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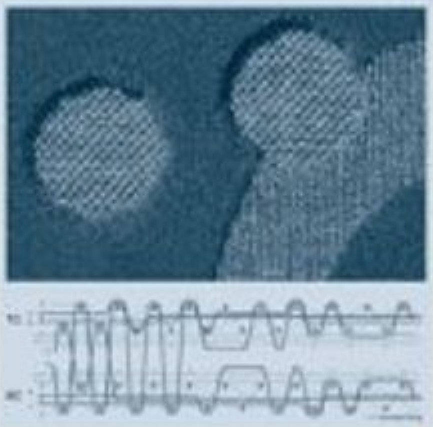

Advances in carpet manufacture

Edited by K. K. Goswami

CRC

The Textile Institute

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1
Carpet types and requirements

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Abstract: This chapter reviews the history of textile floor coverings from prehistoric times up until the present day. It is based almost exclusively upon hands-on experience gained over a working life of 50 years in the carpet industry, rather than being culled from publications. Brief descriptions are included of the main carpet manufacturing processes and of the raw materials used. The subject matter relates in particular to the UK carpet industry but differences in the characteristics of carpets produced in other centres, particularly the USA and continental Europe, are discussed. A tentative glimpse of the future is also the subject of brief speculation.

Key words: Axminster, Wilton, tufted, wool, cotton, jute, polyamide, polyester, polypropylene, thermal insulation, acoustic insulation, carpet properties, impact upon human health.

1.1 The role of textiles in floor coverings

Historically, the first floor coverings were probably animal skins and the earliest floor coverings of textile construction were probably crudely woven textiles made from rushes or grasses. Inevitably, the desire arose to produce floor coverings with a pile of sheep or goat wool to simulate the warmth and comfort of animal skins. Inevitably, no traces of these floor coverings remain.

The oldest known existing carpet is now to be found in the State Hermitage Museum in St Petersburg, having been excavated from a tomb in Southern Siberia and is 2400 years old. It is a pile rug of fine construction with about 3600 tufts/dm^2.

1.1.1 Residential use

Carpets for residential use are made throughout the world with particularly important centres in the USA and Western Europe. Important centres of carpet manufacture are emerging in the Indian sub-continent and in China. The products made in each of these centres have evolved in different ways and display different characteristics of style. In general terms, US carpets often have a pile of polyamide in patterned and textured loop pile, polyester in longer cut-pile referred to as ‘Saxony’s’ and more budget-conscious constructions with polypropylene pile.

Western Europe makes a proliferation of tight, low pile constructions with polypropylene the dominant fibre and polyamide for the better end of the market, whilst UK manufacturers retain a more traditional approach with wool remaining the dominant pile fibre usually in relatively luxurious cut-pile styles. At present the most characteristic UK carpet style is a hard-twist cut-pile plain carpet with a wool-rich pile fibre blend.

In the UK, which has historically had a large woven carpet capacity, heavily patterned carpet styles have dominated for many years and indeed there has been a desire to develop less labour-intensive, higher-speed manufacturing methods for these styles. Recent trends, influenced by large volumes of less expensive tufted carpets imported largely from Belgium and Holland, and through lifestyle programmes and articles in the media, have seen the former dominance of the patterned carpet disappear in favour of plainer styles which are favoured for modern living. The media advise that patterned carpets are now making a comeback but this is not reflected in major changes in carpet production patterns and may be a case of the media trying to establish a trend.

1.1.2 Commercial use

Carpets intended for commercial use are often subjected to greater concentrations of traffic and need to withstand this. Commercial use is varied and can include offices, retail premises, hotels and leisure centres, casinos, theatres and airports. Carpets for offices, particularly modern open-plan offices and for some larger retail premises, feature hard-wearing dense low loop-pile constructions usually with polyamide pile. The carpet tile has found particular favour for this end-use.

Carpet tiles, frequently available in 50 cm square or 45.7 cm (18 inches) square formats, lend themselves particularly to large multi-floor installations. Of particular importance is the ease with which the tiles, packed into easily handled boxes, can be transported to upper floors. The original carpet tiles were of a simple felt face layer bonded to the tile backing. Styles have developed from these through needled floor coverings, plain loop-pile tufted, plain cut-pile tufted and even patterned constructions, at each stage gaining in style, luxury and sophistication.

The carpet tile is a composite material composed of a textile use surface bonded to a tile backing which must have the basic important properties of dimensional stability, and the ability to lie flat on the floor without doming at the centre or the curling up of tile edges. Installation of early tiles gained added interest by adopting what is called chequer-board installation, where the manufacturing direction (always denoted by an arrow printed or embossed on the back of each tile) is laid at right-angles to the adjacent tile. This not only changed the surface aspect of the entire installation but also disguised (through emphasis) the tile edges. With more sophisticated and luxurious styles this simple or utilitarian effect was less desirable and the requirement arose for a uniform appearance with joints between adjacent tiles as invisible as possible.

This is referred to as broadloom or monolithic installation. This demanded carefully cut tiles and was more easily achieved with denser carpet constructions and cut-pile styles.

In recent years sophisticated designs in loop-pile constructions have enabled tiles to be installed without regard for alignment of manufacturing direction and which do not show colour variations from pile shading.

Patterned carpet tiles must be either totally random or carefully engineered to fit design repeat(s) into the tile dimension. Simple tufted carpet designs achieved with stitch displacement devices appeared initially attractive but the failure of the design repeat dimension, often quite small, to fit exactly into the tile dimension created an effect, colloquially known as 'zippering', to occur at tile edges which may be more or less acceptable to the end user. Sophisticated larger repeat designs, sometimes achieved using a woven carpet use surface, or a printed design exactly registered to the tile dimension were inevitably introduced. These included corporate logos which could be inset into plain or lightly patterned areas. The ability of the carpet tile to be easily cut in any direction without fraying lent itself to the creation of particularly large logo installations by carefully creating shapes of different colours and assembling them on the floor.

For the hotel, theatre and airport markets the heavily patterned woven carpet remains important on a global scale. The property of heavily patterned carpets to disguise the inevitable effects of concentrated wear and soiling is extremely important for these end uses and the use of wool-rich pile significantly reduces dangers resulting from burns and scorches from dropped cigarettes.

1.1.3 Carpet properties

Aesthetics

Carpets are available in a wide variety of styles, textures, designs and colours which the skilled interior designer can use to create a stylish interior suited to the activity conducted in the carpeted area. In the home, carpet helps to provide a warm and comfortable environment away from the harsh realities of the everyday world. In commercial buildings carpet helps to make a statement about the enterprise and creates an environment conducive to efficiency.

Thermal insulation

Carpets are excellent thermal insulators, a property that is enhanced further by a good underlay. With conventional heating systems the insulation properties of carpet and underlay can significantly reduce heat loss through the floor. Depending upon construction and specification carpet may have a thermal insulation varying between about 0.1 m^2K/W and 0.3 m^2K/W.

In the case of under-floor heating, however, the apparently excellent thermal insulation properties of the carpet do not excessively impair the efficiency of the heating system. It is believed that this is a function of the fact that in an under-floor heating situation the carpet becomes the heat transmitter to the airspace above. However, excessively thick and luxurious carpets, particularly when installed on a thick felt underlay, can be expected to slow the rate of transfer of heat from floor surface to airspace to an unacceptable level.

Within the EU the thermal insulation properties of carpet are determined according to ISO 8302 *Thermal insulation – determination of the steady-state thermal resistance and related properties – Guarded hot plate apparatus*. In the UK the thermal insulation value of carpets has been measured according to BS 4745 (Togmeter) test, but this is no longer considered to provide a reliable guide since it has been determined that compared with actual usage this 'overstates' the thermal resistance by a considerable margin.

Acoustic insulation

Changes in lifestyle in recent years, in which smooth floors, particularly wood and laminate floor coverings, have gained in popularity, have demonstrated to the public just how noisy an uncarpeted room can be. Carpeting is one of the most effective ways of reducing noise and the best carpets can provide acoustic insulation to the same level as dedicated acoustic insulation materials.

There are three ways in which carpet can provide acoustic insulation. Possibly the most important of these is impact sound absorption. This is concerned with the way in which sound of say a footfall or a dropped object is transmitted into the room below. The pile of a carpet significantly reduces the energy of the impact and has the effect of converting a sharp high frequency sound into a low frequency thud which has significantly less impact on the ear.

Impact sound absorption is measured according to ISO 717-2 using a tapping box device to generate the noise which drops small hammers onto a floor surface at different frequencies and measuring the sound generated in a room below, all under controlled standard conditions. Comparison of the generated sound through the bare floor with that through the carpeted floor, as a decibel ratio, can be used to evaluate the impact sound absorption properties of floor coverings.

Airborne sound reduction is also measured according to standard method. The test method is described in BS EN 20354 and the Sound Absorption Class may be derived from this according to BS EN ISO 11654. The test method involves a purpose-built reverberation chamber which has three loudspeakers which generate sound at different frequencies in the range 250–4000 Hz and five microphones per loudspeaker. The test is conducted with the floor carpeted and the result compared with the figures taken with the floor bare.

The sound reduction coefficient is calculated taking into account area of carpet, dimensions of the test chamber, etc., and is the average of the reduction in reverberation times at each frequency band. A sound reduction coefficient of 1 would be a perfect insulator and 0 would represent a perfect reflector. The more luxurious carpets will have a sound reduction coefficient as high as 0.5–0.7, equivalent to acoustic ceiling tiles and sufficient to comply with the UK Building Regulations for circulation areas in public buildings.

Safety

The textile surface of a carpet and its three-dimensional structure make carpet a particularly safe surface on which to walk. The carpet surface will have excellent slip resistance and will offer a soft, forgiving surface should falls occur.

From 1 January 2007 carpets sold throughout the EU are required to comply with the health, safety and energy saving requirements of the Construction Products Directive. These are described in detail in EN 14041 which also describes the necessary labelling, required in most EU countries, of the associated CE mark.

Impact upon human health

Until fairly recently many articles appeared in the popular media which asserted that carpet presented a health hazard, particularly in respect of asthma and other allergic diseases. However, a review of scientific literature, particularly of those papers written in the last few years, suggests that the opposite is, in fact, the case.

No scientific evidence has been found that proves that the removal of carpet alone has a clinical benefit since carpet removal has only been exercised together with a number of other potentially beneficial actions which might alleviate symptoms. The three-dimensional construction of a carpet with pile is such that it can entrap the fine allergen particles, that give rise to health problems when inhaled, until they are removed from the carpet by periodic vacuum cleaning. A carpet has, therefore, an important role to play in significantly reducing the allergen content of indoor air.

Wool, in particular, is known to absorb gaseous toxic pollutants from the atmosphere such as formaldehyde, sulphur dioxide and oxides of nitrogen. The large fibre surface presented by the pile of a carpet allows significant amounts of such pollutants to be absorbed, thereby contributing to improved indoor air quality.

1.2 Types of textile used as floor coverings

1.2.1 Fibres used in the use surface

Wool

Wool remains the most popular pile fibre for carpets made in the UK. Carpet wools are coarse (>33 μm), crimpy and often medulated. Wool from British mountain and moorland sheep breeds are particularly popular but have the disadvantage of containing kemp and dark-coloured fibres. For carpets of plain, pale colours a white or near white wool, free from dark hairs is preferred and for these styles wools from New Zealand sheep breeds are popular. New Zealand carpet wools are in general considered softer and lustrous as well as free from dark hairs. Carpet wools often come from sheep bred primarily for meat production and can be considered a by-product but some New Zealand breeds are bred for the dual purpose of both meat and fibre production.

Wool carpets are difficult to ignite and can achieve high levels of resistance to flammability without special treatments. The ability of a wool carpet not to show cigarette burns was considered important for hospitality end uses since the small area of char could be brushed from the carpet surface without leaving an ugly black mark. Wool is naturally soil hiding and wool carpets can contain significant quantities of soil without appearing dirty. They respond well to cleaning and the pile often recovers well from flattening during the cleaning operation thanks to the presence of the warm water used in the process. The relatively low resistance to abrasion of wool renders its use in low pile weight constructions risky but the use of wool rich pile fibre blends with the addition of say 20% nylon or other durable synthetic fibre significantly enhances the abrasion resistance of the carpet.

However, the warm and luxurious connotation of wool often lends its use more often to the more prestigious carpet constructions.

Polyamide

Polyamide, in the form of Nylon 66 staple fibre was introduced to the UK carpet industry in the mid-1950s. Research work carried out in the laboratories of British Nylon Spinners Ltd demonstrated that a significant increase in the abrasion resistance of the wool pile carpet could be gained by the incorporation of a percentage of nylon in the pile fibre blend. The work established that the optimum blend was 70% wool, 30% nylon. Above 30% nylon the increase in abrasion resistance was much less marked. Although different manufacturers launched products incorporating from 15% to 30% nylon in blends with wool the most popular blend evolved as 80% wool, 20% nylon. In the UK at this time the industry was almost exclusively manufacturing woven carpets. The 'blending' fibre was a premium product of 13 d'tex, slightly de-lustered by the incorporation of titanium dioxide and with a circular cross-section and was initially in short supply. Since that time, however, significantly more widely available sources provide a range of suitable products, some of which are based on waste fibre streams and have a less defined specification.

In the USA, where the tufting process was already well advanced, DuPont and Monsanto introduced bulked continuous filament nylon yarns supported by strong brand identities. It was not until the early 1960s, however, that such yarns were introduced to the UK tufting industry. Initially of nominally 4060 d'tex with 204 filaments (based on 3 ends of 1155 d'tex, 68 filaments processed together) and a brand requirement that the products made from the yarn should have a minimum total pile weight of 712 g/m^2 (21 oz/yd^2), the competitive nature of the market soon demanded yarns of lower total d'tex for the production of carpets with lower total pile weights.

The yarns had so called tri-lobal cross-section filaments which were partly de-lustered and the yarns had a low twist level of 23 turns per metre to give some cohesion to the yarn during processing and were used in loop pile carpets with a sculptured high and low loop design and which were subsequently piece dyed. Following on from US developments and to increase patterning scope in carpet, dye variant yarns were introduced such that standard, deep, extra deep and basic dyeable versions were developed. The use of cross dyeing techniques in one dye-bath allowed the skilled manufacturer to obtain a wide range of colours.

Simply explained, a carpet composed of different dye variant yarns when dyed with a disperse dyestuff would be overall plain. Add to this an acid dyestuff and the different dye levels of the yarn allowed tonal and simple contrast colours to be achieved. A basic dyeable yarn would be effectively resistant to acid dyes and the acid dyeable dye variant yarns would be effectively resistant to a basic dyestuff so that the further addition of a basic dye would increase the scope for high contrasts in a different colour.

Significant changes to the styles required in the market place render this technology little used by the industry at present. The most significant changes in the use of nylon yarns since their introduction to the carpet industry are as follows:

- The removal of manufacturing license restrictions in the mid 1960s allowing nylon to become available from a wide number or sources.
- The growth in carpet manufacturers who extrude their own nylon yarn, particularly in the USA and Benelux countries.
- Developments in the production of bcf yarns now enable plain cut-pile carpets to be produced from them; something that was thought near impossible 15 years ago. Consequently the call for 100% nylon spun yarns has virtually disappeared.
- The growth of nylon 6 particularly for the volume end of the market and for yarns extruded by small concerns.

Synthetic fibres offer themselves to fibre engineering to achieve additional desirable properties. In the 1960s and 1970s there was a move to make nylon more wool-like from the point of view of processability, handle and appearance. This was achieved through the introduction of a fibre that was a blend of different fibre d'tex, variable staple length and subdued lustre. This fibre had only limited success in woven carpets for which it was intended being limited to low specification Axminster constructions. The high fibre strength of nylon posed a problem in this end use since most pile yarn for woven carpets is spun on the woollen system. Woollen spun yarns contain many fibres considerably longer than the tuft length which may be only insecurely anchored in the tuft and which can work their way out of the tuft in use. Such fibres that remain anchored in the tuft will lie on the carpet surface giving rise to a problem called cob-webbing. The use of semi-worsted spun pile yarns which have more or less parallel fibres roughly similar in length to the length of the tuft does not give rise to a cob-webbing problem in carpet but such yarns are less bulky and less wool-like in handle and appearance.

Basic nylon fibres are similar in appearance to glass rods and have poor soil hiding performance. In fact, they are said to magnify the soil particles and appear far more soiled than they need. Various methods have been introduced over the years to give nylon increased soil hiding properties which have varied from the adding of increased delustrant to make the fibres more or less opaque, to the modification of the fibre cross-section to introduce light-scattering properties. Probably the most successful soil-hiding nylon is of a more or less square cross-section with voids running along the fibre length.

Carpets with nylon pile were also found to allow the generation of static charges on a body when walking on the carpet, which when discharged against a conductive earthed object caused an unpleasant shock. Methods of controlling the build up of static charges have included the inclusion of a low percentage of viscose rayon in a nylon fibre blend on the basis that such fibres absorbed moisture from the atmosphere, increasing the conductivity of the carpet surface, which dissipated the charge induced on the carpet, limiting the size of the charge on the human body. A further development was the inclusion of a very low proportion of conductive fibre in spun nylon yarns. The problem with this was the difficulty of even distribution of conductive fibres and the propensity for the conductive fibres to darken or dull the colour of the carpet. With continuous filament yarns a spun yarn containing conductive fibres or even conductive filament yarns, often coated with or incorporating carbon, has been used.

Polyester

Polyester pile fibres are usually restricted to long pile styles with pronounced tuft definition, known as Saxony styles. The ability of polyester yarns to take a twist set makes them particularly suitable for such styles which are particularly popular in the USA.

Polyester fibres have good abrasion resistance and reasonable recovery from flattening properties. Their major drawback is that they are difficult to dye and are frequently dyed under pressure. Another significant advantage of increasing importance is that a valuable source of raw material comes from used, clear beverage containers which can be ground, re-polymerised and extruded into virgin fibre.

A particular sophisticated end use has arisen, particularly in the UK, with the incorporation of a small proportion, typically 5%, of low-melting point polyester fibre into a pile fibre blend. Yarns containing such fibre blends will have a matrix of the polyester fibres which when subjected to heat in subsequent processing, including dyeing and carpet finishing, fuse at the fibre crossing points and form what can best be described as a scaffold structure within the yarn. Such yarns tend to resist untwisting of the tufts in use, enhancing appearance retention such that single yarns may be used where previously two-fold yarns were the norm. Yarns containing low-melt polyester fibres also tend to shed less fibre in use.

Polypropylene

Polypropylene is a low-cost fibre and is principally used in low-specification carpets. It is characterised by its hydrophobic nature and cannot be dyed from an aqueous dye bath. Dyeable polypropylene has been developed but is not widely used because the added cost of the fibre is unacceptable for the low-price carpets in which polypropylene is used. Polypropylene is coloured by the addition of pigments to the polymer before the yarn or fibre is extruded. Coloured polypropylene staple fibre is used in blends with wool to achieve heather mix effects, when the wool is dyed conventionally, in a range of shades from one yarn feedstock.

Another popular use is in bcf yarns where different coloured polypropylene yarns are air-entangled to achieve heather mix or Berber effects. By substituting some polyamide yarn for one or more of the polypropylene ends before air-entangling, dyeable heather mix effects may be achieved.

A significant drawback of polypropylene as a pile fibre is its poor recovery from flattening. When polypropylene is used in tight low loop pile constructions this of no importance because there is little pile to flatten but in longer cut-pile styles, say greater than 5 mm, then the rapid loss of appearance is only acceptable because of the low price of the product.

The increasing popularity of wood and laminate floors in recent years has in turn created a market for rugs and carpet squares. Very attractive rugs and squares are woven on advanced face-to-face Wilton looms with cut-pile bcf polypropylene pile.

Polyacrylate

Once seen as a wool substitute in woven carpets, the popularity of polyacrylate pile fibres has decreased significantly in recent years and is currently of only minor importance.

Vegetable fibres

Coir fibre is popularly used in so-called coconut matting. Both cotton and jute have been used as pile fibres in conventionally constructed carpets of low importance but cotton remains a popular fibre for bath mats.

Of increasing importance in recent years, however, are sisal and sea grass. These are used as the face fibre in so called flat woven products, such products being popular with many interior designers. Sea grass, however, has poor resistance to abrasion. With both face fibres the effect of water on the appearance of the product is unacceptable when spillages of even clean water can result in staining, and wet cleaning is not possible for the same reason.

1.2.2 Fibres used in the backing structure

Jute

Jute is an ideal carpet backing fibre. It is relatively inexpensive and is relatively inextensible. A particular drawback, however, is the long supply route, mainly from the Indian sub-continent and the uncertainty of consistent supply. Jute is also liable to bacterial attack, particularly if wetted.

Jute yarn has been the most popular choice for the weft of woven carpets and many woven carpets continue to use jute yarn for this purpose. Jute is also frequently used as the 'stuffer' warp in Wilton carpets.

Woven jute fabric (Hessian) is frequently the secondary backing fabric of choice because of its low cost, good dimensional stability and natural appearance. Unreliable supply has, however, affected its popularity for many manufacturers.

Cotton

Cotton yarns have traditionally been used as the warp yarns for woven carpets. Cotton fibre, in blends with synthetics, remains popular for this end use.

Polyester

Spun yarns of high-tenacity polyester have been used in recent years as warp yarns in woven carpet but a more common use is as a cotton polyester blend in chain warp yarns.

Polypropylene

Split film polypropylene yarns have been used as both warp and weft yarns in woven carpet production. In the form of nominal 1000 d'tex yarn as a cotton substitute for Axminster weaving polypropylene offered a less expensive alternative to cotton but led to lower weaving efficiency, since the abrasion of the yarns by the reed and other weaving components caused the yarn to fibrillate and entangle.

As a weft yarn, often pigmented to a natural jute colour, polypropylene is used in weft yarns where high strength and comparatively low cost are advantageous. The yarn is less tension stable than jute but is unaffected by water and is not subjected to bacteriological attack.

Others

Historically, because of jute shortages following the Second World War 'kraft' paper was used as a substitute. This yarn was effectively twisted strips of brown paper. Its use did not continue once jute became available again.

Linen yarn has been used as the weft in some high-density 3-shot Wilton products necessitating a finer yarn of adequate strength.

1.3 Methods of carpet construction

1.3.1 Woven carpets

Wilton

Wilton carpets are characterised by the pile yarn being woven as warp which, when required to form the pile, is lifted above the level of the backing weave. On single-face Wilton looms the pile is usually formed over pile wires, flat metal strips which are oriented in the weft direction. The dimension of the wire determines the pile height. The wires are inserted from the right-hand side of the loom as the back pick is inserted, there being usually two or three picks per pile row, all contained in one shed of the chain warps. A number of pile wires are in woven into the carpet and the one furthest away from the fell is withdrawn and reinserted as part of a new row, the wires being constantly recycled as weaving continues. The left-hand ends of the wires may be plain, so that loop-pile (Brussels) carpet is woven or have formed ends holding replaceable sharp blades when weaving cut pile carpet.

Conventionally, looms have a jacquard capable of selecting from five pile warp yarns, referred to as frames, in each pile column, but simpler looms equipped with a simple cam and lever mechanism are in use for the production of plain carpet. For plain carpets the pile warp may be fed from a beam but multi-frame carpets have the pile fed from a creel.

Modern Wilton looms weave two carpets simultaneously in face-to-face mode and are particularly important for the production of rugs and squares. The two carpets are woven one above the other with the pile passing from the one to the other, forming a sandwich. A knife traversing from side to side of the loom cuts the pile and separates the two carpets. Weft insertion on these looms is achieved using flexible rapiers and the looms operate at significantly higher picking speed than old single-face looms using shuttle weft insertion.

The pitch of single-face looms is commonly 8 per inch – 31.5/dm (traditionally expressed as 216 per 27″) but a few finer-pitch looms remain in operation usually weaving the optional 3-shot weave. These looms have a pitch of 9.5 per inch – 37.4/dm (traditionally expressed as 256/27″). The 216 pitch looms traditionally weave the 2-shot weave variant and use woollen spun pile yarns whilst the 256 pitch, 3-shot looms use fine semi-worsted spun pile yarns. Commonly carpets with tuft densities in the range 870–1650/dm^2 are produced on single-face looms.

Face-to-face looms used to weave rugs and squares have pitches of 350 or 500 per m and achieve very high tuft densities. The author has direct experience of weaving such carpets with more than 3000/dm^2.

Axminster

Axminster weaving processes are used for the production of patterned carpets with a potentially greater number of colours than in Wilton carpets. There are three variants of Axminster carpet but the dominant one is now the gripper jacquard weave. The essential characteristic of Axminster weaving is that the pile yarn is inserted into the backing weave a row at a time and is the only pile yarn in the carpet unlike patterned Wilton weaving in which the pile yarn not selected by the jacquard to form the pile tufts lies 'dead' in the backing weave.

Gripper jacquard

The pile for gripper jacquard weaving is held in a creel. The jacquard, commonly, has a capacity for controlling 8 frames (colours) but 12-frame jacquards are also available. The ends of yarn are fed into a carrier, one carrier for each dent in the reed. Each carrier can be likened to small, narrow boxes placed on top of each other, each box containing a spring and one colour of yarn is threaded into each box and is prevented from pulling out of the box by the spring. There will be 8 boxes in each carrier on a loom weaving 8 frames. From the front of the loom the carriers present 8 levels of cut yarn ends.

Across the width of the loom is a set of grippers, one gripper for each carrier, often likened to birds' beaks, which swing up to the carriers to close on the protruding yarn ends. A length of yarn is drawn through the carriers, cut off and the carriers swing down when the tufts are secured in the ground weave by a weft insertion. Weft insertion is conventionally by a rigid rapier which introduces three double-stranded weft shots per pile row.

The action of the jacquard is to lift each carrier separately by the appropriate number of levels for the grippers to take tufts from the top (rest) position of each carrier. Most gripper jacquard looms have a pitch of 7 per inch – 27.6/dm although variants of 31.5 and 35.4/dm are in operation. Low specification constructions may have tuft densities of 650 tufts/dm^2 whilst tuft densities of 1240/dm^2 may be achieved.

Spool

The Spool Axminster process has the capacity for producing carpets with designs of an almost unlimited number of colours. The process is more labour intensive, however, and is now fairly rare. The pile yarn for Spool Axminster weaving is wound onto spools, each spool having a number of yarns wound side by side, like a small beam. The process of winding the yarn onto the spools is called spool setting. One spool is prepared for each row in the design repeat with the sequence of coloured ends corresponding to the sequence of coloured tufts for that row of the design. The spools are usually either 27″ (0.69 m) wide or 36″ (0.91 m) wide. For broadloom weaving a number of spools are employed across the full width of the loom. Each spool is numbered in sequence corresponding with the number of the row of the design and the spools are mounted in spool frames that allow the spools to revolve and yarn ends are threaded through individual short tubes mounted on the spool frame.

The Spool Axminster loom has an endless chain in a gantry above the loom with a corresponding number of links in the chain to the number of rows in the design repeat or multiple repeats. During the weaving operation the chain is advanced one link at a time for each row of the design and the spool and spool frame at the weaving point is removed from the chain, lowered down into the backing weave with each tube passing between warp ends and the pile ends gripped by a weft shot. The spools rise a short distance to draw off yarn for the row of tufts, the yarn is cut by a pair of horizontal guillotine blades stretching the full width of the loom before the spool and spool frame are swung back into the vacated link in the chains. The ends of yarn are combed up to form a U tuft around the weft shot at the same time. On a spool Axminster loom weft insertion is by two rigid rapiers one above the other which in one traverse and withdrawal of the loom inserts three double-stranded weft shots for each pile row of carpet.

Spool Axminster looms have a pitch of 27.6/dm and weave tuft densities from as low as 430 tufts/dm^2 up to 980 tufts/dm^2. A small plant of unique Spool Axminster looms remains in operation with a pitch of 37.4/dm weaving carpet with a tuft density of 1470 tufts/dm^2.

Spool-gripper

This loom was developed to combine the patterning potential of the Spool Axminster loom with the robust weave structure of the gripper jacquard loom. Spools identical to those used for Spool Axminster were used and also mounted in an endless chain. The loom was fitted with grippers identical to those used for the gripper jacquard loom but their arc of operation was significantly reduced. The spools remained in the chain during the weaving operation.

Modern loom developments

The basic design of the gripper jacquard loom has seen improvements in recent years. These include the use of electronic jacquards eliminating the need for the costly punched jacquard cards, the use of projectile weft insertion and the use of carriers that operate in the horizontal rather than vertical orientation, allowing the grippers to operate through a much reduced arc. Loom speeds have risen considerably through these improvements.

Textile floor coverings without pile

There has been increased interest in so-called flat woven carpets in recent years, although none are produced in the UK. These carpets do not have a pile in the strict sense of the word but the use surface is composed of relatively thick warp yarns which 'float' on the fabric use surface.

1.3.2 Non-woven carpets

Tufted carpets

Tufted carpets came about as a logical progression of the mechanisation of candlewick production developed in Dalton Ga, USA. The basic process is relatively simple but modern developments have resulted in very sophisticated machines. A tufting machine consists, in its simplest form, of yarn feed rollers extending the width of the machine, guide bars to keep individual ends of yarn from entangling, a set of needles extending across the full width of the machine and a set of hooks which interact with the needles to form the pile. The needles, which have eyes near their points, reciprocate vertically and penetrate a horizontal backing fabric tensioned between and advanced by spiked rollers. The hooks, one for each needle, are positioned beneath the backing fabric and interact with the needles when in their lowest position to form loops around the hooks. As the needles rise the hooks withdraw and release the loops before the cycle is repeated at high speed. The pile yarn is usually fed from large creels through plastic tubing. The tubing avoids the necessity for yarn tensioning and eliminates entangling of the yarns. Beams can also be used to feed the yarn to the tufting machine and allow more short runs of a product to be produced more economically than from creels.

For loop pile tufting, described above, the noses of the hooks point in the direction of travel of the backing fabric but different hooks, pointing towards the direction from which the backing fabric is fed, are used in the production of cut-pile tufted carpet. Consequently loops are retained on these hooks and slide along them until cut by flat blades exerting a scissor action against the side of the hooks.

Tufting machines are characterised by the gauge of the needle bar and whether cut- or loop-pile. The gauge describes the distance apart of the needles mounted in the needle bar and varies typically between 3/8″ gauge (10.5/dm) to 5/64″ (50.4/dm) and finer but common gauges for broadloom carpet are 5/32″ (25.2/dm), 1/8″ (31.5/dm) and 1/10″ (39.4/dm). The simplest tufted carpets are limited to plain or striped carpets but sophisticated patterns and textures are now possible.

For loop pile carpets designs and textures can be produced through controlled multiple pile heights. Initially the devices to achieve this were mechanical or electro-mechanical and were limited to two or three pile heights. Such pattern attachments were also fitted to machines equipped with special hooks incorporating a spring device to produce cut- and loop-pile textures, the high pile being formed into cut-pile and the low pile being formed into loop-pile. The most recent advances in this field utilise servo-motor driven, multiple yarn feed rolls which allow accurately controlled multiple pile height loop-pile carpet.

From the early days of tufting, the ability to move the backing cloth sideways was used to create a wave-line effect in an otherwise striped design. The ultimate development of this is the double sliding needle bar mechanism which employs two needle bars, each of twice the machine gauge and with needles staggered so that the needles of the second bar fall in the gaps created between the needles of the first needle bar. Each needle bar can be accurately moved sideways between needle insertions to create designs by employing yarns of different colours threaded through the needles in a specific sequence and by controlling the sequence of movements and direction of movements of the needle bars. CAD systems are used to develop the designs and to create the instructions for the sequence of yarn colours and the needle bar movement. Multiple pile height loop-pile patterns may also be combined with sliding needle bar effects.

A further method of creating more sophisticated cut-pile designs uses a machine with individually controlled needles which can be controlled to tuft or not to tuft for each stroke of the needle bar. Unfinished carpet already tufted on a conventional tufting machine can have a coloured design over-tufted onto it using this technology. A further sophisticated development of this technology is a machine with groups of needles, each threaded with a different coloured yarn which tufts sideways before advancing the backing cloth by one row. Computer control of the individually controlled needles allows the machine to produce true patterned carpet, similar in appearance to Axminster. Patterned tufted carpet is also produced by printing.

Tufted carpets need more complex finishing than woven carpets, which have good dimensional stability from the basic weave. A simple back-coat of synthetic latex is generally required to impart adequate anchorage of the tufts into the ground weave. Tufted carpets, however, have very poor dimensional stability, are very soft and with tufts tenuously anchored in the backing when they leave the tufting machine. A substantial latex pre-coat is necessary to anchor the tufts and to impart a degree of handle and frequently a secondary backing layer is laminated to achieve good dimensional stability. The laminating medium may also be latex but the latest equipment uses hot melt adhesive applied as a powder and melted before the secondary backing fabric is married to the pre-coated carpet. Tufted carpets finished in this way are less stiff and are claimed to be much easier to install.

Needled floor coverings

Felts have long been used as alternative floor coverings to carpets but developments in needling thick webs of fibres has allowed a more rapid method of achieving felt-like floor coverings which are not reliant on the felting properties of wool. The simplest will have a single or multiple layers of coloured fibres, with or without a carrier fabric, which are entangled by the action of closely packed barbed needles. The fabric produced is stabilised by a back-coating or full impregnation of synthetic latex. The simplest products produced using this technology resemble flat felts, with surface interest created by different coloured fibres blended together.

More sophisticated products with pile effect can also be achieved by carefully controlling needle size, length of needle stroke and the placing of the needles in the needle board. Loop-pile effects, ribs and textures are achieved in this way and a longer pile version, resembling a cut-pile velvet is also possible.

Other methods

Fusion bonding of carpets has been discussed as a coming technology for very many years. This technology has, however, so far, made little impact. The process may use yarns in a warp form or a continuous web of fibre. This is adhered to a backing fabric coated with an adhesive. Typically a face-to-face process is used with pile yarn being alternately adhered to opposite fabrics. The adhesive used may be a hot melt adhesive, activated just before meeting the pile or a more conventional adhesive which will need heat curing. As in face-to-face Wilton weaving the two carpets are separated by a traversing knife.

The carpets produced by this process are often of high quality with a very even surface finish. Many variations of the fusion bonding theme have been proposed and used from time to time but the one described above is currently in production in Western Europe.

Warp knitting has also been proposed as an alternative method of manufacturing carpets. Pile fabrics have been produced, possibly more suited as rugs rather then broadloom, but there has been no significant use of this technology.

1.4 Future trends

1.4.1 Fibres and yarns

There have been few significantly new fibre types for carpet manufacture since the advent of synthetic fibres many years ago. Just two new fibres spring to mind.

Poly (trimethylene terephthalate) was introduced about ten years ago and was said to combine the desirable properties of nylon and polyester fibre. In spite of this, the fibre appears to have had little impact on the market.

Reports in the technical press have referred to a new pile fibre based on a protein polymer. Little information is available concerning the important properties of abrasion resistance, recovery from flattening and dye-ability. Instead the emphasis has been on the bio-degradability properties and therefore ultimate low impact upon the environment when disposed of as end of life waste.

1.4.2 Manufacture

There has been no radically new method of carpet manufacture introduced for some considerable time; instead manufacturing methods have been refined and speeded-up. The following most recent significant advances, have already been discussed:

- electronic jacquards for carpet weaving
- high speed gripper Axminster looms
- continually improving face-to-face Wilton looms
- true patterned tufting has arrived when the current demand for patterned carpet has significantly declined
- advances in multi-pile height patterning for tufting allowing more and better defined textures and patterns.

Without a functioning crystal ball to predict the unexpected, one can only predict continued refinement of existing manufacturing processes with emphasis on speed of production, patterned carpet capability without the need for very large amounts of individual colours, and the ability to economically produce unique styles in modest quantity.

1.4.3 Influences

The importance of minimising the effects of climate change will be the most significant driving influence on all industry for the foreseeable future. Emphasis will be increasingly placed upon:

- sustainability of raw materials
- limiting the need for global transportation of raw materials and finished goods

- manufacturing with low consumption of energy and natural resources
- production of finished goods with the minimum of added chemicals and the avoidance of all toxic chemicals
- strict control of all emissions and effluents to air land and water.

The author is also concerned about the potential damaging influences of standardisation. Standardisation ought to be of great benefit to industry and the end user of the product. However, for the carpet industry the end product is considered to be a construction product by standards organisations. This may well be relevant for carpet for commercial use but ignores the fact that very significant volumes of carpet are sold for domestic use where they are considered to be a furnishing. Standards rightly considered as necessary for construction products constitute an unnecessary burden on manufacturers of domestic products.

1.5 Sources of further information and advice

The following sources of further information and advice are strongly recommended:

Trade associations

The Carpet Foundation (UK) www.carpetfoundation.com
European Carpet and Rug Association (BE) ecra@euratex.org
The Carpet and Rug Institute (USA) www.carpet-rug.org
UFTM (F) www.moquettes-uftm.com
VNTF (NL) www.textielnet.nl/partners/vntf
Febeltex (B) www.textielnet.nl/partners/vntf

Testing laboratories and technical advice

The British Carpet Technical Centre www.bttg.co.uk/bctc
Centexbel (BE) http://www.centexbel.be
TFI (D) http://www.tfi-online.de

Publications

International Carpet Bulletin www.world-textile.net
Carpet and Floor Covering Review www.cfr-magazine.com

Textbook

Carpet Manufacture by G H Crawshaw ISBN 0-908974-25-6

2

Structure and properties of carpet fibres and yarns

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Abstract: This chapter discusses the structures and properties of major natural and man-made fibres which are in use in making carpets. It also provides an overview of the various yarn-spinning processes like BCF, woollen, semi-worsted and worsted spinning. The comparison between woollen and semi-worsted spun yarn properties are also discussed. A large part of the chapter deals with carpet yarn engineering in general and wool tarn engineering in particular. Finally, the various yarn-finishing techniques and quality-control aspects are also dealt with.

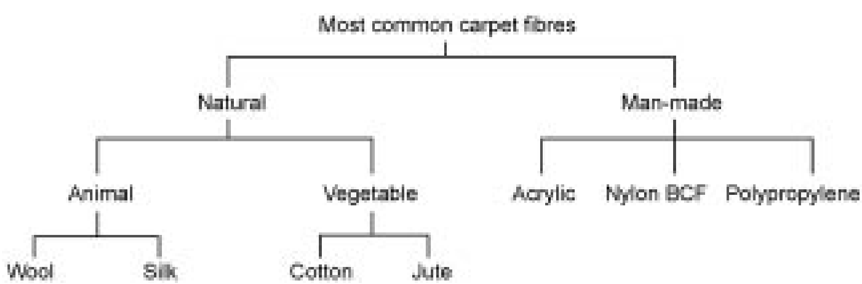
Key words: wool, micron, spinning, woollen, semi-worsted, worsted, BCF, yarn engineering, finishing.

2.1 Introduction

Traditionally, carpets were produced using natural fibres until the advent of artificial and synthetic fibres, which had a significant impact on the carpet weaving industry. But new fibres have not played a very influential or critical role in the development of the industry, as far as tufted carpets are concerned.

Figure 2.1 shows a list of fibres that are commonly used in making carpets.

The most common carpet pile fibres which are currently in use are wool, silk, propylene and nylon and the common fibres used in backing are cotton, jute and polyester. Polypropylene fibre is the only one of its kind that is extensively used both on pile surface as well as backing.



2.1 Fibres commonly used in making carpets.

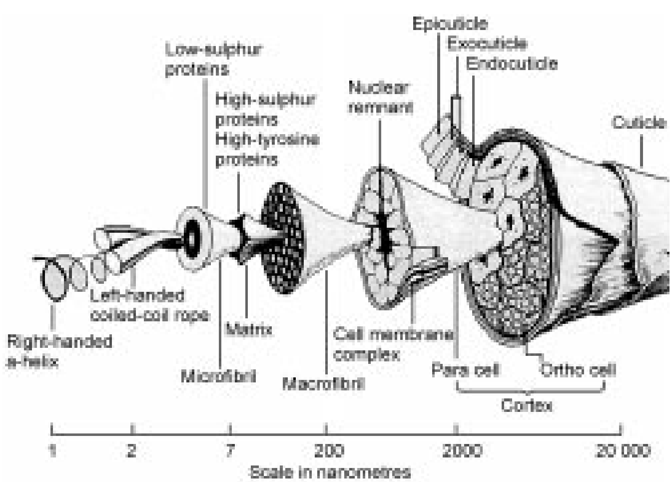
2.2 Structure and properties of carpet fibres

A variety of natural as well as synthetic fibres are being used in textile floor coverings. Although there are many differences between a carpet fibre and an apparel fibre, the most obvious difference is the fibre diameter, since a higher diameter fibre is used in carpet. Apart from the diameter, there are quite a few parameters that play a decisive role in choosing a particular fibre for a specific product. This is applicable for both natural as well as synthetic fibres, e.g. cut length, luster, type of cross section, crimp, dye-ability property; these are very important properties when selecting a nylon fibre. Similarly, the fibre micron, bulk, medullation, vegetable matter content, base colour, and fibre length after carding are the main parameters for selecting a wool fibre.

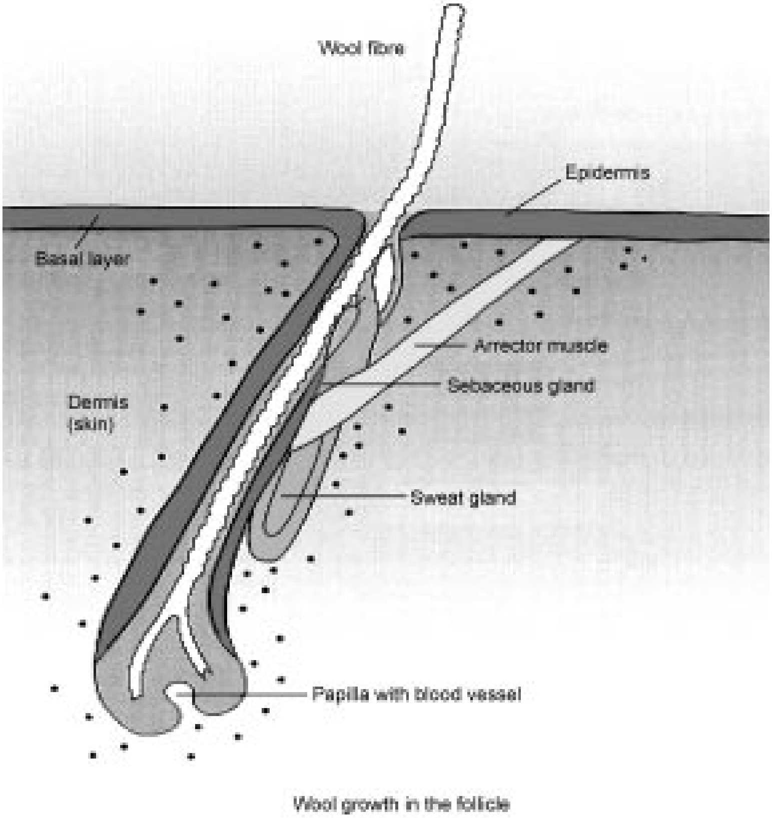
The following section explains the individual fibre properties.

2.2.1 Wool fibre

Wool has traditionally been the choicest pile fibre and is still the fibre associated with high-quality products. It has one of the best balanced ranges of properties for use as carpet pile fibre. In carpet fibres and other applications, wool's texture and resilience enable it to recover well from crushing, resist soiling and clean readily. Its unique fibre construction, along with its natural ability to attract moisture and the protein constituents provide natural flame-resistance and high durability, resulting in a product that retains its appearance for years. Wool is also soil-resistant – releasing soil up to 25% more readily than synthetic fibres. The cuticle, or outer layer of the wool fibre, has a finely waxed surface with overlapping scales to keep soil in the upper area of the tip, where it is easily removed (Fig. 2.2).



2.2 Structure of wool fibre.



2.3 Wool growth in the follicle.

Wool is a complex fibre that has evolved over thousands of years with the sheep who produce it, to protect them over a wide range of climatic conditions. Wool grows from follicles in the sheep's skin (Fig. 2.3), in the same way that hair grows on human skin, and like human hair, wool is also made from the protein keratin, but there the likeness ends.

In cross-section, wool fibre consists of a two-part outer layer (cuticle) and an absorbent core (cortex). The cuticle regulates wool's dual ability to repel liquid, yet absorb moisture vapour. Under a microscope it consists of a thin, porous membrane covering overlapping scales. These scales have a fine wax coating which causes liquid to bead and roll off the surface of wool fabric, while moisture vapour can be absorbed through the porous outer cover. The cortex, which accounts for approximately 90% of the fibre, is composed of very small, cigar-shaped cells, each enclosed in a tough membrane and containing dense fibrous material. Many of the amino acids, in the cortical cells are able to bond physically and chemically with the water vapour. Water vapours coming through the cuticle pores bond with amino acids in the cortex – the main bulk of the fibre. This allows wool to absorb up to one-third of its weight in moisture without feeling damp, making it resistant to static electricity. This moisture-absorption property also helps wool recover from pressure marks. As the atmosphere dries out, the fibre releases the moisture, which quickly gets dispersed through evaporation. The cortex cells come in two different types: the ortho- and para-cortex. These two cell groups lie on opposite sides of the fibre and grow at slightly different rates, which cause three-dimensional cork-screw patterns of coiled springs much like shock absorbers, which provide wool with high elasticity and the characteristic waviness or crimp structure that allows fibre to recover and resume its normal dimensions. Wool fibres can be stretched up to 30% without rupturing and will recover, returning to their original form [1].

