some of the fibres on the surface are less heavily dyed than the surrounding material, or are even undyed. The effect is caused by the lack of a continuous film of dye liquor or print paste on each individual fibre at the steam fixation stage. When the print paste is applied to the carpet and wetting is complete, a continuous film of liquor will be formed, but some degree of frostiness may result if anything interferes with this wetting action (for example, an unsuitable spin finish, a fluorocarbon antisoil finish on the yarn or silicone lubricants which can migrate into the pile from certain types of backing materials). Even when

Table 4.8 Effect of solvent on dye fixation[a]

Concn of CI Acid Red 57 /g kg^{-1}	Fixation after steaming/%	
	No solvent	With 30 g kg^{-1} benzyl alcohol
5	99	99
10	91	97
15	75	90
20	60	78

a Print on nylon 6.6, 200% pick-up, steamed for 3 min

the initial wetting is complete, subsequent mechanical pressure on the fibre bundles (such as the pressure exerted when a carpet passes under a succession of roller squeegees) can leave surface fibres denuded of dye liquor. Frostiness may also be introduced during steaming and this effect is usually ascribed to the condensation of steam on the cold carpet entering the steamer, causing some dye to be flushed away from surface fibres.

In order to overcome these effects it is usual to employ surface-active products known as antifrosting agents. These act as wetting agents, film-formers and foaming agents during the steaming stage, thus forming a continuous, elastic film of dye liquor over the fibres during the printing stage and subsequently forming a viscous foam during the initial stages of the steaming process. Even when antifrosting agents are employed frostiness may not be completely avoided, as long-pile carpet constructions of low pile density and the use of round-filament yarns, rather than those of the more usual trilobal cross-section, tends to aggravate the defect.

Typical antifrosting agents are based either on nonionic fatty acid amides and ethoxylates, or on anionic products such as sulphonated alcohols or sulphosuccinate esters. Apart from the antifrosting mechanisms described above, they may also form complexes with the dyes used and may thereby affect their solubility and fixation characteristics. Since the agents are surface-active, they tend to foam when mechanically agitated and this may cause problems at the dye application stage. The use of antifoams is therefore quite common, but opinions are divided on whether agents of the ethylcyclohexanol type or silicone products are preferable. Both types are, in fact, capable of working satisfactorily, but the silicone antifoams require closer control, as excessive concentrations suppress the formation of foam at the steam-fixation stage and frosty effects may reappear.

4.7.3 Dye selection

Nylon may be printed with acid dyes and also with a few direct dyes, which can be fixed on the fibre without intermediate drying by steaming for 3–10 min. A very wide range of such dyes is available so that selection on the basis of many factors is possible. Apart from selection on the basis of fastness properties, the chief amongst these factors are solubility, fixation and wash-off characteristics.

The acid dyes that can be used for printing nylon fall into two main groups, with advantages and disadvantages as described in Table 4.9. The fixation and fibre penetration characteristics are governed by the molecular size and shape and the degree of polarity of the dye concerned. Typical dye fixation curves are shown in Figure 4.17, in which the very rapid fixation of an equalising acid dye is contrasted with that

Table 4.9 Dyes for printing nylon

Dye type	Advantages	Disadvantages
Equalising acid	Very rapid fixation Very rapid penetration Usually economical Fixation not pH-sensitive Good coverage of irregular nylon	Limited wet fastness in deep depths
Milling acid and metal-complex	Very good wet fastness Best dyes for deep shades if longer steaming times are possible	Slower fixation Inferior fibre penetration Tendency to frostiness Less reproducible