According to WRONZ [2], six main measurable fibre properties are necessary to predict the processing efficiency and product performance of a wool blend. These are:

1. mean fibre diameter
2. fibre length after carding
3. bulk
4. medullation
5. base colour
6. vegetable matter content.

Depending upon the type of carpet to be produced, these six properties rank according to their importance.

2.2.2 Silk fibre

Silk is produced as the cocoon covering of the silkworm, the pupal form of the Asian or mulberry silk moth, *bombyx mori*. The cocoon is spun by the silk moth caterpillar of a single silk fibre that can be up to several thousand feet in length. To harvest the silk, completed cocoons are boiled to kill the silkworms, and then unwound into single fibres which are plied together and spun into thread or silk yarn.

Natural silk is a fibrous protein composed of a number of amino acids, they are:

1. glycine (44.5%)
2. alanine (29.3%)
3. serine (12.1%)
4. valine (2.2%)
5. tyrosine (5.2%)
6. glutamic acid (1%)
7. others less than 1% each.

Chemically, natural silk is $C_{15}H_{23}O_6N_5$. Silk is used to make oriental rugs because silk fibre can be dyed into rich, saturated colours, and has a distinctive, almost translucent lustre.

2.2.3 Cotton fibre

Cotton fibres are formed as multi-layered tube. As the fibre dries up, the tube collapses, forming a ribbon-like structure and the fibre convulsion occurs. Cotton fibre is mixture of mature and immature fibres. Increase in immature fibre percentage in the cotton bale produces neps during spinning and they are also difficult to dye. Because cotton fibres has an unusual bean-shaped cross-section, it is difficult to define its diameter and thus the fibre fineness is described in terms of micronaire values – equivalent fibre diameters measured on airflow apparatus. Micronaire values of different types of cotton fibres typically range from 10 to 22 and staple lengths generally vary from 12 to 33 mm [3].

Cotton fibre is mainly used in bathmats and squares, the category where easy washability is an important criterion. In earlier times, cotton fibre was used as pile fibre in the tufting industry, but then it lost out to other more competent fibres in this category. Currently a trend is being seen in the broadloom carpet industry, wherein cotton fibre is being used as a pile fibre along with melt-bonding fibres as a blend. Also some special yarn construction out of cotton fibres is being used as pile fibre in broadloom carpets. Cotton is also an important member in the backing of carpets, and cotton primary backing is largely being used in the hand tufted carpet industry.

From a dye-ability point of view, cotton can be dyed with variety of dyestuffs and in various shades, mostly by reactive and vat and less commonly by azo dye class.

2.2.4 Jute fibre

Jute is a bast fibre. It is also called lingo-cellulosic fibre as it contains about 20% lignin in addition to cellulose. The basic cells of jute fibre are irregularly polygonal with thick walls and having a lumen of oval cross-section. Jute is a long and stiff fibre and has very low extensibility [3].

A few years back, jute was the most important fibre for backing in both tufted and woven carpet industry. Jute is used as pile fibre in some woven squares on face-to-face systems [4]. It is also used in low-cost squares as pile fibre but it lacks the resilience which makes jute fibre piles stay compressed even after removal of load. The recovery of pile fibres can be promoted by suctioning or shaking. Currently most of the jute fibre finds its use in the third back cloth.

Jute plants are generally grown in the damp, hot regions and the most common jute-cultivating countries in the world are Bangladesh, India, China and other south-east Asian nations of typically similar climatic conditions. The jute plant generally attains a height of about 5–6 metres and the fibrous materials are cemented together by lignin and other gums. Retting of plants is carried out by soaking in pits for about 15 days where the biochemical degradation of the cementing material occurs, which causes dissolution of the cementing material and thus the fibrous material is obtained, which is then dried and sent out to spinning mills for making yarns. The retting process is the most significant step as this determines the quantity and quality of jute fibre obtained. Too much retting may lead to excessive damage to the fibrous material, making it unspinnable, whereas too little retting will lead to difficulty in separating the fibrous material from the stalk.

2.2.5 Acrylic fibre

Acrylic fibres are made from acrylonitrile as one of the major monomers. Amongst the vinyl monomers, acrylonitrile is the only monomer used for the production or synthesis of fibres. Other vinyl monomers lack the cohesive forces between the molecular chains of their polymers and hence cannot compete with acrylonitrile [5]. Pure poly-acrylonitrile fibre is practically undyeable and hence does not find application either in apparel or the home textile segment. The dyeable acrylic fibre is made by co-polymerisation of acrylonitrile with other monomers containing sulphonic acid or carboxylic acid groups. In acrylic fibre, the fibre contains up to 85% by weight of acrylonitrile monomers, whereas the fibre containing between 85% and 50% by weight of acrylonitrile are defined as modacrylic fibres [3].

All acrylic fibres are made from acrylonitrile combined with another monomer. The co-monomers most commonly used are:

- Neutral monomers such as methyl acrylate and vinyl acetate, which enhance the solubility of the polymer in spinning solvents, modify the fibre morphology and improve the rate of diffusion of dye into the fibre.
- Ionic monomers such as sodium styrene sulphonate, sodium methallyl sulphonate or sodium styrene sulphenate to provide supplemental dye sites and to impart differential water sensitivity between elements in bi-component fibres.
- Halogen-containing monomers such as vinyl chloride, vinyl bromide or vinylidene chloride to impart flame resistance.

The spinning processes most commonly used for the production of acrylic fibres are wet and dry spinning. Acrylic fibres cannot be produced by melt spinning as they degrade when heated near their melting point.

In the wet-spinning process the spinning dope is extruded through a multiple-hole spinnerette into a coagulation bath containing a liquid in which the solvent is soluble but the polymer is not. The jets of dope quickly become coagulated into solid filaments that are continuously removed from the spin bath where they are washed free from solvent and then subjected to drawing, drying, crimping and annealing.

In the dry-spinning process the dope is extruded through the spinnerette down into a tower where uncoagulated filaments are brought into contact with an inert gas heated above the solvent boiling point. The solvent evaporates from the filaments as they pass down the column and solidify. The filaments are continuously removed from the bottom of the tower, washed free from solvent and then processed like wet-spun fibre [5]. Both wet- and dry-spun acrylic fibres are in use in the carpet industry.

Acrylic fibre's high elasticity, easy dyeability, voluminosity, ease of washing, resistant to pilling and good light and colour fastness values have helped it find a place in the pile fibre for carpet. But then, it does not have the toughness of nylon, prestige of wool, the settable property of polyester or the low price of polypropylene. Also the acrylic pile is highly susceptible to distortion during piece coloration because of the plasticity of fibre at dyeing temperature, which reduces its appeal to the tufted carpet industry [3].

2.2.6 Nylon fibre

A polyamide manufactured from aliphatic monomers is called nylon, whereas a polyamide in which at least 85% of the amide linkages are joined to aromatic groups is known as aramid. The two polyamide fibres, which have become important commodity fibres, are nylon 6 and nylon 66. Both are based on aliphatic chains.

A polyamide which is derived from a diacid and diamine is called an AABB type (e.g. nylon 66). On the other hand, a polyamide synthesised from an amino acid or a lactam is termed as AB type (e.g. nylon 6) [5].

Nylon 66 is produced by the polycondensation of adipic acid and hexamethylene diamine, and nylon 6 is produced by self-condensation of caprolactam. The manufacturing process of both the polymers differ considerably [6], but for both the cases the final product is polymer chips, which are the starting material for fibre manufacture. Both nylon 6 and nylon 66 fibres are produced by melt spinning.

Both nylon 6 and nylon 66 fibre have excellent elastic recovery, resulting in very good pile resilience, high tenacity (over 4 gm/dtex) resulting excellent resistance to wear, easy dyeability with acid dye classes resulting in bright colours. The melting point of nylon 6 fibre is around 215 ºC while the same for nylon 66 is around 250 ºC, which indicates the difference in molecular structure (crystallinity) between them. Both the fibres can be either heat set or steam set, but the setting conditions are different. The moisture regain at 65% RH and 20 ºC for both the fibres is 4% [3].

Nylon was the first synthetic fibre used as pile fibre for carpets and to date has been the leading fibre in the tufted carpet industry. The fibres are used in the form of filament as well as spun yarns. Although nylon has several advantages for use in the carpet industry, it has some drawbacks as well; they are extremely lustrous for most of the product styles, and also susceptible to soiling and staining during usage. During dry atmosphere, charge separation may occur which may produce unpleasant shocks [3].

Nylon fibre in the form of both filament as well as staple fibre is in use in the carpet industry. Extreme care during dyeing is necessary for the filament yarns, as no opportunity of blending exists for them. Also during cut pile tufted carpet production, any defective cutting of the fibre will produce more serious carpet faults, if filament yarns are being used compared to spun yarn. The spun yarn resembles more woollen-like yarns compared to filament yarns, which make them a better choice. However, in general filament yarns are more in use for loop pile nylon carpets and spun yarns in cut pile carpets [3].

The key fibre properties which are important while selecting the best suited fibre for a particular carpet are as follows:

- staple length
- fibre denier
- fibre cross-section
- lustre
- crimp
- dyeability
- soil/stain resistance
- any speciality treatment given like bacteria resistance, flame resistance, etc.

2.2.7 Polypropylene fibre

Polypropylene fibres are composed of crystalline and non-crystalline regions. The spherulites developed from a nucleus can range in size from fractions of a micrometre to centimetres in diameter. The a-axis of the crystal unit cell is aligned radially and the chain axis is homogeneously distributed in planes perpendicular to this radial direction. Each crystal is surrounded by non-crystalline material. Fibre spinning and drawing may cause the orientation of both crystalline and amorphous regions. If the extension is less than 0.5%, the spherulite deformation is elastic and no disruption of the structure occurs, otherwise spherulites are highly oriented in the direction of the force and finally are converted to microfibrils. These highly anisotropic microfibrillar structures lead to anisotropic fibre properties [5].

Polypropylene is being widely used in carpet manufacturing, either as part of a blend or as a whole. While it withstands footfall well, it is not as resilient as other fibres and can look dull when soiled. As far as cleaning goes, polypropylene is easy to care for. It entered into the carpet industry as a good

Table 2.1 Specific gravity and cover of different carpet fibres [2]

Fibre type	Specific gravity	Relative diameters for the same decitex
Polypropylene	0.91	1.0
Polyamide	1.14	0.89
Polyacrylic	1.17	0.88
Wool	1.32	0.83
Polyester	1.39	0.81

backing material [7], but gradually it has become the second most important pile fibre in terms of square metres. Practically it has replaced the rayon in the low end carpet segment as a pile fibre.

Polypropylene is not as resilient as nylon, but that can be compensated by increasing the pile density, also it has many advantages for use in carpets [8].

Polypropylene can only be dyed by melt pigmentation, which results in excellent fastness standards. The monomer used for making polypropylene fibre is obtained from the petroleum industry, which requires lower conversion energy than other synthetic fibres to convert it into fibre. Its handle also quite resembles wool, and lower specific gravity provides better cover for the carpets compared to other fibres (Table 2.1). Polypropylene has no affinity to water, which makes it resistant to water-borne stains, but oily stains do stain it. There is also no problem of static generation with polypropylene fibre. Generally the carpet grade polypropylene fibre has a tenacity of about 3 to 4 g/dtex and elongation at a break of 80–100%. The polymer is readily degradable in the sunlight, thus it is absolute necessity that the polymer is UV stabilised.

Polypropylene fibre generally comes in round or delta cross-section with small amounts of trilobal cross-section. Generally, for crisper products, fibres of about 30 dtex are used, while for softer products fibres of about 6 dtex are used. For woollen spinning, fibre staple length of 100 mm while for semi-worsted the stale length of 150 mm is required.

Some speciality polypropylene fibres are also available in the market, wherein copolymers of polypropylene and polyethylene are extruded to produce shrinkable fibres. Blending of both standard and shrinkable fibre on semi-worsted spinning system followed by relaxing at 120–130 °C produces bulky yarn.

2.3 Carpet yarn manufacturing

In the carpet industry, both the filament yarns as well as spun yarns are used as pile material. Filament yarns are generally popular in the tufted carpet industry, although spun yarns are also being used, especially in the heavier weights of carpets. All the filament yarn is bulked (BCF). For the woven carpet industry, spun yarns are mostly used as pile material although BCF polypropylene is used in face-to-face carpets [3].

2.3.1 Filament yarns

Texturing of BCF yarns is done by two techniques:

- hot-fluid-jet technique
- stuffer-box technique.

The stuffer-box technique is older and is generally less used nowadays.

The three basic production routes are as follows:

- Direct spinning: the stages are polymerisation, spinning, drawing and texturing. This method of production lacks flexibility and is not used in the carpet industry.
- Single-step process: in this process, spinning, drawing and texturing are done in one machine. This particular method is more suitable for production of standard yarn types in large quantities.
- Two-step process: spinning and winding are done in first step and drawing and texturing in the second step. This is the most flexible amongst all the three methods which allows production of various yarn types.

BCF single-step process

In the single-step process, the polymer chips are fed into the extruder through a dryer and then pass a pump and filtration unit before entering into the spinning assembly. After the spinning, the spun fibre is quenched; spin finish is applied and then textured. The subsequent stages of cooling, tangling and winding are done in the same assembly and a production unit of this type typically produces about 3500 m/min. The most important point to remember during single-step process production is there should be strict control on every aspect of the process as there is no blending operation afterwards.

BCF two-step process

In this process the un-drawn yarn spun to a given specification is wound to a package after spinning and these packages are then draw-textured. This two-step process provides more versatility than the single-step process as yarns of different colour, dyeability or denier can be creeled up in one machine.

2.3.2 BCF polypropylene

BCF polypropylene yarns are manufactured by spin-draw-texturing. The polypropylene fibre is not as susceptible to oxidation as nylon and also has virtually zero moisture pick-up, hence plants for manufacturing polypropylene do not need melting of chips under nitrogen and also strict moisture control is not a requirement. Thus the plants are less expensive than those for nylon. Polypropylene yarn is usually produced in pigmented form as the fibre is essentially undyeable except for a few modified ones.

2.3.3 BCF polyester

Polyester in the carpet industry is generally used in staple fibre form. BCF polyester is relatively new and is generally produced through single-step draw-texturing units. The hot air texturing is typically being carried out at 170–210 ºC. Polyester is commonly available as partially oriented yarns (POY), and this is the starting material for the process. During draw-texturing the yarn passes from the drawing rollers through the texturing unit, where it is subjected to superheated steam and thereby takes three-dimensional crimp while passing through a wider tubing section. The first part of the tube is heated to promote the setting, and the cooling is done at a subsequent stage in a longer length.

2.3.4 BCF nylon

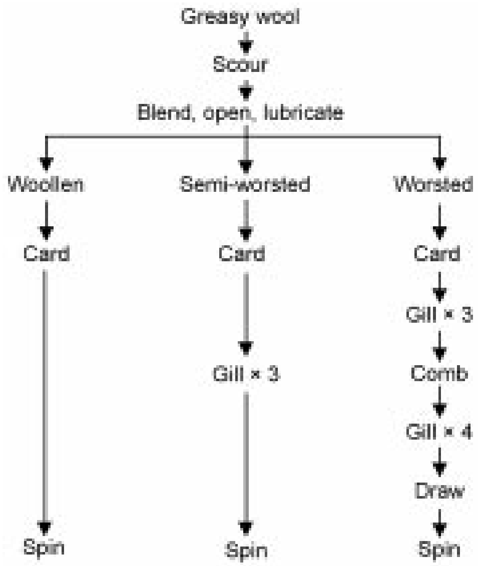
The BCF nylon yarns used in the carpet industry are generally produced in 650 to 5400 dtex while the filament decitex varies in the range of 11 to 30. Generally the coarser ones are used in the loop pile carpets while the finer ones in the cut pile products. Also a major difference between the cut pile and loop pile yarn is in their twist direction of the cabled yarns, loop pile tufting machines require S twist while the cut pile machines require Z twist. Wide ranges of product variation at various production stages are possible while manufacturing nylons.

2.3.5 Most commonly used spun yarn for carpet

Some tufting yarns are produced by unconventional spinning methods but generally three processing systems are commonly used to convert wool fibre into yarn: woollen, semi-worsted and worsted (Fig. 2.4). The systems are distinguished by the degree of preparation of the fibre before spinning, which in turn imposes restrictions on the type of wools that can be processed successfully and influences the characteristics of the yarn produced. During spinning, the fibres are drafted to achieve the desired yarn thickness and regularity and twist is applied to give the yarn strength [1].

2.3.6 Woollen system

The woollen system produces a lofty, bulky yarn, in which the fibres are comparatively randomly oriented. This means that a number of fibres will



2.4 Spun yarns.

protrude on the surface, giving the yarn a fuzzy appearance. Woollen yarn is widely used in carpets, woven fabrics (including blankets) and knitwear.

As there are only three basic stages – blending, carding and spinning – involved in the production route, it provides a comparatively inexpensive system for converting scoured wool into heavier count yarns.

Because of the limited number of stages in the process and the wide range of possible raw material components, it is important that the initial blending operation is efficiently controlled. Fibre lubricant is applied at this stage to help prevent excessive fibre breakage during carding and increase fibre cohesion during spinning.

After blending, the wool is fed into the carding machine, where it passes between a series of rollers covered with fine teeth, which fully open the staples so that the fibres are totally separated. At the same time they are also thoroughly mixed. During this process, the fibres are formed into a thin uniform web, which is finally divided lengthwise at the condenser into a number of narrow ribbons of fibres. These are then consolidated by rubbing into cylindrical, twistless strands called slubbings, which are wound onto bobbins ready for spinning. The slubbings are spun into yarn on ring spinning frames usually at low levels of twist and at low drafts. Woollen ring spinning is unique in that normally false twist is used to control the fibres during drafting. This means that a temporary twist is inserted to hold the slubbings together until the true twist is inserted during spinning.

The principal parameters limiting the suitability of wool for the woollen process are fibre length and vegetable matter content. Short and tender wool can usually be well tolerated, providing there is a proportion of sound wool of adequate length to carry them through the various processing stages. Therefore mean fibre length after carding should be at least 60 mm barbe. However, long and sound wools hinder the separation of the web into slubbings at the condenser; hence a maximum staple length of 150 mm is the recommended upper limit for this system. The woollen system cannot tolerate high levels of vegetable matter contamination, although a smaller quantity (1–2%) can be successfully removed [1].

2.3.7 Semi-worsted system

The semi-worsted system is a comparatively modern concept, developed to provide an alternative route to produce yarns with similar characteristics to worsted spun yarns, but in a shorter and more economical way. Because this route is short, with limited facility for blending/mixing, thorough pre-blending is essential. Raw materials follow the same carding operation as for worsted processing, followed by the gilling stage.

The lack of a combing stage restricts the opportunity to remove the short fibres, which means that to achieve adequate yarn properties, a minimum of short and/or tender wools should be used (e.g., minimum fibre length after carding of 95 mm barbe, and a CVH of no more than 50% in carded sliver). Thus greasy wools intended for semi-worsted processing should be sound and freely openable with minimum staple length of 75–125 mm. Similarly, with very limited facilities for removing vegetable matter, only wools with low levels of contamination will be suitable for this process. The maximum acceptable limit depends on product requirements and typically ranges from vegetable free to up to 0.4% for carpet blends [1].

2.3.8 Comparison of woollen and semi-worsted yarn properties

Semi-worsted yarns are characterised by the parallelised configuration of fibres giving a compact and lustrous look. Woollen yarns have more random fibre distribution and are usually more bulky and matt. The bulk or covering power of semi-worsted yarns can be improved dramatically by selection of suitable wool.

This emphasises the critical nature of wool fibre selection for semi-worsted yarns and it can be concluded that, although the semi-worsted system is initially less expensive, and less labour is necessary for its operation, the fact that the more expensive wools are necessary frequently means that the resulting yarn could be as expensive as the equivalent woollen spun product.

It has frequently been stated that woollen spun yarns set better than semi-worsted yarns, but by careful blend selection, semi-worsted yarns can also be set perfectly well. In fact for semi-worsted yarns, blend selection is more important than the setting system itself.

Table 2.2 Packing factor for woollen and semi-worsted spun yarns

Wool	Packing factor for semi-worsted spun	Packing factor for woollen spun
Lincoln	15.9	9.5
NZ Drysdale	11.4	7.9
NZ Romney	11.3	8.2
NZ Perendale	7.4	7.1

N.B. Lower number indicates more bulky yarns

If a reasonable percentage of highly crimped fibre is incorporated in the blend and after spinning this crimp is allowed to re-develop in the yarn, then the yarn will be more cohesive and tuft definition is achieved. Table 2.2 shows the packing factor for different yarns.

There are two concurrent but opposite trends in the tufted carpet industry at present:

1. a move towards coarser gauges
2. a move towards finer gauges.

The trend towards coarser count favours woollen yarns, whereas the trend towards finer gauges (given low, dense construction) favours semi-worsted yarns. Indeed, the low bulk and compact semi-worsted yarns may be used to advantage to obtain particularly dense, high-quality carpets. The higher the density and finer the gauge, where yarn strength becomes more important, the further the advantage moves towards semi-worsted yarns.

Latex penetration of the yarn during finishing is important in order to avoid excessive fibre loss and for this reason the random fibre configuration in a woollen yarn would seem to be a distinct advantage. Many people believe that semi-worsted yarns are less prone to fibre shedding because they are usually produced with longer fibres. In fact, because of the high degree of parallelisation, fibres can be withdrawn easily from the yarn especially if the carpet is not latexed or latex penetration into the yarn is inadequate [9].

2.3.9 Worsted system

In contrast to the woollen system, the worsted system produces smooth, lean, compact yarn constructed from parallel fibres of reasonably uniform length and fineness. Worsted yarns are used to produce clearly defined light and medium weight woven and knitted fabrics. The key stages in worsted processing are carding, gilling, combing and spinning. This route provides a number of opportunities for mixing/blending between carding and spinning, and as the blend generally comprises wools which are quite similar in character, the initial opening and blending stage is less critical.

Because of the combing process, the major limit to wool suitability for the worsted system is that of length, as wool combs cannot handle either very short or exceptionally long fibres. Typically, the mean staple length for the worsted system is between 60 and 175 mm. Also, because of the combing stage, the system is more tolerant of higher levels of vegetable matter content, accepting up to 6% without serious technical trouble. Short and very tender wools and heavily contaminated wools increase the proportion of noils produced at combing. Therefore, the expected ratio of combed top to noils produced (called tear) is the key factor in selecting wools for worsted system [1].

2.3.10 Unconventional spinning techniques

Friction spinning systems and wrap spinning systems are other methods of producing spun yarns for carpets, but to date none of them has achieved great success.

The wrap spun yarns find some application in the Saxony carpets. In heavy American Saxony carpets requiring strong tuft binding, generally heat set yarns of about R400 tex/2 are tufted, and for lighter European Saxony carpets, generally R168 tex/2 to R60 tex/2 heat set yarns are tufted.

Generally exceptionally heavy yarn counts are being produced by a core spinning technique. Sometimes wool is spun around the core consisting of jute or cotton. Hand-crafted rugs, textured loop pile carpets are often manufactured by using core spun yarns [3].

2.3.11 Spinning of hard rigid fibres

Coir and sisal fibres are commonly used rigid fibres, which are largely used in flat woven carpets. The sisal processing system consists of multiple opening, drawing, spinning, shearing, twisting, and package winding. There is no carding used in sisal spinning. Coir, another hard fibre is spun largely by hand or simple hollow spindle machines as the fibre length is too short to be handled by the hard fibre spinning system.

2.3.12 Jute spinning

Jute yarns are used in the pile material for lower end carpets as well as being used as backing material for both woven and tufted carpets. The jute spinning system typically consists of spreading, carding, drawing, spinning, twisting and winding.

2.4 Carpet yarn engineering

Engineering of woollen yarns to produce the quality yarn to be used in carpet manufacturing is a tricky subject, and many aspects are to be taken into consideration while formulating a blend. For example, a buyer is concerned with price and yield, the dyer with colour and dyeability, the spinner with length and spinnability and the carpet manufacturer with yarn properties, carpet appearance and performance. Thus, selection of wool, blending and spinning and finishing play a critical role in trying to satisfy all these requirements [9]. For convenience, yarn engineering can be divided into three parts:

1. wool selection and blending
2. spinning and twisting
3. yarn finishing.

2.4.1 Wool selection and blending

While selecting wool to formulate a suitable blend, information is required on carpet wools and their properties. Some of the most important properties are as below.

Length

Here the main criterion is not so much for the carpet as for the spinning system. Generally, longer wools are used for semi-worsted and shorter wools for woollen systems. For semi-worsted, the average fibre length of scoured wool should not fall below 75 mm, with not more than 30% of fibres below 50 mm. In woollen spinning short fibres are more usual and maximum fibre length is about 170 mm. In assessing the fibre length, the wool buyer must exercise care and also try to estimate fibre strength, because wools which are of adequate length but tender will break during carding.

Generally, longer fibres produce a strong yarn with lower elasticity whereas shorter fibres produce a more hairy yarn and one which is prone to give shedding (fibre loss) in the carpet [9].

Fibre diameter

In addition to the measurement of mean fibre diameter, diameter distribution for a carpet wool is of more importance. Table 2.3 shows diameter measurements of typical carpet wool grades.

Some wools, e.g New Zealand Slipe and English Cross-Bred, have a relatively small variability in diameter, whereas others, e.g. Indian Joria and Mongolian Yingtze, are more variable.

With heavy count carpet yarns, usually woollen spun, the fibre diameter is of minor importance for spinnability, and whereas fine count yarns (e.g., semi-worsted) finer wools will be required since the minimum number of fibres per cross-section (approximately 50–60) is related to limiting yarn count. Table 2.4

Table 2.3 Fibre diameter of typical carpet wools

Wool	Mean diameter all fibres micron	Coefficient of variation %
English Cross-Bred	35.1	26.2
Indian Joria	42.5	41.2
Mongolian Yingtze	35.1	66.6
Scottish Blackface	43.3	40.9
New Zealand Slipe (grade 5)	35.8	22.9
50% Haslock	42.1	37.9
50% Second Leicester		
Spanish (grade 6)	33.0	34.2
New Zealand Bellies	35.7	26.4
and pieces (type 107)		
New Zealand Second Shear	36.3	21.4
(Type 128)		
Swaledale	37.8	37.4
Buenos Aires	34.5	26.7
Karakul (type 624)	33.0	34.6
Red Kempy Welsh	38.0	40.8

Table 2.4 Spinnable yarn counts

Wool	Micron	Metric count limit (Nm)
40s	38.0	12.5
44s	36.0	14.5
46s	35.0	15.5
48s	34.0	17.3
50s	32.0	19.5
52s	31.0	20.0
54s	29.0	22.0
56s	28.5	24.0
58s	26.5	27.5

shows the finest yarn counts that can be spun from different wools on worsted spinning systems. Coarser yarn can be spun without difficulty.

Medullation

The three types of wool fibre can be classified according to the extent of medullation. They are 'true', 'heterotype' and 'kemp'. The medullation by volume of various carpet wools is shown in Table 2.5.

Medullation can influence many carpet yarn and carpet properties.

Table 2.5 Medullation results

Wool	Medullation by volume %
English Cross-Bred	3.2
Indian Joria	27.2
Mongolian Yingtze	24.9
Scottish Blackface	24.3
New Zealand Slipe	3.6
Haslocks	21.6
Spanish (grade 6)	6.7
New Zealand Bellies	0.5
New Zealand Second Shear	0
Swaledale	11.9
Buenos Aires	0
Karakul	0
Red Kempy Welsh	26.2

Hairiness

Yarns produced from medullated wools are extremely hairy. The outer hairs tend to be kemps and medullated fibres. These outer fibres, being more brittle, can lead to excessive fibre loss in carpet manufacturing and in the carpet during wear. In addition, the appearance of yarns used and most buyers of plain carpets prefer the appearance of non-medullated wools.

On the other hand, people generally add a proportion of medullated wool because it imparts a harder finish to a carpet as this is generally considered a desirable property particularly in Europe [9].

Coloration

Medullation has a very big effect on dyeing and coloration. Even if two wools have the same initial colour (e.g., New Zealand Slipe and Indian Joria), the colours may be quite different after dyeing. Highly medullated wools appear to dye to paler colours than non-medullated wools, although they absorb as much as dyestuff. This is a phenomenon of colour physics due to internal light reflection in the hollow fibre.

It is highly undesirable to blend wools with such widely different coloration properties in plain carpets because blending cannot be so efficient as to guarantee freedom from streaks. In the tufting sector, new techniques of coloration such as piece dyeing, carpet printing and yarn printing are becoming important for wool. Most of these techniques are based on the pad-steam-rinse-dry principle. A particular problem with pad-steam dyeing is that, in addition to the paler colour, the dyestuff on these outer hairs is diluted during steaming, resulting in even paler shade. For this reason, heavily medullated and kempy wools should be avoided for such end use [9].

Fibre crimp/bulk/compressibility

Usually when a spinner buys wool, he squeezes a sample in his hand. He is subjectively assessing the compressibility and bulk. Work has shown that there is a good correlation between wool bulk, yarn covering power and carpet compressibility. Fibre crimp is a factor which influences yarn bulk or covering power, crimpy wool produce more bulky yarn. In fact, fibre crimp is the most important factor influencing yarn bulk. It is important for both semi-worsted and woollen yarn but particularly important for the former [9].

Blending

Different wools are blended together for a variety of reasons. Price and availability must be considered in addition to the technical parameters, carpet type, dyeing system, etc. Probably the most important factor is price. When a blend component becomes expensive, the manufacturer usually looks for cheaper wool to replace it and there is a wide scope of choice.

The spinner of weaving yarns usually considers blend, price, carpet appearance, but the spinner of tufting yarns must also consider yarn strength and has to be somewhat more critical in his blend selection. For high strength, the basis of a tufting yarn should be long, well grown wool relatively free from kemp and tender wool. Fortunately most widely available carpet wool (New Zealand Romney 44–48s) fills these requirements admirably. It also has a good colour, which is critical for plain carpets, where use of discoloured wools can give rise to stripiness in a carpet. A carpet for printing also requires a white wool and again New Zealand wool should be the main constituent.

The only disadvantage of New Zealand Romney is that it tends to be difficult in crimp, and a good proportion of crimpy wools must be included if a bulky non-lustrous yarn is required.

Suitable blends for both woollen and semi-worsted yarns are therefore based on New Zealand Romney of various types. The balance in a semi-worsted yarn should be made up from strong crimpy types of good colour (e.g., New Zealand Pareandale, English Crosses, and Irish Cheviot). Additionally, yarns may be filled with cheaper wools or shorter wools, such as New Zealand Crutchings, face clippings, first pieces, etc.

Berber yarns have no requirements of uniformity of appearance; rather a particularly rough appearance is often desired. A base of well grown wool such as New Zealand Romney is still important for achieving strength and performance in spinning, but the balance is mostly medullated or even kempy wools. Some of this may be naturally pigmented but stained wool must be avoided or fastness to light is poor. Alternatively wool may be dyed to natural colours [9].

2.4.2 Spinning and twisting

The requirements of good strength, uniformity of strength and freedom from joints leads the newcomer in wool tufting to think of semi-worsted yarns with their high long fibre content and large package size. But there is much more to making carpet than ease of manufacture. The properties of finished carpet are more important. Both woollen and semi-worsted yarns are in use in the carpet industry, depending on the type and ultimate performance of the carpet required.

Twist direction is very important for tufting yarns. Usually 'Z' folding twist is used for cut pile and 'S' folding twist is used for loop pile. The reverse is possible if machines are suitably modified.

The main difference between weaving and tufting yarn is a more stringent strength requirement for tufting. Dunlop studied the forces involved and showed that the maximum peak tension in a tufting yarn was always less than 500 gm.

A typical tufting yarn strength figure is 2.5 kg and this would seem to be more than adequate. However, the coefficient of variation of strength is also important, as it is the fraction of yarn with strength below 500 gm which is of practical interest. This fraction may be kept lower by having a higher mean strength or a smaller variation in strength.

For a yarn with 2.5 kg mean strength a modest requirement of a coefficient of variation of 20% gives less than 1 break per 1000 m which should be adequate for most tufters. Yarn extension is also important, because there is a discrepancy between the yarn required by the geometry of the tufting system and the yarn which is actually delivered. Some of the discrepancy may be accommodated by robbing back, but a modest degree of yarn stretch is also needed. The amount is difficult to specify but experience has enabled minimum extensions at break to be laid down.

Yarn regularity is probably more important than either strength or extensibility. Large slubs behave very much like knots and the yarn must be reasonably regular if it is to tuft well. Count variation is commonly used as a measure of regularity in the carpet industry, but twist variation is important in its own right because it can be a cause of texture variation in the finished carpet [9].

2.5 Yarn finishing

2.5.1 Scouring

Pile yarns containing large residues of fibre processing aid will soil during wear and may also give rise to undesirable odours. The final extractable matter (Woolmark Test method No. 136) should not exceed 1.0% and for pale colours even lower levels are desirable. Yarns spun with the aid of water-soluble fibre processing aids may be removed in the rinsing associated with yarn dyeing, piece dyeing or printing, but many firms prefer to scour yarns spun with such products in order to remove dirt and reduce the residues or wool grease especially if the original blend contained components which had not been thoroughly scoured.

Scouring is usually carried out in a continuous tape scour or for heavy duty scouring, a brattice machine. Liquours may be neutral with non-ionic detergents or alkaline (sodium carbonate or bi-carbonate) with non-ionic detergent or soap. If berber yarns containing natural pigments are to be scoured, a neutral liquour must be used since alkaline scouring loosens natural pigments and apart from colour change during scouring, there may be problems of bleeding if the resulting carpet is accidentally wetted.

In areas where effluent problems are acute, solvent scouring may be done in hank form using tumbling equipment of about 100 kg capacity. There may be cost advantages for processing stock-dyed and berber yarns in this way, because of reduced drying and labour costs – scouring and drying are carried out in the same machine [9].

2.5.2 Milling – batch process

There is current interest in felted yarns for new textures, and also in felting as a means of improving fibre bind in coarse textures form very heavy count yarns, which would otherwise be poor due to low twist and inadequate latex penetration.

The older milling methods such as stocks or dolly mills are not suitable for milling tufting yarns in hank form as they lack reproducibility and are unable to handle large batches. For this reason, more modern methods have been developed: one such method uses an emulsion of water in perchlorethylene in a solvent processing machine, while another aqueous method uses a large laundry washer/extractor. For either method, yarn is prepared in hank form with yarn count, singles twist and cable twist and reel length all adjusted to allow for the shrinkage which occurs during the yarn milling process. At least six figure-8 tie bands are used. Once the cycle has been established, the system can be punch-card controlled to ensure identical batch treatments.

When formulating a blend which is to be used for a felted yarn, two factors need to be considered: the type of wool and the spinning systems. In semi-worsted yarn, crimpy wools are essential because they felt within the yarn before the yarns cross-felt. If straight wools are used in semi-worsted yarn, cross-felting can occur to such extent that it is impossible to re-wind the hank.

In the case of woollen spun yarns, blend selection is not quite so critical. Cross-felting does not take place so quickly and within-yarn felting is more rapid than for semi-worsted yarns. However, the use of 'poor felting wools' (Welsh, English Cross-bred, etc.) does minimise the risk of cross-felting and only a small compensatory increase in felting time is necessary [9].

2.5.3 Milling – continuous process

An additional process now becoming available to yarn spinners is continuous yarn felting. The 'Periloc' felting system manufactured by Signaalapparaten BV of Holland is now available to interested spinners for development work.

Basically, yarn or sliver or roving is passed through a short flexible tube containing a felting solution. The tube is continuously squeezed in a similar manner to a Peristaltic pump. This action results in the yarn becoming felted.

Currently yarn is fed to net bags for drying and rewinding, although it is planned that the machine should be continuous package to package. The machine is not so critical of wool types at the batch felting methods, although in this case straighter wools (e.g., New Zealand Romney or Karakul) do felt more readily and provide higher production rates [9].

2.5.4 Twist setting

In cut pile carpets, it is usually preferable for tuft definition to be retained during processing and during wear. To achieve this, untwisting of the yarn must be prevented by a setting operation. Yarn dyeing coincidentally sets the twist, but for stock dyed carpets, cut pile berbers, and carpets manufactured for piece dyeing and printing, a separate setting process is required.

A wide range of setting techniques is available, including boiling in water, autoclave steaming, continuous pressure steaming, chemical treatment and radiofrequency heating. The steaming method depends on the degree of set required for the product, equipment available, etc.

The degree of set achieved is clearly influenced by the parameters of the setting process, but also increases with twist factor and increasing number of plies in the yarn. Woollen yarns are easier to set than typical semi-worsted yarns but semi-worsted yarns spun from highly crimped wool can be set just as well as woollen yarns [9].

2.5.5 Mothproofing

Wool carpet yarns may be mothproofed in scouring or in a dye bath using Eulan Wa New, Eulan U33, Eulan Asept or Mittin LP, and in the dye bath using Mittin FF, Mittin N. Mothproofing in solvent scouring may be done with the aid of Eulan BLS. Synthetic pyrethroids are probably associated with fewer environmental problems than many mothproofing agents and are now marketed quite widely, e.g. Perigen W (Wellcome) and Shell Agent '79 [9].

2.5.6 Static control

Non-chemical methods for static control are well established and include incorporating conductive fibres in the blend (e.g. 0.2% Bekinox) or twisting with a conductive yarn (e.g. wool/steel blend). In such cases a conductive backing is also necessary. Disperstat W manufactured by Stephenson Brothers, Bradford, is unique in that it can be exhausted onto carpet yarn from a dyeing machine. It is also effective without an associated treatment of the carpet backing. The product is currently generally applied either after hank dyeing or stock dyeing, although work is in progress to develop tape scour, spinning lubricant systems and spray systems [9].

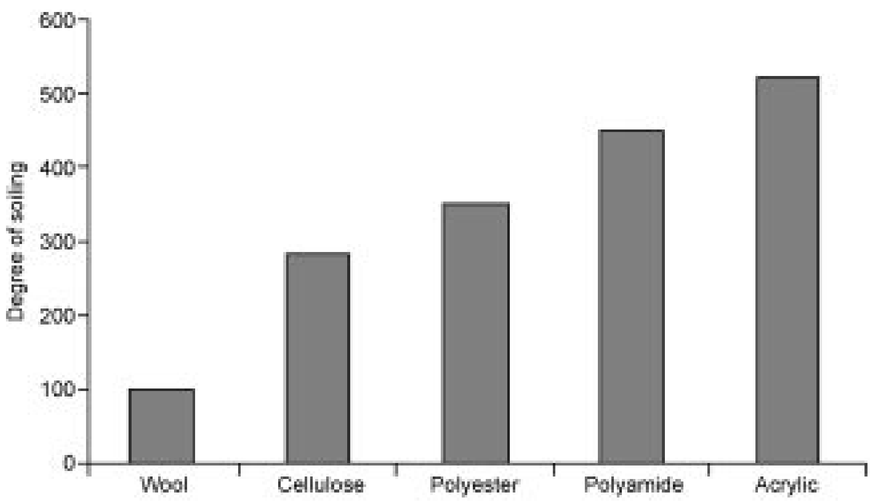
2.5.7 Flame resistance

The Woolmark Zirpro treatment may be applied to wool carpet yarns in the exhausted dye baths as well as at other stages of manufacture to meet stringent flammability requirements.

2.5.8 Anti soil/anti stain

The colour of a carpet has a strong bearing on the ability of a carpet to hide soil; light colours, dark colours and very bright colours are more susceptible to apparent soiling. Fibre influences not only the soil-hiding power of a carpet, but also actual soil retention. For vacuum cleaning, wool is in a particularly favourable position relative to other fibres (Fig. 2.5) [10].

Wool carpets made from clean scoured yarns have superior resistance to soiling, but improved resistance to staining is considered desirable for some applications. Treatment with fluorocarbon products increases resistance to soiling. Silicone treatments also increase resistance to staining, but are not recommended for wool because they increase soiling.



2.5 Relative soiling of pile fibres.

2.6 Carpet yarn testing and quality control

Yarns are the basic raw material used to manufacture carpets and thus testing of yarns is as critical as testing the final carpets. Evaluation of yarns will provide guidance to the manufacturer regarding the final properties of the carpets and therefore strict quality control testing facility should be in place for a competent carpet manufacturing organisation.

Laboratory evaluation for both synthetic fibre and yarn should be carried out. The following are the major properties which should be evaluated at the fibre stage:

- product denier
- cut length
- crimp
- cross-section
- dyeability
- any special finish applied.

Similarly for the yarn stage, the properties which are of importance are count, fibre length, fibre diameter, amount of bulkiness imparted (if any) and any special properties (if claimed).

For woollen yarns, as they contain large variations due to their natural origin, the testing should include different parameters to assess their properties. For woollen yarns, the following are the properties that need laboratory evaluation:

- count
- ply
- non-wool fibre content %
- volatile matter content %
- DCM (Di-chloro methane) extract %
- average fibre length
- twist
- vegetable matter content
- fibre diameter.

Each parameter has a very significant contribution to the final properties of the yarn. Careful selection and blending of the wools compatible with the processing system to be used will ensure optimum processing performance.

Parameters such as fibre length and vegetable matter content are the main factors which limit the suitability of the wool to be used in the woollen and semi-worsted spinning system.

2.7 Future trends

Woollen spun yarn will continue to constitute a major share of the hand-made carpet category, but for the machine-made carpet segment, the semi-worsted yarn will continue to dominate. This is due to the obvious reason of better regularity and related properties of semi-worsted yarn, which are of more importance in manufacturing machine-made carpet.

2.8 Sources of further information and advice

To know more about the properties and specification of wool to be used in manufacturing carpets, *The New Zealand Wool Industry Manual* may be consulted. For understanding the different methods of wool carpet manufacturing, *The Manufacture of Wool Carpets*, published by The Textile Institute, Manchester, UK and edited by G.H. Crawshaw may be consulted. For details of different fibres used to manufacture the carpet yarns as well as their processing techniques, the book published by WRONZ Developments, Christchurch, New Zealand and written by Geoffrey H Crawshaw may be consulted. The technical paper published in *Textile Trends Journal* in February 1987 titled 'Engineering of Wool Carpet Yarns' written by Dr. S. K. Chaudhuri and Dr. J. Ince may further be consulted for the details of wool carpet yarn engineering and properties of wool fibres, spinning and finishing.

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3
Advances in carpet weaving

S DEMEY, N V Michel Van de Wiele, Belgium

Abstract: This chapter explains in detail the newest developments in weaving machines for machine-made carpets. It covers the complete range of single-, double- and three-rapier weaving machines and stresses the efforts that have been made to increase production output, speed and flexibility. There is a growing tendency towards carpets with a finer reed density and with more colours. Serious efforts have been made to obtain a clearer backside of the carpet. There is also a growing trend towards carpets with relief, high-low effects, high pile or shaggy effects, combinations of cut pile, loop pile and flat weave effects.

Key words: carpet-weaving machine, face-to-face weaving technique, Axminster weaving, Wilton and loop pile weaving, Van de Wiele.

3.1 Introduction

For a long time, high production output and high speed were the most important factors in the new developments for the carpet weaving industry. Recently, a new aspect has become important as well: flexibility or versatility. Carpet weavers want to weave different styles and change quickly from one quality to another. Flexibility is as important as productivity.

Developments in raw materials contribute positively to this new trend. New dyeing techniques, chemical compounds, and treatments improve the quality of the yarns but also the choice of raw material.

Another definite contributor is the new developments and technical improvements of the carpet-weaving machines. This chapter will explain in detail the newest developments in machine-made carpets. In the face-to-face weaving technique, there is a growing tendency towards carpets with a finer reed density and with more colours. Nowadays, it is already possible to weave carpets with 700 reed dents/m and eight colour frames. Serious efforts have been made to give a clearer backside to the carpets and to weave a carpet with a backside like a hand-knotted carpet and without warp yarns visible at the backside of the carpet. There is also a growing trend to produce carpets with relief, high-low effects, high pile or shaggy effects, combinations of cut pile, loop pile and flat weave effects, etc. Designers want to draw carpets using their full creativity without any limitations. A complete new revolution in Axminster weaving is the first high-speed Axminster weaving machine in 16 colour frames.

To cope with the increasing variety of qualities, modern carpet-weaving mills are equipped with a network especially developed for the needs of carpet weaving.

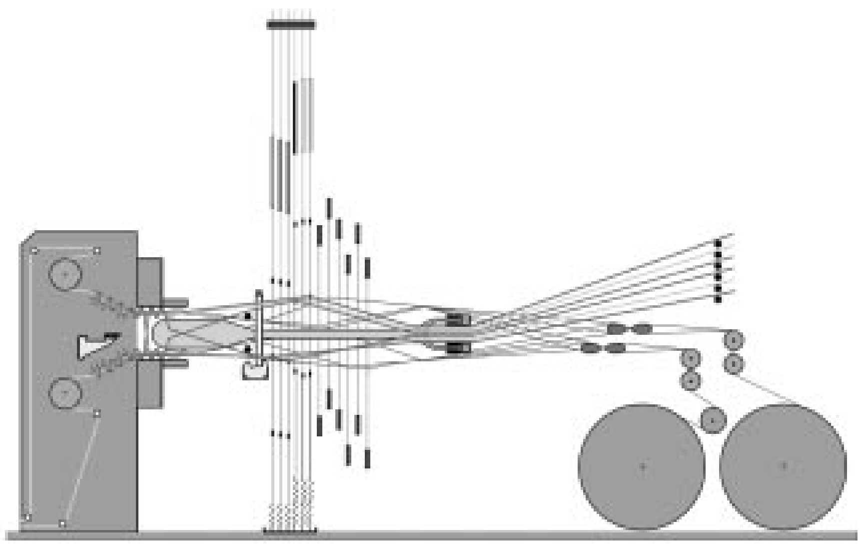
3.2 Face-to-face carpet weaving

According to the face-to-face technique, two identical carpets are woven at the same time. To obtain this, two superimposed ground fabrics are woven, interlaced by the pile yarns. The fabric so produced is cut in the middle on the weaving machine to obtain two carpets: a bottom and a top carpet (see Fig. 3.1). By using the technique of dummy fillings and lancets, loops can be woven into the top and bottom carpet. This way, a three-dimensional fabric is obtained; a two-dimensional ground fabric with pile tufts and/or loops standing straight on it.

3.2.1 Double rapier weaving for cut-pile carpets

Applications

Carpets with cut pile have always been the most well known kind of carpets. They are especially characterised by the design, the number of colours and the number of points (= product of the reed density and the pick density). Ancient style as well as modern style carpets and area rugs are woven with this technique. The reed density (= number of dents/m) varies in general from 160



3.1 The face-to-face weaving technique, illustrated with a schematic working principle of the Shaggy Rug Pioneer SRP92 (Van de Wiele).

dents/m up to 500 or 700 dents/m for the highest qualities. The number of colours varies in general between 5 and 8, but even carpets with 10, 12 and 14 colours have been made with this technique.

The main products made according to the double rapier face-to-face weaving technique are area rugs. The raw material for the pile can include polypropylene (BCF, Heat set or CF), acrylic, wool or viscose.

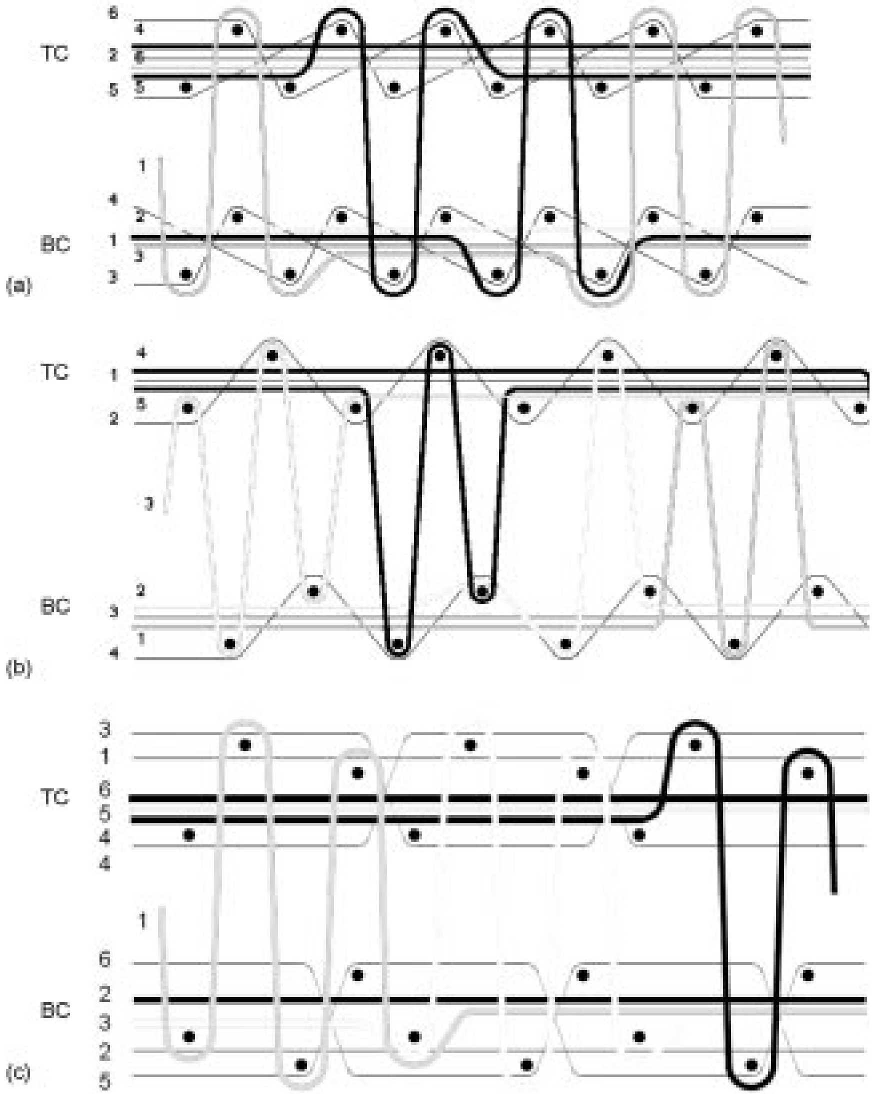
Weaving technique

In the double rapier weaving technique, two rapiers insert two fillings at the same time in two sheds, one shed for the top carpet and one shed for the bottom carpet. This way, a pile tuft is formed every two fillings and the weave structure is called 1/2 V (see Fig. 3.2a). The 1/2 V can be woven through to the back (the design is visible at the backside of the carpet, always used for area rugs) or not through to the back (the design is not visible at the backside, it is used more for wall-to-wall carpets) with different ground weave structures: 4 × (1/1), 2 × (1/1) and 4 × (2/2), etc. The last weave structure is used for higher pick densities as the fillings can slide slightly above each other. The pile yarns that are not visible at the pile side are called the dead pile and are incorporated half in the top carpet and half in the bottom carpet. Previously to this, these incorporated pile yarns were floating on the backside of the bottom carpet and were then removed during finishing. The technique with incorporated pile yarns has numerous advantages:

- Top and bottom carpets are completely similar (in case of floating dead pile, one pile tuft was lost on a colour change, resulting in bottom carpet of lower quality).
- No supplementary operation to remove the floating pile yarns is required.
- No yarns are lost as the non-working or incorporated pile yarns are woven in the back of the carpets.
- The extra weight of the incorporated pile results in a heavier carpet or it enables decrease of the pick density (and increase in production accordingly) to compensate the extra weight of the incorporated pile yarns.

Single rapier weave structures are obtained when one alternating filling is inserted in top and bottom carpet. This way, a pile tuft is formed every filling and the weave structure is called 1/1 V (see Fig. 3.2b). This weaving technique is well adapted to weave very dense carpets. The dead pile can be incorporated as in 1/2 V or floating in the middle, both with different ground weave structures.

The 1+1/2 V is a new weave structure, a combination of 1/1 V and 1/2 V. Figure 3.2c shows this weave structure. The incorporated dead pile yarns lay completely at the inside of the carpet in a separate layer and each pile tuft goes to the back of the carpet. This ensures a very good pile fixation and a nice backside of the carpet. With the ground weave structure 2 × (3/1) and 2 × (4/4) it is possible to weave high pile row densities. Moreover, the same ground



3.2 (a) The 1/2 V weave structure with a pile tuft every two fillings, woven through to the back (b) the 1/1 V weave structure with a pile tuft every filling, with the dead pile incorporated with tight warp (c) the 1+1/2 V weave structure for a perfect pile fixation and clear backside of the carpet. woven on the Carpet and Rug Pioneer CRP92 from Van de Wiele.

weave structure can be used for 1/2 V and 1/1 V, without any disc change or machine stop.

In order to obtain relief carpets, areas with cut pile and areas with flat weave effects (visible pile floatings) are combined as shown in Fig. 3.3. With the same technique, carpets with only flat weave effects can also be made.

3.3 Carpet with cut pile and pile floating effects.

Weaving machine

The Carpet and Rug Pioneer CRP92 forms the newest generation of face-to-face carpet-weaving machines (see Fig. 3.4). The Carpet and Rug Pioneer is characterised by a high production output, flexibility and low maintenance cost. The ergonomic design guarantees good access to all the yarns.

A powerful microprocessor with menu-driven display allows adjustment of the speed of the machine, the pick density, the machine settings, etc., and gives a detailed production follow-up.

Two sets of rigid rapiers insert the fillings. The insert rapiers bring the filling in the shed to the middle, where the receiving rapier takes it to the other side

3.4 The highly productive and versatile double rapier Carpet and Rug Pioneer CRP92 weaving machine, made by Van de Wiele. Available in widths of 3 m, 4 m and 5 m.

(Dewas principle). The rapiers are guided on air cushions in order to reduce friction and heat development. The temperature is continuously monitored. A three-dimensional cam drives the knife of the cutting motion. The cam is designed for optimal cutting across the full width of the machine. A powerful parallel reed beat-up produces at high speed a clean back and nice pile aspect.

The shedding for the ground yarns is normally done by a cam disc machine because this gives the weaver the freedom to regulate the timing of the crossing of the heddle frames independently as the conjugated cams can be made asymmetric. On the newest generation of carpet-weaving machines like the CRP92, however, servomotors can drive the heddle frames for the tight warp and dobby rotors can drive the heddle frames for the slack warp. Thus, the weaver can still regulate the timing of the heddle frames of the tight warp and the motion of the heddle frames can be programmed, but he has the possibility to quickly change the weave structure and switch between different carpet qualities.

The electronic Jacquard machine on top produces the design in the carpet. A compact, reliable and simple selection mechanism without springs, pivot points and pistons, with only one solenoid per harness band, allows the three positions that are needed for double rapier carpet weaving (under, between and above the rapiers) to be obtained. Only one flexible hook has the ability to move, this makes the system impervious to dust. As the solenoid is current driven, the selection is independent of the temperature, guaranteeing a fault-free selection in all conditions.

The pile yarns are levelled in layers, this way the crossing point of the different colours is shifted. This considerably increases the weaving efficiency and produces a clean back with less incorporated pile yarn, mainly with sticky yarns like wool and acrylic.

For weaving single rapier weave structures, the rapiers insert an alternating filling in the top and bottom carpet. With the rapier switch-off system, only one rapier is inserted per cycle. The system uses a minimum of moving parts and no empty rapier goes into the shed. This increases weaving efficiency. Alternatively, the filling scissors can be programmed as well for presenting only one filling per machine revolution.

3.2.2 Triple rapier weaving for cut pile carpets

Applications

Just like the carpets produced according to the double rapier weaving technique, the carpets made according to the triple rapier weaving technique are mainly area rugs. The triple rapier weaving technique is generally used for weaving high-end carpets.

With the recent development of Van de Wiele, carpets with a back like hand-knotted carpets can be woven on a three rapier weaving machine. This kind of carpet has no visible warp yarns on the backside of the carpet. The carpets are also characterised by a high reed density.

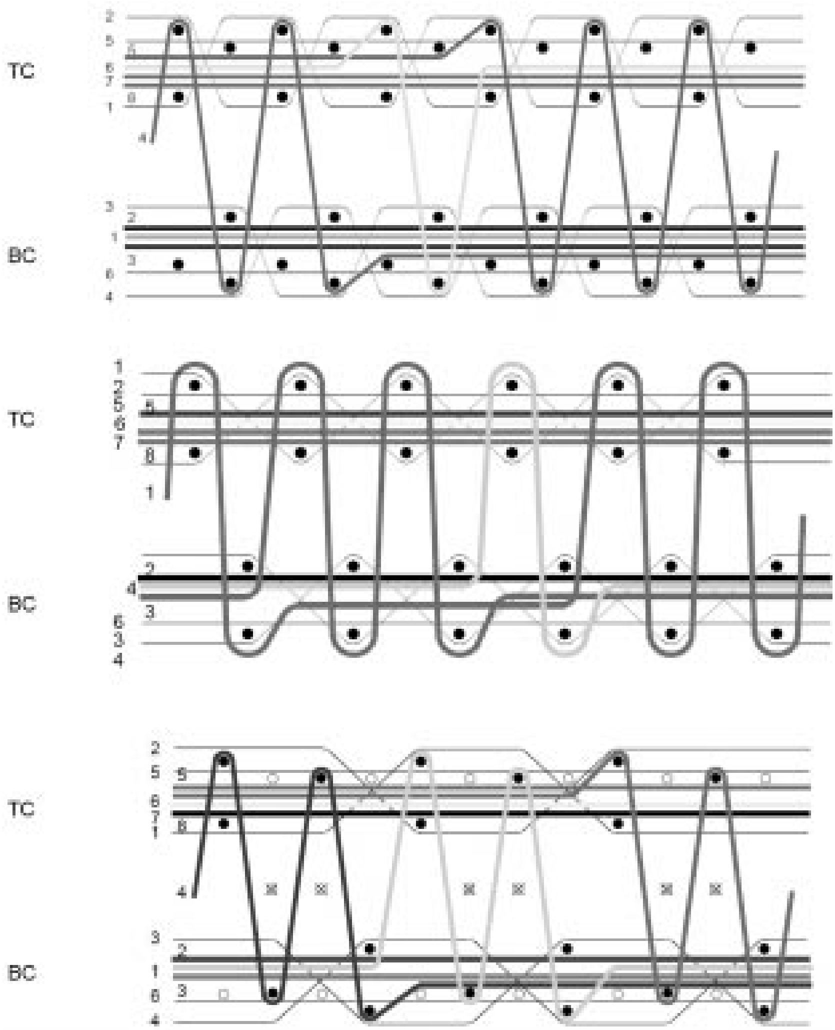
Weaving technique

The three rapier weaving technique was invented and patented by the Van de Wiele company in Belgium. The three rapier weaving machine inserts up to three fillings per cycle. A shed for top carpet and a shed for bottom carpet are formed. The most common three rapier weave structures are (see Fig. 3.5):

- 2/3 V Every cycle, three fillings are inserted. During the first cycle two fillings are inserted in the top shed and one in the bottom, the next cycle one in the top and two in the bottom shed. This way, a pile tuft is formed around two fillings. Sometimes, a thinner filling is used for the middle rapier to obtain a better pile surface and pile fixation. This three shot 2/3 V weave structure gives 50% more production than the old three shot weave structure woven with two rapiers.
- 2/2 V Every cycle two fillings are inserted: during one cycle two fillings are inserted in the top shed and during the other cycle two in the bottom shed. For this, the exterior rapiers are alternating not inserted. A pile tuft is formed around two fillings.
- 1+2/3 V In the 1+2/3 V weave structure, a pile tuft is formed once around two fillings and once around one filling. The incorporated pile yarns lie in a separate layer above the tight warp and each pile tuft comes to the back of the carpet, so that they can be fixed very well and the back of the carpet becomes very clear.

The above weave structures can be woven with different weave structures in a ratio of 4 or 8, depending on the pick density. There is even a set of cams that is suitable to weave the different weave structures without machine stop. With three rapiers, the incorporated pile yarns remain stationary, i.e. less incorporated pile yarn and higher weaving efficiency.

The ultimate aim of machine-made carpets has always been to approach the hand-knotted carpets as closely as possible. One of the most typical aspects of hand-knotted carpets is the clear backside without visible ground warp yarns. Van de Wiele has developed a new weave structure for this, called the hand look weave structure. Figure 3.6 shows the backside of a hand look carpet together with the weave structure. It is made on a three rapier carpet weaving machine with filling selector and programmability of the filling scissors. As the carpet has a 1/2 V weave structure, the pile fixation is perfect and designs can be made in ratio 1, this means that one line in the design results in one pile row in the carpet or many more design points than the conventional carpets in 1/1 V woven in ratio 2. The backside as well as the pile side shows a crystal sharp design.

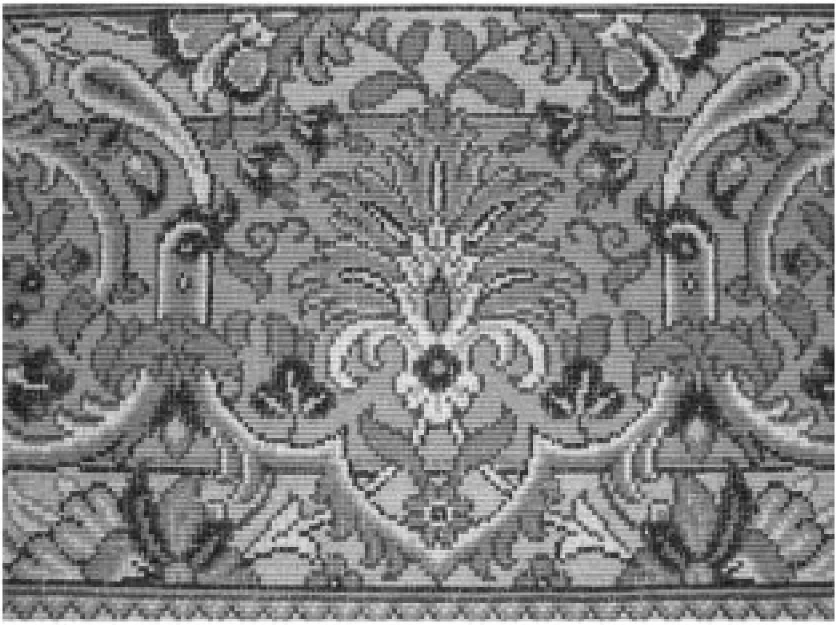


3.5 The most common three rapier weave structures (from top to bottom): 2/3 V, giving 50% more production than old three shot; 2/2 V and 1+2/3 V.

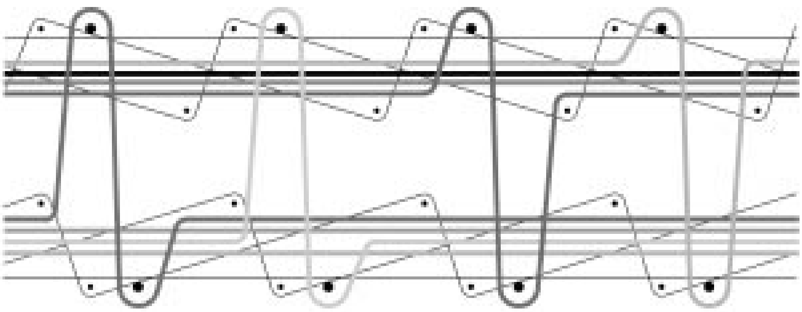
Weaving machine

The Carpet and Rug Pioneer CRP93 is the three rapier version of the Carpet and Rug Pioneer CRP92. The technical details have already been explained in the previous section. The big difference is the three rapier system. This means that per machine revolution, up to three rapiers can be inserted.

The Hand Look eXplorer HLX93 produces carpets with a backside like hand-knotted carpets. The HLX93 is also a three rapier machine, however, with a filling selector and with adapted weaving cyclus.



(a)



(b)

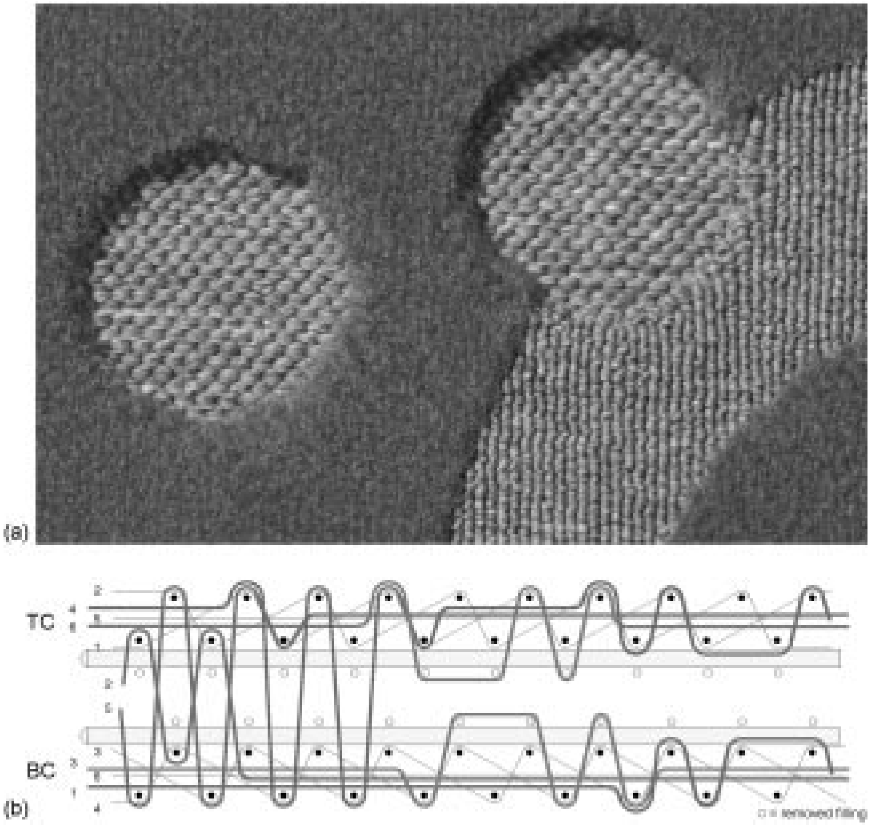
3.6 Carpet with a hand knotted look back (top), without visible warp yarns, woven with the three rapier hand look weave structure (bottom).

3.2.3 Triple rapier weaving for cut and loop pile carpets

Applications

The growing demand of the market for carpets with high-low effects has pushed the machine manufacturer to develop new structures. Carpets with a cut-loop weave structure can have at every point in the carpet, without any design limitation one of the following effects:

- cut pile
- soft loop pile (over one or more picks)
- flat weave.



3.7 A carpet woven on the Universal Cut Loop Pioneer UCP93; with cut pile, soft short and long loops and flat weave effects (top); produced with the three rapier cut-loop weave structure (bottom).

Figure 3.7 shows a typical cut-loop carpet. This kind of carpet is mainly used as area rug.

Weaving technique

The most economical way to produce this kind of carpet is a face-to-face carpet weaving machine with three rapiers. Figure 3.7 shows the cut-loop weave structure.

The bottom rapiers insert the fillings for the ground structure of the bottom carpet. The top rapiers insert the filling for the ground structure of the top carpet. The middle rapiers insert 'dummy' fillings for the top and bottom carpet in between lancets. Loops are formed around these dummy fillings. The loops can float over one or more fillings. The dummy fillings are afterwards removed on both sides. Cut pile is formed as on the classical 'face-to-face weaving machines' by a knife cutting the working pile between top and bottom carpet. All traditional single, double and three shot weave structures can be woven.

Tests have been done to produce the cut-loop carpets with two rapiers; however, it is not possible to produce two identical carpets this way and the carpet industry has not accepted this technology due to the heavy waste and low productivity.

Weaving machine

The Universal Cut Loop Pioneer UCP93 carpet weaving machine with three rapiers and equipped with a 4-position open shed Multihook jacquard machine weaves the cut-loop weave structures with two lancets above one another and per reed dent. There is a first lancet between top and middle rapier and a second lancet between middle and bottom rapier.

The 4-position open shed Multihook jacquard machine enables a choice between four positions of the pile yarn for each pick: bottom, between bottom and middle rapier, between middle and top rapier or completely at the top.

The bottom rapier inserts a filling for the back of the bottom carpet. The top rapier inserts a filling for the back of the top carpet. The middle rapier inserts, alternating for top and bottom carpet, thin false fillings between the lancets to support the pile loops. These false picks are cut in the middle and both ends are removed during weaving on both sides.

As the Multihook enables four positions, pile yarn can still move between top and bottom rapier and in this way cut pile can be woven. Beside loop and cut pile, flat weaves are also possible in top and bottom carpet. During weaving the incorporated pile does not move. Only the pile yarns make pile move. This means a cleaner back, less incorporated pile yarns and less pile yarn ruptures, consequently a higher weaving efficiency.

The UCP93 runs smoother, hence a nice pile aspect, a beautiful back of the carpet and a higher weaving machine efficiency. Furthermore names and logos can be woven in loop pile, in flat weave and also on the back of every carpet. As no wires are inserted, the Universal Cut Loop Pioneer UCP93 runs at an industrial speed, three times higher than a wire weaving machine even with heat-sensitive yarns such as polypropylene. Pile yarns such as polyamide, polypropylene, acrylic, wool, etc., can be used.

When the lancets are removed, instead of a false pick, a thicker filling is inserted by the middle rapier, alternating in the top and bottom carpet, the sisal look weave structure is woven (see Section 3.2.5). This weave structure is formed by pile yarns that form loops over one or more thick fillings. The thick fillings give relief to the carpet. In combination with a weft selector on the middle rapier, different filling colours and different thickness of fillings are also woven. The sisal look effects can be combined with cut pile as well. Sisal look carpets are used both indoors and outdoors for rugs and wall-to-wall carpets.

The reversible or recto-verso carpet has a design that is visible on both sides of the carpet. The design is made by pile yarns floating over one or more fillings. The UCP93 can weave two reversible carpets on top of each other.

Summing up all the possibilities, it may be said that the Universal Cut Loop Pioneer UCP93 is the most universal and productive carpet-weaving machine. The 4-position open shed electronic jacquard machine, the three rapier technique and the special lancets in the weaving machine are the factors for the success of this weaving machine.

On the Universal Shaggy Loop Pioneer USP93, high-pile carpets in cut pile and loop pile can be woven. The pile height for cut pile can be up to 2×50 mm and the loops can be up to 2×20 mm. A combination of V and W structures guarantee the pile fixation and give special effects to the carpet.

3.2.4 Double rapier weaving for long pile carpets

Applications

Long pile or shaggy area rugs are more and more popular. The carpets are also called Berber carpets or Tibetan carpets. They are characterised by a long pile height, a coarse reed, thick pile yarn (wool, acrylic, polypropylene, etc), few colours and a basic design as illustrated in Fig. 3.8. The shaggy carpets are mainly used as area rugs in the living room and bedroom. However, bathroom rugs (with cotton pile yarns) are also very common.

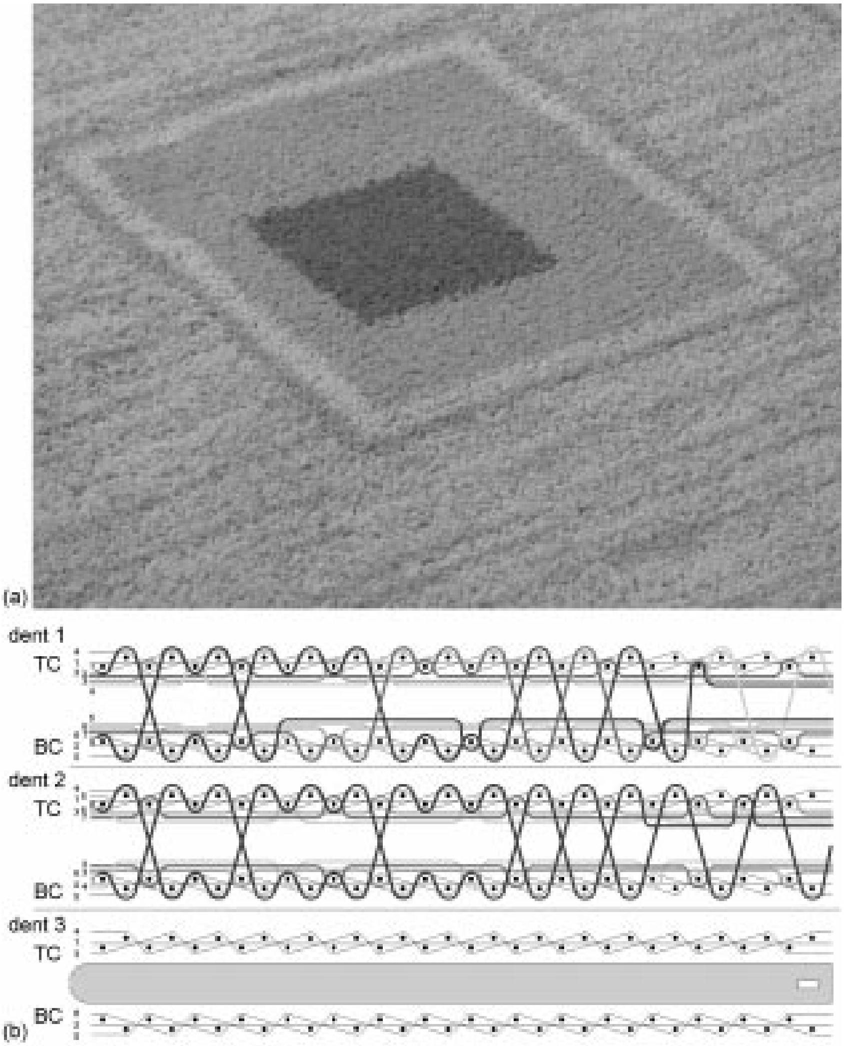
A very recent application of the long pile carpets is woven synthetic grass with strong pile fixation due to the W weave structure, a water permeable ground structure and straight pile. More details can be found in Chapter 5.

Weaving technique

On of the most critical aspects of long pile carpets is the pile fixation. Due to the long pile height, the pile yarns could be more easily pulled out. To avoid this, the most common weave structure is a W-structure like illustrated in Fig. 3.8. This weave structure shows however the possibility as well to combine V and W weave structures to become special effects with areas with a different pile density.

Weaving machine

The Shaggy Rug Pioneer SRP92, developed by Van de Wiele, is a double rapier carpet machine for weaving long pile carpets. A special lancet holder for spoon lancets up to 140 mm allows weaving carpets with a pile height up to 70 mm per carpet. The pile yarns enter the machine in the middle of the double lancet holder to reduce the forces on the harness and Jacquard machine.



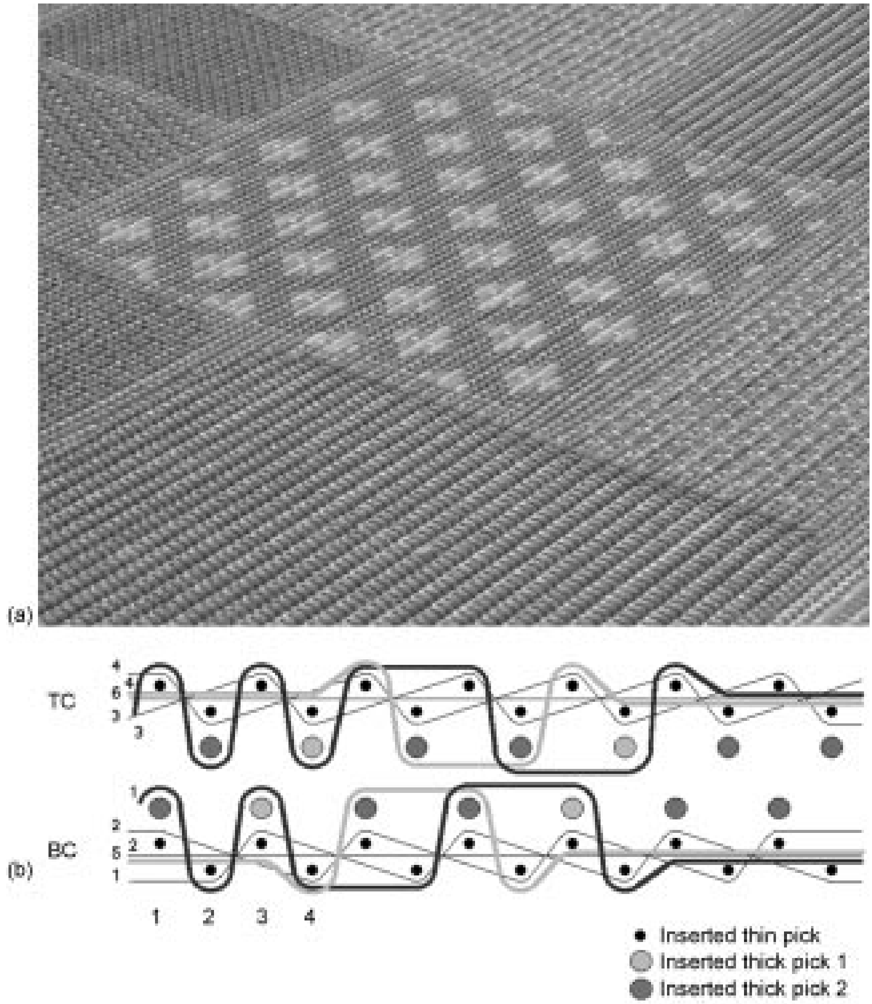
3.8 Shaggy rug with a W-weave structure, ensuring a perfect pile fixation.

When the producer uses polyethylene, polypropylene or polyamide pile yarns, he can immediately weave artificial grass on the machine, including logos or white line markings if required.

3.2.5 Triple rapier weaving for sisal look carpets

Applications

Sisal look carpets follow the increasing tendency towards natural colours and products: they have a natural look with natural colours like beige, brown, black,



3.9 A typical sisal look carpet with polypropylene pile yarns, floating over one or several thick fillings with filling selector, produced with the three rapier sisal look weave structure.

white, etc. Sisal look carpets have mostly a pile surface in polypropylene, but it looks like natural sisal. Sisal look carpets have a structured pile surface, formed by pile yarns floating over one or more thick fillings, giving relief to the carpet (see Fig. 3.9). The carpet can have an additional colour effect by using a filling selector, using up to three different colours.

Sisal look carpets are well suited for area rugs as well as wall-to-wall carpet, both for indoor and outdoor applications.

Weaving technique

The sisal look carpets are woven on a three rapier weaving machine according to a technique similar to the face-to-face technique (see Fig. 3.9). Top and bottom pieces are not connected and no cutting motion is needed. Three rapiers insert three fillings at the same time. The top rapiers insert a filling for the backing of the top carpets, the bottom rapiers one for the backing of the bottom carpet and the middle rapiers insert a thick filling that is alternately woven in the top and bottom carpet. The pile yarns float over these thick fillings, giving relief to the carpet. This way, the special patented three rapier sisal look weave structure is obtained.

Weaving machine

The Sisal Look Pioneer SLP93 is a three rapier weaving machine especially developed for weaving sisal look carpets. The basic machine is the CRP93 although the cams of the main motions have been adapted for the patented sisal look weave structure. When equipped with a servomotor-driven filling selector for the middle rapier, additional colour effects can be woven in the carpet.

The design in the top and bottom carpet can be totally different as they are independent of each other. This means that the carpet weaver can make his planning as on an 8 m machine, e.g. 4 m wall-to-wall carpet in the top carpet and 2×2 m area rugs in the bottom carpet. Logos and company names can easily be woven without mirror effect. The Carpet and Loop Pioneer CLP91 (see Section 3.4.2) can also produce sisal look carpets in single face.

3.3 Axminster weaving

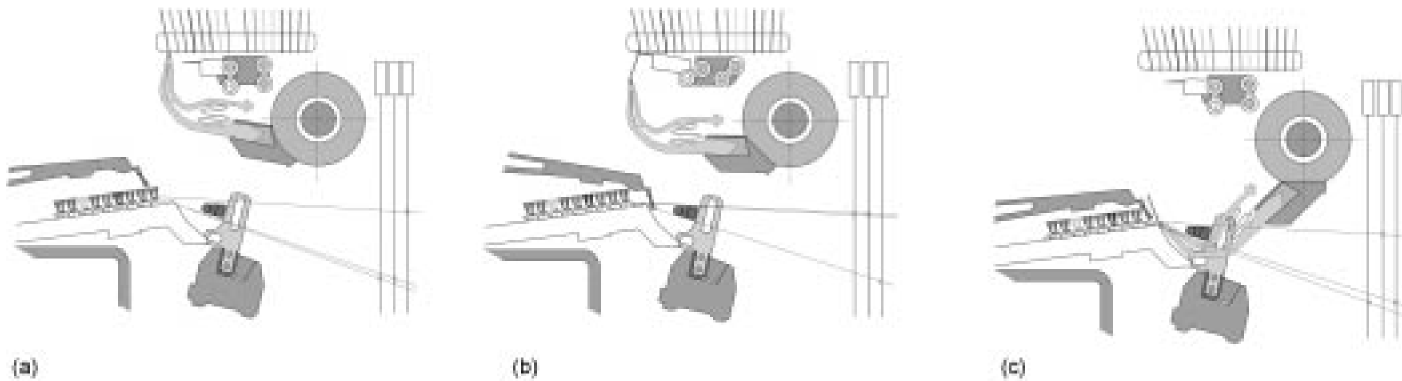
Applications

Traditionally, Axminster carpets have been used for the contract market for hotels, cruise ships, casinos, etc., with a pile yarn in wool, nylon or wool/nylon (80/20%). Texts and logos can easily be woven. However, with the development by Van de Wiele of a completely new Axminster machine, the market for Axminster carpets for area rugs is growing. It is even possible to use a heat-setted polypropylene yarn.

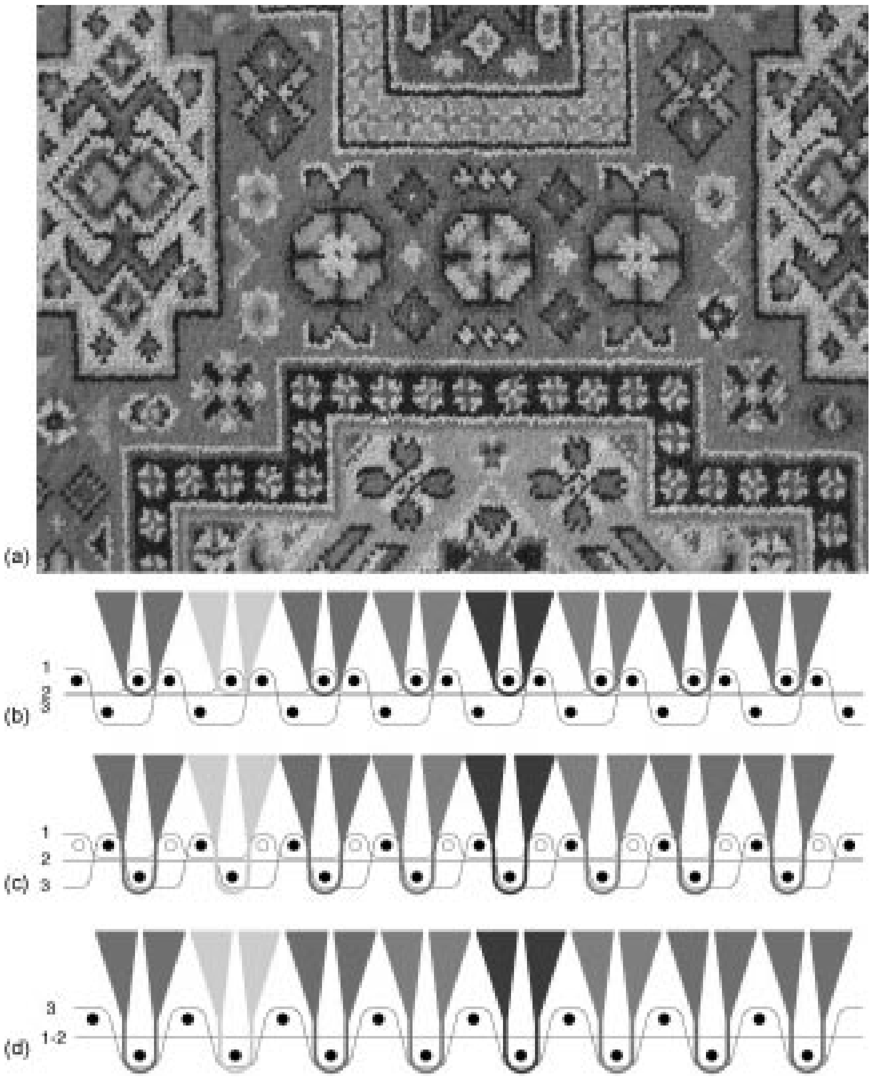
Axminster carpets have a reed density in pitch 7 DPI, dents per inch (~275 dents/m) with up to 16 colour frames.

Weaving technique

In the Axminster technique, a fabric with fillings and ground yarns is woven. The Jacquard carriers present in each reed dent the selected pile yarns, the grippers take these and bring them into the woven fabric (see Fig. 3.10). A single face carpet is produced in this way.



3.10 The weaving process of the Axminster weaving machine MAX91 (Van de Wiele). From left to right: presenting and gripping the pile yarn; cutting the pile yarn; inserting the pile yarn in the carpet.



3.11 A typical Axminster carpet with some different Axminster weave structures woven through and not through to the back for contract qualities and area rugs.

In Axminster carpets, only the visible pile yarn is used and no pile yarns are incorporated. Figure 3.11 shows a typical Axminster carpet and some Axminster weave structures, woven through or not through to the back in double and three shot weave structures. Axminster carpets can have up to 16 colours.

Weaving machine

The Master in Axminster MAX91 is the first machine in history that has been completely designed and developed for weaving Axminster carpets at a high speed. The MAX91 has a stable basic machine with a robust ground frame. The pile yarn presentation is done through a non-reset system with individual stepper motors, giving the possibility to work with up to 16 colours. The carriers move horizontally in 17 positions. The knife bit carriers are driven by a servomotor programmed for a quick motion during cutting and with a slow return motion to reduce the temperature.

It is possible to weave with different tuft lengths. The new patented gripper is made in one piece, without pivot point and without bearings. This lightweight gripper is suitable for gripping thick and thin yarns, even mixed in the same carpet. The MAX91 has a robust ground frame. The spike roll has double bearings in the middle and there is a rigid connection between the spike roll and the latch. The reed has a stable motion.

All motions are by integrated cam boxes. The ground yarns normally come from a creel and pass the ground warp delivery rolls controlled by stepless adjustable motor let-off. The pile yarns – up to 16 colour frames – run from the bobbins in the creel, through the tubes to the collector board.

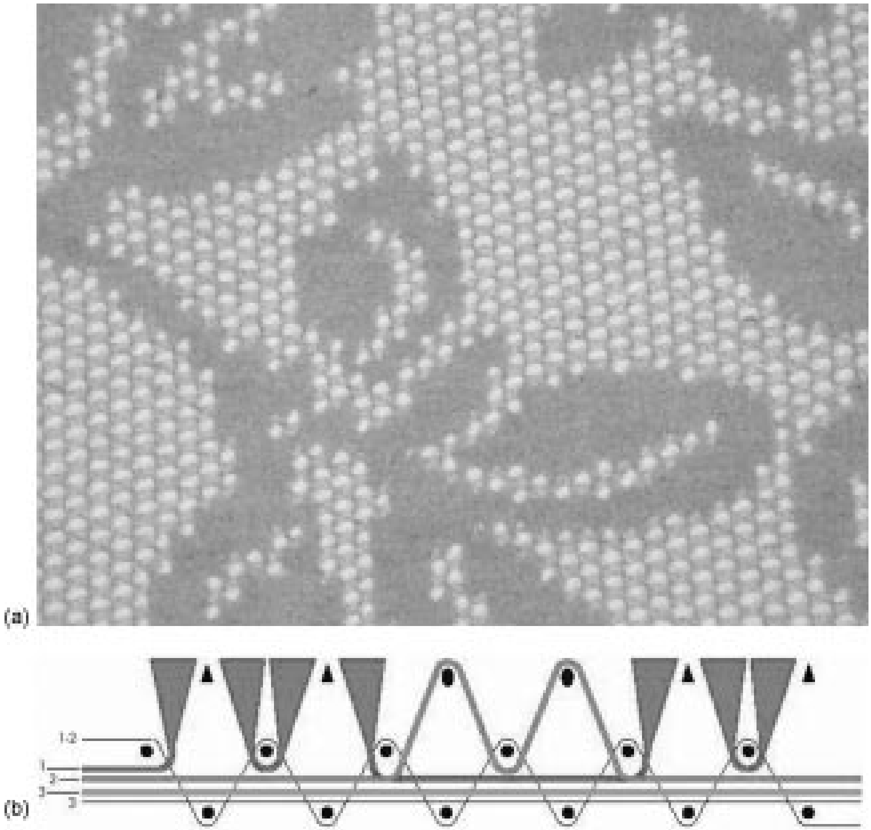
The filling (jute, polypropylene or cotton) is inserted by a flexible rapier, not sensitive to dust and sticking yarns. A servo-driven filling catch device prevents the filling from jumping back. The missing pile end detection equipped with high-resolution optics, detects missing pile tufts. Using software, the results can be filtered and the machine stops are design driven. Second quality carpets are reduced. All controls (machine, Jacquard and missing end detection) are integrated in a user-friendly machine control, the Human Machine Interface (HMI), with touch screen. The HMI can be connected in a network. Virtual creel changes (colour mapping) and presentation of the design are possible on the HMI.

3.4 Wire Wilton and loop pile weaving

3.4.1 Wire Wilton weaving

Applications

Wire Wilton carpets are high-quality carpets, mainly used for wall-to-wall carpet (contract and residential market) with loop pile, cut pile or a combination of both as illustrated in Fig. 3.12. The pile material is mostly wool, nylon or a mix of both. Texts and logos can easily be woven. With the wire Wilton technique, the pile aspect is equal over the complete width of the machine and for carpets woven in several shifts, this means no problems for shading, side matching, etc.



3.12 Typical Wilton carpet and weave structure with cut pile, loop pile or a combination of cut and loop pile, woven through or not through to the back for contract qualities and area rugs.

Weaving technique

The wire Wilton technique is one of the oldest weaving techniques. In wire weaving, loops of pile are formed over metal wires (inserted every two picks in filling direction in the pile shed), which are later extracted. During extraction of the wire, the pile is cut if a knife is fixed on the wire, if not the pile remains a loop (see Fig. 3.12). Several weave structures are possible: woven through or not through to the back, long or short loops, high-low effects, different ground weave structures, cut and/or loop pile, etc.