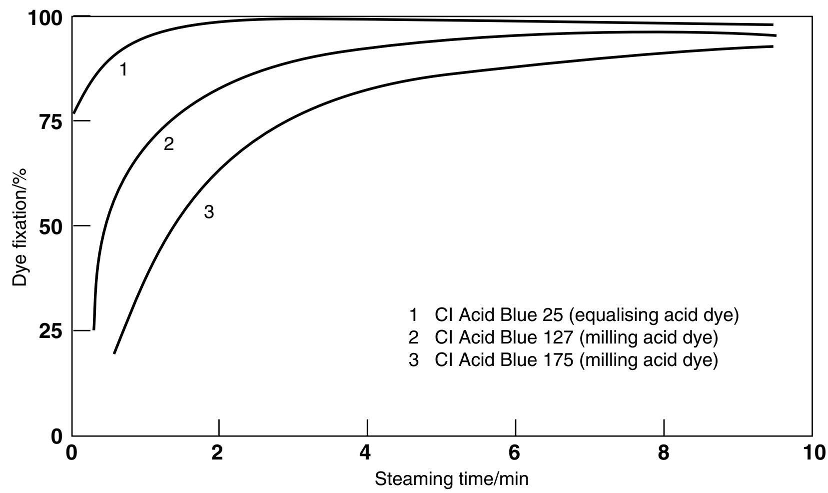

Figure 4.17 Dye fixation on nylon 6.6

of two milling acid dyes. In practice it is desirable for the dye to reach an equilibrium fixation value by the end of the steaming process. Thus, of the three dyes illustrated in Figure 4.17, only one would be fully satisfactory if fixed on nylon 6.6 by steaming for, say, 4 min. The fixation of any dye is, however, considerably faster on nylon 6, particularly if the yarn has been heat-set, the equilibrium fixation levels being achieved in approximately half the steaming time required on nylon 6.6.

The lower rate of fixation of dyes with larger molecules probably arises from their tendency to form aggregated solutions, as well as from their inferior rate of diffusion from the surface to within the fibre. The difference in fibre diffusion rates can be readily observed from cross-sections of nylon carpet yarns after dye fixation has proceeded for various times (Figure 4.18). The inferior penetration characteristics of the milling acid and metal-complex dyes can lead to problems with reproducibility. This is because, although a high level of fixation is achieved, increasing fibre penetration leads to increasing visual colour yield. Thus if there is any variation in steaming time (for example, if goods have been left in the steamer for longer than usual due to a stoppage) a difference in colour will be observed. Furthermore, if short steaming times (2–3 min) are used, the presence of ring-dyed nylon fibres in the carpet can give rise to 'abrasion frostiness' when used in areas of high surface wear, such as doorways. This problem was formerly associated mainly with the warp-printing

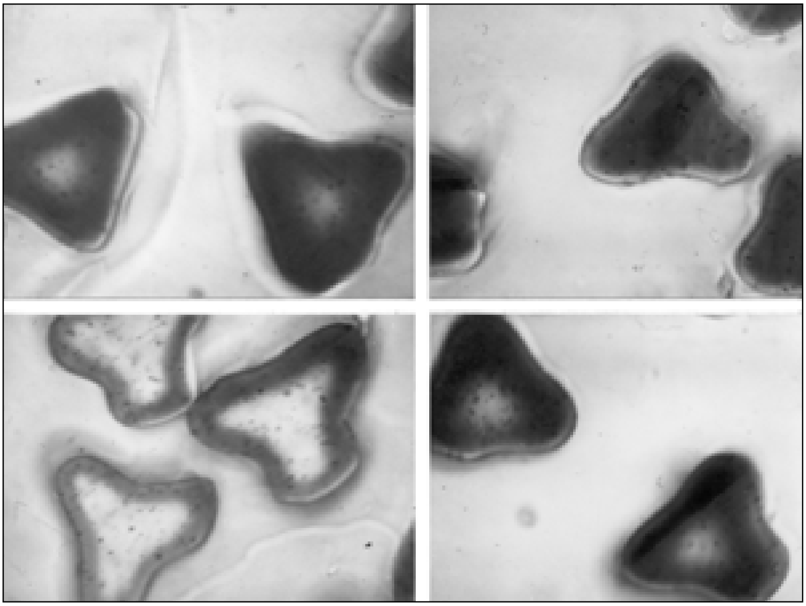

Figure 4.18 Diffusion of dyes into nylon carpet fibre; top – CI Acid Red 266, bottom – CI Direct Red 81 after 2 min (left) and 10 min (right) steaming

process, as the steamers used for both carpet and knit–deknit yarn-printing processes usually allow longer steaming times.

Problems of dye compatibility do not generally arise in printing, although dye separation between the top and the base of the carpet pile, or at the edge of a printed area, can sometimes occur. This is due to one dye of high affinity temporarily blocking the dye sites on the surface of the fibre, so that the dye of lower affinity and slower fixation characteristics migrates beyond the original print area. In knit–deknit space dyeing, the high-affinity dye will also remain on the surface of the knitting stitches, whilst the slower-fixing dye penetrates further into the sock. This is one reason why it is sometimes difficult to change space-dyeing recipes without at the same time altering the character of the final effect.

In general, dye fixation on nylon is efficient, 90–95% fixation being usually achieved. Nevertheless some unfixed dye remains, and needs to be washed off using copious quantities of cold water. Usually this presents no problem but, since fixation efficiency decreases with increasing concentration of applied dye, problems of staining of unprinted areas or of pale grounds can arise with dark colours. The staining properties of the individual dyes vary considerably and no single class of dye is superior to another. When the problem does arise, therefore, it is necessary to examine the dyes in use, and establish a maximum concentration at which each gives an acceptable degree of cross-staining under the particular washing-off conditions employed. The addition of sodium carbonate or of certain cationic ethoxylates to the wash liquor will also reduce the tendency to stain back by reducing the affinity of the dye for the fibre.