Weaving machine

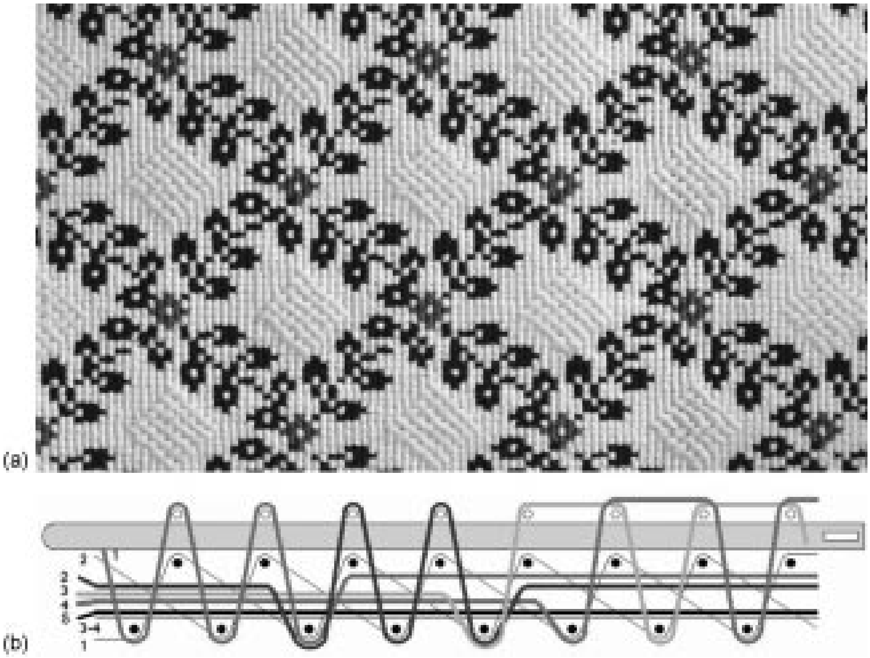
The Advanced Wire Master AWM51 is a wire weaving machine. Flexible rapiers, driven by dust-free gearboxes, insert the filling. A timing belt and conjugated cams drive the wire. The profile of the cams is developed to minimise the development of heat. Positive opening of the wire hook guarantees a stable wire extraction. A sensor, preventing inappropriate wire handling, monitors the position of the wires during insertion and extraction and guarantees the quality of the carpet. The speed can be steplessly adjusted. The AWM51 is equipped with an electronic Jacquard machine to weave different pile weave structures and designs in up to five colour frames.

3.4.2 Loop pile weaving

Applications

Carpets made according to the loop pile weaving technique have a broad range of use. On the one hand, nice area rugs in polypropylene, wool, acrylic, etc., can be made with soft short loops, soft long loops, high-low effects, etc. (see Fig. 3.13).

On the other hand, high-quality carpets, mainly used for wall-to-wall carpet (contract and residential market) with loop pile are produced in this way as well as providing the possibility to weave texts and logos. A new application is aircraft carpet, a 100% loop pile carpet with the loop pile in wool.



3.13 A typical loop pile carpet with the loop pile weave structure with short and long soft loops, woven through the back.

Weaving technique

The loop pile weaving technique is a recently developed technique to weave at high speed carpets with loop pile. Programmed by the electronic Jacquard machine, high-low effects (sculptured rugs), short or long loops, names and company logos can be woven.

Loop pile carpets are woven on a double rapier machine. Figure 3.13 shows the most common weave structure that can be either woven through to the back (mainly for area rugs) or not woven through to the back (used for most wall-to-wall carpets). The bottom rapiers insert the fillings for the ground structure of the carpet. The top rapiers insert dummy fillings above gauges every two picks. These gauges determine the loop height. The pile yarns form loops around these dummy fillings. After the loop formation, the dummy fillings are cut in the middle and removed on both sides of the machine during weaving.

As with the loop pile weaving technique, no metal wires are inserted, the industrial speed is up to three times higher than on a wire Wilton weaving machine.

Any type of natural or man-made yarn can be used, also heat-sensitive yarns: polypropylene, polyamide, acrylic, cotton, wool, etc. On a wire Wilton machine, no heat-sensitive yarns can be used, as the heating of the metal wires (caused by friction during extraction) would melt the yarns.

Weaving machine

The Carpet Loop Pile Pioneer CLP91 is a double rapier weaving machine, developed for weaving loop pile carpets according to the above mentioned technique with lancets and dummy fillings. The basic machine of the CLP91 is similar to the face-to-face carpet weaving machine as described under Section 3.2.1, however adapted for weaving loop pile carpets. This means amongst others equipped with a rapier switch-off system for the top rapiers to insert the dummy filling only every two picks, foreseen with one spike roll and take-up system for one carpet, equipped with an electronic Jacquard machine for weaving different weave structures, etc.

The CLP91 can also be equipped with a dobby machine and a servo-drive pile delivery system to control the pile yarns for weaving plain or dobby-designed carpets.

When leaving out the gauges, the machine can also weave sisal look carpets as described in Section 3.2.5.

3.5 Automation in carpet-weaving mills

3.5.1 Introduction

In carpet-weaving mills with numerous machines, it can be difficult to schedule and monitor all the weaving machines. To cope with this, Van de Wiele has developed a software system, called We@velink, which makes it possible to prepare, plan and control all weaving machines (in one or more locations) from a central planning office. The software was especially developed for the needs of the carpet industry.

3.5.2 CAD/CAM

The first step is making the design. This is called the CAD (computer-aided design) part of the preparation process. Nowadays, the carpet weavers make their designs with special design software. This software has tools and automated creation wizards for designing carpets. Besides the basics tools like copy, paste, cut, drawing lines and circles, etc., the carpet CAD software has tools to automatically compose borders, to create circular and polygonal designs, to repeat design and motifs, to reduce the colours of a scanned image, etc. In order to obtain a clear design in the carpet without mix-contours and double points, some design rules have to be respected. The Design Master of the We@velink software can detect whether these rules are followed, this is explained in Section 3.6.2.

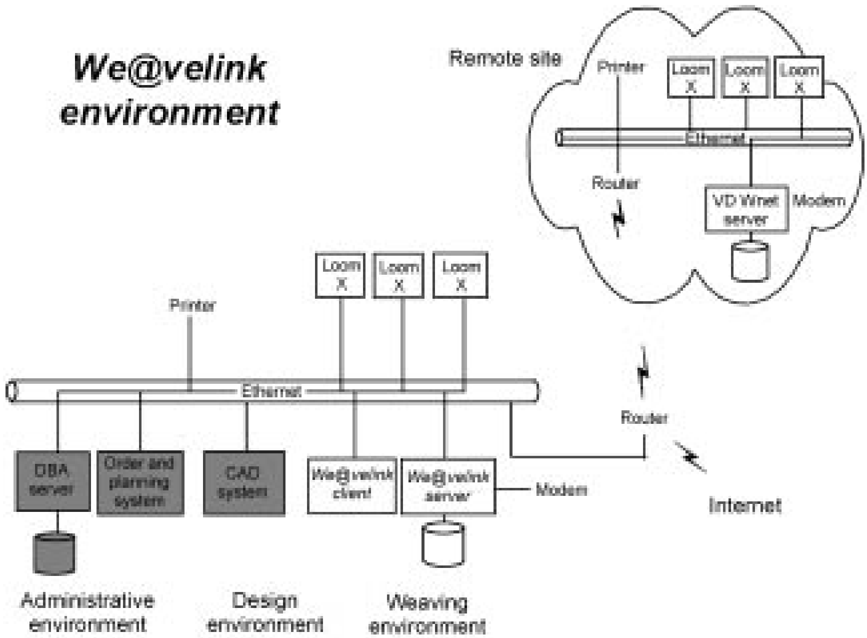
The next step, after creating the design, is processing the design or the CAM (computer-aided manufacturing) part of the preparation process. This is translating the design in to a weavable file in the language of the electronic Jacquard machine, taking the creel set-up, weave structure, into account. The We@velink system has a broad range of weave structures available (cut pile in single, double and three shot, loop, cut-loop, flat weave, sisal, long pile, Axminster, etc.). The software can make automatic corrections to avoid mix-contours, double points, etc. It is in this step possible to add automatically names on the backside of the carpet or on the jute in between two carpets. The cross-section module allows checking the course of the yarns on each point of the carpet.

The intranet We@velink design library helps the designers in storing the designs with automatic name generation, depending on parameters and retrieving them from a library. As one carpet-weaving mill has many designs, this powerful tool is a must to avoid mistakes.

Another powerful tool provides the visualisation and simulation of carpets. With this tool, the designer can show, both in the factory as well as to key customers, how the carpet will look once it is woven, taking the colours into account. It is possible to visualise all effects like cut pile, loop pile, flat weave, etc., in a very accurate way. It is also possible to simulate how a carpet will look in a specific interior, taking light, shadows, etc., into account.

3.5.3 Networking and process control

An essential tool for controlling a modern carpet-weaving factory is a network (see Fig. 3.14) in which the carpet-weaving machines are connected with a



3.14 A set-up of the We@velink network to connect weaving machines in one or more factories to a computer in a central planning office.

central computer, allowing tracking of the complete process and production.

The We@velink network software is built in a modular way. Depending on the needs of the company, it is possible to:

- prepare the optimal planning and corresponding weave schedules in order to use the full width of the machine by weaving side by side different designs
- send over the network the weave schedules to the best adapted carpet weaving machines (with visualisation of the carpets before sending if wished)
- monitor the production by registering the woven schedules with corresponding efficiency
- print out the data of the actual woven rugs
- visualise the weave schedules according to the creel set-up before weaving
- queue numerous weave schedules for long runs, for example during night shifts or weekends
- calculate the yarn consumption
- get a complete report of all machine stops including the reason, duration, etc., with real time information and different efficiencies
- control and adapt automatically the content of the hard-disk of each connected controller
- communicate with CAD/CAM systems and administrative environment

- weave with the incorporated pile names and logos in the back of the carpet or in the leno between the carpets
- make data available on other computers through an intranet system.

The production engineer can use the software either in an interactive way or as a black box as connection between the carpet-weaving machines and an administrative or planning system. Even in the interactive way, many processes can be automated and run in background.

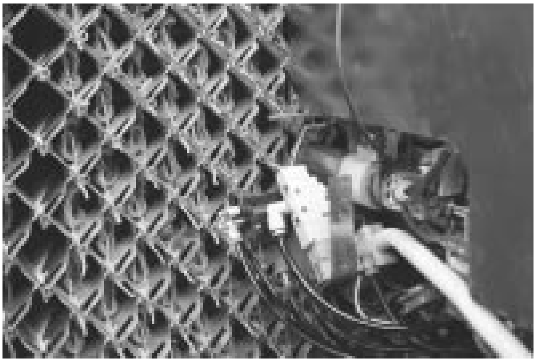
On a higher level, the We@velink planning software prepares an optimal plan of the carpets for the machines on an electronic planning board, starting from the commercial order book, taking several parameters into account like delivery time, creel set-up, width, etc. This software, however, is mainly customer made.

The We@velink software for networking and planning saves a lot of time and money: no more running to the weaving machines with disks or USB sticks, accurate production information, easier planning, etc. As the planning is done on a central computer, the complete flexibility of the machines can be used in an optimal way. Networking is an essential tool for each carpet-weaving company in a growing competitive market.

3.5.4 Automated creel

One of the most time and manpower consuming actions in a weaving plant is the creel changes. Therefore, the manufacturers are trying to reduce the number of creel changes while the market demands a large variety of colours. In order to cope with these conflicting demands, Griffith (member of the Van de Wiele group) developed a new type of automated pile creel, called the Smart Creel.

The Smart Creel (see Fig. 3.15) consists of a matrix of cells with pile yarn. A robot fills the cells with pile yarn supplied from big bobbins, eliminating the time-consuming creel changes. These cells replace the traditional pile bobbins.



3.15 The automated Smart Creel saves raw materials, reduces manpower and shortens the machine down-time.

The robot is programmed to fill the matrix of cells with a quantity of yarn adapted to the design, this means with a minimum of lost yarn.

The main advantages of the Smart Creel are the saving of raw material, the reduced machine down time and the saving of manpower.

3.6 Management of carpet-weaving factory

3.6.1 Complete carpet-weaving process

A carpet-weaving plant consists of several departments. In general there are three departments:

- preparation
- weaving
- finishing.

In the preparation department, there are several divisions. One part makes the designs and converts them into weavable files, this is also called the CAD/CAM part and has been described in Section 3.5.2.

Another part of the preparation department prepares the yarns for the weaving machine. A direct beaming machine puts the ground yarns (mostly cotton/polyester, cotton/viscose, etc.) for the weaving machines on beams. In carpet weaving, the beaming is mostly done a direct beaming machine, rather than on a sectional beaming machine, as a direct beaming machine guarantees hard beams with equal tension over the complete with of the beams, thus avoiding waves in the carpets. The Super Direct Beaming machine or SDB91 is in this respect an ideal machine.

Besides the beaming machine, this department contains also some bobbin winders that can have two functions. In case of wool and acrylic, the yarns are mostly on conical bobbins or hanks. The bobbin winders wind the yarns from hanks or conical bobbins to cylindrical bobbins, suitable for face-to-face weaving. In the case of polypropylene, the yarns are in general extruded on cylindrical bobbins that can be used immediately on the weaving machines. The second function is rewinding rest yarns. During weaving, it is better to change the pile bobbins in the creel before they are completely empty in order to avoid machine stops and in order to avoid too much difference in tensions between full and empty bobbins. The bobbin winders can make new full bobbins from several almost empty bobbins in order not to lose any raw material.

The next department is the weaving department where the weaving machines as described in the previous chapters are installed.

The last department is the finishing department where there is a backsizing and shearing machine. The backsizing machine puts a thin layer of transparent glue on the backside of the carpet. The shearing machine does tip shearing in order to obtain a perfect pile surface. Depending on the type of yarn, the carpet passes one or more shearing heads. In general, the low cost qualities in polypropylene pass one head and the higher qualities in wool pass three or even more heads. The shearing is of course not done for 100% loop pile and sisal look carpets.

The final step is preparing the carpets for sale. Small Titan Deconinck machines put fringes or edges on the carpets, depending on the request of the final customer. This process can be automated with special lines or with the DK4600 Titan robot edging the four sides of the carpet.

Finally, the carpets have to be packed and labelled. They are ready for sale.

3.6.2 Design possibilities

The designers have a lot of freedom to design carpets; however, for some qualities some specific design rules have to be taken into account.

The main difference that can be made in carpets is of course the design. The electrical Jacquard allows weaving of each design, from traditional Persian designs to modern designs. The number of colours and the number of design points determine the design. The number of design points per square metre is the multiple of the number of reed dents per meter with the number of design lines in weft direction. The number of points in a carpet can go from 80 000 points/m^2 for the economical qualities up to more than 3 000 000 points/m^2. For symmetrical carpets, only one-quarter of the carpet is designed. More details about designing can also be found in the CAD/CAM section (3.5.2).

Besides the creativity of the design, there are several other ways to include special effects in the carpet:

- using different yarns (BCF polypropylene, heat set polypropylene, frisé polypropylene, wool, acrylic, viscose, silk, etc.), even different yarns in one carpet and yarns with special effects (with metal look, shrink yarns, yarns with another colour in the middle, etc.)
- combining cut pile with flat weave effects or loops
- using single, double and triple loops or any combination
- using a filling selector to insert different colours of filling
- high-low effects with gauges or wires of a different height
- etc.

For some weave structures, e.g. 1/2 V, it is possible that mix-contours or double points occur in the carpet when some design rules are not respected. In a mix-contour, two yarns mix with each other on specific colour changes. In a double point, two yarns make at the same time a loop on the back of the carpet. Thanks to the processing software of the We@velink system, many of these mix-contours and double points can be avoided, when taking specific rules into account such as always drawing a double colour line between two single colour lines.

Van de Wiele has developed a software system, called the Design Master, that can highlight in a design, so before weaving it, where mix-contours will appear for a certain creel set-up and weave-structure. With this software, it is possible to visualise and simulate all kinds of carpets and effects (cut pile, flat weave, loop pile, etc.) before weaving it, in order to have a perfect design before starting to weave, thus reducing lost materials for trials and second choice carpets. This software is a real revolution for the development of new carpet designs and qualities.

3.6.3 Maintenance of machines

Proper maintenance of the machines is of course a key factor for a smooth-running carpet-weaving mill, for first-quality carpets and for a long lifetime of the machine and parts. This chapter gives some general guidelines for the maintenance of face-to-face machines. The machines have been developed for minimal maintenance and minimal down-time during maintenance.

The basic machine is equipped with oil circulating systems: on the left side one for the gearboxes of the rapier motion and the Jacquard drive, one for the gearbox of the direct drive (transmission) and one for the gearbox of the spike rolls; on the right side one for the gearboxes of the rapier motion, knife motion and Jacquard drive. An oil flow detector monitors the oil flow. The other gearboxes (e.g. reed motion) are equipped with bath lubrication. A centralised lubrication system distributes the grease to different points. With an automatic lubrication system, a film of lubricant is applied automatically to the rapier toothed racks via the rapier drive socket. The quantity of lubricant, the lubrication period as well as the lubrication interval are user settable.

The HMI (Human Machine Interface) machine control has counters to indicate when oil and grease has to be changed, thereby the weaver gets a reminder on time.

The quality of the oil and grease has a big influence on the lifetime of the parts and on the frequency of changing oil and grease. The frequency of changing is different for the different gearboxes and points in the machine. Proper maintenance of the oil filters and pressures filters helps maintain the quality of the oil. The machine has been designed in order to have easy access to all maintenance points.

A central dust collecting system connected to the filling insertion removes the abrasive jute dust and lint. This improves the lifetime of the rapiers, the pile harness and other machine components sensitive to dust.

For efficient working of the machine, some daily, weekly and monthly checks have to be made:

Daily:

- check the knives of the cutting motion
- measure the pile height of top and bottom carpet
- remove dust during weaving with compressed air

- empty the reservoir of the cleaning system
- check the rapier rods for dust
- remove dust from the filters.

Weekly:

- check the pile and ground stop motions for proper working
- clean the grinding stones
- check the oil level of the pneumatic cylinders for the weft scissors
- check the cutting rope for wear and tension and the clearance of the knife carriage
- remove dust from non-visible places.

Monthly (or with every beam change):

- remove, clean and check the rapiers and rapier wheels.

Every six months:

- check bolts and nuts for correct torque and tighten if necessary.

3.6.4 Raw material specification

The pile yarn can be polypropylene, wool, acrylic, cotton, polyamide, viscose, etc. The pile yarns give the main aspect to the carpet, as it is the yarn that is visible and touchable on the front side of the carpet. The ground yarns (coming from beams) are mainly cotton/polyester or polyester/viscose. The filling is jute, polypropylene or stabilised cotton.

The characteristics of the raw materials are always a compromise between cost price and minimal requirements for an efficient working of the weaving machine. It is, however, extremely important to have good raw materials in order to obtain good weaving efficiencies and top-quality carpets. Besides the raw materials, the conditions in the weaving mill like humidity, air conditioning, temperature, etc., should be respected as well.

The storage of the yarns and bobbin winding should be under the same climatic conditions as in the weaving room: 67% to 73% relative humidity and temperature of 20 to 25 ºC, without extreme fluctuations.

Table 3.1 gives some indicative raw material specifications for some common carpet qualities. For all mentioned yarn specifications, mean linear irregularity, number of thin and thick places, number of knots should not exceed the 25% of the Uster statistics. Faults resulting from bobbin preparation, such as crossed ends, run out ends, slack ends, double ends, opening knots, sticking ends should not exceed 10% of the total yarn breaks.

3.6.5 Calculation of production and unit cost

In face-to-face weaving, production depends on the number of rapiers inserted simultaneously. For two rapiers going in the shed at the same time, production

Table 3.1 Indicative yarn specifications of some common carpet qualities

Machine type	CRP92	CRP92	UCP93	SRP92	MAX91
Reed density	320 d/m	500 d/m	320 d/m	160 d/m	275 d/m
Number of colours	6	8	8	8	16
Weave structure	1/2 V	1/1 V	cut-loop	shaggy	1/3 V, not through to the back
Pile yarn	BCF or heat set polypropylene, 2600 dtex	Heat set polypropylene 1350–1450 dtex or equivalent in wool/acrylic	BCF polypropylene in 2600 dtex for weaving with 6 to 7 total picks/cm or heat set	Heat set polypropylene: 2 × 2350 dtex for weaving 1/2 V with 6.4 to 10 total	Wool/polyamide: 4/3 Nm and 3.2/Nm or polyamide 3 × 220 and 2 × 315 tex or
	strength at rupture: 3600 g or more elongation at rupture: 20 to 25% ensimage spinning oil contents: 1.2 to 1.6%	strength at rupture: 3600 g or more elongation at rupture: 20 to 25% censimage spinning oil contents: 1.2 to 1.6%	strength at rupture: 3600 g or more elongation at rupture: 20 to 25% censimage spinning oil contents: 1.2 to 1.6%	strength at rupture: 3600 g or more elongation at rupture: 20 to 25% censimage spinning oil contents: 1.2 to 1.6%	strength at rupture: 3000 g or more elongation at rupture: max 16% censimage spinning oil contents: 1.2 to 1.6%
Ground yarn	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 3000 g Yarn elongation at break: max. 10 to 12%	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 3000 g Yarn elongation at break: max. 10 to 12%	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 3000 g Yarn elongation at break: max. 10 to 12%	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 3000 g Yarn elongation at break: max. 10 to 12%	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 4500 g Yarn elongation at break: max. 10 to 12%
	Tight warp: cotton – polyester 20/5 Nm Yarn strength: min. 5000 g Yarn elongation at break: max. 8 to 10%	Tight warp: cotton – polyester 20/5 Nm Yarn strength: min. 5000 g Yarn elongation at break: max. 8 to 10%	Tight warp: cotton – polyester 20/5 Nm Yarn strength: min. 6000 g Yarn elongation at break: max. 8 to 10%	Tight warp: cotton – polyester 20/5 Nm Yarn strength: min. 6000 g Yarn elongation at break: max. 8 to 10%	Slack warp: cotton – polyester 20/3 Nm yarn strength: min. 4500 g Yarn elongation at break: max. 10 to 12%

Filling	Jute 9–12 picks/cm: 4.8/2 Nm 7–10 picks/cm: 3.0/2 Nm 6–8 picks/cm: 2.4/2 Nm 4.5–6 picks/cm: 1,8/2 Nm	Jute/cotton 9–10 picks/cm: 4.2/2 Nm 10–12 picks/cm: 4.8/2 Nm 12–14 picks/cm: 6.0/2 Nm 14–15 picks/cm: 7.2/2 Nm	Jute 6 picks/cm: 2.4/2 Nm 8 picks/cm: 3/2 Nm 9 picks/cm: 3.6/2 Nm	Jute 6–7 picks/cm: 1.8/2 Nm 7.1–8 picks/cm: 2.4/2 Nm 8.1–9 picks/cm: 3:2 Nm 9.1–10 picks/cm: 3.6/2 Nm	Fibrillated polypropylene 7.1–9.5 picks/cm: 3600 dtex 9.6–11.8 picks/cm: 2220 dtex
	Yarn strength: min. 3000 g yarn elongation at break:	Yarn strength: min. 3000 g yarn elongation at break:	Yarn strength: min. 3000 g yarn elongation at break:	Yarn strength: min. 3000 g yarn elongation at break:	Jute 7.1–9.5 picks/cm: 1.8/2 Nm 9.6–10.6 picks/cm: 3/2 Nm 10.8–11.8 picks/cm: 4.2/2 Nm yarn strength: min. 3000 g yarn elongation at break: max. 3%

General

For face-to-face weaving

BCF Polypropylene for face-to-face weaving must be air entangled with regular tangle points circa every 2.5 cm to 3 cm.
Heat set polypropylene for face-to-face weaving must be correctly twisted about 120 turns per metre and stabilised by correct heat setting.

For Axminster weaving

Recommended twist level for spun yarns e.g. wool or wool/PA (80/20):140 turns/m.
Recommended twist level for 2 or 3 ply multifilament yarns e.g. polyamide PA:180 turns/m to 200 turns/m.
The twist level must be regular with max. ± 5 turns/m deviation towards the nominal twist level.

for the two shot weave structure in square metres per hour can be calculated as follows:

$$\frac{2\text{ (rapiers)} \times \text{speed (rpm)} \times 60\text{ min/h} \times \text{weaving width}}{\text{total picks/cm} \times 100\text{ cm}} \times \text{weaver's efficiency}$$

For a common carpet quality with a reed density of 320 dents/m, 6 colour frames, 5 total picks per cm in 1/2 V or 2.5 pile rows/cm with polypropylene pile yarn, woven on the Carpet and Rug Pioneer CRP92-400 with first-quality raw materials, production is around 180 m^2/h (weaver's efficiency of 85%).

For three rapiers going in the sheds at the same time, the production in square metre per hour can be calculated as follows:

$$\frac{3\text{ (rapiers)} \times \text{speed (rpm)} \times 60\text{ min/h} \times \text{weaving width}}{\text{total picks/cm} \times 100\text{ cm}} \times \text{weaver's efficiency}$$

It is obvious that the production in the three shot weave structure 2/3 V, woven with three rapiers, is 50% higher than the three shot weave structure woven on a double rapier weaving machine.

For a three shot carpet quality with a reed density of 400 dents/m, 8 colour frames, 15 total picks per cm in 2/3 V or 5 pile rows/cm with a heat set polypropylene pile yarn, woven on the Carpet and Rug Pioneer CRP93-400 with first quality raw materials, production is around 75 m/h (weaver's efficiency of 85%).

The weaver's efficiency takes into consideration the machine stops for yarn breakages and the time needed to repair. When calculating the production per month, another efficiency, called the weaving mill efficiency, should be taken into account. The weaving mill efficiency contains the stops for creel changes, beam changes, general maintenance of the machines, etc.

Production is of course a very important factor in calculating the cost price of a carpet. The most important cost, however, in the total price of a carpet, is the raw material. The following list gives an idea about all the costs that should be taken into account when calculating the cost per square metre together with their average percentage in the total cost:

- raw material: 70–85%
- machine depreciation (preparation, weaving and finishing): 6–8%
- building: 2–4%
- salary: 8–12%
- energy: 2–3%
- overhead: 6–8%

The raw material is easy to calculate as it is just the sum of cost of each of the raw materials (pile, jute, filling and coating) per square metre.

The machine and building depreciation is calculated as follows:

$$\frac{\text{machine and building cost} + \text{interest for the loan}}{\text{total production in square metre during depreciation period}}$$

The salary cost per square metre is calculated as follows:

$$\frac{\text{Total salary cost per month}}{\text{production in m}^2\text{ per month}}$$

3.6.6 The market for woven carpet

The market for woven carpet is a growing market. The sales of wall-to-wall carpet have gone down as people prefer a stone or wooden floor. As a consequence, however, the sales of area rugs increases as people like to decorate this hard floor with carpets and area rugs. Table 3.2 shows the consumption of woven carpet in different parts of the world for the years 2004, 2005 and 2006.

There is a general tendency towards higher-quality carpets, this means carpets in higher reed densities, carpets with more colours, and carpets with high-quality raw materials (like heat set polypropylene, acrylic or wool). Where before the most common carpet had 320 dents/m and five colours, nowadays, hardly any company is still investing in this kind of machine. The quality of carpet is strongly related to the buying power of the customer. The majority of the carpets still have 320 dents/m, but in 6 to 8 colour frames. New carpet qualities with 500 up to 700 dents/m and with more than 1 000 000 points/m^2 are getting a bigger market share, especially in Europe and Iran.

Table 3.2 The consumption of woven carpets in the world for the years 2004, 2005 and 2006 in m^2

	2004	2005	2006
Western Europe	122 000 000	127 000 000	128 000 000
Eastern Europe	25 000 000	27 000 000	29 000 000
North America	116 000 000	125 000 000	136 000 000
Middle East	62 000 000	73 000 000	85 000 000
Far East	42 000 000	48 000 000	55 000 000
Others	22 000 000	24 000 000	27 000 000
TOTAL	389 000 000	424 000 000	460 000 000

3.7 Conclusions

A wide and growing variety of carpet styles and structures exist: carpets with cut pile in single, double and three rapier weave structures, carpets with loop pile, carpets with cut pile and loop pile, sisal look carpets, Axminster carpets, long pile carpets, etc.

Each of these carpets has specific characteristics and applications: area rugs, wall-to-wall carpets for indoor and outdoor use, etc.

A carpet has become more and more a fashion product with fast changing colours, trends and tastes. It is up to the carpet weavers to adapt themselves to these new market evolutions. Where before they only needed to offer quantity, they now have to offer diversity in quality, style and colours.

In this respect, the machinery of Van de Wiele described in the chapter fulfils the needs of the carpet weavers. On the one hand, the carpet weaver can use highly productive weaving machines for each kind of carpet. On the other hand, the machines are versatile due to the use of advanced electronics, new working principles and the networking system.

It is the task of both the carpet weavers and the carpet weaving machine manufacturer to look continuously for new carpet qualities and applications but also to improve the performance and the quality of the carpet weaving machines.

4
Developments in wool carpet manufacture

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Abstract: This chapter discusses recent developments in the various processes and technologies for wool which are relevant to machine-made carpets. It includes a review of production and early stage processing of carpet wools, as well as fibre, yarn and carpet treatments that enhance processing and product performance. The chapter concludes with a review of testing methods and the future prospects for wool fibre in carpets.

Key words: wool, early stage processing, yarn manufacture, carpet tufting, performance testing.

4.1 Introduction

This chapter outlines the ways in which wool and its associated technologies have adapted in order to keep the fibre to the forefront of modern carpet manufacture. The principal references for the topics covered in this chapter are the texts by Crawshaw,[1] and Simpson and Crawshaw.[2] In addition, the series of Carpet Technical Information bulletins, published by Wools of New Zealand, cover all aspects of wool carpet manufacture in detail, from raw material to finished product. The most relevant of these bulletins to the topics covered in this chapter are listed in Section 4.10.

4.1.1 A brief history

Wool has a long and proud history as a premium carpet fibre. The oldest existing carpet, which can be viewed in the State Hermitage Museum in St Petersburg, was found in a tomb in Southern Siberia in 1953. It is reputed to be around 2400 years old.

While the art of carpet making was known to the Greeks and the Romans, it was lost in the fall of Rome. However, carpet makers continued to thrive in the East, and from the 7th century the Moslems dominated carpet weaving and centres of weaving were to be found from Turkey to China. Today, Asia and China remain major regions for hand-made carpets, which continue to use mainly wool as the pile fibre.

With the arrival of the Industrial Revolution, mechanical weaving with powered looms began, and wool remained the fibre of choice for the Brussels, Wilton and Axminster types of carpet.

Tufting developed from the bedspread industry in the USA from the 1930s to become the dominant method of carpet manufacture by around 1970. Wool was challenged to meet the technical requirements of this new method, as well as confronting the growing competition from man-made fibres in carpets. These pressures stimulated considerable research and development efforts to ensure that this traditional carpet fibre was not left behind.

4.1.2 Properties of wool

The wool fibre has a unique structure and set of properties that make it an excellent pile fibre in floor coverings. Wool consists of a protein, keratin, which is composed of long-chain molecules. There are many cross-linkages (especially the disulphide bonds) between the long, coiled chains, and this structure is largely responsible for the outstanding elastic and flexural properties of wool.

In common with other mammalian fibres, its exterior surface consists of overlapping scales, called the cuticle, which control the frictional properties of the fibres as well as inhibiting the attraction of soil particles and the penetration of liquid water. The matt surface and opaque nature of wool means that the visual effect of flattening of a wool carpet is less obvious than with many other types of pile fibres.

Water vapour moves readily into and out of the fibre, depending on the ambient humidity and temperature. This gives wool carpets the ability to exert a degree of 'climate control' in the indoor environment, especially in buffering the effects of fluctuating humidity levels. In addition, the presence of water vapour within the fibre contributes to low static charge accumulation and the flexibility and elasticity of the fibre. Under normal atmospheric conditions, static electricity is not a problem with wool carpets.

The natural wave-like crimp of the wool fibre contributes to the excellent resistance to compression of a carpet pile, and its recovery to the original thickness after compression. Crimp affects the space-filling capability (or bulk) in a yarn, which in turn affects the cover and resilience of a carpet pile.

Because of its chemical composition, wool has a high affinity for a range of dyestuff types, enabling it to be dyed to the richest colours. In addition, the disulphide bond structure of wool allows the fibre to be set into a pre-determined configuration such as in a twisted yarn using hot water, steam or a chemical agent such as sodium metabisulphite.

Other properties of wool which are important to consumers include its exceptional ability to resist burning, and to improve the indoor environment through its ability to absorb odours and noxious gases such as sulphur dioxide and formaldehyde.[3] Not only does wool neutralise these air contaminants more quickly and completely than synthetic carpet fibres, it does not re-emit them, even when heated. When burning, wool has low levels of smoke generation and heat release, which make it much safer than most competitor fibres.

Larvae of some moths and beetles eat wool and may cause damage to carpets. To prevent this, wool pile yarns are given a durable insect-resistant treatment during manufacture.

4.2 Wool supply and early stage processing

The production and early stage processing pipeline for wool is unique amongst the carpet fibres, so it is worthwhile to briefly review these aspects here.

4.2.1 Carpet wool production

Wools that are suitable for carpets are produced in many countries; however, these vary widely in their quality and volume, and in most cases do not fully satisfy the local requirements for this type of fibre. New Zealand is the world's largest supplier of carpet wools, and exemplifies the most modern systems of wool production, marketing and early stage processing.[4] The sheep that grow wool suitable for carpets are dual-purpose breeds, producing lambs for the meat export market as well as wool. New Zealand sheep are farmed outdoors, all year round, on a wide range of terrains. The wool is shorn from the sheep in a flock by a team of expert shearers every 6–12 months, and the fleeces are dispatched in bales to a wool broker's store to await sale.

The selling season for New Zealand wool extends over almost 12 months, from July to June, and an open-cry auction is conducted every week during the season by wool brokers. Buyers (often called 'wool exporters' because they are mostly purchasing on behalf in clients in other countries) bid on farm lots at the auction. Their buying decisions are largely based on:

- the visual appraisal of samples on display over the week prior to an auction, and
- objective data on each lot, the results of testing core samples extracted at the wool broker's store and sent to a testing laboratory ('test house'). The results, which are presented in the auction catalogue, include the key parameters of mean fibre diameter (or micron), colour and yield.

While the auction system is the traditional method of selling wool in New Zealand, more wool is now sold by a private treaty between a wool grower and wool buyer. Forward contracts to supply a quantity of wool on a future date are becoming an increasingly common method of sale transaction.

Most New Zealand wool leaves the country in the scoured form. The buyer arranges for the transportation of the purchased wool to a wool scour, where it is blended with other lots to form a consignment for export. The scouring process for carpet wools is outlined in Section 4.2.2.

A typical processing consignment is a blend of three types of wool:

Table 4.1 Wool blends for different carpet types (Wools of New Zealand Ltd)

Yarn manufacturing system	Carpet type		Wool components		
			Mainstream	Filler	Speciality
Woollen	Woven	Axminster	30%	50%	20%
		Wilton	45%	35%	20%
	Tufted	Loop pile	30%	55%	15%
		Cut pile	65%	20%	15%
		High twist	45%	40%	15%
Semiworsted	Woven	Face-to-face	80%	–	20%
	Tufted	Loop pile	50%	40%	10%
		Cut pile	60%	25%	15%
		High twist	60%	35%	5%

1. Mainstream wools, which are annually shorn or six-monthly shorn fleeces, are chosen for their good colour, length and ease of spinning. In some countries these wools are often used to 'carry' inferior local wools through spinning.
2. Speciality carpet wools are frequently included to contribute special properties with respect to appearance and handle to a carpet. They may contain medullated fibre and/or have a high bulk.
3. Filler wools are inferior quality wools, used primarily because of their relatively low price.

The proportions of these types varies, depending on the carpet being produced, with the highest proportion of top quality wools generally being required for blends for cut pile tufted and face-to-face woven carpets (Table 4.1).

A wool carpet blend may also contain:

- colour effect materials in the form of dyed neps, knops or slubs to produce berber and tweed textures
- melt-bonding fibres (typically 10% of polyester or polyamide fusible bonding fibres) to enhance the texture retention of cut pile carpets (see Section 4.8)
- polyamide fibres (typically 20%) to enhance the abrasion resistance of a wool carpet.

4.2.2 Wool scouring

The first step in the conversion of raw wool into carpet is the wool scouring process.[2] This is a high production, yet gentle, washing treatment to remove grease (wool wax), suint (potassium (sweat) salts) and dirt from the wool fleeces to deliver a homogeneous, clean, good colour product ready for spinning. A

4.1 A wool scouring line.

typical scouring line for coarse (carpet) wools (Fig. 4.1) integrates the following steps:

1. Blending of grower lots and opening and mechanical cleaning to maximise scouring effectiveness.
2. Scouring in three successive scouring bowls, with squeeze presses located between the bowls. Usually three bowls containing water at 60–65 ºC with a non-ionic detergent are used. The wool is immersed by a suction drum as it enters each bowl, and is gently transported across the bowl by the reciprocating action of a series of rakes.
3. Rinsing in two cold water bowls and a final hot water rinse bowl.
4. Hot air drying to a specific moisture content (regain).
5. Post-scouring dust removal by mechanical action.
6. Baling – usually compressed into high density packages around 450 kg.

Almost all operations in New Zealand scouring plants are conducted under the control of sophisticated computer-based systems, which have evolved through an intense R&D effort over the past 25 years. These modern systems ensure that:

- the final product is of a consistently high quality, especially with respect to cleanliness and colour;
- water, detergent, chemicals, energy and labour are used efficiently; and
- the effluent is treated and disposed of in an efficient and environmentally responsible manner.

Near-infra-red reflectance (NIR) instruments are used in all New Zealand wool scouring plants to continuously monitor the moisture level, grease content and colour of the scoured wool as it is packaged. The NIR results enable prompt corrective action to be taken in the plant whenever deviations from the required processing outcomes are detected.

4.3 Processing routes for wool

While wool yarns may be manufactured using any of three spinning routes (woollen, worsted and semiworsted),[4] for carpet yarns the woollen route is the most commonly used. This route is distinguished from the other two routes by:

- having the highest versatility with respect to the range of wool types that can be used;
- incorporating the smallest number of processing steps in converting scoured wool into finished yarn;
- producing a relatively irregular, hairy and bulky yarn which is suitable for a wide range of carpet types.

4.3.1 Woollen spinning

A typical processing sequence for woollen spun carpet yarns involves the following essential steps:

1. opening, blending and the application of a carding lubricant to the wool;
2. woollen carding to produce a thin, continuous strand of fibres, slubbing;
3. ring spinning to convert slubbing into twisted singles yarn;
4. twisting to combine two or three singles yarns.

Thorough, multi-stage blending is carried out prior to carding to ensure that a yarn of consistent quality and character is produced, and thus reduce the risk of visual stripes occurring in the carpet. The woollen system provides only very limited opportunities for reducing yarn variation after the carding stage.

Dyeing may occur before carding (loose stock dyeing) or on the yarn (hank dyeing or package dyeing). The former is mostly used in the production of wool for plain shade carpets, where large quantities of dyed fibre are required and any colour variations between dye batches can be eliminated by subsequent blending. Yarns for the manufacture of woven carpets or patterned tufted carpets are usually dyed in hank form to enable smaller amounts of various colours to be produced economically.

It is usual practice to scour the finished yarn to remove residual lubricant and other surface contaminants, unless the yarn has been ‘dry spun’. Dry spinning on the woollen system requires the application of a lower level of lubricant (i.e., less than 1% rather than the usual level of around 3%) so that yarn scouring is unnecessary.

Yarns destined for cut pile carpets must usually be set; i.e., the twist is stabilised so that carpet tufts resist the tendency to untwist. For wool yarns this may be achieved by boiling the yarn in a dye vessel, steaming in an autoclave, or by immersing the yarn in a bowl of sodium metabisulphite solution in a tape scouring machine or a Twistset™ machine (see Section 4.4.1).

4.3.2 Semiworsted and worsted carpet yarn

A significant amount of wool carpet yarn is produced on the semiworsted system, especially where a finer count and a smoother, firmer yarn is required. These yarns may be used in some dense tufted level loop pile constructions, and Wilton and face-to-face woven carpets. The semiworsted route, which was originally developed as a high production spinning system for man-made staple fibres, is suitable for wool, provided the raw material is of reasonable fibre length, has good tensile strength and has minimal contamination from vegetable matter. New Zealand produces a large quantity of wool annually that meets these stringent requirements.

The essential differences between semiworsted and woollen spinning are:

- A lower level of lubricant is applied, thus avoiding the need for subsequent yarn scouring.
- The card produces a sliver, rather than slubbings, so that considerable drafting is required in gilling and spinning to achieve the required yarn count.
- Several gillings are carried out to straighten and make parallel the fibres in the sliver, and these steps provide further blending.
- Ring spinning is also used to produce a single yarn, but the draft applied to the sliver is much higher than that applied to slubbings in woollen spinning.

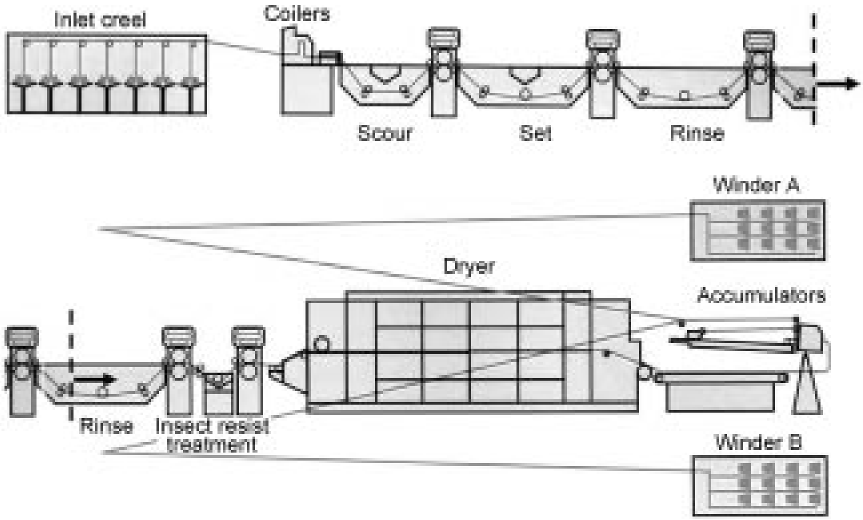
A small proportion of carpet yarn is produced via the worsted route, and is restricted to fine count yarns that cannot be produced efficiently on the woollen or semiworsted systems. The removal of short fibres by combing, plus the greater degree of fibre organisation imparted by gilling and drafting, facilitates successful spinning with as few as 40 fibres in the yarn cross-section. Such yarns are used in face-to-face carpets to produce delicate, pin-point textures.

4.4 Technologies for wool carpet yarns

Most machines and processes used in the production of yarns from man-made staple fibres can be used in the production of wool and wool-rich yarns, some with limited modifications. However, certain processes are unique to wool, and technologies have been specially developed for these purposes. The most notable of these technologies is the Twistset™ process.

4.4.1 Twistset™ (formerly known as Chemset[5])

Unless the dry spinning route is used, woollen spun carpet yarns must be scoured to provide a clean, residue-free product for the carpet manufacturer. Furthermore, if the yarn is destined for a cut pile carpet, it will usually need to have its twist set in place to prevent the cut ends of the tufts untwisting and bursting in subsequent processing, or in use. While boil setting in a dyebath,



4.2 WRONZ Twistset™ system (Andar).

autoclave setting or adding a chemical setting bowl to a tape scour are three commercial setting options for wool yarns, the Twistset™ process is the most significant development.

Twistset™, which was developed by WRONZ and supplied by Andar Holdings Ltd, New Zealand, is a continuous package-to-package scouring and setting system for wool carpet yarns (Fig. 4.2). Up to 36 ends of yarn from a creel are coiled to form twin mats on a perforated conveyor that carries them through four wet processing bowls. Each bowl has a squeeze head. The coiled yarn is then dried, uncoiled and passed to twin accumulators, which enable the machine to operate continuously during doffing, etc. Finally the yarn is wound onto cones by multi-head auto-doffing winders.

The first bowl of the machine is used for scouring, the second contains a solution of sodium metabisulphite (MBS) and the third and fourth bowls rinse away residual MBS. The setting bowl contains a 5–10 g/l solution of MBS at 85 ºC and the dwell time for the yarn is approximately two minutes. A small fifth bowl may be used to deliver an insect-resist treatment to the yarn.

The mat of yarn is lightly constrained on the conveyor so that a high level of unbalanced twist can be introduced into the yarn without kinking occurring. This is not possible with hank setting. The MBS provides a mild bleaching effect to the yarn, enabling brighter colours to be dyed. Other advantages of the Twistset™ process are the avoidance of multiple handling of the yarn and excellent uniformity of the treatment.

A texturising attachment, resembling a stuffer box, may be placed between the creel and the mat-forming head. This unit is used to produce a textured yarn for friezé type carpets. Steam is applied to the confined yarn and this intentionally introduces kinks and crimps into the yarn as it buckles under pressure. The Superba MF2 Friezing Machine is a proven device for this treatment.

4.4.2 Melt-bonding

Melt-bonding fibres are available as polyamide, polyester and polypropylene staple and they have been used by the nonwovens industry for many years. These fibres were first incorporated in wool carpets in the 1990s.[6] The objective was to enhance the twist setting of wool and wool rich yarns. By using a blend, typically 80% wool/10% polyamide/10% melt-bonding fibre, and heating the yarn to fuse the bonding fibres to each other, a network is formed within the yarn to create a more cohesive structure. The following advantages have been identified in cut pile wool carpets:

- improved tuft definition and retention of tuft definition in processing and in use arise from the enhanced twist set achieved using melt-bonding fibres;
- resistance to fibre shedding and abrasive wear;
- improvements in yarn bulk, strength and extension.

On the other hand, the dyeing of a blend of wool and melt-bonding fibre is a more complex operation to achieve a successful outcome than the dyeing of 100% wool blends.

4.4.3 Twisting

The twisting operation for wool carpet yarns has been traditionally carried out on a ring-frame (or ring-twister). However, there has been a significant move in the past decade to using two-for-one twisting, especially for finer types of carpet yarn. As preparation for this process, assembly winding transfers two ends of yarn onto one package. Twist is then inserted on a separate machine, a two-for-one twister, as the yarn is wound off the assembly wound package. The operation is so-called because two turns of twist are inserted for each rotation of the twisting element.

4.4.4 Felted yarn

Felted yarns are used in some wool carpets to provide additional styling possibilities or to provide stable yarns that are bulky. Felting is generally more appropriate for heavier count carpet yarns, which are used in a wide range of machine-made and hand-crafted carpets and rugs.

Felting processes exploit the propensity of wool fibres to felt when subjected to mechanical action while wet, due to their unique surface structure. Wool yarns may be felted by the tumbling of wet hanks in a laundry washer or the proprietary Periloc process. In this process, which was developed by the

International Wool Secretariat, the yarn and a felting solution pass through a flexible tube which is agitated by six rotating arms, each carrying a freely running roller. The flexing and partial compression of the tube causes the yarn to contract in length (with an associated increase in diameter) due to irreversible fibre migration which produces felting.

Felted yarns tend to give a higher abrasion resistance to carpets than would be expected from equivalent carpets using conventional yarns of the same linear density. They are also superior with respect to resistance to compression, fibre shedding and retention of pile texture in use. However, the highly interlocked fibre structure of such yarns inhibits recovery from compression.

The felting process also provides opportunities for innovation in the design of carpet yarns, such as including a core with a colour that contrasts strongly with the rest of the yarn, or using extremely high counts.

4.4.5 Insect-resist treatments

Wool and other keratin fibres are attacked by the larvae of certain moths and beetles. Therefore, it is necessary to apply insect-resist (IR) treatments to wool destined for carpets. These are usually applied during wet-treatment operations. In recent times the most commonly used agent has been a synthetic pyrethroid, permethrin, and this is effective against all wool-damaging insects. However, low levels of permethrin in effluent are toxic to some aquatic organisms. Also, currently used insecticides become less effective over time as resistance has increased in some beetle species. These issues have encouraged the use of alternative IR agents, and the development of alternative methods of application.

The Lanaguard™ process,[7] developed by WRONZ, is an environmentally friendly powder IR agent which is applied to a carpet pile surface during the finishing process. A purpose-designed powder applicator is used to distribute the IR powder and fuse it to the fibres in an enclosed chamber, which increases the efficiency and safety of application. An additional benefit is that no liquid effluent is generated by the process.

New generation IR agents have been introduced to reduce the aquatic toxicity and resistance problems of permethrin. The first of these contained bifenthrin, a newer generation synthetic pyrethroid. The aquatic toxicity (to Daphnia species) of the formulated bifenthrin agent is around 85 times lower than a permethrin-based product.

Recently, a new agent based on chlorfenapyr, an insect growth regulator, has been introduced by Catomance. This has a 32 times lower Daphnia toxicity and a 9 times lower trout toxicity compared to permethrin. Both bifenthrin- and chlorfenapyr-based formulations show excellent control of all moth and beetles, including permethrin-resistant species.

Two surfactants have been discovered that discourage insects from eating wool. They are less toxic than conventional insecticides and are biodegradable.

4.4.6 Zeacrimp™ high bulk nylon (HBN)

This is a high bulk nylon 6.6 fibre specially developed by Solutia Inc. and Canesis for use in wool blends for carpets. Zeacrimp™ HBN fibres have a unique crimp shape and setting treatment to make them compatible with wool processing routes. Because it has a significantly higher bulk than traditional nylon fibres, including Zeacrimp™, HBN as blend component gives significantly better cover and resilience to a carpet pile. Its inclusion in a blend also enhances fibre cohesion, resulting in lower levels of fibre shedding from the pile surface in the early stages of use.

4.5 Manufacturing techniques for wool carpets

As the traditional carpet fibre, wool carpets are manufactured by almost all of the traditional and modern methods:[1]

- hand knotting and hand tufting
- weaving by the Axminster, Wilton and face-to-face techniques
- machine tufting
- fusion bonding.

Other methods, such as needling and electrostatic flocking are less commonly used to produce a wool face surface.

Wools of New Zealand have estimated the following allocation of NZ wool between the principal methods of carpet manufacture:[1] tufting – 52%, weaving – 27%, handcraft (knotting and tufting) – 19%, other – 2%.

Through the research and development efforts of Wools of New Zealand (and its predecessor the International Wool Secretariat (IWS)), WRONZ and Canesis, wool yarns are able to be well engineered to meet the technical requirements of modern carpet manufacture, i.e., regularity, tensile strength, twist stability, colour retention, etc.

Wools of New Zealand provide technical advice on fibre content, yarn construction and other processing information to assist wool carpet manufacturers to optimise production and products. For example, Table 4.2 summarises the production and properties of wool tufting yarns for a range of products.[8]

4.6 Technologies for tufting wool carpets

4.6.1 Tufting needles

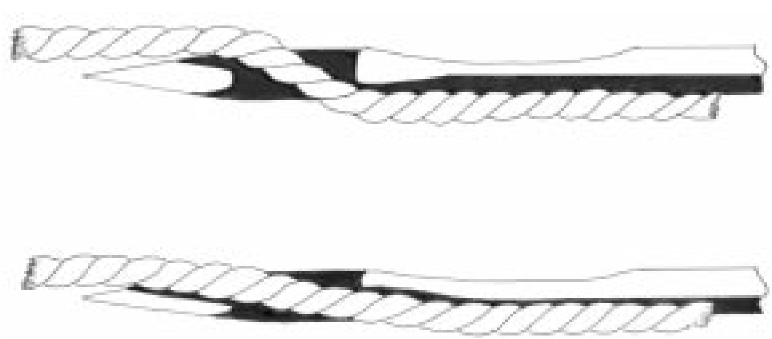
Of all the methods of making carpets, tufting exerts the highest stresses on the yarn. With a yarn of relatively low tensile strength such as wool, breakages in tufting will be more common than with synthetic fibre yarn, leading to reduced manufacturing efficiency. Furthermore, any thick places in a yarn, such as slubs or yarn joins, may jam in the eye of a tufting needle and cause a stoppage.

Table 4.2 Production and properties of typical tufting yarns

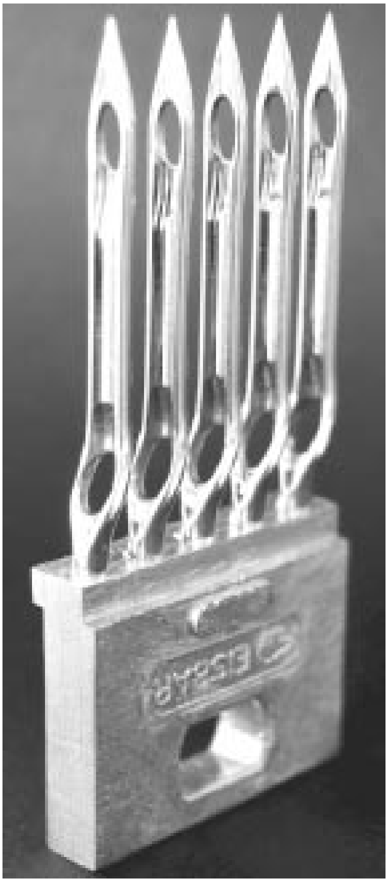
Tufted product	Processing route	Yarn construction	Finished yarn tensile properties
Woollen-spun heather yarn for velour carpet	Stock dye Woollen spun Scour/chemical set	Count: R 480 tex/2 Singles twist: 185 tpm S Folding twist: 130 tpm Z	Breaking strength: 1.5 kgf Breaking extension: 10.0%
High twist yarn for frisé carpet	Stock dye Woollen spun Scour/chemical set	Count: R 520 tex/2 Singles twist: 196–210 tpm S Folding twist: 305 tpm Z	Breaking strength: 2.2 kgf Breaking extension: 11.0%
Yarn for heavy gauge loop pile	Stock dye Woollen-spun Scour	Count: R1960 tex/2 Singles twist: 95 tpm Z Folding twist: 55 tpm S	Breaking strength: 7.3 kgf Breaking extension: 19.3%
Semiworsted yarn for patterned loop pile contract carpet	Stock dye Semiworsted spun No yarn finishing	Count: R440 tex/2 Singles twist: 180 Z Folding twist: 120 S	Breaking strength: 3.2 kgf Breaking extension: 16.0%
Saxony yarn for winch dyeing	Woollen-spun Twistset	Count: R690 tex/3 Singles twist: 195–200 tpm S Folding twist: 175–180 tpm Z	Breaking strength: 2.4 kgf Breaking extension: 10.2%

Carnaby *et al.*[9,10] investigated the limitations in using wool yarns for carpet tufting and identified the causes of machine stoppages. The outcome of these studies was the so-called WRONZ-Eye needle, a re-designed tufting needle which provided a much straighter yarn path through the needle, and a larger eye. Figure 4.3 compares the yarn path through a conventional tufting needle (top) with the path through a WRONZ-Eye needle (bottom). Significantly improved tufting performance with the modified needle was clearly demonstrated, and it rapidly became the preferred tufting needle for a wide range of wool carpet yarns. This needle is now manufactured by Groz-Beckert AG.

A more recent innovation is the Eisbar Fernmaster needle, developed by WRONZ and Groz-Beckert.[11] A needle has two eyes (Fig. 4.4), with the second



4.3 Conventional tufting needle (top) and WRONZ-Eye needle (bottom).



4.4 Fernmaster tufting needles.

eye holding the yarn within a yarn protection groove which runs lengthwise down the needle. This combination of eyes and groove reduces stress on the yarn in tufting and gives significant improvements in carpet quality. Furthermore, needle insertion forces are reduced by up to 70%, in comparison to conventional needles. Consequently, the primary backing fabric retains more strength after tufting.

4.6.2 Yarn supply to tufting

The wool carpet industry is increasingly using beams for yarn storage in the tufting of plain carpets, particularly because of the significant saving in floor space over creels. In addition, tension differences between yarns are less than those delivered from a creel. However, creels must continue to be used for tufting of patterned carpets where the yarn consumption varies between needles.

Furthermore, it is necessary to stop the machine to change beams. Manual joins must be made, resulting in 2–4 hours of downtime and requiring additional staff to be deployed.

4.6.3 Technologies to enhance wool carpets

As a natural fibre produced by a biological process, it is inevitable that wool has some inherent limitations which are not present with man-made carpet fibres. However, its surface characteristics, internal structure and chemical reactivity enable wool to be modified in various ways to enhance its performance. WRONZ and Canesis have utilised the special features of wool to develop a range of treatments, most of which involve wet processes which can be carried out in a dye vessel or a scouring bowl.

Anti-photobleaching treatment

When wool carpets are exposed to sunlight, colour changes may be observed, particularly in pastel shades. This effect, known as photobleaching, may occur soon after a carpet is laid, a period when consumers are particularly aware of acceptable product performance. All wool will photobleach to some degree, due to the influence of the blue component of sunlight on its creamy pigments. However, the extent of apparent photobleaching depends on: (1) the initial colour of the wool, (2) any yellowing that may be caused by processing and (3) the shade to which the carpet has been dyed.

Canesis developed a method of counteracting photobleaching of wool by sunlight,[12] and this was commercialised as a Clariant product, Lanalbin APB. This product photoyellows at the same rate that wool photobleaches, so that the two effects cancel each other out. The result of the Lanalbin APB treatment is a stable colour for wool, whether undyed or dyed, despite the presence of intense sunlight over an extended period.

Lanalbin APB was originally developed as a dyebath additive, but a subsequent formulation, Lanalbin S, was developed for application in a wool scour. It is a particularly cost-effective way of treating wool which would otherwise require a blank dyeing to apply the anti-photobleaching treatment.

The Lanalbin S formulation is pumped directly into the final bowl of the woolscour at a rate depending on the wool throughput. Acid is also added by a separate metering pump to ensure that an optimum pH in the range 4–5 is maintained. The flow rates of the chemicals must be checked regularly to ensure correct metering, and adjusted if the wool throughput changes.

The optimum application temperature is 75 ºC. If the bowl temperature falls below 70 ºC, the treatment will be insufficient.

The Lanalbin treatment is fast to subsequent wet processing, including dyeing, chemical setting and yarn scouring. The best protection from photobleaching is achieved with wools of reasonably good colour (i.e., with yellowness indices Y–Z less than 4–5).

Stain blocking

Wool has a natural stain resistance, due to its hydrophobic surface. However, once wet, wool carpets can stain, although at a slower rate than nylon. Most nylon carpets are treated with a stain blocker and these finishes are also effective on wool. These products are concentrated near the surface of the fibre and provide an ionic barrier to anionic stains. Thus they are most effective against the acid food dyes commonly found in food and drinks. They generally contain sulphonated aromatic compounds which can cause significant photo-yellowing at higher levels of addition. Unfortunately, the levels required for an effective treatment on wool are 5–10 times higher than the levels required on nylon, so, when used on wool, photo-yellowing was often a problem. However, most stainblocking treatments recently developed for wool are non-yellowing.

The higher level required for wool, in comparison to nylon, was thought to be due to the greater number of reactive groups in wool. However, when a stain blocking treatment is applied to a wool staple, only low levels (similar to those appropriate for nylon) are required to prevent staining of the bulk of the staple. On the other hand, the weathered tip of the wool staple requires a much higher level of treatment.

Enhanced scouring treatment

Exceptionally white, bright and clean wool can be produced by an enhanced scouring process that enables excellent pastel shades to be achieved in dyeing as well as pure white yarns. The patented process, known commercially as Glacial, improves wool colour by the removal of extra dirt and woolgrease, while three colour-enhancement steps mean that the scoured product is at least 7 Y tristimulus units brighter than conventionally scoured wool and at least 4 Y units brighter than peroxide bleached wool. Greater colour stability is also assured, especially in dyeing and chemical setting. The improvement is very significant if a small amount of hydroxylamine sulphate is added to the dyeing recipe.

Agents for rapid wool dyeing

In today's wool-carpet yarn manufacturing plants, the dyehouse is often the bottleneck in the processing chain. Installing additional dyeing equipment is an expensive option and often requires extra space. Various dyeing agents are now available that significantly decrease the time required for wool dyeing and obviate the need to enlarge dyeing facilities.

The rapid dyeing method developed by WRONZ using Linsegal™ WRD (from Chemie Impex) can increase wool dyeing productivity by around 50%.[13] Linsegal™ WRD can also be combined with low-temperature dyeing to further reduce yellowing and hydrothermal damage to the fibre.

Linsegal™ WRD and similar rapid dyeing agents from other manufacturers have found most application in loose-stock dyeing of wool. These products can also be used successfully for hank dyeing, including 80/20 wool nylon blends.

Fibre surface modification

The scales on the surface of the wool fibre largely control its frictional properties, and therefore they have an influence on carpet performance. Lanasan NCF is a recently developed nanotechnology from Canesis and Clariant, using carefully-sized silicon nanoparticles which adhere to the fibre surface.[14] They increase inter-fibre friction, which leads to stronger yarns and a more stable carpet pile. The results are improved resistance to abrasion in all wool carpets, lower fibre loss (shedding) in cut pile products and less surface fuzzing in loop pile products. In addition, the Lanasan NCF nanoparticles occupy the soiling sites on the fibre surface and thus impart an improved soil resistance to the treated carpet.

Lanasan NCF may be added to the dyebath for hank dyeing or applied continuously in a tape scour.

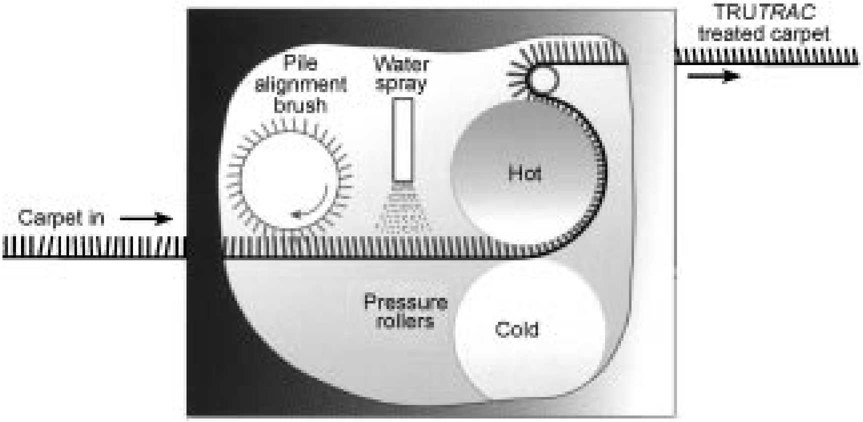
Prevention of pile reversal

Pile reversal (also known as shading, pooling, water marking or pile bias) is the visual effect where areas of a cut pile carpet appear to become lighter or darker in colour than the surrounding area, depending on the direction from which the affected area is viewed. It is caused by variations in the predominant direction of pile lay across the carpet surface and is made visible by the different manner in which light is reflected from the surface. The ends of tufts appear darker than sides of the tufts.

Shading can occur with any pile fibre, including wool, with carpets containing lustrous fibres being more susceptible. The propensity for shading is not particularly sensitive to the construction of the carpet. However, its visual impact depends strongly on the nature of the carpet. For example, carpets made from low-lustre yarns or with a bold pattern may not show shading effects even though pile reversal has occurred in some areas.

A solution to the shading problem has been developed for wool carpets by WRONZ.[15] The TRUTRAC machine (Fig. 4.5) uses a combination of heat, water and pressure to impart a pronounced and consistent direction of pile lean to cut pile tufts during carpet finishing.

Foot traffic on the treated carpet will tend to gradually force the tufts to lean further in the *same* direction, rather than forcing the tufts to reverse their



4.5 Principle of the TRUTRAC process.

direction of lean. The result of using TRUTRAC is a uniform reflection of light across the carpet surface, irrespective of the viewing direction.

The TRUTRAC treatment conditions are readily adjusted to suit individual carpet types and are designed to accommodate the varying degrees of resistance to pile reversal required for different carpet styles and uses.

4.7 Wool carpet performance

The desirable performance characteristics of wool carpets can be simply explained by a 'chain of carpet properties', in which each link should be sound for a product to provide a totally satisfactory performance in use. The 'links' of the chain can be conveniently classified into three groups thus:

1. Initial properties: acoustic comfort, walking comfort, walking safety, thermal comfort.
2. Wear properties: durability (abrasion resistance), tuft bind, appearance retention (with respect to texture, colour and soiling), dimensional stability.
3. Location-specific properties: flammability, electrostatic propensity, hygiene.

To a large extent, the ability of a carpet to display superior initial properties depends mostly on the fibre(s) used, and the construction of the pile (especially the pile density). Because of the nature of the fibre, and the thicker and heavier constructions normally used for wool carpets, they tend to rate very highly with respect to the various types of comfort.

4.7.1 Performance testing

The Woolmark and the Wools of New Zealand product classification schemes for wool carpets utilise over 20 tests that enable most of the above properties, especially those in Groups 2 and 3 above, to be quantified. The purpose of these schemes is to provide information to the consumer that (a) indicates suitable location(s) for a product, and (b) provides an assurance that the product will fully meet their performance expectations over an extended period of use.

Some performance tests are optional, depending on the type of carpet and its intended use. Mandatory tests for both wool carpet grading schemes are:

- surface pile mass
- pile thickness
- appearance retention test using the Hexapod Tumbler Tester
- tuft bind.

Durability

The durability of a carpet is determined mostly by the type(s) of pile fibres used and the density of the pile.

The values for the surface pile mass P of a carpet (in grams per square metre) and its pile thickness t (in mm), enable an empirical durability parameter P^2/t, the 'surface pile mass density', to be calculated. Generally, the higher the value of P^2/t, the greater the expected wear life of a wool carpet, and this trend was validated by extensive floor trials and laboratory testing conducted by the International Wool Secretariat (IWS) over a number of years. For 100% wool carpets the surface pile mass density has been shown to provide a useful predictor of their durability (i.e., their likely long-term wear performance).

A performance-based test for wool carpet durability, based on the WIRA Abrasion Tester, is also widely used. Carpet specimens in the form of small discs are rubbed against an abrasive fabric for a measured number of revolutions. The original version of the test involved determining the number of revolutions of the machine for the carpet specimen to reach its 'end point', i.e., the point where the backing is just becoming visible as the tufts abrade away. The now widely preferred version of the WIRA test subjects the specimen to 5000 revolutions and the resulting loss of fibre from the pile is determined. Based on industrial experience, a weight loss of around 55 mg per 1000 revolutions is considered satisfactory by Wools of New Zealand while a score of above 70 mg/1000 revolutions indicates significant fibre damage and highlights a potential performance problem.

No research has been undertaken to theoretically validate the correlations between the long-term performance of wool carpets with their WIRA Abrasion and P^2/t scores. However because it is possible to set recommended minimum values for these scores, based on the experience of many years of manufacturing and grading of wool carpets, both parameters serve as useful predictors of the performance of a given product. The IWS (and subsequent) performance studies have enabled robust criteria for the location-based grading of wool carpets to be established (Section 4.8).

It must be emphasised that the various carpet durability tests that have been developed (e.g., WIRA Abrasion Machine, Lisson Tretrad, Baumberg Rollstuhl castor chair tester), show very poor agreement with actual floor wear, when different types of pile fibres are compared. Invariably wool carpets perform significantly better on the floor, relative to other fibre types, than might be predicted by machine testing. Provided appropriate pile densities are used, wool carpets compete well with other fibres with respect to durability.

Appearance retention

For wool carpets the retention of the original 'showroom' appearance is arguably the most important performance attribute to the consumer.

The testing of a carpet for appearance retention involves two separate steps:[16]

1. treating the carpet specimens, followed by
2. assessment of the treated and untreated specimens by an expert panel.

The Hexapod Tumbler Tester provides a method of reliably predicting the extent to which original pile texture is retained over the early period of a carpet's life, i.e. up to 5–6 years. Two levels of treatment are used in the Hexapod test (i.e., 1500 revolutions and 8000 revolutions of the Hexapod drum). The worn and unworn specimens of carpet are compared by the panel of experts under standard illumination and viewing conditions in order to assess their level of appearance retention.

Subjective grades, ranging from 5 (no change in pile texture) down to 1 (extreme change in pile texture), are assigned by the panel, which is guided by sets of standard carpets that have been worn to pre-determined levels. A set of grey scale cards is used in a similar manner to assess the degree of colour change in the pile.

The Vetterman Drum tester operates on a similar principle to the Hexapod Tumbler Tester, and both machines have equal status as internationally recognised test methods.

Tuft bind

The tuft bind test, which measures the force required to withdraw individual tufts, checks that the latex application to the primary backing, and the subsequent marriage of the two backing fabrics, has been effective. It is recommended by Wools of New Zealand that the minimum level of tuft bind in flat locations (i.e., not stairs) should be set at 3.5 Newtons (i.e., 0.35 kgf). However, higher tuft withdrawal forces are usually aimed for, to allow for a gradual deterioration in the latex properties with age. A typical level for cut pile tufted carpets is around 10 Newtons (1 kgf).

4.8 Selecting the most appropriate wool carpet

Minimum requirements for durability (P^2/t) and appearance change (Hexapod score) are specified in the Woolmark and Wools of New Zealand[17] schemes, depending on the intended location.

Table 4.3 gives the location suitability for wool carpets under the Wools of New Zealand grading scheme.

As an example, a carpet with a surface pile mass of 1000 grams per square metre must not have a pile height exceeding 11.1 mm in order to attain the required minimum P^2/t value of 90 000 to be assigned the Heavy Duty Residential grade. On the other hand, for a carpet with a pile height of 8 mm, a surface pile mass of 850 g/m^2 will suffice.

Wools of New Zealand has also provided guides to selecting of the most appropriate wool carpet for specific domestic and commercial locations, taking into account varying levels of foot traffic intensity. Table 4.4 has been prepared as a guide to selecting a carpet for a commercial (or contract) location. Table 4.4(a) enables the traffic rating for the location to be determined, and Table 4.4(b) takes into account the traffic rating and the projected wear life in selecting the most appropriate grade. For example, in an area which is subjected to a medium traffic level (1500–5000 passages per week) and for which a wear life of 11–14 years is required, the most appropriate grade is Heavy Duty Contract.

Additional steps in the decision-making process are provided to take into account installation on stairs and the influences of colour and design.

Table 4.3 Location suitability for wool carpets

Location suitability	Minimum pile mass density (P^2/t)*	Minimum overall Hexapod grade
Medium duty residential	70 000	2–3
Heavy duty residential	90 000	3
Extra heavy duty residential	125 000	3–4
Light duty commercial	80 000	3
Medium duty commercial	115 000	3
Heavy duty commercial	150 000	3–4
Extra heavy duty commercial	200 000	3–4

* *P* is measured in grams per square metre and *t* is measured in millimetres

4.9 Future trends

Despite the growing dominance of man-made fibre carpets in the global marketplace since the mid 20th century, wool carpets remain the benchmark for quality and performance at the prestige end of the floor coverings market. A number of aspects must be taken into account when considering the future of wool as a premium carpet fibre:

Table 4.4 Deciding on the most appropriate performance grade for a commercial wool carpet (Wools of New Zealand Ltd)

(a) Determining the traffic rating

Location	Traffic density	Traffic rating
Hotel guest rooms, private offices, small meeting rooms	Up to 1500 passages per week	Light traffic
Hotel guest corridors, conference rooms, small shops, larger offices	Between 1500 and 5000 passages per week	Medium traffic
Restaurants, larger function rooms, open plan offices, large shops, hotel main corridors	Between 5000 and 15 000 passages per week	Heavy traffic
Hotel lobbies, office entrance areas, department stores (ground floor) cash counters, bars	Over 15 000 passages per week	Very heavy traffic

(b) Determining the carpet grade taking into account the traffic rating and the projected wear life

Wear life (years)	Traffic rating			
	Light	Medium	Heavy	Very heavy
5–7	Medium duty commercial	Medium duty commercial	Medium duty commercial	Heavy duty commercial
8–10	Medium duty commercial	Medium duty commercial	Heavy duty commercial	Extra heavy duty commercial
11–14	Medium duty commercial	Heavy duty commercial	Extra heavy duty commercial	Extra heavy duty commercial (custom made)
15+	Heavy duty commercial	Extra heavy duty commercial	Extra heavy duty commercial (custom made)	Extra heavy duty commercial (custom made)

- A decline is expected in the availability of raw materials for man-made carpets as the world's oil stocks diminish.
- There is a growing worldwide concern for the environment, favouring sustainable methods of fibre production and product manufacture, and minimising the sizes of the ecological footprint of the processes involved.
- Wool has a long and proud heritage in carpets and rugs which brings a sense of history and tradition into the home.
- Wool remains the fibre of choice for much woven carpet production, both machine-made and hand-made, throughout the world.

- Sophisticated computer-aided design systems are widely applied for the design of attractive, top-end wool carpets for prestige locations. For example, Wools of New Zealand applies these techniques in producing its annual Trend Collection. This provides forecasts of designs, colour combinations and pile textures to aid the manufacturers of wool carpets in the development of stylish, innovative products.
- Because of its excellent flammability properties, wool will continue to be a popular fibre for carpets in aircraft and high-rise buildings.
- Wool has the unique ability to enhance the indoor environment by buffering changes in humidity and absorbing odours and noxious gases.
- Despite myths to the contrary, carpets offer better protection from asthma than hard floor coverings.[18] This is because carpets act like a filter by trapping allergens away from the breathing zone so that movement in a room generates a much lower concentration of fine dust in the air. Furthermore, wool controls the humidity in the carpet to reduce the high humidity environment in which dust mites propagate.

The above are all positive factors for wool carpets. There are other factors relating to marketing and supply issues that are relevant to the future of wool in quality floor coverings.

4.9.1 Marketing and promotional needs

An appreciation of the qualities of wool as a textile fibre has declined in many countries over the years. There is now a generation of consumers who have had no significant exposure to any generic wool promotion, so they might be described as being ‘fibre agnostic’. This means that they are driven in their purchasing decisions by colour, design and price of products rather than the fibre type. Organisations such as the International Wool Secretariat that once led major international initiatives to promote the benefits of wool in carpets and to assist manufacturers in technology uptake and product development, have either disappeared or have severely down-sized their operations.

While wool is now a relatively small player in the global marketplace for commodity-level carpets, it remains firmly established at the luxury end of the main markets in the most developed countries. It is popular in the most demanding contract market segments including hotels, casinos, cruise ships, government offices, aircraft, etc. This is because of its exceptional overall performance, styling opportunities and a fine balance of durability, appearance retention, ease of maintenance, comfort, feel and ambience. The natural origins and sustainable methods of production have recently added to its appeal, but it is wool’s overall appearance and performance, and reasonable prices that make it the preferred fibre for many locations.

The time is right for wool to get its message to the world, but a compelling case must be communicated to end users, or at least the key influencers of consumer buying choices. Wool is a niche fibre with special attributes and it needs to be treated as such in marketing and promotion, rather than using the commodity approach of the past.

4.9.2 Maintenance of supply

New Zealand has a well-earned reputation for supplying large quantities of carpet wool of high quality to the world. However, the growers of the coarser wool most suited to carpets have in recent years received unacceptably low returns for their product.

Since the mid-1980s sheep numbers in New Zealand have dropped from around 75 million to less than 40 million in 2008. Sheep numbers may continue to reduce as farmers continue to switch to other land uses, leading to a worldwide shortage of suitable wools and possibly increased prices. This trend to alternative, more lucrative farming systems such as dairy farming has been especially strong in New Zealand.

International supply and demand for carpet wools ebbs and flows, however, and if the prices increase in the future, the farmers will have an incentive to continue with sheep and to increase their production. New Zealand woolgrowers are experimenting with a variety of new ways of selling their wool to maintain profitability, and are determined to secure the future of their fibre.

4.10 Sources of further information and advice

4.10.1 Wools of New Zealand *Carpet Technical Information* Bulletins

These bulletins cover in detail the conversion of wool into carpet yarn, carpet manufacturing methods, and various aspects of the performance of wool carpets. They are published by:

Wools of New Zealand Ltd
P O Box 39135, Harewood
Christchurch
New Zealand
Fax: 64 3 357 0083
www.woolsnz.com

Technical Bulletins most relevant to this chapter are:

1.4 *Wool Scouring in New Zealand*
2.1 *Woollen Spinning*
2.2 *Semi-worsted Spinning*
3.1 *Yarns for Tufted Carpets*

3.2 *Yarns for Face-to-face Weaving*
3.3 *Yarns for Axminster Weaving*
3.4 *Yarns for Wire Wilton Weaving*
3.5 *Yarn Bonding Technology*
4.1 *Yarn Scouring*
4.2 *Twist Setting of Wool Carpet Yarns*
4.3 *Yarn Felting*
4.4 *Chemical Treatments*
4.5 *Insect Resist*
5.1 *General Principles of Carpet Coloration*
5.2 *Loose Stock Dyeing*
5.3 *Hank Dyeing*
5.4 *Yarn Package Dyeing*
5.5 *Continuous Dyeing of Wool Carpets*
5.6 *Printing of Wool Carpets*
5.7 *Photobleaching of wool as it affects colour fastness in carpets*
6.1 *Introduction to Face-to-Face Weaving*
6.2 *Axminster Weaving*
6.3 *Wilton Weaving*
6.4 *Broadloom Tufting*
6.5 *Primary and Secondary Backings for Tufted Carpets*
6.6 *Backcoating Technology*
6.9 *Carpet Finishing.*

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* Available from AgResearch Ltd (www.agresearch.co.nz).

5

Developments in textile sports surfaces

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Abstract: The use of artificial turf for sport surfaces has seen an enormous increase in recent years. The reasons for this are various and artificial turf is increasingly being used for soccer applications, especially with the development of the so-called 'third-generation' artificial turf consisting of artificial fibres tufted on a backing with an infill of sand and rubber granules.

Many good results have already been obtained with fibres of the right geometry, a good behaviour in resilience and resistance to fibrillation. The temperature profile during sliding is very important for the comfort of the player and avoiding burn wounds in combination with other characteristics of the artificial turf, such as shock absorption, energy restitution and quality of the yarns.

For the future, a better insight will be obtained in the relationship between the fibre structure and resilience and resistance to fibrillation. This will lead to possible developments of polymers with better properties, maybe used in multilayered artificial grass blades, and much better control of the processing of these polymers.

The future generation of artificial turf fields will be based on two types of fibres, one that is standing upwards and another that will be constructed of crimped fibres without infill of rubber particles. This will increase the demand for playing on artificial turf fields.

Key words: artificial turf, resilience, fibrillation, friction coefficient, polymer.

5.1 Introduction

The use of artificial turf for sport surfaces has seen an enormous increase in recent years. The reasons for this are various: climate and weather independent, better wear and tear behaviour compared to natural turf, less maintenance, more even and uniform playing surface. For this reason, for more than 30 years artificial turf has been used for hockey, and for many years it has been commonly used in tennis and rugby. Recently, it is increasingly being used for soccer applications, especially with the development of the so-called 'third generation' artificial turf, consisting of artificial fibres tufted on a backing with an infill of sand and rubber granules.

This 'third generation' artificial turf – also called 'football turf' – receives full support by official soccer organisations such as FIFA and UEFA [1], in their striving to standardise the soccer game. Despite this support, there is still some resistance among players and clubs. These prejudices are partly based on bad experiences in the past, when soccer was played on older types of artificial turf, not adapted for the specific demands of soccer, but also partly due to shortcomings of the newest types of artificial turf, specifically designed for soccer applications.

One of the most common complaints is that the ball roll behaviour is different from that on natural turf. In general, players tend to perceive that the ball speed is higher and is sometimes considered too high. Joosten (2003) [2] found that 77% of the players experienced the ball speed and ball roll capacity as high. Some players prefer fields with a faster ball roll, especially for training purposes, as it facilitates a more technical way of playing. However, most players want a field with a normal ball speed when it comes to official games.

It is known from experience that these ball roll problems on artificial turf start within a few months of installation. Whereas the ball roll behaviour on a newly installed artificial pitch is acceptable and even comparable to that on natural turf, this is no longer the case for an artificial field that has been played on for some months. A clear degradation in playing quality over time is noticed. This is often indicated as a lack of 'resilience' of the field.

Another main problem with artificial grass is the possible occurrence of burns when sliding is performed [3,4]. Since the existing standardisation is insufficiently developed in this respect, a new testing method was developed.

In the existing standards, there is no mention of a temperature change measurement during sliding, although this appears extremely relevant in the light of burns occurring. Moreover, the current measurement is done:

- at a constant speed (instead of a decelerated movement such as in a real sliding)
- according to a circular movement (instead of a linear movement). Furthermore, logically the circular measurement is repeatedly performed on the same piece of artificial grass which will thoroughly change in its friction properties after a certain period of time
- at a load which is much too low.

The developed test set-up approaches the sliding phenomenon in a more realistic way, having the following advantages compared to the existing FIFA test:

- a linear movement over a realistic sliding distance (instead of a rotating movement on a small piece of grass)
- a decelerated movement
- a realistic order of magnitude of load
- a temperature measurement.

A good and reliable experimental method was developed for the measurement of the temperature increase at the surface of the skin during sliding. A theoretical approach to sliding was studied and the resulting analytical results correspond very well with the practical results. A simulation of the temperature increase during a slide is possible and the influence of different parameters can be studied directly from the calculations, together with their importance to the temperature increase during the slide. This temperature profile during a slide can be very important for the comfort of the player in combination with other characteristics of the field such as shock absorption, energy restitution and quality of the yarns. The friction coefficient of the used fibres, their geometry, and the number of fibres per square metre and the free height of the yarns in the total artificial turf structure are the most important parameters for the slide and the effect on human skin.

The physical stability and weathering resistance of the fibres are other important factors in their use in textile sports surfaces.

5.2 Key requirements of sports surfaces

The key requirements of artificial sports surfaces are related to the characteristics of natural turf structures and are described in the FIFA 2 star and IRB regulations [5]. These standards reproduce the characteristics of the best quality natural turf football or rugby pitches. The test methods used to assess sports turfs and installed artificial turf fields are described in either the *FIFA Handbook of Test Methods for Football Turf (FIFA standards)*, International Standards (ISO standards) or European standards (EN standards).

The key requirements of artificial football sports surfaces and related to the used fibres are summarised in Table 5.1. From this table, the most important or key requirements for the textiles or fibres are the mechanical properties such as function of time and outdoor weathering, the friction coefficient of the fibres and the resilience and fibrillation resistance of the yarns. The complete artificial turf structure and the fibres must withstand temperatures from −30 ºC up to 70 ºC. Another important parameter is the stability of processing the fibres, either as fibrillated tapes or monofilaments, to ensure good and constant material properties. The other characteristics of the artificial turf are related to the complete structure with infill and shock pad if present. Some of these key requirements will be described in more detail in the following paragraphs.

5.3 Types of textiles used in relation to the sports surfaces

Recently, artificial turf has been increasingly used for soccer applications, especially with the development of the so-called ‘third generation’ artificial turf, consisting of artificial fibres tufted on a backing with an infill of sand and rubber granules (Fig. 5.1).

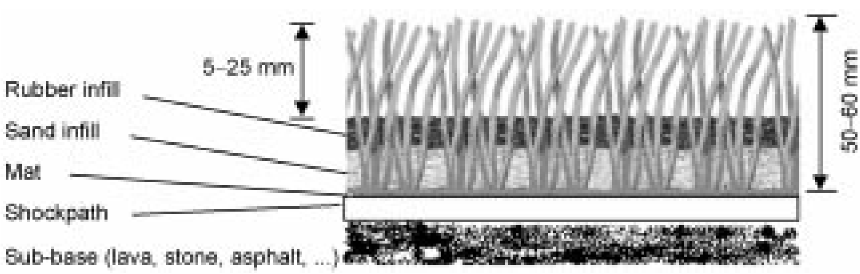
This ‘third generation’ artificial turf – also called ‘football turf’ – gets full

Table 5.1 Key requirements of artificial football sports surfaces

Property	FIFA recommended Two Star	FIFA recommended One Star
Vertical ball rebound	0.60–0.85 m	0.60–1.0 m
Angle ball rebound	45–60% (dry conditions)	45–70% (dry conditions)
Ball roll	4–8 m	4–10 m
Shock absorption	60–70%	55–70%
Vertical deformation	4–8 mm	4–9 mm
Rotational resistance	30–45 Nm	25–50 Nm
Skin/surface friction	0.35–0.75	–
Skin abrasion	~30%	
Artificial weathering		
Component	Property	Requirement (recommended One and Two Star)
Artificial turf	Colour change	≥ Grey scale 3
Pile yarn	Tensile strength	Percentage change from unaged to be no more than 50%
Polymeric infill	Colour change	≥ Grey scale 3

support from official soccer organisations in their striving to standardise the soccer game. Also, an artificial turf field can replace at least three natural grass fields. To keep the field in an acceptable condition, a natural grass field can withstand 300 to 400 hours of play per year and an artificial turf field can withstand more than 2000 hours of play per year. This constitutes another important factor for the use of artificial turf fields. The use of artificial turf is increasing worldwide in recent years, rising from 80 billion m^2 up to 110 billion m^2 in 2006. In Western Europe, the production of artificial turf has increased from 16.9 billion m^2 in 2003 to over 25.6 billion m^2 in 2005 and up to 28 billion m^2 in 2006.

As already mentioned, the third-generation artificial turf comprises artificial fibres tufted on a backing with an infill of sand and rubber granules [6–14]. The



5.1 General structure of the third-generation artificial turf.

total height of the artificial turf is between 50 and 60 mm with a free pole height of the fibres from 5 to 25 mm. The length of the fibres is selected depending upon the depth of the infill material and the resilience of the artificial turf structure. The sand infill is currently used to stabilise the artificial turf and the layer of rubber granules is normally necessary for the shock absorption. The thickness of the respective layers is between 15 and 25 mm. The backing sheet may consist of a sheet of plastic material such as a non-woven fabric which is impregnated with a latex, such as a SBR latex.

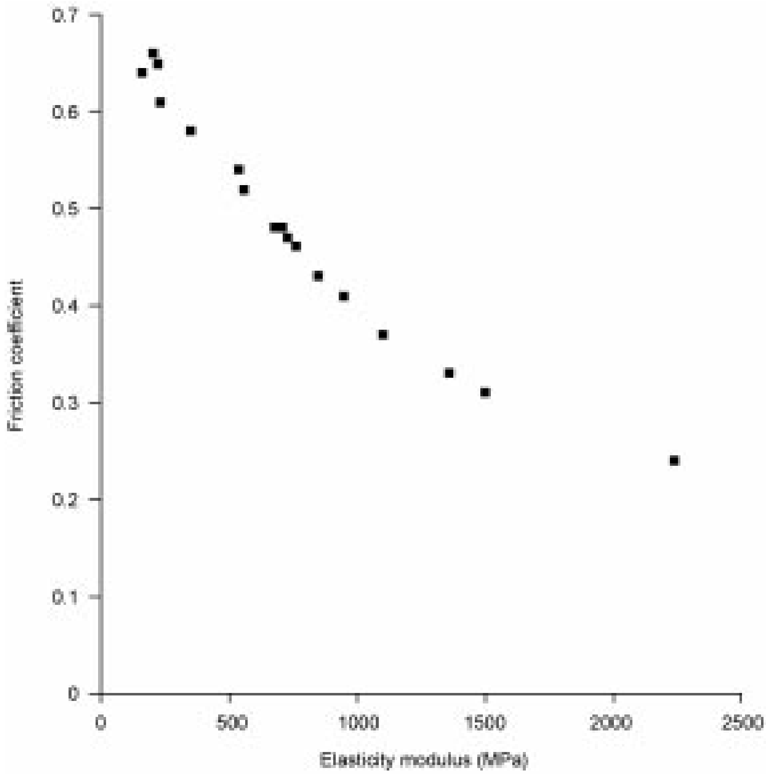
5.4 Role of textiles in meeting performance requirements

5.4.1 Choice of polymers for artificial turf fibres or yarns

The polymers used for the production of fibres or yarns in the form of monofilaments or fibrillated tapes are chosen from the family of polyolefines (mostly for soccer applications) or polyamides [15] (mostly for hockey applications). Examples of polyolefines are homo- or copolymers of propylene (PP), block copolymers of propylene and ethylene, and polyethylenes such as high density polyethylene (HDPE), medium density polyethylene (MDPE), linear low density polyethylene (LLDPE) and classical low density polyethylene (LDPE). The mechanical properties of these polyolefines are related to their structure and corresponding degree of crystallisation. These polymers are transformed to fibrillated tapes or monofilaments. The monofilaments can be characterised by different geometries such as cylindrical, rectangular, bilobal or trilobal [16–20]. The current production of fibrillated tapes or monofilaments for use in artificial grass is based on post-stretching in a solid condition at a controlled elevated temperature, between 10 and 40 °C between the melting temperatures of the polymers used [21]. This cold stretching generally leads to enhanced classical mechanical properties, such as stiffness and strength [22]. This is a result of an increased orientation of the individual polymer chains in the stretching direction. Some of the polyolefins, more specifically HDPE and PP, are characterised by a low coefficient of friction [30]. As explained later, this is an important parameter or characteristic of the fibres for the artificial grass application. This coefficient of friction is related to the nature of the polymer, polar or non-polar nature of the polymers, and to the mechanical properties such as the elasticity modulus.

This is illustrated in Fig. 5.2 wherein the measured coefficient of friction of polyethylene against the same polyethylene surface is represented as function of the elasticity modulus.