In order to increase the variety of effects that can be obtained by the various printing techniques, it is sometimes necessary to be more selective with the dyes employed. This is the case where resist printing effects (see section 4.7.4) are produced as well as for direct printing on differential-dyeing nylon fibres. Resist printing may be attractive for various reasons:

- for flexibility, where dyeing as well as printing equipment is available, as a 'latent' pattern can be printed on carpet piece or yarn with colourless resist agents and a variety of coloured effects then subsequently produced by piece dyeing
- where the printing equipment is suitable for overprinting on coloured grounds (the Stalwart machine, for instance), but not for printing 'fitting' designs
- to ensure that patterns having large areas of one ground shade appear with the optimum degree of levelness.

4.7.4 Products for discharge, resist and displacement printing

In a constant search for novelty the carpet-printing trade has developed a wide variety of processes in which the applied dyes are selectively discharged or resisted by chemical means, or physically displaced from the carpet surface. Physical displacement was the basis for the Gum-TAK process developed in the USA (see section 4.3.4) using liquors and print pastes that differed in their viscosity.

Normal discharge printing methods using, for example, an acidic paste containing either sodium formaldehyde sulphoxylate or thiourea dioxide have been used to produce white printed effects on coloured ground shades. The ground may be applied to the carpet but not fixed, or a predyed ground may be used. The former process is more successful since the discharge agent can more readily reduce dye that has not diffused into the fibre. Experience has shown, however, that the quality and sharpness of the discharge are difficult to control and reproducibility is poor. 'Illuminated' discharges can be produced by incorporating a discharge-resistant acid dye into the discharge recipe, but it is difficult to find suitable blue dyes for this purpose.

Resist styles have enjoyed much greater commercial success, although there is often a degree of mechanical displacement as well as a chemical resist effect in these processes. Three types of resist agent have been used:

– reactive agents that permanently alter the affinity of the fibre for acid dyes (for example, Sandospace S and DP (S))
– substantive, anionic agents which tend to prevent fixation of dyes having lower neutral affinity or those of large molecular mass, that is, slower-diffusing dyes (for example, Thiotan SWN (S), Matexil FA-SNX (Zeneca), Mesitol NBS (BAY))
– cationic agents that tend to form complexes with dyes of large molecular mass, such as 1:2 metal-complex and milling acid dyes (for example, Basacryl Salt KX (BASF), Thiotan TR (S)).

There are many possible application sequences, and each printer chooses the one most suited to the equipment available (the printer and dye applicator systems). Types of dye used for these processes are:

Type A: monosulphonated equalising acid dyes
Type B: 1:2 metal-complex dyes (both mono- and di-sulphonates) or selected milling acid dyes
Type C: disulphonated equalising acid dyes (high-contrast dyes)
Type D: reactive wool dyes, such as Drimalan F (S)).

In general ground shades are applied using thickeners that suffer a considerable loss of viscosity during steaming (such as modified locust bean gums), as these assist penetration of the ground shade into the pile and enhance the resist effect. Too much drainage during steaming can lead to 'frostiness' in the ground shade, but this can be controlled by adding a small amount of a thermally stable thickener such as a xanthan gum. Xanthan gums are also suitable for the printed resist operation.

The pH of the ground shade liquor and the overprint paste must be controlled for reproducible effects. Typically the pad liquor is at pH 4–5 and the illuminating overprint at pH 6–8. For white resist effects the displacement of the ground shade can be further enhanced by using an alkaline (pH 9) overprint.

4.8 PRINTING OF CARPETS TUFTED FROM FIBRES OTHER THAN NYLON

Although nylon meets most of the criteria of a good carpet fibre, wool, viscose rayon, acrylic, polyester and polypropylene fibres have also been used. Each has its own attractions, such as cheapness, appearance, freedom from static problems or even mere novelty.

4.8.1 Viscose

Viscose was, in fact, the main fibre used during the early development of carpet printing and, although in the past cheap one- or two-colour overprinted viscose rayon carpets enjoyed a long commercial success in the UK, they are now of little importance (Table 4.10). The printing technique used was very simple, since many direct dyes can be fixed by steaming for 5–10 min. In the case of Stalwart machine printing (using no thickener), the prints had sufficiently good fastness properties without any washing-off treatment being given.