The human skin has, of course, other surface characteristics compared to polyethylenes. The human skin is more polar [23] than polyethylene or polypropylene and we tried to use a polymeric film with the same surface

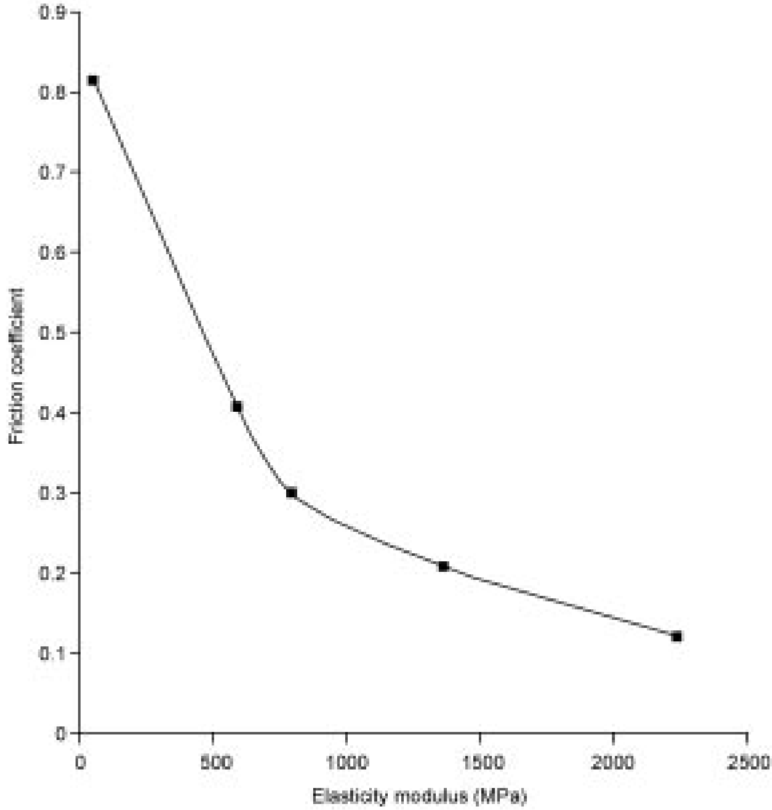


5.2 The coefficient of friction of polyethylene/polyethylene contact as a function of the elasticity modulus of the tested polyethylene.

characteristics as the human skin and with comparable mechanical properties. The measured friction coefficient of this polymeric layer in contact with a film of polyethylene is represented in Fig. 5.3.

From these figures, it is clear that the choice of the polymers for the production of the fibres or yarns for artificial grass applications is important for the resulting friction behaviour of the complete artificial turf structure.

Cold stretching or drawing of a semicrystalline polymer, such as polyethylene or polypropylene, results in a structural transformation of spherulites into microfibrils [24]. Normally, cold stretching enhances the classical mechanical properties, such as the elasticity modulus, and diminishes the friction coefficient of the produced fibres. An improvement in mechanical properties upon stretching is ascribed to taut tie molecules, which interconnect crystalline blocks of the same or different microfibrils. However, cold stretching increases the mechanical or internal stresses in polymers and this can lead, at a later stage, to reduced resilience (flattening of the artificial grass structure after being played on repeatedly) and a reduced thermal resistance (flattening of the artificial grass structure after being exposed to an elevated temperature). In



5.3 The measured friction coefficient of the artificial skin layer in contact with a layer of polyethylene as function of the elasticity modulus of the used polyethylene.

addition to the aforesaid deterioration of the mechanical properties as a function of time and use, fibrillation or splitting of the filaments or tapes in the longitudinal direction is another problem that may occur when cold stretching is carried out [25]. In some cases, only small intermolecular forces are present between the strongly oriented polymer chains and the mechanical cohesion in the transverse direction is limited due to the high level of orientation. A good balance has to be obtained between the classical mechanical properties such as the elasticity modulus and strength and the other properties of the fibres such as resilience, friction behaviour and fibrillation. The right choice of the polymer and processing conditions is very important in order to obtain a high quality result.

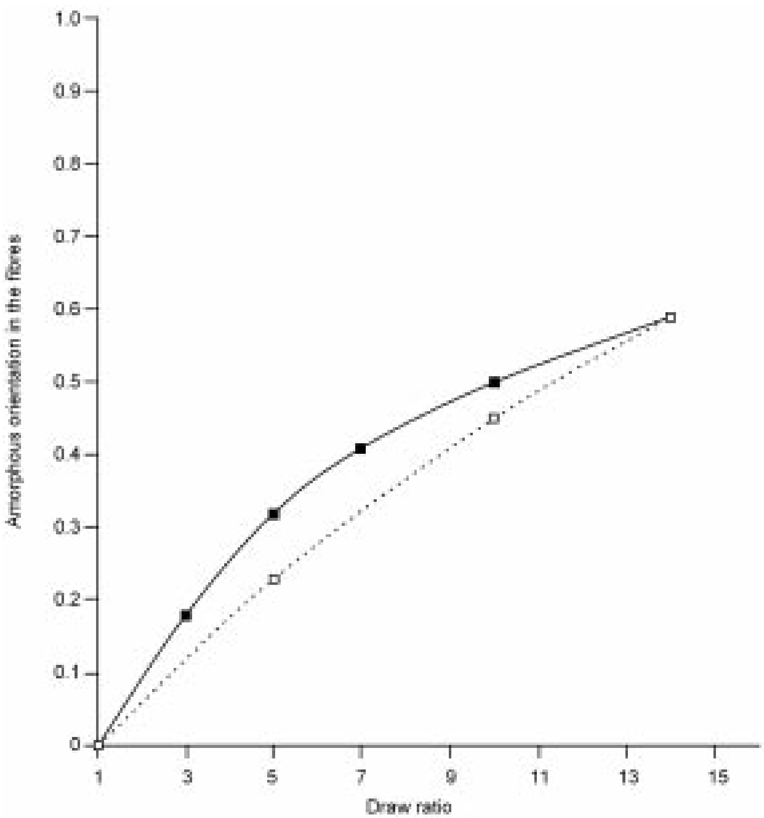
Drawing or cold stretching transforms the lamellar structure of the polyolefines into a highly oriented fibrous structure with a completely new morphology. The basic elements are microfibrils with an average length of 10 μm and a diameter of 10 nm. The microfibrils in the fibrous structure are highly aligned and are bundled into fibrils. As a consequence, the lateral boundary of fibrils may be weaker than that of individual fibrils. Hence, the boundary between fibrils permits axial shearing displacement and fails more easily than the boundary between microfibrils of the same fibril. As a result of drawing or cold stretching, an oriented fibre can be viewed as a body composed of uniaxially oriented fibrils that are held together by forces of cohesion. Initially the axes of fibrils are parallel to the fibre axis. The most important deformation mode for fibrillation is the twisting of the fibre. During twisting of the fibres, longitudinal and shear strains are present on every layer of fibrils of a twisted fibre and their values are proportional to the distance of the fibrils from the fibre axis. Here, fibrils are under a certain amount of tension and the shear force acting on these fibrillar elements can be very high. The inherent cohesiveness of the fibrillar structure opposes the possible separation of the fibrillar elements due to the shear force acting on this fibrillar structure. As a result, the most important factor for the fibrillation behaviour is the behaviour of the amorphous phase in the oriented fibres characterised by their orientation, as the fibrils are embedded in the amorphous matrix.

As a result, the characterisation of molecular orientation in fibres based on semicrystalline polymers is of great interest. Molecular orientation has a strong relationship with the physical and mechanical properties of polymers. An important factor is amorphous orientation [27]. This amorphous orientation can be measured by birefringence measurements or polarised infrared spectroscopic techniques. The orientation factor varies between 0 and 1; 0 means no orientation and 1 complete orientation of the measured phase along the fibre axis.

The amorphous orientation is strongly influenced by the drawing ratio of the fibre or by the ratio of the final length of the fibre to the initial length by cold drawing. An example of the measured amorphous orientation as a function of the draw ratio is represented in Fig. 5.4 for high density polyethylene fibres by two different temperatures, 95 and 120 ºC. A clear correlation between the draw ratio and the amorphous orientation can be observed [26].

The influence of the amorphous orientation on the fibrillation behaviour is represented in Fig. 5.5 for the same oriented HDPE-fibres [26]. The calculated shear force for fibrillation starts from a relative high value to a value of 0 as the fibre is completely oriented.

The fibrillation behaviour can also, to some extent, be related to the tear resistance of the monofilaments or fibrillated tapes. As already explained, the fibrillation behaviour is an inherent property of the polymer but strongly influenced by the processing of the polymer and more specifically by the cold stretching behaviour [27, 28]. The fibrillation behaviour and resilience can be related to the absence of taut tie molecules in the direction perpendicular to the drawing direction and to the interlamellar shear deformation in the amorphous phase. Notice also that the glass transition temperature of the used polyethylenes



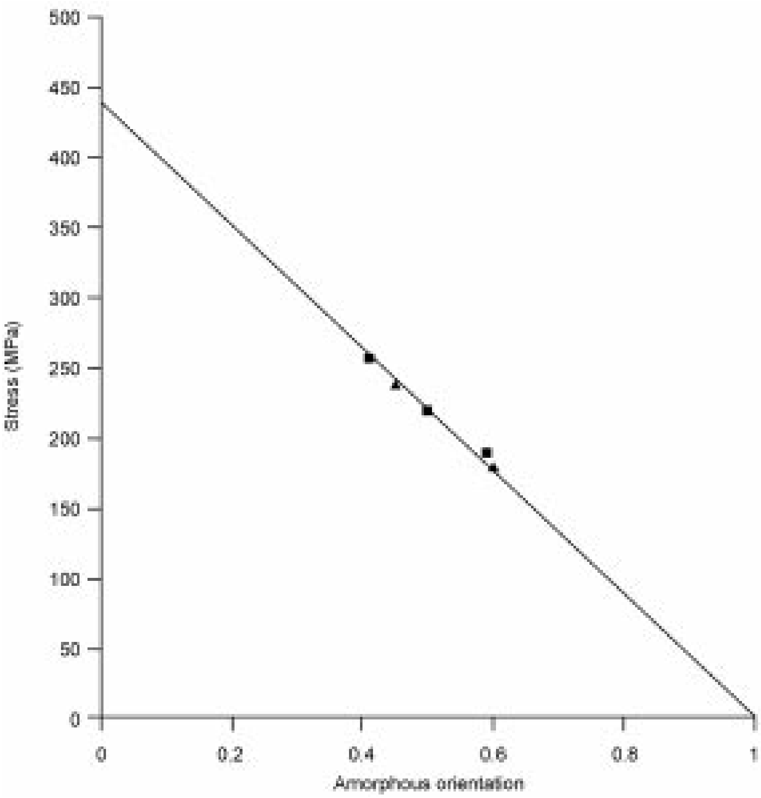
5.4 The relationship between the orientation of the amorphous phase and the imposed draw ratio of the fibres by cold drawing at two different temperatures (■ = 95 °C; □ = 120 °C).

and some polypropylenes is below the deformation temperature of the fibres or yarns.

For example: a linear low density polyethylene (LLDPE) with a density of 0.92 g/cm^3 starts from a tear resistance of 173 N/mm [22] to arrive at 7 N/mm for the monofilaments produced from this polyethylene. The monofilaments of high density polyethylene (HDPE) are characterised by a tear resistance between 2.4 and 3.2 N/mm.

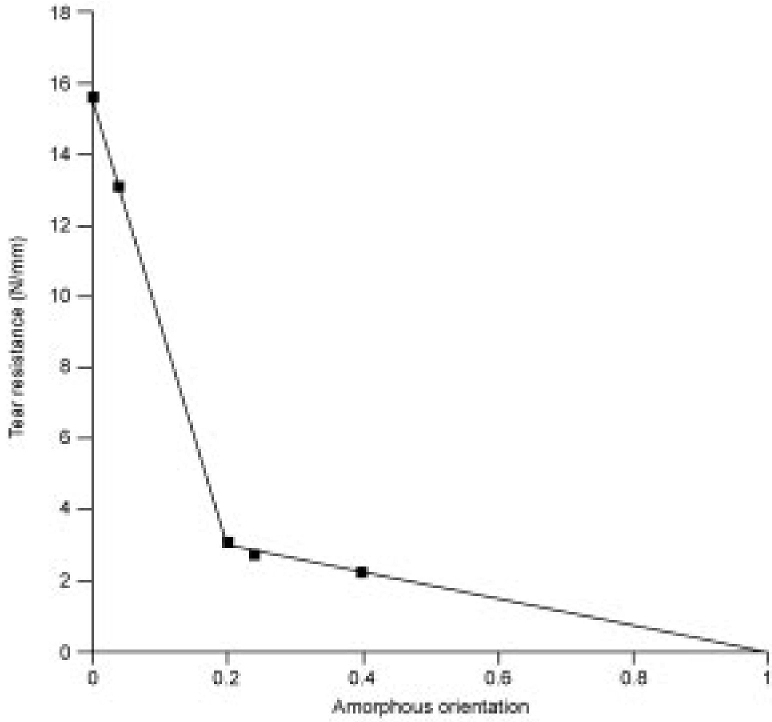
Another example is the Elmendorf tear resistance of uniaxially oriented isotactic polypropylene films as a function of the measured amorphous orientation and these results are represented in Fig. 5.6.

As for other polyolefines, a strong decrease of the tear resistance in the drawing direction is measured up to an amorphous orientation of 0.2, followed by a slow decrease to zero at an amorphous orientation of 1. This gives an indication of the strong decrease of the fibrillation resistance with the amorphous orientation of the polyolefines or applied draw ratio.



5.5 The measured fibrillation resistance for oriented HDPE-fibres as a function of the amorphous orientation induced by cold stretching of the fibres.

Other polymers that can be used as fibres or yarns for artificial turf applications belong to the family of polyamides, such as polyamide 6, polyamide 66 or combinations of these two polyamides. The polyamides are characterised by a relatively high value of the glass transition temperature. For these polyamides, drawing or cold stretching increases the amorphous glass density due to the formation of a rigid amorphous phase with a higher density than the classical amorphous phase [29]. For these polymers, the structural transformation of spherulites into microfibrils is accompanied by an increase of the rigid amorphous phase with a higher density and transition temperature than the classical amorphous phase. As a result, the polyamide fibres are characterised by a much better resilience and a very good fibrillation resistance. These properties are much better for the polyamide fibres than the polyolefin fibres or yarns and will be discussed in more detail in the next section concerning the role of the resilience of the fibre or yarns. But, generally, the cost, rigidity and the friction coefficient are higher for polyamide fibres compared to polyolefin fibres. If the fibres are too hard and the friction coefficient is too high, the risk of



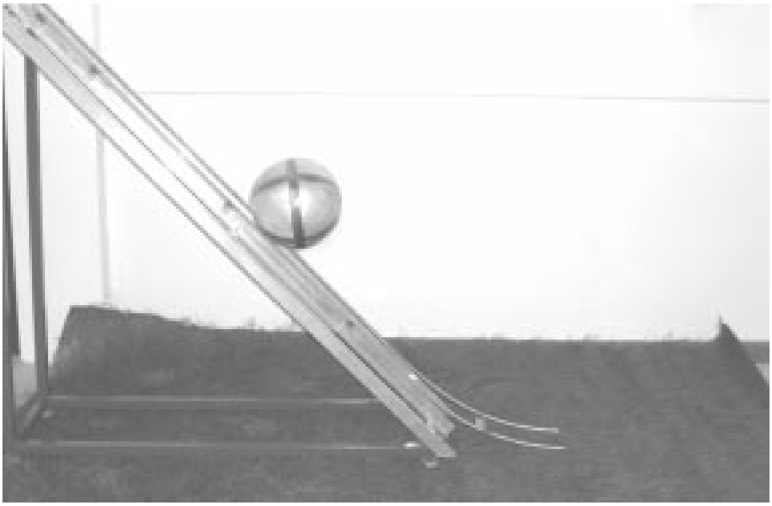
5.6 Elmendorf tear resistance in the draw direction as a function of the amorphous orientation in the same direction.

wounds due to abrasion of the skin or burning of the skin is increased. Therefore, a good balance of all the properties of fibres or yarns is necessary for artificial turf applications.

5.4.2 Role of the resilience of the fibres and yarns

Ball roll behaviour is currently tested by FIFA and UEFA by means of a standard ball roll test (Fig. 5.7). A ball is released from a ramp from 1 m high, and the rolling distance of the ball is measured. In order to get the FIFA one star certificate – which corresponds to the level for community play, training and national level – this distance should be between 4 and 10 m. In order to get the FIFA two star certificate, which corresponds to an international level, the ball roll should be between 4 and 8 m [5].

This test is performed in laboratory conditions (on a field 11 m long) as in installed conditions. This test can be done on a newly installed field, as well as on a field that has been played on for a certain period of time. Measurements like this confirm the experience of players that the ball roll gets longer as the fields are used more. Often it occurs that a field, that is within FIFA one or even



5.7 FIFA ball roll test setup.

two stars limits just after installation, no longer passes these requirements after some time of use.

Although this test gives a clear indication of the degeneration of ball roll quality, it cannot be used as an objective criterion to examine the effect of the ball roll degradation, as this test is sensitive to several influences. External factors such as wind speed and direction, slope of the field, wet or dry conditions have an important impact on the ball roll distance. Moreover, the test result depends a lot on the condition of the fibres: tests with the FIFA ball roll setup have shown that the ball speed – and thus the ball roll – is affected to a great extent by brushing the fibres. This implies that the measured ball roll will depend if the maintenance of the field has been done correctly or not.

In order to assess the degradation of the playing quality of the field, FIFA and UEFA have a test called Lisport (Fig. 5.8). This test consists of two rolling cylinders with studs, moving on an artificial turf sample of 0.8 by 0.4 m. This test simulates the wear and tear of a field over time: 1000 cycles correspond to one year of playing. As a result of this test, one gets a qualitative idea of the durability of the field, the (undesired) fibrillation of the fibres and the amount of breaks in the fibres.

However, this test also has some drawbacks:

- It is a qualitative method, not a quantitative one.
- It is difficult to assess whether the degradation in playing quality, as observed visually after the Lisport test, is due to the fibre itself, the used infill or the interaction between infill and fibre. This is of particular interest for artificial turf yarn producing companies.
- It requires the production of an artificial turf sample of 0.8 by 0.4 m, which is

5.8 Lisport test equipment.

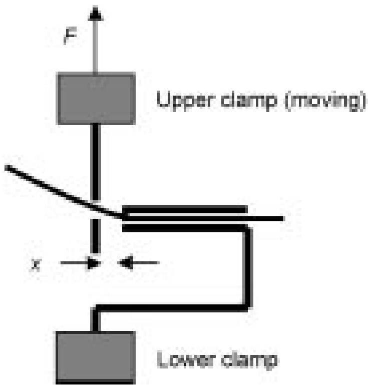
laborious and time-consuming in the development process as yarn producing companies want immediate information on the quality of their fibre.

- As the Lisport test allows the analysis of artificial turf samples restricted to 0.8 by 0.4 m, it is impossible to quantify the effect of the (visually observed) degradation of playing quality of the turf on the actual ball roll behaviour, as this can only be tested with a turf sample of at least 10 m long.

Artificial turf yarn producing companies need feedback on the ball roll behaviour of different types of artificial turf. The problem is that they have to wait several weeks or months after development to get information on this from standardised test methods as described above, or even up to one or two years after production and installation of an entire field to get feedback from players. It is clear that there is a need for a quicker testing method. The aim of this method is to quantify the evolution of quality of the artificial turf fibre over time. This method will be able to measure the resilience of a fibre in a fast way.

5.4.3 Materials and methods for resilience measurements

The first method is a cyclic bending test on a single filament (Fig. 5.9). The apparatus used for this test is a Favimat R (from Textechno) which has been modified for this purpose, making it possible to flex a one-side-clamped



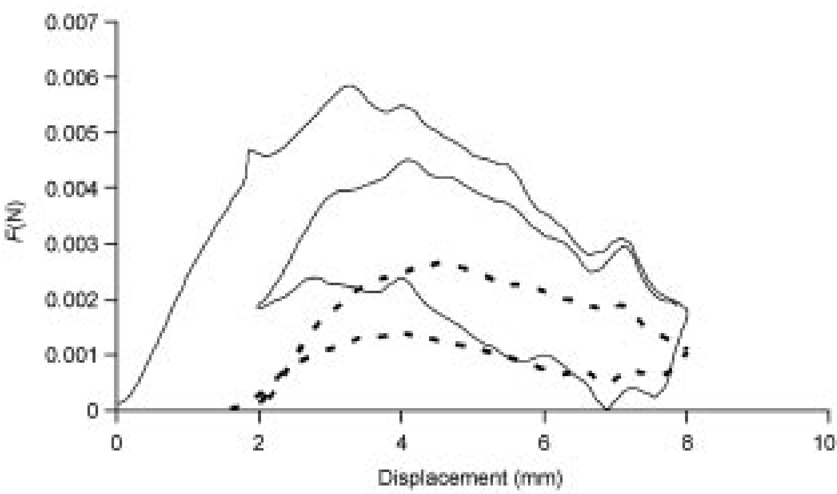
5.9 Cyclic bending test setup.

filament. The test can also be done on eight monofilaments. One end of the filament(s) is clamped, while the other free end is subjected to a perpendicular force.

The filament(s) is bent 300 times. The force needed to cause the bending is measured in the both the advancing and receding part of each cycle (hysteresis) [28]. The resilience is expressed as being the ratio between the maximal force of the 300th bending and the maximal force of the first bending (in the advancing part of the hysteresis).

A yarn is 100% resilient if the force needed to bend the filament(s) the 300th time is the same as the first time.

Figure 5.10 is an example of the graph after 300 cycles/bendings.



5.10 Hysteresis loops (full line = first bending and recovery and the 2nd bending; interrupted line = 300 th bending and recovery).

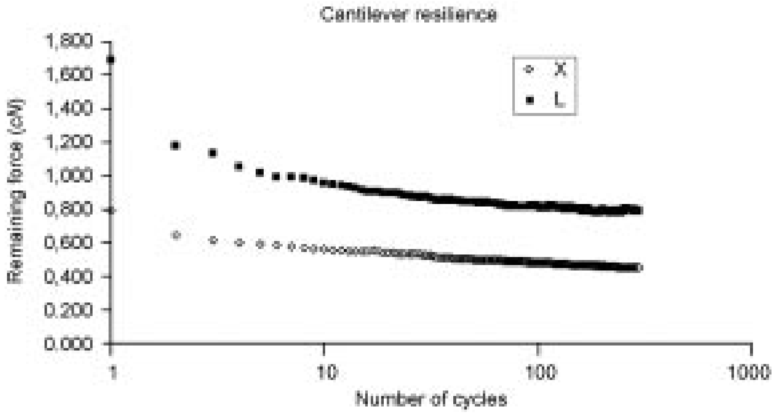
The maximal force of each bending is measured and these maximal force and possible loss in resilience is followed as a function of the number of bendings. Each test results in two graphs: one is the graph with the absolute force and one with the relative force, which is indicative of the resilience of the fibres (first force = 100%).

The most important graph is the variation of the relative force as a function of the number of bendings, because this graph is related to the decrease in ball roll. The original ball roll distance is the reference value and put to 100%.

The second resilience method is the 12m-Lisport. The Lisport wearing machine is the most used apparatus for artificial turf. In this test there are two rolls of 30 cm on the artificial turf at a constant speed. After the test vertical ball rebound, rotational resistance, shock absorption, energy restitution and vertical deformation are determined. All these parameters are determined more by the infill and underlayers then by the type of yarn. The most important parameter to test the quality of the yarn is the ball roll. This parameter is measured during the field tests. In the lab test the ball roll is only measured after 50 cycles with a hand-pulled roller. That is why we, in co-operation with Deltec, have built the 12m-Lisport (Fig. 5.11).

This apparatus runs on a sample of 12 m by 1 m. This makes it possible to determine the degradation in ball roll as a function of the number of cycles. The rolls are 1m long and weigh 100 kg each. The speed can be varied, but for these

5.11 12m-Lisport.



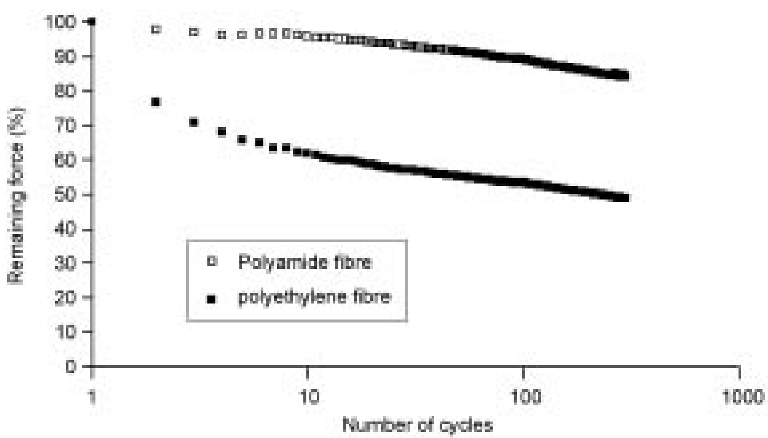
5.12 Remaining force as a function of the number of cycles for two different samples representing polyethylene fibres used for artificial turf applications.

tests the speed is kept constant at 0.25 m.s^{-1}. One roll is rolling 40% faster than the other roll.

As mentioned above, the results of Cantilever fatigue tests on two different polyethylene fibres are represented in Fig. 5.12.

The maximal force of filament L decreases from 1.70 cN to 0.80 cN and the force of filament X decreases from 0.80 cN to 0.45 cN after 300 cyclic deformations. The variations of the relative maximal forces are represented in Fig. 5.13 for a typical polyethylene fibre and a polyamide 66 fibre.

The relative force of the polyethylene filament decreases from 100% to 53.4% after 100 cycles and to 48.7% after 300 cycles. The relative force of the polyamide filament decreases from 100% to 89.1% after 100 cycles and to



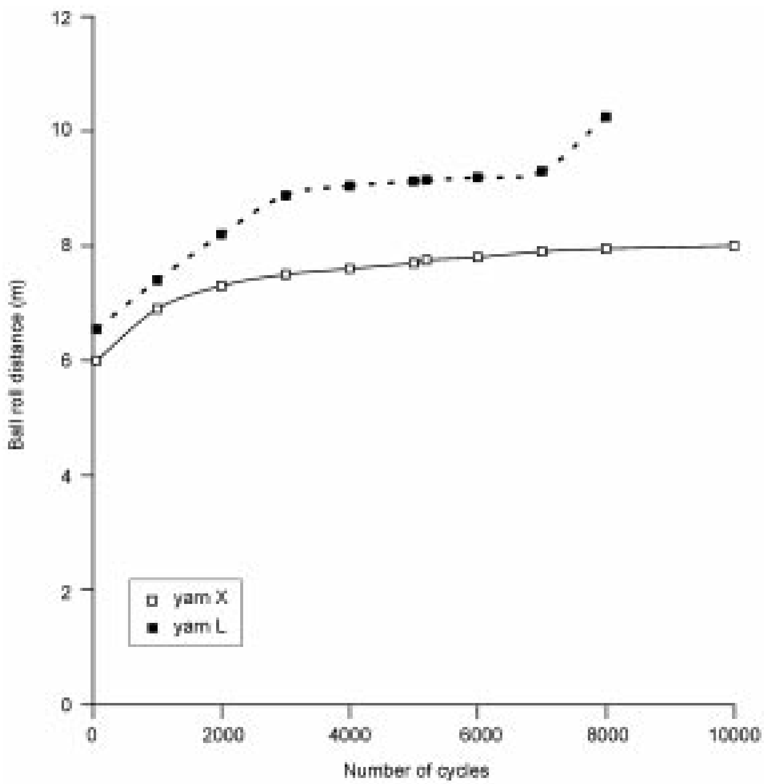
5.13 Relative remaining force as a function of the number of cyclic deformations for the two different fibres used for artificial turf applications (□ = polyamide fibre; ■ = polyethylene fibre).

84.1% after 300 cycles. The difference in bending behaviour between the two types of fibres is remarkably observed in the first 10 cycles where the remaining force is still 95.6% for the polyamide fibre and reaches quite a low value of 61.1% for the polyethylene fibre. These results are characteristic for the differences in resilience behaviour between different types of polymers, in this case between polyethylene and polyamide fibres.

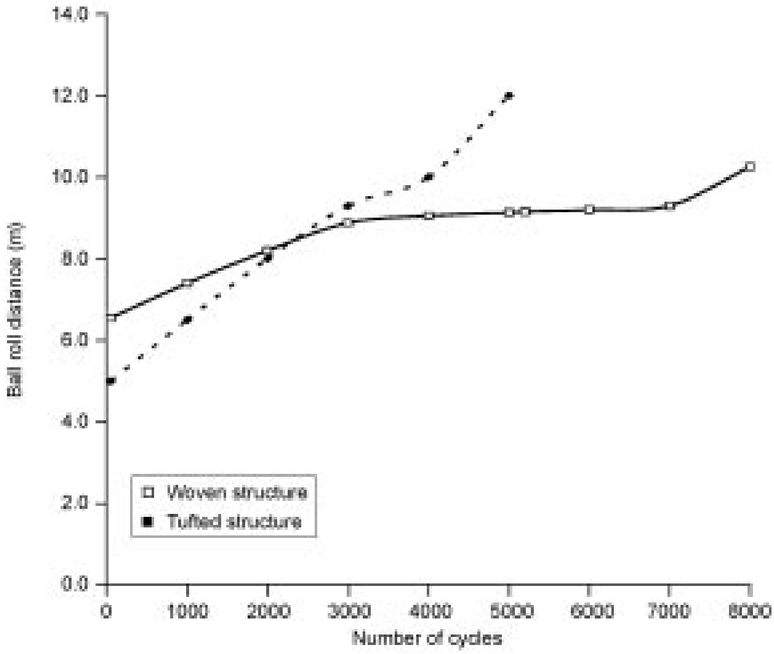
The yarns L and X were woven into a mat and used in the artificial turf structure. The 12m-Lisport is done on those two samples and after every 1000 cycles the ball roll is determined (Fig. 5.14).

The ball roll of the artificial turf structure with yarn L increases from 5 m to 10.5 m after 8000 cycles. The ball roll distance of the artificial turf structure with yarn X increases from 6 m to 7.7 m after 5000 cycles and to 8 m after 10 000 cycles.

To conclude, yarn X is better then yarn L, supported by the relative bending forces. We can see that the drop in bending force is 54% for yarn L, while yarn X only lost 43% of its initial bending force. So the conclusion should be: yarn X is more resilient than yarn L.



5.14 Ball roll distance as a function of the number of cycles (□ = yarn X, ■ = yarn L).



5.15 Differences in ball roll distance between a woven and tufted artificial turf structure with the same fibres (□ = woven structure; ■ = tufted structure).

The measurements with the 12m-Lisport show that the ball roll of the sample that is woven (X) stabilises after 5000 cycles. The ball roll of the woven sample with yarn L increases still further after 6000 cycles. The main drawback of this method is that it is very time consuming because the velocity is the same as for the small Lisport.

The basic characteristics of the fibres are important, such as resilience and resistance to fibrillation, but the way to construct the artificial turf structure is also important. Figure 5.15 represents the result on a woven and a tufted structure.

An important increase of the ball roll distance is observed for the tufted structure, in contrast with the woven structure.

5.5 Sliding and temperature, related to the used textiles

5.5.1 Problem and objective

The main problem with artificial grass is the possible occurrence of burns when sliding is performed. Since the existing standardisation is insufficiently developed in this respect (from discussions with representatives from FIFA, it appears that they also consider this to be the largest inadequacy of their standardisation), a new testing method has been developed.

In the existing standards, there is no mention of a temperature change measurement during the sliding, although this appears extremely relevant in the light of burns occurring. Moreover, the current measurement is done

- at a constant speed (instead of a decelerated movement such as in a real sliding)
- according to a circular movement (instead of a linear movement). Furthermore, logically the circular measurement is repeatedly performed on the same piece of artificial grass which will thoroughly change in its friction properties after a certain period of time
- at a load which is much too low.

The developed test set-up approaches the sliding phenomenon in a more realistic way, having the following advantages compared to the existing FIFA test:

- a linear movement over a realistic sliding distance (instead of a rotating movement on a small piece of grass)
- a decelerated movement
- a realistic order of magnitude of load
- a temperature measurement.

5.5.2 Design of the test setup

The concept involves a trolley having a variable load which is coming from a slope. The height on the slope can be set and, because of this, the horizontal speed at which the trolley arrives on the grass is adjustable. At the end of the slope, the trolley is released from the rails and makes a smooth contact with the grass by means of a synthetic material fixed at the bottom of the trolley. Consequently, the trolley slides on the grass which equals a sliding [31].

The height of the slope is 2 m, which (theoretically) allows for speeds to reach 23 km/h. In practice, friction losses are observed because of the rolling resistance of the trolley on the rails in the order of magnitude of 5%, which leads to a maximum speed of something over 20 km/h. This is a particularly realistic value, considering that in sprints speeds up to 30 km/h can be achieved and that sliding will never be performed at this top speed since some speed is automatically lost when starting the sliding movement and when coordinating and adjusting the movement in order to be able to intercept the ball at the right time.

The slope is installed in the laboratory for a 2.5 m × 1.25 m container with a piece of artificial grass or natural grass inside.

At the bottom of the trolley, a synthetic material is applied having the same friction properties as human skin. Thermocouples are applied to this 'artificial skin' which enable the measurement of the temperature change during sliding by means of a measuring card and a PC. By applying the thermocouples in different places, one is able to get an idea of the temperature variation according to the linear direction of the carriage. Because of the friction underneath the carriage, a net moment on the trolley will occur which makes the trolley tend to support more on its ‘nose’. The pressure under the trolley will be higher in front than in the rear, and consequently the temperature increase in the front will be higher than in the rear. This is confirmed by measurements with a thermographic camera at the bottom of the carriage. That is why the thermocouples are fixed at a regular distance of the front of the carriage, say at 1, 2 and 3 cm.

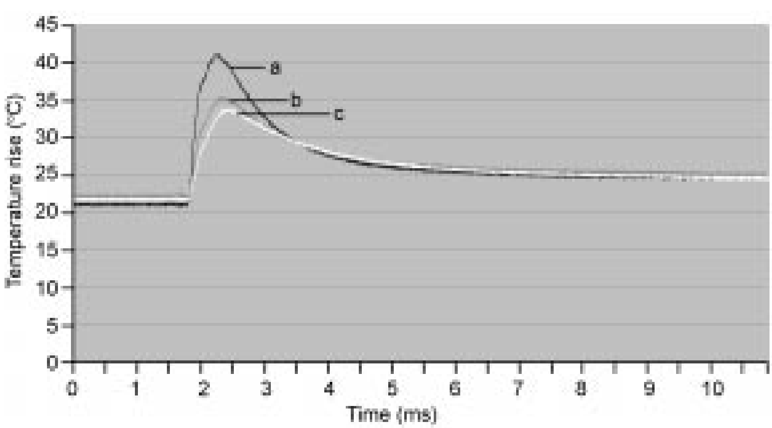
5.5.3 Measurements: temperature and sliding distance

The temperature curves obtained through measurements with the thermocouples have the shape shown in Fig. 5.16 [31, 32].

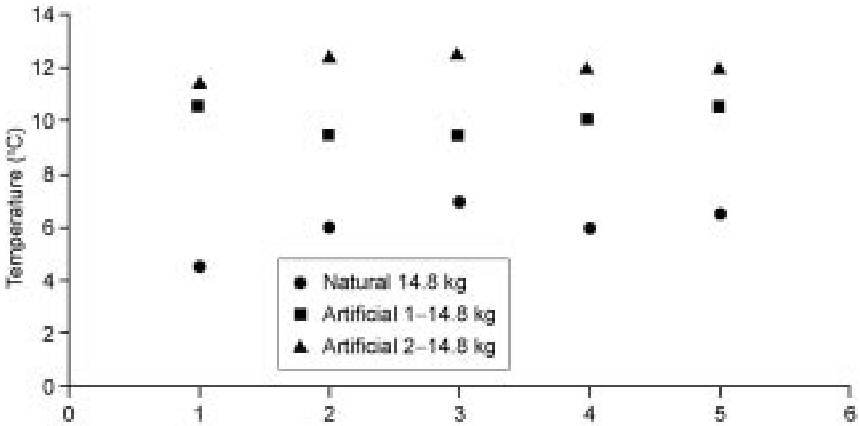
As soon as the carriage arrives on the grass, the temperature strongly increases, but slowly decreases afterwards. The graph also clearly shows that the temperature in front of the carriage (at 1 cm of the front) rises more than in the rear.

By considering the temperature increase (difference between the temperature before arriving on the grass and the peak temperature obtained during sliding), it is possible to compare between different types of subsoils. The aim is obviously to keep the temperature increase as low as possible in view of possible burns. When performing measurements on two different types of artificial grass, and comparing the results to natural grass, it is shown that the temperature increase on natural grass is considerably lower, which was to be expected (Fig. 5.17).

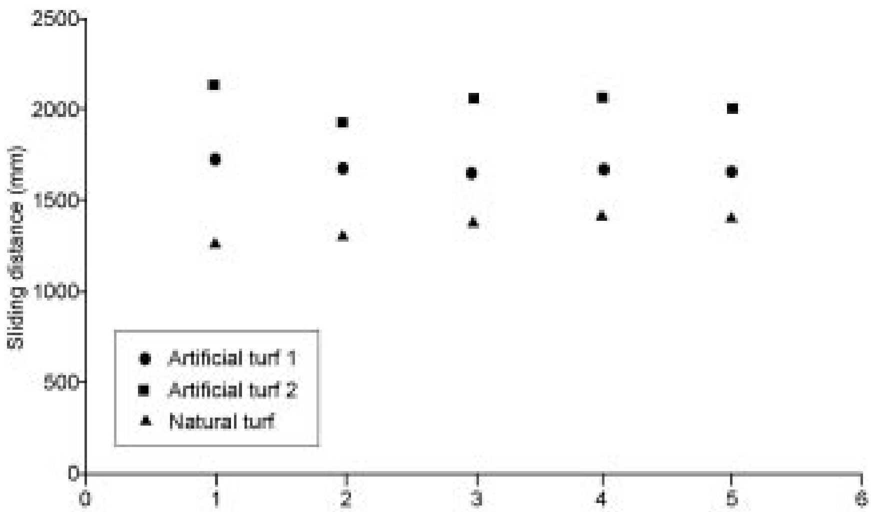
Besides the temperature change, the sliding distance of the carriage is also measured. This is a measure for the friction coefficient between the polymeric layer and the field.



5.16 Measurements of the temperature increase as a function of time and position.



5.17 Temperature increase for natural or artificial turf field as a function of the number of tests.



5.18 Sliding distance for natural or artificial turf fields as a function of the number of tests.

It is clear that different surfaces have a different friction coefficient, which leads to a different sliding distance (Fig. 5.18).

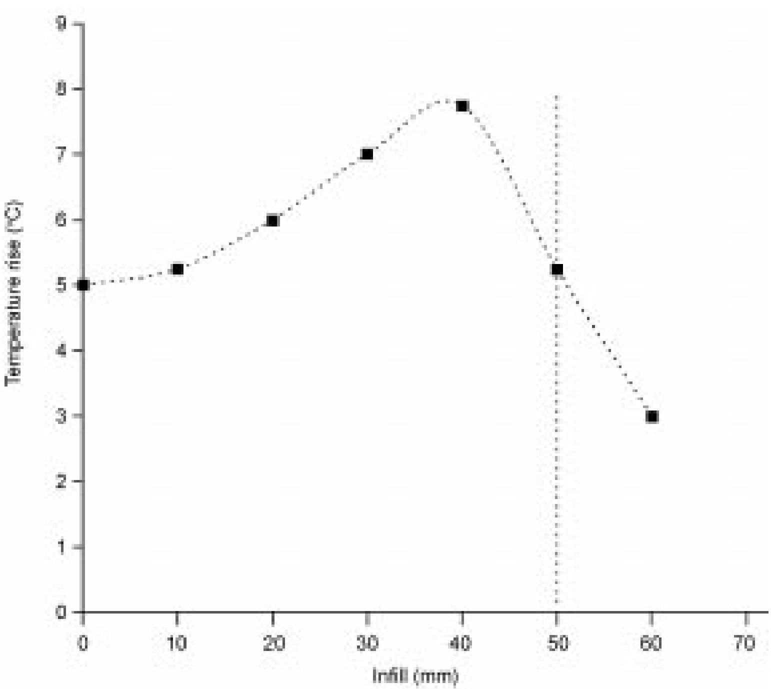
5.5.4 Influence of the height of strewing of infill material on the sliding

Many tests have already been performed on fields of natural grass and artificial grass (in open air) as well as on artificial grass in laboratory conditions. Tests will be done on artificial grass with a varying height of infill strewing, and on different types of materials (e.g., a pure PE film, a pure rubber film) in order to be able to estimate the influence of the separate materials in the artificial grass. These measurements will serve as a basis for the numerical simulations.

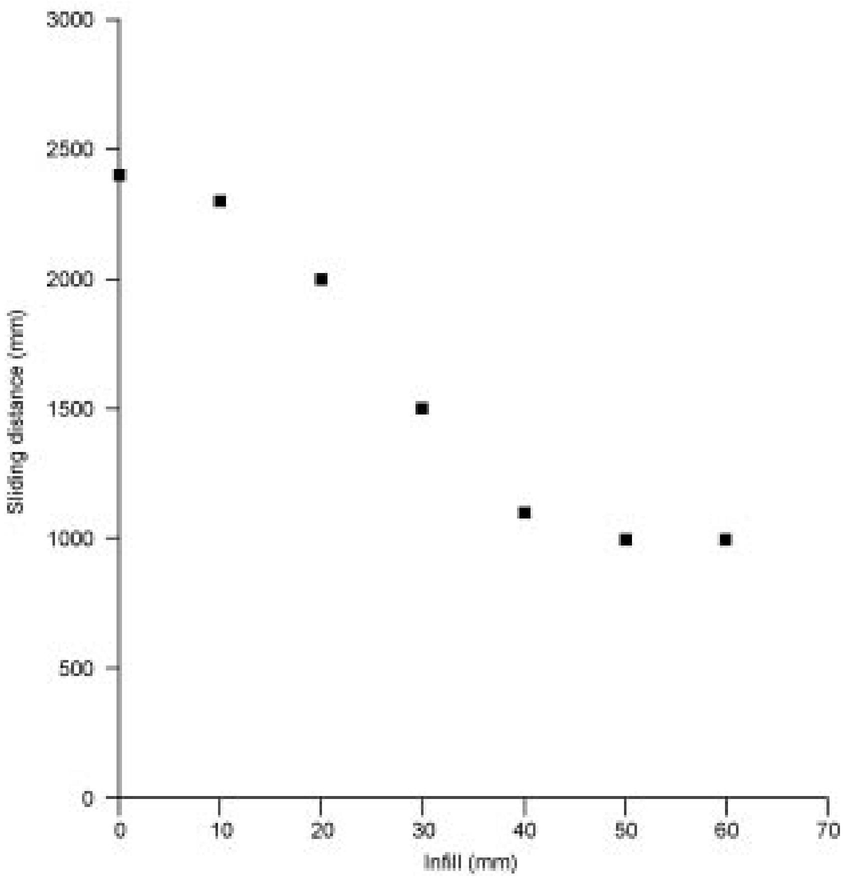
For the gradual strewing of the grass, a specially designed sieve was used. The sieve is first closed at the bottom by means of a wooden shelf. Then it is filled with rubber granules (infill) and subsequently it is levelled off at 1 cm height. In that way, a layer of exactly 1 cm lies above the sieve. Next, the wooden shelf is withdrawn and the rubber granules fall in the grass. To tamp down the granules, a metal tube is rolled three times over the grass. The grass-stalks are combed upright and the grass is ready to be tested. This procedure allows an equal strewing of layers on the grass, with a considerable accuracy for the layer thicknesses, which is obviously an advantage for the repeatability of the tests.

A summary of the temperature measurements as a function of the infill height of the artificial grass field is shown graphically in Fig. 5.19. An infill height of 50 mm corresponds with the height of the monofilaments.

The temperature increases up to an infill height of 40 mm (free height of the monofilaments of 10 mm), and the temperature decreases afterwards due to the mobility of the rubber particles. From that infill height on, the rubber particles



5.19 Temperature rise as a function of the infill height.

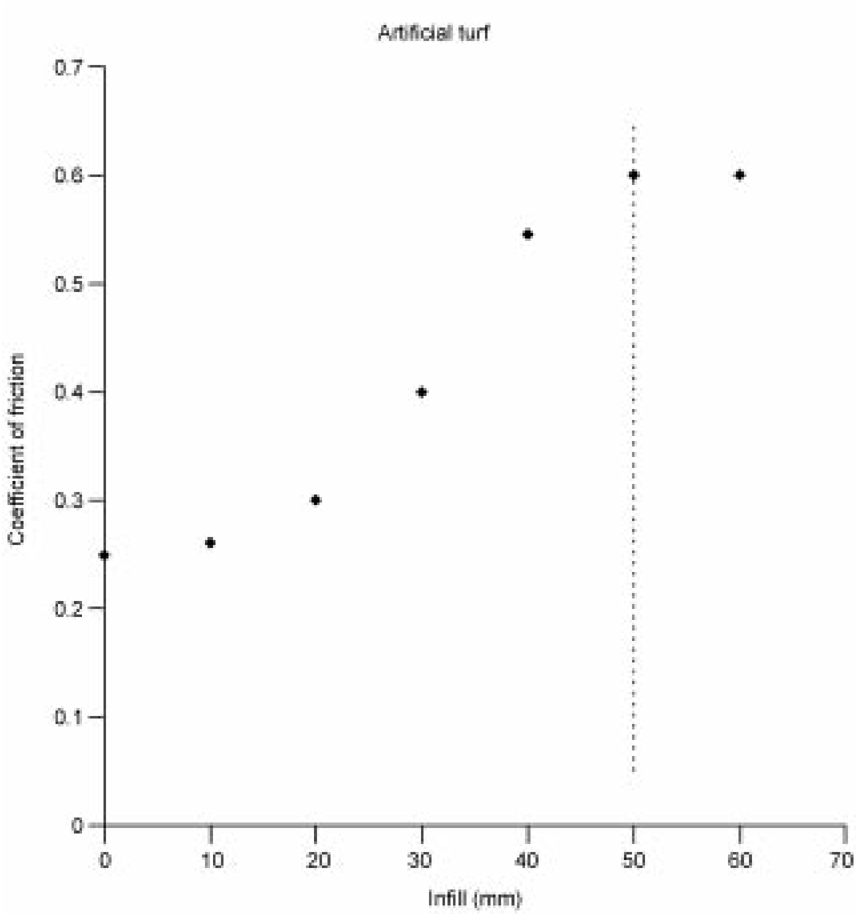


5.20 Sliding distance as a function of the infill height.

have the possibility to roll during the sliding movement and the total friction force is decreased.

The sliding distance as a function of the infill height is represented in Fig. 5.20. The sliding distance decreases when increasing the infill height and also for the bed of rubber particles, infill height of 60 mm.

The calculated friction coefficient as a function of the infill height is represented in Fig. 5.21. This friction coefficient starts at a value of 0.25, classical value for polyethylene or polypropylene, increases up to a value of 0.6 for the bed of rubber particles. The value of 0.25 for the field of monofilaments, without rubber particles, is also measured by another independent method. Therefore, a good correlation was obtained between the two possible measurements of the friction coefficient. A film of rubber, compact film, is characterised by a friction coefficient of 0.815. The differences in friction coefficient between film and particles are the result of the mobility of the rubber particles.



5.21 Coefficient of friction as a function of the infill height.

5.5.5 Calculation of the temperature increase at the surface of the skin

We have tried to simulate and calculate the temperature rise as a function of the different parameters that can be important in this test.

The sliding surface (part of the skin) is constantly in contact with the artificial turf surface with a temperature T_2, due to the sliding movement over the field, and the initial skin temperature is T_0.

Definition of the other parameters:

M = mass of the player
S = contact surface of the player with the artificial turf surface
g = falling acceleration ($9.8\,m^2/s$)
k = thermal conductivity of the skin

$C_p =$ specific heat
ρ = density
$v_H =$ sliding speed
$\mu_k =$ friction coefficient
index 1 is for the skin and index 2 for the polymer
t_e = sliding time
V = vertical force = $g * M$
t = sliding time (sec)
Time $t_e = Mv_H/(\mu_k V)$

Calculated factor for the temperature T_{calc}:

$$T_{talc} = \frac{2\mu_k g M v_H}{S(\pi k \rho C_p)^{0.5}} \left(1 - \frac{t}{2t_e}\right) t^{0.5}$$

This is the expression for the calculation of the temperature at the skin surface as a function of the sliding time and the other defined parameters.

For the described experiments, the values of the parameters are the following:

Polymeric film used as artificial skin:
$T_0 =$ 25 ºC
k = 0.275 W/(m ºK)
ρ = 1420 kg/m^3
$C_p =$ 1465 J/(kg ºK)
Temperature of the field: 25 ºC
Sliding parameters: v_H = 3.46 m/s
Surface S = 0.01 m^2
Mass M = 15 kg

The physical constants of the artificial grass field are comparable with the values of the polymeric film used as artificial skin.

The temperature increase at the surface of the artificial skin can be simplified to:

$$\Delta T = 19\mu_k t_e^{0.5}$$

This gave the values in Table 5.2.

A good correlation between the calculated and measured values of the temperature rise was obtained. This gave us the possibility to use these analytical relationships for calculating the temperature rises in real situations, by simulating the characteristics of the skin and of the artificial grass field, the results of which are summarised in Table 5.3.

For the human skin (epidermis):

k = 0.22 W/(m ºK)
$C_p =$ 3578 J/(kg ºK)
ρ = 1200 kg/m^3

Table 5.2 Temperature increase at the surface of the artificial skin

	Sliding time	Sliding distance	Friction coefficient	Temperature increase
Field without infill	1.36 s	2500 mm	0.25	5.6 °C
Field with infill 40 mm	0.62 s	1100 mm	0.545	8.15 °C
Rubber film	0.42 s	730 mm	0.817	10.1 °C

Table 5.3 Temperature at the outer surface of the skin and temperature increase by sliding (under extreme conditions; indications of upper limits)

Material	Density kg/m^3	Specific heat J/(kg °K)	Friction coefficient	Temperature outer surface of the skin °C	Temperature increase °C
Natural grass	1088	3679	0.45	65.0	33.0
HDPE	964	1855	0.21	62.7	30.7
Polypropylene	910	1805	0.24	65.7	33.7
PA6 dry	1130	1599	0.48	78.3	46.3
PA6 wet	1122	1754	0.70	86.3	54.3
Artificial grass 1	932	1827	0.49	79.4	47.4
Artificial grass 2	932	1827	0.24	65.2	33.2

Player: $v_H = 5$ m/s
Surface $S = 0.015$ m^2
Mass $M = 70$ kg
Temperature of the field $T_2 = 32$ °C
Temperature of the skin $T_0 = 32$ °C

$$T_{calc} = 94.81\mu_k^{0.5}$$

The temperature increases for natural grass and for an artificial field with a coefficient of friction of about 0.24 are comparable. The water content of natural grass is very important for the friction coefficient (can reach values of 1.4 at low pressures) and the specific heat.

A good and reliable experimental method was developed for the measurement of the temperature increase at the surface of the skin during sliding. A theoretical approach to sliding was studied and the resulting analytical results correspond very well with the practical results. A simulation of the temperature increase during sliding is possible and the influence of different parameters can be studied directly from the calculations, together with their importance on the temperature increase during sliding. This temperature profile during sliding can be very important for the comfort of the player in combination with other characteristics of the field, such as shock absorption, energy restitution and quality of the yarns.

5.6 Future trends

Many good results have already been obtained with fibres, especially the monofilaments with the right geometry. The advantage of the monofilaments is the freedom of choice of the geometry to obtain a fibre with a good behaviour in resilience and resistance to fibrillation and to avoid the possible twisting forces of the fibres. These twisting forces can be the origin of fibrillation of the monofilaments. In the future, the geometry of the fibre will be calculated in accordance with a better understanding of the structure of the used fibre and relation with the forces working on those fibres during bending and possible twisting of the monofilaments. The geometry of the monofilaments is important for long term use in artificial sports fields and will be optimised in the future.

As results of ongoing research continue, a better insight will be obtained in the relationships between the fibre structure and its resilience and resistance to fibrillation. This will lead to possible developments of polymers with better properties and a much better control of the processing of these polymers. The macromolecular properties of the polymers and their processing conditions are important for the final orientation in the amorphous phase, which is important for resistance to fibrillation and its resilience.

The fundamental question is: is it possible to combine the good values of friction coefficient and impact resistance of some polymers, like high density polyethylene, with good resilience and resistance to fibrillation from some other polymers, like polyamide 6 or 66? Is it possible to obtain a combination of all these properties in one polymer or in blends of polymers or is it necessary to use multilayered fibres?

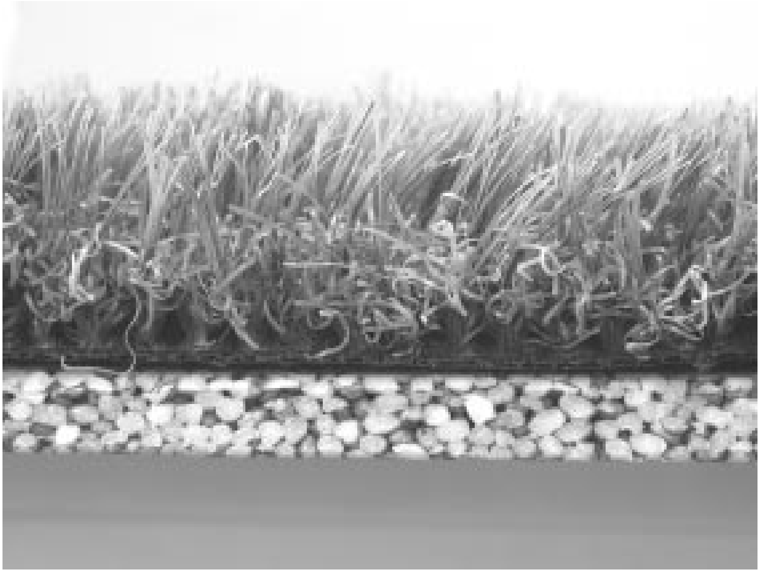
The use of multilayered fibres seems to be the most promising. In such fibres, the outer layer is characterised by a low value of the friction coefficient, good impact resistance and a low value of amorphous orientation to avoid a possible fibrillation of the fibre. The inner layer, or core, of the fibre is chosen for resilience and impact resistance. A possible combination is polyamide 6, 66 or blends of these two polyamides as the core material and a high density polyethylene as the outer layer. But the problems to be solved are twofold: the interfacial adhesion between the two layers must be sufficient to withstand deformation over a period of years and the processing temperatures must be optimised for the two polymers in order to obtain a well induced oriented structure in the polyamides and to minimise the orientation in the polyethylene layer. If these problems can be solved then multilayered structures can be developed and used for future artificial sports field applications. This is just an example; one can imagine other combinations of industrially produced polymers. But the processing of multilayered fibres will still be more complex and more difficult to control than a monolayer fibre. The advantages of a multilayered fibre structure must be clear in order to overcome the processing difficulties of such fibres.

An easier solution at the moment and for the future is the monolayer fibre structure. What is necessary is to find a polymer or a blend of polymers that combine the already mentioned properties for an excellent fibre for artificial sports applications [33]. The solution can be twofold, either a polyolefin or blends of polyolefines [34] with the resilience of the polyamides or a polyamide or blends of polyamides with low friction coefficient and low temperature impact resistance of polyolefins [35–38].

Research is ongoing to develop artificial sports fields without infill. For these structures, two different kinds of fibres are normally necessary and one of the two will belong to the class of crimped fibres. These crimped fibres must be characterised by a rather high value of friction coefficient to avoid slippage of the players during running. In this case, the choice of polyamide as polymer seems to be the most logical one, but new insights and developments can go to the use of fibres with more intrinsic rubbery characteristics or due to the relative high absorption of water, comparable to the water absorption of natural grass. The fibres with rubbery characteristics can replace the rubber infill used today.

Another future development for the polymers in this field may be the use of polymers with a well controlled degree of long chain branching, combining, for example, in the field of polyolefins the good properties of LDPE and the typical crystalline structure of the linear polyolefins. A good control of the length of the long chain branches and their number may be necessary for the future development of polymers with interesting properties in this field. An optimum will be achieved for fibres with a completely reversible deformation under bending, no irreversible deformation due to structure transformations in the normal temperature region for these applications, and without fibrillation. This will create fibres with very good and interesting properties for use in artificial sports applications. A good insight into the possible structure transformations in the bending mode of the fibres will be the next necessary step for optimising fibre properties.

The important issue for the future development of the fibres or yarns for artificial turf fields is: can the different required properties be obtained with a monolayer structure or will it be necessary to move to a multilayer structure? The multilayered structure requires the use of the co-extrusion technique and is already well developed and in use for the production of multilayered films. This will be the comeback of the artificial grass blades instead of the monofilaments. This simple geometry is the easiest to obtain with the technique of co-extrusion. The production of monofilaments by co-extrusion is much more difficult, especially for the design of the extrusion dies. The multilayered artificial grass blades of simple rectangular geometry can combine the soft touch, low friction coefficient and water absorption outside of the filaments and the resilience and temperature resistance is obtained by the inner layer. The simplest combination of polymers is, for example, low density PE/high density PE/low density PE. In this example, the presence of the low density polyethylene at the outer surface creates a good link with the backing layer and the shock pad in combination with



5.22 Example of the possible next generation of artificial turf construction. No infill will be necessary and the shock pad is an elastic foam (grey layer on the picture).

the soft touch and low friction coefficient. The combination of a soft polymer at the outside and a more rigid polymer for the inner layer is probably the most interesting solution for the next generation of fibres for artificial turf fields.

The future development for fibres used for artificial turf fields will probably be provided by further research and development of the multilayered artificial grass blades obtained by the extrusion of multilayered films, followed by an orientation at temperatures below the melt temperature of the highest one in the multilayered combination.

The future generation of artificial turf fields is represented in Fig. 5.22. Probably, use will be made of two types of fibres, one type which is standing upwards and another which will be constructed of crimped fibres. A backing layer is also present and the shock absorption will be optimised by the use of an elastic foam under the backing layer.

5.7 Applications and examples of artificial turf fields

5.7.1 Existing artificial turfs

Artificial turf has been manufactured since the early 1960s and was and still is produced using manufacturing processes similar to those used in the carpet industry. Since the start, the product has been improved through new designs and better materials. The newest synthetic turf products have been improved, as explained in the preceding chapters, to be more wear-resistant and less abrasive. The sliding properties are much better now than in the beginning of artificial turf applications.

In 1966, artificial turf was first used in professional sports, baseball, and gained its first application when the Astrodome was opened in Houston, Texas. This stadium had a covered baseball field of natural grass in 1965 with a surface of 13 935 m^2, which needed to be kept nice and green. The Astrodome had been built with a transparent roof for sunlight, using an acrylic polymer, but the glinting of the sun on the roof impeded the players when catching high balls. It was decided to paint the roof to solve this problem but then the grass would not grow properly. Those responsible decided to use an artificial playing surface, a grass carpet made from polyamide fibres. After the success of the first installation, the artificial market expanded further in closed and domed stadium construction around the world. Today, more than 500 sports arenas in 32 countries are using artificial turf fields.

The world production of artificial turf increased from 80 billion m^2 in 2004, to over 95 billion m^2 in 2005 and 110 billion m^2 in 2006. With a mean area of 7500 m^2, this corresponds to the equivalent of 14,667 sport fields. Of this, 40% is used for soccer, 40% for tennis, 10% for hockey and 10% for landscape applications.

5.7.2 Costing of turfs

As a general rule, an artificial turf field can replace three natural grass fields of high quality or five natural grass fields of low quality. In Table 5.4 all costs are expressed in Euros.

The feeling in the industry is that a lifespan of 10 years is a realistic time scale. If the lifespan can be increased to 15 or even 20 years, a still more favourable cost analysis is obtained for an artificial turf field. One of the goals of the new artificial turf fields is to reach a lifespan of at least 15 years.

One additional discussion point in the economic evaluation is the recycling of the materials after use. When natural grass pitches have to be renovated, the top layer is often used for making compost at minimum cost. For artificial turf pitches, recycling of the fibres and the rubber costs money in most cases. In some economic schemes, the cost of recycling artificial turf is estimated at a value of 10 Euros/m^2. For a total artificial field of 7500 m^2 this is representing a total cost of 75,000 Euros.

Associations like FIFA, UEFA and IRB all state that ‘high-quality natural grass’ is the ideal playing surface for football or soccer. The problem is that good grass pitches are difficult and expensive to maintain as indicated in Table 5.4. The maintenance of high-quality natural grass is still more difficult in the modern football stadia.

For most of the clubs, and especially the smaller soccer clubs, a low-

Table 5.4 Costing of turfs (in Euros)

	Natural grass			Synthetic turf		
	Low	Medium	High	1st generation	2nd generation	3rd generation
Hours of play per year	200	300	400	2000	2000	2000
Total installation cost	100 630	114 630	131 630	396 840	403 140	361 460 (recycled rubber)
Maintenance cost over 10 years	260 700	260 700	260 700	52 500	70 000	72100
Capital costs over 10 years (5%)	27 673	31 523	36 198	109 131	110 864	99 402
Total costs over 10 years	389 003	406 853	428 528	558 471	584 004	532 962
Cost per hour of play over 10 years	194.50	135.62	107.13	27.92	29.20	26.65
Pitches needed	5	4	3	1	1	1
Total cost over 10 year period	1945 016	1627 413	1285 585	558 471	584 004	532 962

maintenance artificial turf field will be the most economical solution. The installed artificial pitch is expected to last up to at least 10 years, in contrast to natural grass fields that have to be re-laid up to four times a year in order to guarantee the high quality of the natural pitch. The artificial pitch can be hired out, with no risk of damage, when the club is not using it.

Aside from the economic reasons, FIFA states ‘FIFA is responding to the growing demand for playing football on artificial turf, chiefly in regions where the climate makes it impossible to organise football matches on good natural turf all year around’.

5.7.3 Advantages of artificial turf fields

- Artificial turf can be a better solution when the environment is particularly hostile to natural grass, due to severe weather conditions or where there is little natural light.
- Ideal for homes, no maintenance of the lawns and always of good appearance.
- Suitable for roof gardens and swimming pool surrounds.
- Artificial grass can last up to at least 10 years and their toughness makes them more suitable for multi-use stadia.
- Some artificial turf systems allow for the integration of designs by using different coloured fibres or by the integration of fibre-optic fibres into the artificial turf.

- Use for residential and commercial landscaping artificial lawns. This trend has been driven by two functions: the quality and variety of synthetic grasses has improved dramatically and cities and organisations have begun realising the value of artificial grass as a conservation measure.

5.7.4 Weaknesses of the existing artificial turf fields

Temperature of the artificial turf field

Artificial turf fields can attain higher temperatures than natural grass fields in outdoor conditions. In summertime, the temperature of the artificial turf fields can attain mean temperatures of 47 ºC between 7 am and 7 pm with a maximum temperature of 69 ºC at noon. The natural grass fields attain mean temperatures of 26 ºC with a maximum temperature of 32 ºC. The differences in surface temperatures are due to the black infill in the third generation turf fields and the absence of absorbed water as in natural grass that can attain values of 80 wt%.

Irrigation of the artificial turf fields is necessary to reduce the temperature and obtain good playing conditions. As already explained, the surface temperature is an important factor for controlling and avoiding burn injuries together with the friction coefficient of the artificial turf field. Good control of the quality of the used water is necessary to avoid the build-up of algae and slimes on the fibres of the artificial turf. Some solutions are already proposed for this, for example by adding chitosan to the used water.

In recent applications, large holding tanks have been built beneath outdoor installations. The water that runs off the surface is held in tanks, and used later in watering practice fields or nearby lawns or, at least, reused for the irrigation of the artificial grass after quality control.

Rubber infill

In the third generation artificial turf, recycled rubber from tyres is most commonly used as infill. During normal playing over one year, this artificial turf field can lose approximately 3 tonnes of material, rubber granules and sand. Some researches reported that artificial turf with an infill of recycled rubber granules releases volatile organic compounds which give off a ‘rubbery’ smell that can cause problems for asthma suffers. Some organisations recommend the use of green and new polymeric elastomers, like EPDM, instead of the black recycled rubber. But the price of this freshly produced EPDM is three times higher than recycled rubber and introduces an extra cost of 135 000 Euros for a total artificial turf field. Using recycled rubber granules can pollute groundwater with zinc and other unwanted chemicals.

In conclusion, the use of recycled rubber as infill is a favourite option from the standpoint of shock absorption and price but still more research is needed for its use in future applications. Treatment of the rubber granules is necessary to eliminate the volatile substances, for example by heating the granules in a vacuum, and the leaching of zinc and other chemicals by a treatment with water before use. An extra coating of the rubber granules can avoid the high temperature rise outdoor, by coating with a green-coloured elastomeric polymer. These treatments of the rubber granules are technologically feasible.

The rubber infill layer can also be compacted during normal play. It will lose some of its positive effects for the artificial turf field, like shock absorption and shoe-surface traction. More research is necessary to obtain a satisfactory solution for this problem.

Ball response for soccer

On a natural grass field in optimal conditions, the ball response is well known including the speed, spin and bounce of the ball. The ball response on the field is dominated by two main factors, the rebound of the ball on the field and the friction between the ball and the field. The behaviour on a natural grass pitch is more or less known: a football striking the ground with a speed of 14 m/s below an angle of 25° will continue its way at a reduced angle of below 17° with a speed of 10 m/s. These are standard values for a good quality natural grass field. But this can change a lot as a function of the time this field is used, in combination with the weather conditions influencing the quality of the natural grass pitch.

The ball response on artificial grass is still different from the response on natural grass, but is approaching this more and more. The question is: must this be the same?

But the ball response can change during the time of use as a result of the compaction of the rubber infill layer and the lack of resilience of the fibres. The ball roll and bounce will be influenced by these changes; the ball roll will increase due to the laying down of the fibres on the artificial turf field. As already discussed, good resilience of the fibres is an important issue in the context of the artificial grass.

5.7.5 Conclusions concerning existing artificial turf fields

In conclusion, the soccer application of artificial grass is the most demanding of all possible applications of artificial turf. The easiest application and the fastest growing is the landscape application. Artificial grass is already well adapted for hockey and tennis. These sports are non-contact sports, compared to soccer, which is a contact sport. Artificial grass is a major topic of research and new insights and solutions will create better acceptance and playing characteristics than the existing artificial turf applications. Especially once the complaints concerning the hardness of the artificial grass fields and the discussions concerning the rubber infill are taken into account. Probably, the next generation of artificial grass will be used without infill by the application of extra crimped fibres and by the optimisation of the shock pads under the artificial grass. Much research is going on, in university and industry research facilities, and good solutions will be reached in the near future. This will increase the demand for playing football on artificial turf, chiefly in regions where the climate makes it difficult to obtain good natural turf all year round and in regions where open space is very limited.

For the future, a better understanding of the biomechanical interaction between the player and the field is necessary to develop the next generation of artificial turf fields. Most sports, and certainly soccer, require players to perform a range of actions. They have to be able to run forwards, backwards, sideways, jump, slide, start, and stop and change direction abruptly. A good knowledge of the corresponding biomechanical properties related to these actions is a fundamental condition to improve the quality of the artificial turf fields and to obtain a better acceptance of the professional players.

As general conclusion, if artificial turf wins over the sporting world, it would be a victory against the odds and the bad reputation of the ‘plastic grass’ acquired in the past during the 1960s and 1970s.

UEFA announced that starting in the 2005–2006 season, approved artificial surfaces would be permitted in their competitions. Compared to football and soccer, the introduction of artificial turf fields has significantly changed field hockey. Competitions are now mostly played on artificial surfaces in Western countries. The speed of the game has considerably increased and has changed the shape of the hockey sticks. For field hockey, the artificial turf field does not try to reproduce the natural grass field and is made from shorter fibres than the ones used for football pitches. The shorter fibre structure has increased the speed of the game. A major problem for field hockey is the use of water. The goal of the research supported by the manufacturers is to produce new pitches that will be suitable for a variety of sports and not limited to one sport because many local communities cannot afford to build two or more artificial pitches related to every type of sport.

5.8 Acknowledgements

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6
Developments in handmade carpets: introduction

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Abstract: This chapter begins by covering the development of handmade carpet production. It discusses current centres of production such as India, Iran and Turkey, including typical patterns and production techniques. The chapter also reviews markets for handmade carpets. It includes aspects of handmade carpet technology and the role of handmade carpets in modern carpet production

Key words: handmade carpets, carpet belt.

6.1 Introduction

Carpets may be made from woven, knotted, tufted, knitted, braided or non-woven materials. Carpet materials include the felted, thick, heavy textiles used primarily for floor coverings, but also those for table and wall coverings. The words carpet and rug can mean essentially the same thing. Some experts define a carpet as a covering for floors and stairs, made of a heavy, usually woven and tufted fabric that is fixed to a floor, whilst a rug is defined as a floor covering that is loose-laid, most often for decorative purposes. Historically some have distinguished between carpets and rugs based on size (the former being larger) or use (carpets used mainly on floors, rugs used mainly on beds or by the hearth). For the sake of clarity, some experts also differentiate between carpets and carpeting. In this usage, the latter is laid on floors wall-to-wall, is often woven or tufted, and comes in rolls in widths ranging from 12 to 15 feet. Associated or synonymous terms for carpet are: rug, mat, runner, fitted carpet, carpet tiles, carpeting, floor-covering and flooring. Kilim, durry, galeecha, kaleen and kambal are local terms for types of carpet. The Dutch, French, German, Italian and Spanish names for carpet are *tapitj*, *moquette*, *Teppich*, *moquette* and *alfombra* or *moqueta*, respectively.

Carpets, when manufactured manually, are known as handmade carpets, of which the hand-knotted, woollen carpet is particularly important with regard to artistic heritage and local skills in a number of countries. Customer-driven markets have resulted in a multitude of varieties in terms of manufacturing techniques, materials, etc., which will be described later.

6.2 The history of handmade carpets

It is difficult to pinpoint where and when the first carpet and the art of carpet making originated. The general areas where carpets may first have been produced are thought to be Persia (Iran), Turkmenistan, Central Asia, Mongolia and China, often referred to as the carpet belt.

It is said that the tomb of the Persian King Cyrus, who was buried at Pasargadae (Persepolis), was covered with precious carpets. Even before his time, it is very likely that Persian nomads knew about the use of knotted carpets. With their herds of sheep and goats, they were skilful carpet makers using Turkish knots. In the provinces of Azerbaijan and Hamadan, where Seljuk influence was strongest and longest lasting, the Turkish knot is still used to this day.

Ornamental rugs or carpets have always played an important role in Islamic culture in particular and achieved unprecedented heights in Baghdad, Damascus, Cordova, Delhi and the fabled cities of Central Asia. References to carpets in Arabic and Persian literature are numerous. Wherever Muslim culture has flourished, carpet weaving has been a part of it. This is especially true of the Arab Middle East and Central Asia. Table 6.1 provides a summary of key developments in carpet making.

Table 6.1 History of carpet making

BC	
7000	The origin can be traced back to the Neolithic age (7000 BC). Certain products of the era, consisting of warp and weft textiles resembling flat weave kilims, have been found. After that, the rugs were created by forming knots to make a pile.
6000	Evidence of goats and sheep being sheared for wool and hair, which was then spun and woven.
1480	Egyptian fresco of handloom (discovered in 1953).
400–540	• When Cyrus conquered Babylon in 539 BC, he was struck by its splendour, and it was probably he who introduced the art of carpet making into Persia. • The hand-knotted pile carpet probably originated in Mongolia or Turkestan between the 4th and 2nd millennium BC. • The earliest surviving pile carpet in the world is called the 'Pazyryk Carpet'. It is usually dated to the 5th century BC. It was excavated by Sergei Ivanovich Rudenko in 1949 from a Siberian burial ground where it had been preserved in ice in the valley of Pazyryk. The origin of this carpet is debated. It has been proposed that it is a product of either the Iranian Scythians or the Persian Achaemenids. This carpet is 200 × 183 cm (6′6″ × 6′0″) and has 360 000 knots/m^2. It is in the Hermitage Museum in Leningrad. It has all the characteristics of a modern Persian or Anatolian carpet with a pile and Ghiordes knot.

Table 6.1 Continued

AD	
Up to 640	• The first documented evidence of the existence of carpets came from Chinese texts dating back to the Sassanid Dynasty (AD 224–641). In AD 628, the Emperor Heraclius brought back a variety of carpets from the conquest of Ctesiphon, the Sassanian capital. • The Arabs also conquered Ctesiphon in 637, and among the spoils brought back were said to be many carpets, one of which was the famous garden carpet, the 'Spring time of Khosroe'. This carpet has passed into history as the most precious of all time. Made during the reign of Khosroe I (531–579), the carpet was 90 feet square. The Arab historians' description is as follows: 'The border was a magnificent flower bed of blue, red, white, yellow and green stones; in the background the color of the earth was imitated with gold; clear stones like crystals gave the illusion of water; the plants were in silk and the fruits were formed by color stones'. However, the Arabs cut this magnificent carpet into many pieces, which were then sold separately.
1000-1600	• Marco Polo confirms rug making in Central Anatolia. From there the technique spread through the Caucasus, Turkomania, Persia, Meshed, Herat, Kabul, and India including Kashmir. Traders took rugs to Samarkand, Bokhara, Tashkent, Sinkiang and Peking; the craft swept through Tunisia, Biskra, Bou Saada, Marakesh and Fez. • After the period of domination by the Arab Caliphates, a Turkish tribe, named after their founder Seljuk, conquered Persia. Their domination (1038–1194) was of great importance in the history of Persian carpets. • The Mongols provided them with high-quality and durable wool for this purpose. The Seljuk conquest and control of Persia (1220–1449) was initially brutal. However, they soon came under the influence of the Persians. The palace of Tabriz, belonging to the Ilkhan leader, Ghazan Khan (1295–1304), had paved floors covered with precious carpets. • The Monghol ruler Shah Rokh (1409–1446) contributed to the reconstruction of much that was destroyed by the Mongols and encouraged all the artistic activities of the region. However, the carpets in this period were decorated with simple motifs, which were mainly geometric in style. • Robert Rothe imported weavers from the East to make rugs on his estate in Kilkenny. • Cardinal Wolsey imported Turkish rugs to England. • Carpet knotting exhibited by Richard Hicke. • Verulam carpet made for Elizabeth I • Aubusson carpet centre set up in Beauvair. • Ardebil carpet (now in Victoria and Albert Museum, London) made by Maksud the Keshani. (A few suggest 1586 while others assert 1540. One of a pair made for the Mosque of Ardebil. The other is in the Los Angeles Museum of Art.)

Table 6.1 Continued

	• Pierre DuPont set up weaving carpets in Palais Royal Paris (Jacobs suggests 1604). Moved in 1620 to soap works 'Savonerie'.
1600–1801	• Under Akbar the Great carpet weaving was introduced to India and during Jahangir period, 1605–1727, activity flourished further. • Carpet factory built at Wilton. • Huguenot weavers fled France; some settled in England and started weaving in Wilton. Wilton carpet weavers received Royal Charter in 1699. • Earl of Pembroke persuaded weavers from Savonnerie factory to work in Wilton and teach locals to make Brussels carpet. (Legend has it that the Duke smuggled the weavers out of France in wine barrels.) The Duffossy family still live in Dorset. The court period of the Persian carpet ended with the Afghan invasion in 1722. • Royal Society of Arts presented premiums for finest carpets. Won by Whitty three times and Passavant once. • Handmade carpet making flourished and attracted designers such as the Adam Brothers and Laverton. • Brintons, previously cloth makers, started making carpets. The dynasty still exists and is the largest privately owned carpet company in the UK (1997). • Whitty made carpet for the Throne Room at Carlton House and Brighton Pavilion and supplied £1000 carpet to Sultan of Turkey. Coals to Newcastle. It became the fashion to match carpets to ceilings, a trend that is still followed by today's equivalent of Whitty's factory, Axminster Carpets of Devon. (See Axminster Contract page – Number One Nob Hill, San Francisco.) • Moore opened in Moorfield and Whitty opened in Axminster, closing in 1835. Looms moved to Wilton. Original hand-knotted looms still in operation at Wilton. • Jacquard invented method of presenting different coloured yarn to weaving face. Revolutionised patterned fabric making; the system is still in use. • Decline in fine handmade carpets due to Napoleonic War and competition from machine-made carpets. More looms introduced in Kidderminster, Yorkshire and Scotland. • Three-ply fabric commenced in Kilmarnock. In America, hand-knotted rugs and rag rugs made, plus imports from England. In 1791 Sprague opened carpet factory in Philadelphia and in 1825 opened mill in Massachusetts. • Industrial development in England. Population increased from 7 million to 18 million. End of cottage industries. Industrial revolution brought textile inventions by Hargreaves, Arkwright, and Crompton. Cartwright and Watt's steam engine. • Crossley Carpets started in Halifax (Crossley Carpets are still made under Carpets International brand by new owners, Shaw Carpets of USA. Descendants of Crossley still make carpets in Yorkshire).

Table 6.1 Continued

	• Whytock invented method to print yarn and then weave it into flat fabric with design incorporated. Tapestry Carpet Loom. Start of Henry Widnell Stewart Ltd in Edinburgh, later bought by Stoddard – who still manufacture carpet. Whytock leased Tapestry Carpet Loom rights to Crossley. • James worked with Quigley to perfect the Chenille Axminster loom. Chenille expanded to meet demand for large seamless patterned carpets at an economic price. Chenille eventually succumbed in 1968. It grew to a multi-million company over 150 years and was bought by Stoddard around 1970. Quigley took his share and disappeared in America around 1850. • Erasmus Bigelow in America invented power loom to make double ingrain and sold it to Scottish and English manufacturers who installed steam power. In 1951 he introduced a steam-powered Brussels loom at the Great Exhibition and demonstrated it at Hoobrook in Kidderminster (near the site of today's Brockway Carpets), and eventually Crossley purchased it. • William Grosvenor built steam-driven factory in Green Street, Kidderminster, where the company still occupies a listed building.
1801–1900	• Alfred Stoddard, an American, took over the tapestry factory of Ronalds at Elderslie, near Glasgow, to make carpets. By 1867 he was selling 75% in America. Stoddard now owns and still makes carpets on the original site. • Spool Axminster, invented by Halcyon Skinner in America, introduced into England by Tomkinson and Adam in Kidderminster. (Both families still making carpets – 1997.) Morris opened hand-knotting factory in Hammersmith. • William Gray of Ayr developed seamless Kidder carpets. • Brintons develop Gripper Axminster (also from Halcyon Skinner of Yonkers) with efficiency advantages over traditional Spool. Later the two techniques were combined in Spool-Gripper. • Donegal hand-made factory set up and still in operation. • Brintons produce carpet from first power-driven wide loom 15 ft wide (4.57 m). • Next to three British sponsored companies M/s E. Hill & Co, Tallery House (GFD) and Obeettee, Indian Master Peer Mohammad followed by M/s M.A. Samad & Co started export. In the year 1925, M/s Abbas Waziri firm came into existence. Thereafter early manufacturers and exporters list of India swelled to well over five hundred. (Source: Silver Jubilee Special, AICMA Bhadohi, 1986.) • David Crabtree, loom builders since 1853, started to export wide Gripper looms, three yards or three metres wide, 10 ft 6in introduced in 1932. • India entered the prime decade of carpet making, produced in Agra, Amritsar, Srinagar, Jaipur, Mirzapur/Bhadohi, Gwalior and Shahjahanpur. • Decline in tapestry carpet in favour of huge increase in Gripper Axminster, especially for 'Seamless Squares'.

Table 6.1 Continued

	• The great depression, followed by World War II, led to a scarcity of raw materials as India's carpet industry struggled to maintain itself. • Tufted carpets developed in USA from candlewick weaving techniques. • Chenille Axminster disappeared under avalanche of tufted carpet. • Tufted carpet limited to plain yarn effects but gradually printing white carpet improved. • With the decline of the Shah, Iran lost its position as a major Western supplier of oriental carpets and India, along with China, emerged as a centre of carpet weaving for the global market. India's prime positioning had been on account of programmed carpets, having the capability to cater for any given design, size and colour, resulting in increased acceptance and adaptability of oriental rugs for the customers. • Woven carpet production declined by 70% but tufted production increased by 300% in UK. • Fully patterned tufted carpets produced in England by Ryalux Carpets. Individual coloured yarns presented to substrate effectively for the first time. Patterned tufted carpet produced to rival woven (Gripper Axminster and Figured Wilton) carpets. • Indian Institute of Carpet Technology became functional in 2001 (www.iict.ac.in). • First world conference on handmade carpets was held on 4–5 November 2003: the then Prime Minister of India declared on the occasion 'We shall be happy to offer this platform to any country and to the industry on a mutually agreed-upon framework of cooperation'.
1901–2007	• Carpet choice has never been so diverse. Identifying the need to move with the changing demands of the consumer, the carpet manufacturers across the world offer a huge variety of diverse carpet ranges. Thousands of textures, colours, designs and styles leave no stone unturned, adding technology and economy to this art and craft as appropriate.

6.3 Modern handmade carpet production

In spite of the fact that technological advancement and development has taken place over many years, handmade carpet manufacturing practices today are largely the same as they used to be hundreds of years ago. The art and craft of weaving a carpet has been passed on for many generations, consisting of several different steps that are all part of a genuine handicraft. For hundreds of years it was rare for people, except the very wealthy living outside the Orient, to possess a carpet. Most classical/oriental handmade carpets are from areas reaching from Morocco in the West, over to the Balkans (Romania and Bulgaria), Turkey

(Anatolia), Persia (Iran), Caucasus, Afghanistan, Turkmenistan, Pakistan, India, Tibet, Nepal, and all the way to the Western parts of China.

Towards the end of the 19th century, the demand for handmade carpets increased in the West and more and more countries began producing them for export. The increased production led to diverse quality levels both in motifs and designs and in the raw materials mix and the colour of the materials used. The development of the industry also resulted in some carpets being manufactured by machines (for example, Wilton and Axminster tufted carpets). The quality of these mass-produced carpets is not comparable to that of handmade carpets. Today, machine-spun yarns are used in the production of some handmade carpets but, despite this, the traditional handicraft techniques are still used and are very much appreciated by customers. Hand-knotted carpets are mostly made in the home, where the women often do this for an extra income while running the household. This is the main reason why handmade carpets are still considered special, considering the work put into them. Such carpets today are still seen as well worth their price in relation to their quality.[1]

The material used in a carpet determines the final quality of the carpet and how it performs with age. The most commonly used material is sheep wool, although other materials may also be used. Wool is used for the pile, warp and weft in most carpet-producing countries; Cotton is often used in the warp and the threads for the weft. Goat hair is not used for the pile nowadays; it is mostly used in the warp, weft and for the sides in, for example, Beluch carpets. Silk is used in the warp, weft and the pile in more exclusive carpets.[2]

There are six leading handmade carpet producers in the world market: India, Iran, China, Pakistan, Nepal and Turkey, which have emerged as dominant players to meet global requirements, as evident from current statistics and surveys (see Tables 6.2–6.4 and Figs 6.1 and 6.2).

6.4 Carpet production in India

In the late 19th and early 20th centuries, India emerged as a major manufacturer and exporter of handmade carpets. The Indian carpet industry has been strengthened by United Nations Development Programme (UNDP)-assisted carpet initatives, including the creation of designs based solely on Indian motifs and the introduction of computer technology in design. The success of the industry has been made possible due to the availability of skilled artisans and the collaboration of entrepreneurs and government intervention.

In India, the art of making woollen carpets was known as early as the 5th century BC. Different types of carpet have been traced back to different periods:[4]

- Indian woollen carpets – 3rd to 5th centuries BC
- Turkoman (Turkmenistan) woven carpets – before 6th century BC

Table 6.2

(a) Statistics for the import of handmade carpets into the European Union (EU)[3]: January–June 2006/2005

From	Volume (square metres)			Value (1000Euro)		
	Jan–Jun 2006 (% to total)	Jan–Jun 2005 (% to total)	Change in %	Jan–Jun 2006 (% to total)	Jan–Jun 2005 (% to total)	Change in %
India	2611723	2653034	−1.56	58898	55808	5.54
Iran	940071	1025277	−8.31	71930	71096	1.16
China	879811	388151	126.67	8334	6637	25.57
Pakistan	686296	863668	−20.54	39934	39315	1.57
Nepal	450328	475077	−5.21	20306	18824	7.87
Turkey	442091	518671	−14.76	25024	10541	137.40
Others	253888	294536	−13.80	5806	6249	−7.09
Morocco	151344	145547	3.98	4611	4582	0.63
Afghanistan	28956	20264	42.89	1018	752	35.57
Tunisia	13720	13135	4.45	1252	1287	−2.72
Total	**6458228 (100)**	**639736 (100)**	**0.95**	**237113 (100)**	**215091 (100)**	**10.24**

(b) Statistics for the import of handmade carpets into the USA market*

Country	$ Million		Million Sq. m	
	2006	2007	2006	2007
World	1027.00	997.20	30.90	30.20
India	354.60	358.05	12.70	13.00
China	173.30	167.60	7.30	6.70
Pakistan	113.00	100.60	1.20	1.20
Iran	108.60	90.10	1.70	1.60
Nepal	31.40	35.80	0.37	0.36

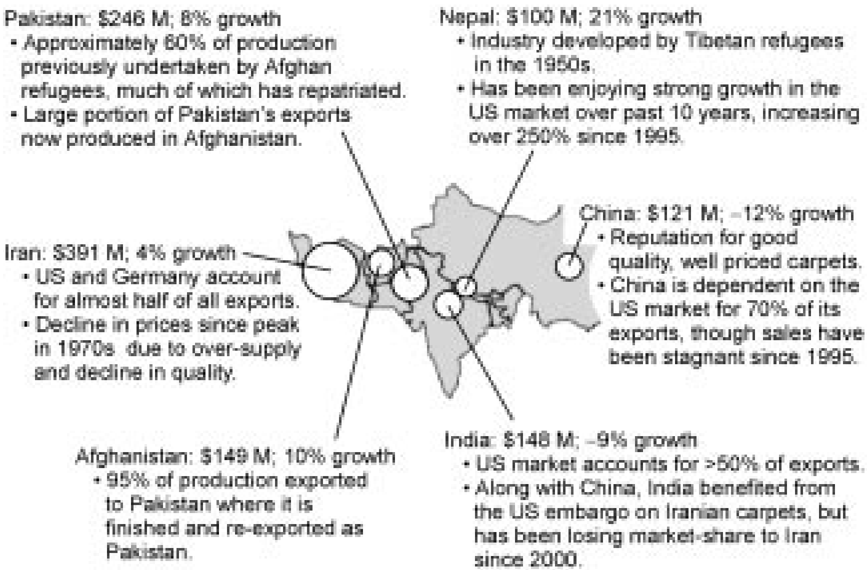
*Source: Wymen Lisa, RUG News, USA, Carpet Conclave, Varanasi 8 July 2008

Table 6.3 Country-wise import (in million US$) for top 5 global buyers

Country	1998	1999	2000	2001	2002	2003	2004
UAE	25	45	52	46	46	50	50
Italy	106	96	81	69	67	72	88
Germany	529	494	420	366	264	270	301
USA	385	472	553	509	504	511	531
UK	65	59	56	52	51	44	48
Total	**1110**	**1166**	**1162**	**1042**	**932**	**947**	**1018**

Table 6.4 Value of US imports (in million US$) from top 5 supplying countries

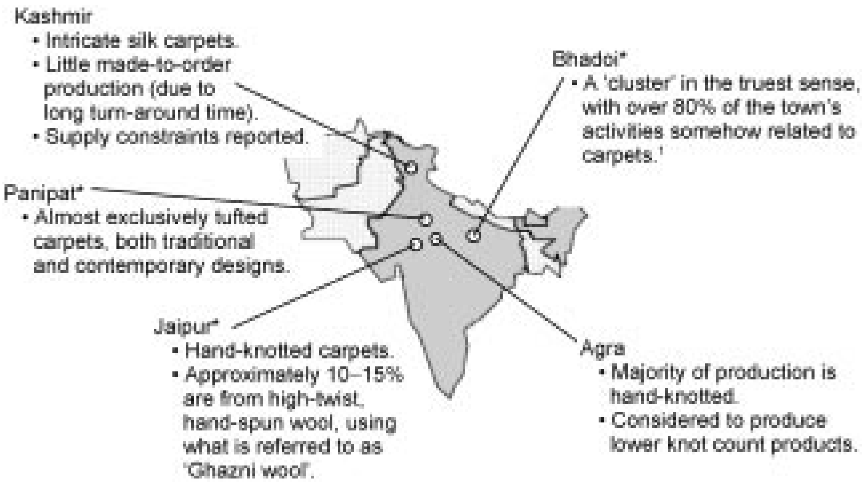
Country	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
India	91	107	153	185	175	152	151	158	177	182
Iran	–	–	–	–	106	103	109	113	108	111
Pakistan	51	65	77	86	101	92	93	95	103	117
China	64	66	77	83	75	73	75	73	60	50
Nepal	9	15	23	23	28	28	23	21	28	32
ROW	26	36	42	45	48	40	32	28	32	38
Total	**241**	**289**	**372**	**422**	**533**	**488**	**483**	**488**	**508**	**530**
		Growth			**Stagnation**			**Revival**		



6.1 International carpet market: top suppliers (2004). (Adapted from: presentation to the World Bank's AFTPS Group, 29 November 2006 by OTF Group (www.ccca.org.af).

- Persian knotted carpets – before 6th century BC
- Caucasian woven carpets – 8th century AD
- Chinese felt carpets – 8th century AD
- Turkish knotted carpets – 12th century AD.

The tradition of making pile-formed carpets using silk and wool, with designs of flowers, animals, birds and monuments, in the country dates back to the 16th century. The Mughal Emperor, Akbar the Great, brought some Persian carpet weavers to India and set up the royal workshop in his palace. Carpet weaving thereafter continued to spread and thrive in India. As a result of the Great



6.2 Indian carpet production centres. (Adapted from presentation to the World Bank's AFTPS Group, 29 November 2006 by OTF Group (www.ccca.org.af).

Exhibition in London in 1851, Indian carpets were, for the first time, appreciated worldwide for their orientally-inspired patterns and fine quality with a high number of knots. Today the industry has a large and diversified production base, with an estimated 300,000 looms, providing employment for 1.5 million carpet weavers and other allied activities. The industry is export-oriented and is a positive net foreign exchange (NFE) earner, contributing to the growth of the Indian economy in general and the textile industry in particular.[5]

The closer the weave of a carpet, the more highly it is priced. Indian carpets are woven in every possible fineness from 12 knots per square inch upwards. It is gratifying to record that one small Indian picture carpet showing Shiva dancing, continues to be seen as one of the most intricate ever woven anywhere in the world, with an incredible 2900 knots per square inch (Source: Wattal H K (1983), Art of Carpet Weaving, Vol V, 63, *Carpet E World*).

Bhadohi-Mirzapur is the best-known carpet making area of India and accounts for around 80% of production and export, but production is gradually spreading throughout the country. Major carpet production centres in India are:

- Uttar Pradesh: Varanasi, Bhadohi, Gopiganj, Khamaria, Ghosia, Madhosingh, Mirzapur, Agra, Shahjahanpur
- Jammu and Kashmir: Srinagar, Baramulla, Anantnag, Jammu, Leh
- Rajasthan: Jaipur, Bikaner, Tonk
- Punjab: Amritsar
- Haryana: Panipat
- Madhya Pradesh: Gwalior
- Bihar: Obra, Danapur, Madhubani
- Himachal Pradesh: Dharmshala

- West Bengal: Darjeeling
- Andhra Pradesh: Elluru and Warangal
- Karnataka: Bangalore
- Pondicherry: Pondicherry.