4.8.2 Wool

Wool has significantly increased its importance as a fibre for tufted carpets, but only a

Table 4.10 Individual fibre share of UK tufted carpet market

	Share (by area)/%		
Fibre	1970	1980	1990
Viscose	60	7	1
Nylon	20	64	46
Acrylic	17	4	2
Wool	2	6	17
Polypropylene	0.5	16	31
Polyester	0.5	3	3

few printed qualities have appeared on the market. A wide range of acid dyes can be fixed on wool by steaming for about 10 min. Blends of wool/nylon, used where superior abrasion resistance is desired, can usually be printed with the same dyes, as there are no problems of unequal dye partition between the two fibres (which are common in batchwise dyeing processes). On the other hand, the appearance of the printed carpet shows a considerable dependence on the quality of the wool used and the finer worsted-spun, chemically set yarns of good whiteness are preferred to the normal coarser woollen-spuns. The main objection to the use of wool is the cost of the fibre content of the final carpet; on the other hand, the appearance and feel of wool fibre is an important sales criterion in a market accustomed to Wilton and Axminster carpets.

4.8.3 Acrylic fibre

At one time the use of acrylic fibre offered the nearest approach in appearance and handle to wool carpets. Unfortunately the handling of acrylic carpets in piece form can be troublesome, owing to the thermoplastic nature of this fibre. Thus, after steaming, a gradual decrease in temperature rather than the 'thermal shock' of the conventional cold water wash-off is required. It may also be necessary to use special heat-finishing treatments to improve pile appearance. Modified basic dyes are employed for printing acrylic fibres and, although there is a wide range of products which give good fixation and fastness properties after steam fixation for 5–10 min, problems can arise in deep shades. The rate of fixation of modified basic dyes printed on acrylic fibre depends on their rate of diffusion into the fibre, which is not directly related to the Compatibility Values (CV or Beckman K factor) of the dyes. Thus although in batchwise dyeing applications CV 1.5 dyes exhaust more rapidly than CV 3 or 5 dyes, this is not the case in printing applications. It is, however, necessary to select dyes of similar CV to avoid incompatibility problems (colour variations within the carpet pile). The rate of fixation is further affected by the degree of fibre saturation attained at any particular depth, which depends on the individual acrylic fibre and dye(s) used. Even with the best dyes, when printing on standard acrylic fibres, it is necessary to use a swelling agent to achieve optimum fixation levels in short steaming times. Various solvents are suitable for this purpose, including γ-butyrolactone, ethylene or propylene carbonate or chlorphenoxyethanol.

4.8.4 Polypropylene

Unmodified polypropylene fibre has been used for carpets (more particularly needlefelt floor coverings) for many years, but because it cannot easily be dyed or printed mass coloration methods have been used. This led to the development of modified polypropylene fibres which could be coloured using disperse, acid or special chelating dyes. For carpet printing and space dyeing a nickel-modified polypropylene has been used. This can be printed with special disperse dyes which contain chelating groups that form a complex with the nickel contained in the fibre. This fibre type is still used for space dyeing. Forms of polypropylene that can be dyed with acid dyes have recently been introduced for printing, but problems still arise in achieving good levels of both light fastness and wet fastness.

Despite these difficulties polypropylene is taking a greater share of the carpet fibre market (Table 4.10) and at the moment most of the fibre used is either mass-pigmented or undyed (being used as an intermingled yarn or fibre blend together with nylon, which can be dyed by conventional methods). The main reasons for the gain in market share of this fibre are its low cost and good all-round performance, together with the fact that larger firms can install relatively cheap fibre-spinning plant and produce the required carpet yarns in-house.

4.8.5 Polyester

The use of polyester in carpets has never been extensive, despite earlier long-term forecasts that this fibre would become increasingly attractive economically as compared with nylon. This advantage is at present rather offset by a higher cost of coloration and the need to employ higher pile weights of polyester to achieve wear performance standards comparable with those of nylon. Polyester has an advantage over nylon in appearance retention when heat-set, so that it has found most use in longer pile Saxony and shag-type carpets, particularly in the USA. Printed Saxonies have been particularly popular in some markets but these are mainly of nylon, owing to problems associated with printing unmodified polyester fibres. The latter must be printed with disperse dyes and, although dye fixation can be achieved by steaming for 10–15 min in the presence of a dye carrier such as *o*-phenylphenol, it is necessary to give a hot soaping aftertreatment to achieve adequate rub fastness of the prints. But with the advent of modified polyester carpet fibres (both 'deep dyeing' so-called disperse-dyeable and basic-dyeable types), polyester carpet has become more attractive. With these modified fibres it is possible to obtain good fixation of both disperse and modified basic dyes under normal steaming conditions without having to use either a dye carrier or an aftersoaping treatment. Examples of modified polyester carpet fibres are the extensive Trevira 800 series produced by Hoechst.

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