It can be seen from the above list that there are nine major centres in Uttar Pradesh, which is more than in any other State. As has been stated, this cluster or belt of carpet-producing centres together account for around 80% of the country's production. Moreover, each centre is surrounded by clusters of weavers/manufacturers/processors related to all types of carpet.

6.5 Carpet production in Iran[6]

An Iranian carpet is called a gelim and it is the oldest form of floor covering. Iran, previously known as Persia, has become synonymous with rugs and carpets. The traditional gelims are the Iranian counterpart of the Turkish kilims. They are woollen rugs with a cotton warp. The patterns are created using the coloured woollen weft. They are flat weaves made on horizontal or vertical looms in urban and rural areas, respectively. The patterns and sizes differ with each region. The patterns of a gelim are the artistic representations of the weaver, woven from memory and without a drawing to follow. Whilst in urban regions horizontal looms are used, in rural areas a vertical loom is employed. The weavers use a special instrument known as a dafleh or dafnin in order to strengthen the fibres and the threads (warp and woof).

Carpet-weaving is undoubtedly one of the most distinguished manifestations of Persian culture and art, and dates back to the Bronze Age. The Pazyryk carpet amazed the world of archaeology and art, having been preserved in its original state for nearly 2500 years, due to the fact that the water which filled the tomb had turned into ice. Its year of manufacture and its origin have been a matter of debate among experts. Lately it has been claimed to be of Iskit or Hun origin. The dimensions of this carpet, which is estimated to have been woven between the 5th and 3rd centuries BC, are 2.00 × 1.85 m. Its warp and weft, as well as its knots, are all wool. It was woven using the double knot method, with 36 double knots to a square centimetre. In addition to its highly superior weaving technique, it has a historical significance. This carpet of extraordinary fineness and superior quality has motifs that reveal cultural manifestations of a typical nomadic or semi-nomadic society. Named after its location, the Pazyryk carpet is exhibited at the Hermitage Museum in St. Petersburg (Leningrad), Russia.

Apart from its use as a floor covering, the gelim has traditionally been used in the fabrication of bags, saddlebags (satchels), folding bedclothes, horsecloths and adornments for the sides of tents. Archeologists have discovered remains of a gelim in the east of Anatolia which dates back some 7700 years. Verni, a unique type of design from Azarbaijan, is a carpet-like gelim with delicate and fine threads, woven without a previous sketch by the creative talents of nomadic women and girls in Dasht-e Moghan, the Ahar region, Arasbaran and Meshkinshahr. Shiriki pich is another model of gelim whose name was chosen by nomadic and village weavers. At first glance it resembles a carpet with images produced by knots. Jajim, another art of nomadic women, is popular in many villages and nomadic tribal regions. The only differences between the various Jajims are their colour and delicacy of thread and patterns.

Persian knotted carpets are also classified as a type of Iranian carpet that developed from the traditional gelim over time and with innovations. The pile may be of silk or wool, and warp and wefts of cotton, silk or wool, depending upon the style and desired use. Patterns are individual to the tribe of origin. The Persian carpet is an essential part of Persian (Iranian) art and culture. The earliest surviving corpus of Persian carpets comes from the Safavid dynasty in the 16th century. However, painted depictions prove a longer history of production. There is much variety among classical Persian carpets of the 16th and 17th century. Common motifs include scrolling vine networks, arabesques, palmettes, cloud bands, medallions, and overlapping geometric compartments rather than animals and humans. This is because Islam, the dominant religion in that part of the world, forbids their depiction. Still, some show figures engaged in either hunting or feasting scenes. The majority of these carpets are wool, but several silk examples produced in Kashan still survive.

Perhaps the most important time in the history of Persian carpets came with the accession to power of the Safavid rulers (1499–1722). Approximately 1500 examples of carpets from the Safavid period are preserved in various museums and in private collections worldwide. During the reign of Shah Abbas (1571–1629), commerce and crafts prospered in Persia. Shah Abbas encouraged contacts and trade with Europe and transformed his new capital, Isfahan, into one of the most glorious cities of Persia. He also created a court workshop for carpets where skilled designers and craftsmen set to work to create splendid specimens. Most of these carpets were made of silk, with gold and silver threads adding even more embellishment.

In the last quarter of the 19th century and during the reign of the Qajar rulers, trade and craftsmanship regained their importance. Carpet making flourished once more with Tabriz merchants exporting carpets to Europe through Istanbul. At the end of the 19th century, some European and American companies even set up businesses in Persia and organised craft production destined for Western markets.

Today, carpet weaving is by far the most widespread handicraft in Iran; it is also the best known one abroad. Persian carpets are renowned for their richness of colour, variety of patterns and quality of design.[7] One third of Iran's non-oil earnings comes from exporting carpets to world markets. Experts believe that carpet weaving has an 80% value added, while the foreign exchange needed to supply the required raw materials is less than 10% of the total production cost.

Almost ten million people are active in the various stages of carpet production: sheep shearing, wool washing, spinning, dyeing, producing looms and the other tools required, weaving the carpet and then selling them in domestic and foreign markets. About one third of the active working population of the country finds a job through carpet production.

6.6 Carpet production in China[8]

Carpets have been made in China from at least as early as the fourth century BC. Of all the carpets in the world, the classical Ningxia weavings from western China still remain among the least well known. One reason for this is that so few existing examples can be attributed with any real certainty to before around 1700, when the art reached its peak. The vast majority are from the 19th and 20th centuries, when the art was effectively dead but the production of Chinese carpets was at its highest. As we become more familiar with them, the classical Chinese carpets made between around 1550 and 1735 will show themselves to be masterpieces of both art and technique. The great skill of their weavers allowed them to create the most complex curvilinear designs as well as simple geometric forms, with perfect balance and symmetry. These people were among the most highly skilled, sophisticated and sensitive weavers, craftsmen and artists in the history of carpet making.

Today, less than five hundred classical Chinese carpets that can be attributed to the high period of the art, 1550 to 1735, are known to survive in Western collections. Few appear to survive today in China, as most were exported a century ago when China sold off much of this type of its artistic heritage. Classical Chinese carpets can be divided chronologically into a number of groups:

- carpets from the 15th century and earlier
- Ming dynasty examples from the first half of the 16th century
- Ming dynasty Imperial Palace carpets from the second half of the 16th century
- Imperial Palace and other Ming period carpets from the first half of the 17th century
- Qing dynasty carpets from the second half of the 17th century
- Qing carpets from the first half of the 18th century.

Examples from the latter group demonstrate the beginning of the decline in the art of Chinese carpet-making, and help to place the true classical examples in context. The classical Chinese carpets of Ningxia represent the fusion of two different traditions, both of which may once have stemmed from a common heritage. The first is the traditional symbols of the ancient tribal peoples of Asia, for whom the carpet was a prime medium of artistic expression. The second is the wider artistic developments of the Ming and Qing dynasties.

Unfortunately, nothing was written contemporaneously about the history of the Chinese carpet. Our knowledge, thin as it is, has been drawn from the close study and comparison of the few surviving examples. Until recently few people in Europe and America understood the original functions and importance of oriental rugs, which were mostly acquired merely as luxurious floor coverings. When we look at an oriental rug today, we can try to grasp its full importance and significance, but older examples represent a lost language illustrating the traditions, beliefs and fears of forgotten cultures. The classical Chinese carpets that survive are recognised, collected and admired by a relatively small group of people, and apart from these few true experts, connoisseurship seems to be lacking in this tiny corner of Chinese art history.

6.7 Carpet production in Pakistan

The carpet industry plays a vital role in Pakistan's economy.[9] It is not only a major earner of foreign exchange for the economy as a whole, but it also contributes to the relief of poverty in rural areas. Carpet making is a cottage industry that covers the whole of Pakistan, especially in remote rural areas, and is a major source of income for families who have few other means of making a living apart from basic agriculture. Families can easily begin working in carpet-making, as it requires few infrastructural facilities.

Historians believe carpet-making was introduced to the region that now constitutes Pakistan as far back as the 11th century with the coming of the first Muslim conquerors, the Ghaznavids and the Ghauris. During the Mughal period, carpets made on the Indo-Pakistan subcontinent became so famous that there was a mounting demand for them abroad. These carpets have distinctive designs and boasted a rich knotting density. The tradition has remained strong over the last 400 years, although it has also had its ups and downs during this period. After the partition of the subcontinent in 1947 to establish the new Muslim State of Pakistan, most of the Muslim population in India involved in carpet-making migrated to Pakistan and settled either in Lahore or in Karachi. It was these people who formed the backbone of the carpet industry in Pakistan.

The type of carpet made is not a mass-market type of domestic floor covering, but can be more appropriately characterised as part of the exotic 'rug' trade. The rugs are individually made from a process of knotting, using a unique pattern, rather than being mass-produced. In the world market, such rugs are best known as 'Persian' rugs and Turkish rugs, although Iran and Turkey are not the sole suppliers. According to the Pakistan Carpet Manufacturers and Exporters Association, there are 150 000–200 000 looms in the country. The number of weavers is estimated at between 200 000 and 250 000. Carpet-making takes place in all the four provinces of Pakistan (source: http://www.chinapost.com.tw/supplement/2007/08/14/118375/Carpet-industry.htm).

6.8 Carpet production in Nepal[10]

The art of weaving is an old tradition in the Kingdom of Nepal, especially in the mountainous region of the country. Radii, Pakhi, Bakkhu, and Darhi (with pile) are well-known Nepalese carpet products made in these regions using indigenous wool. These products used to be confined to the domestic market. The development of an export-quality carpet was initiated with the influx of the Tibetan refugees in the early 1960s. Credit is given to the Swiss Agency for Technical Assistance (SATA) for its contribution to the development of the carpet industry in Nepal through financial and technical support given to the Tibetan refugee resettlement programmes. Initially it was launched as a source of livelihood for the Tibetan refugees and marketing was limited to tourists visiting the kingdom. Efforts to gain access to the international market arena paid off in 1964 when the first commercial shipment left for Switzerland. With vision and entrepreneurial skill, Nepalese carpet-making was transformed into an internationally recognised commercial commodity and remains the most important export from Nepal.

Nepalese-Tibetan carpets are made predominantly by hand and qualities range from 60–150 knots per square inch. Monitoring systems are in place to ensure that only wool from the highest quality fleeces is imported for use in these carpets. The traditional designs of the Nepalese-Tibetan carpet are basically influenced by Buddhism, but in recent years Nepalese manufacturers have introduced modern designs and colours in line with present-day market tastes. The traditional size has been replaced by a wide range of sizes from 0.25 sq m to 56 sq m in circular, octagonal and customised shapes. The desired designs, styles and shades are created by local designers and technicians with regular feedback from the market. At present, 95% of carpet production is concentrated in the Kathmandu valley with the remaining 5% spread over a number of other districts of the country.

6.9 Carpet production in Turkey[11]

Turkish carpets are among the most desirable household items all over the world since Marco Polo commented on their beauty and artistry in the 13th century. Their rich colours, warm tones, and extraordinary patterns with traditional motifs have contributed to the status that Turkish carpets have maintained ever since. A number of carpets from this period, known as the Seljuk carpets, were discovered in several mosques in central Anatolia, beneath many layers of subsequently placed carpets. Mosques are considered as communal centres in a Muslim community. In addition, since praying requires kneeling and touching the ground with one's forehead, the mosques are covered from wall to wall with several layers of carpets, contributed by the faithful as an act of devoutness. The Seljuk carpets are now in the museums of Konya and Istanbul in Turkey. It is very exciting to imagine that we might be looking at the very same carpets that Marco Polo praised in the year 1272.

The art of weaving was introduced to Anatolia by the Seljuks towards the end of the 11th and the beginning of the 12th centuries when Seljuk rule was at its strongest. In addition to numerous carpet fragments, many of which are yet to be documented, there are 18 carpets and fragments which are known to be of Seljuk origin. The technical aspects and vast variety of designs used prove the resourcefulness and the magnificence of Seljuk rug weaving. The oldest surviving Seljuk carpets are dated from the 13th to 14th centuries. Eight of these carpets were discovered in the Alaeddin Mosque in Konya (capital of the Anatolian Seljuks) in 1905 and were woven at some time between the years 1220 and 1250 at the high point of the Seljuks' reign. Of these 8 striking rugs, 3 are large complete rugs; 3 are large fragments from small rugs, and 2 are fairly small fragments originating from large rugs. Three more carpet fragments from the Seljuk period were discovered in 1930 in the Esrefoglu Mosque in Beysehir. Today, these rugs are displayed in the Mevlana Museum in Konya and the Kier collection in London. A third group of 7 carpet remnants was recovered in Fostad (old Cairo) in 1935–1936, which were identified as having originated in Anatolia in the 14th century. The most common design characteristics of these rugs are the Kufic border, the eight-pointed star, and the hooked (geometric) motif.

The Turkish rug, which originated in Central Asia, preserved all of its characteristics until the 14th century. After the Ottomans gained control over the whole of Anatolia, changes began to appear in the composition, in the characteristics of the motifs, and in the sizes of the still traditionally woven Turkish rugs. During the Ottoman reign, several Turkish tribes decided to settle down and built a number of villages and small towns. Notably, the village of Hereke was settled on the edge of the Marmara Sea, some 60 kilometers east of Istanbul. The first Ottoman court carpet workshop was established in Hereke and began to weave carpets of uncommonly large sizes to be used in decorating Ottoman palaces. These exceptionally fine rugs were also used to cement relationships with European countries, and were given as gifts to kings and queens, as well as to key army commanders and statesmen. Towards the end of the 14th century, these rugs began to enter European homes, churches and castles through intermediaries such as merchants from Florence and Genoa.

In the 19th century, additional court workshops were opened in Istanbul in the districts of Kumkapi, Topkapi and Uskudar. In 1891 Sultan Abdullhamid II also increased the number and sizes of the carpet workshops in Hereke. Throughout their development – from Central Asia to the Caucasus region to the Anatolian plains, steppes, and costal areas – and through the Seljuk and Ottoman eras, Anatolian rugs have maintained the wholesomeness and uniqueness of their origin. Turkish court rugs were originally influenced by local communities brought under Turkish control, but were modified to Turkish standards and requirements.

Anatolian rugs are unbelievably rich in design, colour and symbols. Today, these fine rugs are woven in more than 750 villages and tribal (nomadic) areas. Each of these rugs is different in their particular design, symbolism, and relative size. These characteristics are passed on from mother to daughter, and thus for centuries they have kept the same designs, symbols, and beautiful shades of colour.

6.10 Carpet production in Europe

Oriental carpets began to appear in Europe after the Crusades in the 11th century. Until the mid 18th century they were mostly used on walls and tables. With the exception of royal or ecclesiastical settings, they were considered too precious to cover the floor. From in the 13th century, Oriental carpets begin to appear in paintings (notably from Italy, Flanders, England, France, and the Netherlands). Carpets of Indo-Persian design were introduced to Europe by the Dutch, British, and French East India Companies of the 17th and 18th century.

6.10.1 Spanish carpets

Although isolated instances of carpet production predate the Muslim invasion of Spain, the Hispano-Moresque examples are the earliest significant body of European-made carpets. Documentary evidence shows production beginning in Spain as early as the 10th century AD. The earliest extant Spanish carpet, the so-called Synagogue carpet, is a unique surviving example dated to the 14th century. The earliest group of Hispano-Moresque carpets, Admiral carpets (also know as armorial carpets), has an all-over geometric, repeat pattern punctuated by blazons of noble Christian Spanish families. Many of the 15th-century Spanish carpets rely heavily on designs originally developed on the Anatolian Peninsula. Carpet production continued after the re-conquest of Spain and eventual expulsion of the Muslim population in the 15th century. Sixteenth-century Renaissance Spanish carpet design is a derivative of silk textile design. Two of the most popular motifs are wreaths and pomegranates.

6.10.2 French carpets

In 1608 Henry IV initiated the French production of ‘Turkish-style’ carpets under the direction of Pierre Dupont. Production was soon moved to the Savonnerie factory in Chaillot, just west of Paris. The earliest recognised style produced by the Savonnerie factory, then under the direction of Simon Lourdet, can be seen in the so-called Louis XIII carpets. This is a misnomer, however, as they were produced in the early years of Louis XIV’s reign (*c.* 1743–1761). They are densely ornamented with flowers, sometimes in vases or baskets, the designs being based on Dutch and Flemish textiles and paintings. The most famous Savonnerie carpets are those made for the Grande Galerie and Galerie d'Apollon in the Louvre *c.* 1665–1685. These 105 masterpieces, made under the artistic direction of Charles Le Brun, were never installed as Louis XIV moved to Versailles in 1678. Their design combines rich acanthus leaves, architectural-style framing, and mythological scenes together with emblems of Louis XIV. Pierre-Josse Perrot is the most well-known of the mid-18th-century carpet designers. His many surviving works and drawings display graceful rococo s-scrolls, central rosettes, shells, acanthus leaves, and floral swags. The Savonnerie manufactory was moved to the Gobelins district in Paris in 1826. The Beauvais factory, better known for its tapestry, made knotted pile carpets from 1780 to 1792. Carpet production in small, privately owned workshops in the town of Aubusson also began in 1743. Carpets produced in France typically employ the symmetrical knot.

6.10.3 English carpets

Knotted-pile carpet-weaving technology probably came to England in the early 16th century with Flemish Calvinists fleeing religious persecution. Because many of these weavers settled in Eastern England in Norwich, the 14 extant 16th and 17th century carpets are sometimes referred to as 'Norwich carpets'. These display either adaptations of Anatolian or Indo-Persian designs or employ Elizabethan-Jacobean scrolling vines and blossoms. All but one are dated or bear a coat of arms. Like the French, English weavers used the symmetrical knot.

There are documented and surviving examples of carpets from three 18th-century factories: Exeter (1756–1761, owned by Claude Passavant, three extant carpets); Moorfields (1752–1806, owned by Thomas Moore, five extant carpets); and Axminster (1755–1835, owned by Thomas Whitty, numerous extant carpets). However, English carpets will forever be associated with the town of Kidderminster in the English county of Worcestershire. This town became the heart of the UK carpet industry throughout the Industrial Revolution. Even now, a large percentage of the town's 55 000 population is still employed in this industry.

The Exeter and Moorfields factories were both staffed with weavers from the French Savonnerie and, therefore, employed the weaving style of that factory and its Perrot-inspired designs. In the early 1800s the neoclassical English designer Robert Adam supplied designs for both Moorfields and Axminster carpets based in part on Roman floor mosaics. Some of the best-known rugs using his designs were made for a number of aristocratic houses in England: Syon House, Osterley Park House, Harewood House, Saltram House, and Newby Hall. Six of the Axminster carpets are known as the 'Lansdowne' group. These have a tripartite design with reeded circles and baskets of flowers in the central panel flanked by diamond lozenges in the side panels. Axminster Rococo designs often have a brown background and include birds copied from popular, contemporary engravings.

6.10.4 Scandinavian carpets

The traditional Scandinavian carpet is the rya, made from hand-knotted wool. Dating from the 15th century, the first ryas were coarse, long-piled, heavy covers used by fishermen instead of furs to protect them whilst at sea. The rugs then became lighter and more ornamental and by the 19th century they were often splendid festive tapestries. Nowadays ryas use a wide range of designs, with individual artists identifiable by distinctive colors, patterns and techniques.

6.11 The international trade in carpets

Statistical information is vital to understand carpet trading from a technological, economic and sociological perspective. The handmade carpet sector has traditionally been driven by a single force: art and craft (AC). More recently, the industry has sought to combine this with an additional force, technology and economy (TE) to improve productivity and ensure consistent quality. The combination of the two forces (AC+TE) has been used to help accelerate the growth of the sector.

6.11.1 Handmade carpet export, import and the market share as at 2001[12]

The handmade sector exported US$1 759 855 000 as at 2001 compared to US$8 120 102 000 for floor covering as a whole for the same period (Table 6.5). The contribution of the handmade sector in value terms to the entire floor covering sector is 21.7%. The industry represents millions of years of time spent by the hundreds of thousands of workers in the industry. This can be estimated

Table 6.5 Handmade carpet exports in 2001

Country	$1000	Compare to year 2000	World market share (%)
World: handmade	1759855	−11%	100
Iran	537243	−17%	30
India	330245	−6%	18
China	227111	−9%	12
Pakistan	211089	−3%	11
Nepal	116430	−17%	6
Turkey	97957	0%	5
World: overall floor covering	8120102		

Table 6.6 Handmade carpet imports in 2001

Country	$1000	Compare to the year 2000	World market share (%)
World: handmade	1631538	−9%	100
America	540521	−8%	33
Germany	407873	−8%	24
Japan	82680	−15%	5
Italy	67625	−23%	4
Britain	66769	−4%	3
U.A.E.	227111	−6%	2
Switzerland	211089	−4%	2
France	116430	−4%	2
Canada	97957	−15%	1
World: overall floor covering	7949639		

on the basis of square metres of production per person year based on type of carpet (e.g., hand knotted), knots per square inch and other specifications. As a comparison, Table 6.6 illustrates the handmade carpet imports for 2001.

6.11.2 International trade statistics[13]

The analyses produced in Tables 6.7 and 6.8 show the positions of five handmade carpet exporters in the list of the top 20 exporting countries, indicating the consumer's preference for handmade carpets. The top six positions in the list of the top 20 importing countries belong to the USA, the UK, Germany, Canada, Japan and France as evident from Tables 6.9 and 6.10.

6.11.3 Trade in wool knotted carpets by the top 20 countries[14]

Details are provided in Tables 6.11 and 6.12.

6.11.4 Trade in wool woven carpets by the top 20 countries

Details are provided in Tables 6.13 and 6.14.

6.11.5 Trade in wool tufted carpets by the top 20 countries

Details are provided in Tables 6.15 and 6.16.

6.11.6 Value and volume

Details are provided in Table 6.17.

Table 6.7 Export statistics of top exporting countries (in US$ '000)

Sr No.	Country	2001	%	2002	%	2003	%	2004	%	2005	%
1	Belgium	1,941,350	23.91	2,029,849	24.31	2,276,160	23.92	2,482,956	23.22	2,319,398	20.14
2	India**	583,774	7.19	616,115	7.38	726,976	7.64	771,178	7.21	1,125,573	9.78
3	Netherlands	569,117	7.01	620,087	7.43	812,943	8.54	1,009,288	9.44	1,078,033	9.36
4	USA	737,105	9.08	716,655	8.58	717,974	7.55	812,972	7.60	934,437	8.12
5	China**	496,090	6.11	561,195	6.72	638,387	6.71	774,148	7.24	933,781	8.11
6	Turkey**	263,281	3.24	286,619	3.43	381,114	4.01	517,751	4.84	670,141	5.82
7	Iran	601,951	7.41	625,103	7.49	666,081	7.00	629,688	5.89	637,962	5.54
8	Germany	439,903	5.42	438,147	5.25	505,187	5.31	608,046	5.69	580,750	5.04
9	UK & Northern Ireland	353,250	4.35	327,843	3.93	358,062	3.76	401,406	3.75	396,600	3.44
10	France	253,213	3.12	259,837	3.11	293,146	3.08	322,720	3.02	326,815	2.84
11	Pakistan**	265,187	3.27	243,590	2.92	230,745	2.42	252,352	2.36	287,598	2.50
12	Canada	203,697	2.51	202,728	2.43	208,335	2.19	232,603	2.17	242,796	2.11
13	Italy	125,393	1.54	124,287	1.49	155,790	1.64	175,180	1.64	182,497	1.58
14	Denmark	122,230	1.51	123,627	1.48	145,323	1.53	155,628	1.46	175,665	1.53
15	Saudi Arabia	58,958	0.73	87,728	1.05	121,242	1.27	114,667	1.07	154,554	1.34
16	Switzerland	98,869	1.22	96,719	1.16	97,190	1.02	114,167	1.07	112,743	0.98
17	Thailand	50,405	0.62	51,634	0.62	67,433	0.71	89,761	0.84	100,214	0.87
18	Austria	70,647	0.87	68,953	0.83	80,813	0.85	99,527	0.93	96,519	0.84
19	Poland	44,882	0.55	48,798	0.58	57,567	0.60	72,051	0.67	93,984	0.82
20	New Zealand	43,233	0.53	58,069	0.70	74,824	0.79	79,804	0.75	80,239	0.70
	TOTAL	8,120,102	100.00	8,350,797	100.00	9,515,649	100.00	10,694,921	100.00	11,514,024	100.00
	Non-exporting countries out of 148	18		18		23		37		47	
	No. of exporting countries out of 148	130		130		125		111		101	

* Where 1 indicates highest and 20 indicates lowest in value term export

** Recognised and leading handmade carpet exporting countries.

Table 6.8 World ranking with respect to export of floor coverings

Sr. No.	Country	Ranking* amongst Top 20 exporting countries 2001	2002	2003	2004	2005
1	Belgium	1	1	1	1	1
2	India**	4	5	3	5	2
3	Netherlands	5	4	2	2	3
4	USA	2	2	4	3	4
5	China**	6	6	6	4	5
6	Turkey**	9	9	8	8	6
7	Iran**	3	3	5	6	7
8	Germany	7	7	7	7	8
9	UK & Northern Ireland	8	8	9	9	9
10	France	10	10	10	10	10
11	Pakistan**	11	11	11	11	11
12	Canada	12	12	12	12	12
13	Italy	13	13	13	13	13
14	Denmark	14	14	14	14	14
15	Saudi Arabia	17	16	15	15	15
16	Switzerland	15	15	16	16	16
17	Thailand	18	19	19	18	17
18	Austria	16	17	17	17	18
19	Poland	19	20	20	20	19
20	New Zealand	20	18	18	19	20
	No. of exporting countries out of 148	130	130	125	111	101
	Export value in '000 million dollars	8.120	8.351	9.516	10.695	11.514

* Where 1 indicates highest and 20 indicates lowest in value term export

** Recognised and leading handmade carpet exporting countries.

Table 6.9 Import statistics of top importing countries (In US$ '000)

Sr. No.	Country	2001	%	2002	%	2003	%	2004	%	2005	%
1	USA	1,509,519	18.99	1,638,080	20.64	1,781,400	20.13	1,967,183	19.23	2,142,305	20.28
2	UK & Northern Ireland	954,784	12.01	1,035,841	13.05	1,209,431	13.67	1,523,027	14.89	1,421,051	13.46
3	Germany	1,166,786	14.68	1,040,929	13.12	1,109,430	12.54	1,306,469	12.77	1,157,883	10.96
4	Canada	504,700	6.35	508,367	6.41	533,600	6.03	605,335	5.92	696,718	6.60
5	Japan	376,870	4.74	369,985	4.66	395,552	4.47	465,588	4.55	506,797	4.80
6	France	354,396	4.46	354,265	4.46	410,695	4.64	449,502	4.39	441,498	4.18
7	Netherlands	248,829	3.13	233,362	2.94	277,623	3.14	341,241	3.34	359,341	3.40
8	Italy	183,592	2.31	192,043	2.42	223,709	2.53	259,953	2.54	270,949	2.57
9	Belgium	208,334	2.62	205,742	2.59	229,340	2.59	249,238	2.44	256,276	2.43
10	Australia	103,590	1.30	123,503	1.56	161,110	1.82	195,478	1.91	211,933	2.01
11	Switzerland	170,895	2.15	162,258	2.04	174,092	1.97	191,510	1.87	189,667	1.80
12	Spain	116,511	1.47	130,912	1.65	157,910	1.78	180,273	1.76	188,485	1.78
13	Czech Republic	74,682	0.94	94,360	1.19	116,173	1.31	139,468	1.36	176,422	1.67
14	Mexico	170,102	2.14	173,314	2.18	169,099	1.91	167,390	1.64	170,878	1.62
15	Sweden	123,677	1.56	116,858	1.47	139,286	1.57	148,919	1.46	156,104	1.48
16	Austria	132,342	1.66	115,143	1.45	131,950	1.49	152,554	1.49	155,134	1.47
17	Turkey	51,841	0.65	58,233	0.73	70,764	0.80	114,457	1.12	145,053	1.37
18	Poland	96,995	1.22	98,561	1.24	99,840	1.13	121,936	1.19	139,460	1.32
19	Greece	43,911	0.55	67,533	0.85	93,681	1.06	94,912	0.93	107,580	1.02
20	Saudi Arabia	114,644	1.44	94,144	1.19	80,404	0.91	89,397	0.87	105,143	1.00
21	Ireland	79,629	1.00	69,318	0.87	78,431	0.89	98,922	0.97	102,859	0.97
22	Denmark	70,602	0.89	83,770	1.06	93,434	1.06	94,324	0.92	93,785	0.89
	TOTAL	7,949,638	100.0	7,935,290	100.0	8,849,858	100.0	10,229,916	100.0	10,561,127	100.0
	Non-importing countries out of 171	10		12		15		30		54	
	Importing countries out of 171	161		159		156		141		117	

Table 6.10 World ranking with respect to import of floor coverings

Sr. No.	Country	Ranking* amongst top 20 importing countries 2001	2002	2003	2004	2005
1	USA	1	1	1	1	1
2	UK & Northern Ireland	3	3	2	2	2
3	Germany	2	2	3	3	3
4	Canada	4	4	4	4	4
5	Japan	5	5	6	5	5
6	France	6	6	5	6	6
7	Netherlands	7	7	7	7	7
8	Italy	9	9	9	8	8
9	Belgium	8	8	8	9	9
10	Australia	16	13	11	10	10
11	Switzerland	10	11	10	11	11
12	Spain	14	12	13	12	12
13	Czech Republic	20	17	16	16	13
14	Mexico	11	10	12	13	14
15	Sweden	13	14	14	15	15
16	Austria	12	15	15	14	16
17	Turkey				18	17
18	Poland	17	16	17	17	18
19	Greece		20	18	20	19
20	Saudi Arabia	15	18	20		20
21	Ireland	18			19	
22	Denmark		19	19		
	Importing countries out of 171	161	159	156	141	117
	Import value in '000 million dollars	7.950	7.935	8.850	10.230	10.561

* Where 1 indicates highest and 20 indicates lowest in value term import

Table 6.11 Top 20 countries exporting wool knotted carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
India	29,757	30,751	32,357	34,000	34,331
Iran	24,538	26,771	20,673	16,473	13,211
China	27,989	14,946	15,555	13,399	12,418
Pakistan	5,756	11,775	8,675	8,910	9,342
Nepal	15,027	11,849	6,974	7,645	6,508
USA	1,200	1,566	1,117	1,377	1,666
Turkey	2,654	2,015	1,386	1,634	1,500
Morocco	3,570	2,570	1,740	1,673	1,382
Germany	2,138	3,062	1,603	1,671	1,243
Afghanistan	549	402	1,832	1,257	1,000
Australia	122	934	392	542	932
United Kingdom	1,347	1,262	847	844	660
Ireland	255	889	726	495	449
Sweden	269	404	173	184	356
France	86	174	178	154	284
Belgium	791	510	401	375	271
Netherlands	80	202	600	524	264
Denmark	22	118	242	274	207
Italy	364	167	188	137	205
Mongolia	53	57	214	110	150
Total	118,562	110,424	95,873	91,678	86,379

Table 6.12 Top 20 countries importing wool knotted carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
USA	15,143	25,448	32,890	32,201	31,176
Germany	49,564	32,151	20,275	21,328	18,782
Italy	8,001	5,955	4,503	4,682	3,730
United Kingdom	3,895	3,643	3,010	3,421	3,988
Canada	3,325	4,248	3,431	2,175	2,500
Turkey	16	1,485	1,866	2,440	2,500
Netherlands	1,479	2,544	1,553	2,451	2,158
France	2,954	2,601	1,759	1,920	1,828
Spain	1,739	1,753	1,647	1,863	1,671
Sweden	1,602	1,596	1,118	1,386	1,522
Austria	2,442	2,060	1,034	1,178	1,439
Switzerland	3,192	1,890	1,436	1,300	1,313
Greece	731	811	1,257	987	1,158
Belgium	2,154	1,482	1,101	1,053	1,078
Japan	4,269	1,297	1,016	939	873
Australia	856	1,135	5,141	3,995	845
Denmark	806	689	1,030	993	743
South Africa	300	487	475	587	518
Norway	598	761	411	398	408
Portugal	260	387	341	367	351
Total	103,326	92,423	85,294	85,664	78,581

Table 6.13 Top 20 countries exporting wool woven carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
India	5,083	6,250	15,045	21,005	20,829
Belgium	11,680	13,845	10,984	9,297	8,431
United Kingdom	8,910	6,685	6,026	6,416	5,419
China	168	927	3,169	4,782	4,435
Portugal	1,134	2,246	1,895	2,312	1,973
Poland	840	959	2,050	2,260	1,900
Spain	1,933	1,792	1,598	1,710	1,788
Moldova	663	686	789	1,060	1,370
Switzerland	662	869	928	1,086	1,192
Sweden	177	514	790	816	1,163
Netherlands	1,722	2,649	2,207	2,100	1,070
South Africa	600	2,155	2,504	1,178	1,067
Turkey	2,189	2,989	1,740	2,036	1,067
Ireland	1,314	1,450	1,418	1,300	1,034
Denmark	541	776	1,075	802	909
Germany	492	467	541	645	703
Austria	386	286	420	530	675
France	673	726	449	497	610
New Zealand	1,821	1,084	1,258	1,211	579
Italy	629	917	698	744	566
Total	41,617	48,272	55,584	61,787	56,780

Table 6.14 Top 20 countries importing wool woven carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
USA	10,118	15,416	17,028	18,032	20,249
United Kingdom	5,355	7,259	8,249	8,928	10,116
Germany	4,338	3,361	4,418	5,504	5,829
Sweden	863	1,138	1,714	2,248	3,226
France	3,547	3,323	3,173	2,916	2,694
Greece	650	321	865	2,204	2,105
Netherlands	1,142	1,927	1,580	1,610	1,782
Austria	753	647	837	1,215	1,461
Spain	296	544	840	1,127	1,418
Ireland	1,311	1,143	1,667	936	1,336
Italy	1,883	1,384	1,120	1,295	1,330
Japan	2,584	1,840	1,568	1,509	1,104
Belgium	648	1,563	593	786	1,036
Hong Kong	1,083	1,090	1,011	1,067	1,011
Australia	2,318	3,418	1,357	969	855
Switzerland	799	798	828	792	844
Russia	539	474	894	880	800
Canada	722	963	1,082	839	691
Norway	1,326	1,029	785	683	642
Poland	223	372	637	620	550
Total	40,498	48,010	50,246	54,160	59,079

Table 6.15 Top 20 countries exporting wool tufted carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
Belgium	23,787	20,220	28,123	31,438	29,943
India	6,077	18,268	23,012	27,702	27,401
Netherlands	5,137	2,311	8,101	14,185	13,077
China	9,426	11,605	12,944	12,649	12,185
New Zealand	2,239	10,109	11,461	10,823	11,062
Greece	323	392	4,431	4,118	4,378
Denmark	2,717	2,727	3,002	2,815	3,176
Portugal	1,172	2,130	2,722	2,786	3,010
United Kingdom	4,736	2,801	3,268	3,180	2,713
Thailand	344	2,189	676	1,809	2,653
USA	498	1,390	2,284	2,050	2,056
Australia	1,068	2,928	2,920	4,431	1,754
Italy	184	726	1,398	1,348	1,385
Germany	1,329	1,918	1,759	1,597	1,080
Bulgaria	1	895	1,285	1,147	1,000
Spain	197	194	184	214	654
France	336	314	926	681	618
Switzerland	1,414	419	315	312	431
Ireland	2,328	906	757	760	336
Sweden	101	151	236	290	261
Total	63,414	82,593	109,804	124,335	119,173

Table 6.16 Top 20 countries importing wool tufted carpets (Units: tonnes (act. wt))

Country	1995	2000	2003	2004	2006 (P)
United Kingdom	9,848	17,526	32,499	38,395	36,493
USA	18,146	28,247	33,100	33,027	34,758
Australia	2,122	2,711	4,695	5,669	6,546
Germany	14,623	9,810	7,981	7,869	6,118
Ireland	2,521	2,061	2,847	2,900	3,689
New Zealand	870	1,567	2,066	3,583	3,600
Canada	1,149	2,519	2,581	2,878	3,305
Netherlands	4,472	2,418	1,930	2,468	2,626
France	3,808	3,983	2,789	2,438	2,021
Hong Kong	1,506	1,142	1,000	1,227	1,415
Belgium	1,162	716	974	718	1,013
Sweden	539	462	554	977	853
Spain	463	549	806	882	852
Switzerland	2,161	998	713	637	668
Greece	179	97	386	519	641
Italy	525	359	451	867	546
Japan	1,373	491	421	529	528
Denmark	283	514	435	364	527
Poland	237	427	620	450	430
Russia	274	206	428	442	377
Total	66,261	76,803	97,276	106,839	107,006

Table 6.17

(a) Unit value realisation of import to EU by exporting countries[15]; Wymen Lisa, RUG News, USA, Carpet Conclave, Varanasi 8 July 2008.

Exporting country	Unit value (Euro/m^2) 2006	Unit value (Euro/m^2) 2005	Change % (2006 over 2005)
Iran	76.52	69.34	10.35
India	22.55	21.04	7.18
Nepal	45.09	39.62	13.81
China	9.47	17.10	−44.62
Pakistan	58.19	45.52	27.83
Afghanistan	35.16	37.11	−5.25
Morocco	30.47	31.48	−3.21
Turkey	56.60	20.32	178.54
Tunisia	91.25	97.98	−6.87
Others	22.87	21.22	7.78
Total	36.71	33.62	9.19

(b) unit value realisation of floor covering imports to US: wool*

Country	UVR $/m^2		Change % 2007 over 2006
	2006	2007	
World	33.24	33.02	−0.66
India	27.92	27.54	−1.36
China	23.74	25.01	5.35
Pakistan	94.17	83.83	−10.98
Iran	63.88	56.31	−11.85
Nepal	86.03	100.80	17.17

* Wymen Lisa, RUG News, USA, Carpet Conclave, Varanasi 8 July 2008

6.12 Terminology in carpet production

Common/traditional terminologies[16] relevant to handmade carpets, consisting of various terms and definitions arranged alphabetically (A to Z), are shown in the Appendix on pages 173–81.

6.13 The role of handmade carpets in modern carpet production

It is usually easy to distinguish between a manmade and handmade carpet. Looking at the back of any rug will reveal the structures of knot. Handmade rugs have irregular knots and an uneven structure. In machine-made carpets the more regular sequence of knots is due to the controlled tension of the threads used to create the knots. Pinching a manmade carpet tightly results in greater compression with the sensation that the fingers seem to be going right through to the other side. Given the more irregular pattern of knots, one feels much more body and substance in pinching most hand-knotted rugs. Selvedges and ends are another way to identify if a rug is machine-made or hand-knotted. Observe carefully how perfectly even the sides and ends of the machine-made rug look compared to hand-knotted which will be irregular and imperfect.

Production times for handmade carpets are based on the size of the carpet, manufacturing technique, the materials used, the knot count, the design, the skill of the weaver, and scheduling or time allotted for the item. Some large carpets and high knot count silk carpets can even take years to finish. It takes almost a week to weave one metre-square of a kilim.

In the world of modern carpet production, handmade carpets combine the aesthetic appeal of luxury items such as jewelry, on the one hand, and utility, like consumer goods, on the other. A craftsperson spends an amazing amount of time, skill and energy to dye the wool for a handmade carpet, create the design and weave the carpet itself. The effect on the senses can be the same as a work of art. Genuine hand-knotted oriental rugs and carpets are also special in the way they perform, age, clean and appreciate in value compared to machine-made carpets. The following discussion highlights the continued importance of handmade carpet production.[17–18]

Machine-made carpets predominantly use synthetic fibres while hand-knotted rugs and carpets predominantly use natural fibres such as wool. Unlike synthetic fibres, wool is a known sound and heat insulator and is breathable. Wool repels dirt very well and is easily cleaned. Wool ages better because wool fibres soften over time. With proper care and use wool carpets can develop an attractive patina. Pure wool-based carpets become ‘glazed’ when used. The glazing happens when wool develops a sheen. The sheen is, in fact, oil from human hands and feet that have over time coated each fibre. Carpets develop a shine as the wool fibres are polished through use over time. In addition natural dyes used in many handmade carpets also soften over time, staying the same colour but changing in shade. This patina caused by age and use can enhance the appearance and feel of the carpet. Every time a hand-knotted carpet is used and washed its natural aesthetics are enhanced, becoming in the process more valuable and desirable.

Many machine-made carpets are less easily cleaned and more disposable. Because machine-made carpets are loomed in one continuous reel they can sustain damage more easily and are more difficult to repair. Machine-made carpets do not have knots. Rather, threads are looped and subsequently backed using cold or hot latex. This latex backing can emit harmful and noxious fumes. Machine-made carpets are designed to display complete uniformity in design and manufacture unlike hand-made carpets which are more individual. Synthetic materials look their best the day one buys them and then tend to deteriorate with age. Machine-made carpets can be hard to clean properly. All rugs and carpets tend to accumulate dirt near the 'roots' of the pile fibre. Passing water through the back of the rug removes dirt and grime thoroughly. Water can pass through the mesh-like backing of a hand-knotted rug but not through the latex backings of many machine-made rugs. The result is that a machine-made carpet cannot be cleaned as well as many hand-knotted carpets. Acrylic colours do not soften in the same way as natural dyes but eventually start to fade. Eventually the latex backing often hardens, becomes brittle and damaged.

Handmade carpets are sometimes seen as more expensive than machine-made carpets. In reality the better machine-made rugs are relatively expensive even compared to a handmade carpet and can exceed the cost of other hand-knotted carpets of comparable size and design. Handmade carpets often age well, retaining their aesthetic appeal and, as a result, retain their value. Machine-made carpets must often be replaced as they age. Besides their aesthetic appeal, their ability to be cleaned and maintained properly, a good hand-knotted rug or carpet has better resale value. In the long term, the value of handmade carpets is increasing. More people around the world are able to afford furnishings such as quality handmade carpets. The traditional role of young artisans learning this craft is disappearing in the primary carpet-making countries. Moreover, productivity is often lower. As a result, increased demand combined with declining supply is tending to increase prices.

Handmade carpets have excellent sound absorption qualities. Depending on the frequency of a particular sound and the structure of the carpet, the sound absorption coefficient can be as high as 90. Handmade carpets also have characteristics that increase insulating properties. This is because of:

- low conductivity (high thermal resistance) of the fibres used
- the trapping of air in spaces between the fibres and yarns due to the more irregular structure and greater average thickness of a handmade carpet, increasing its insulating properties.

The fibre and structure of handmade carpets greatly reduce the radiation of heat from the surface of the fibres. In addition they are often better at reflecting light.[19]

Every handmade carpet,[20] with its patterns, resembles a collection of messages, beliefs and symbols. Every pattern that is woven onto a carpet is a picture of a feeling, a desire or a wish. Every carpet represents a living history from the distant past to the present in which craftspeople have represented their thoughts and feelings in complex codes of pattern, symbol and colour. Carpets have their own language, each different pattern on a carpet having a particular meaning in which artisans could express their feelings. It could, on occasion, say what words could not. For example, in ancient artisan tribes, when a girl loved someone, she could not tell her parents if they disapproved of the match. However, the 'chain' motif woven into a carpet indicated her desire to marry soon and start a family. Such motifs are still used in kilims today. Traditionally, a carpet weaver puts a planned imperfection in the design as recognition that 'only God is perfect'. A challenge is finding that part of the carpet different from the principal design pattern.

Many handmade carpets use natural dyes.[21] Nature provides its own store of colours. Trees, flowers, plants and even certain types of soil (particularly those containing iron oxide) supply incredibly beautiful colours. Certain archaeological findings indicate that such plant dyes have been used for a very long time. They developed into a trade from regions like Anatolia to Europe. The discovery of the composition of the Turkish red (cramoisi) dye, as a result of the analytical studies by C. Liebermann in 1868, led to its chemical production in Europe, dealing a serious blow to the production and export of root dyes in Anatolia. Chemical dyes were introduced in Turkey in 1882 and from then on production of root dyes in Anatolia began to decline as a result of aniline dyes imported from Europe.

Today a handmade carpet is usually made using at least some commercially available chemical dyes alongside traditional natural dyes. Even tribal carpets are commonly made of a mix of vegetable and chemical dyes. The continued use of naturally dyed wools, however, still makes handmade carpets and rugs unique and unsurpassed in quality. Pine husk and rubia plants, for example, are used for red colours, oleander and develik plants are used for green colours. Some other plants used in dyes are Madder root, indigo, St. John's wort, onion, saffron, sumach, camomile, rhubarb, turmeric, sage, poppy, buckthorn, quince, almond, walnut, chestnut and henna. It is said that when using natural dyes one never can achieve the exact same shade of a colour a second time. This is one of the things that makes every piece/lot unique.

The use of underage and child labour in traditional carpet making is a serious concern in many parts of the world. Many carpet manufacturers in developing countries were/are prone to exploit children for their inexpensive labour in situations where economic pressures often prevail over education needs and health concerns. Today all carpet-producing countries are committed never to use children in the manufacture of their products. In most countries, legislation does not condone such practices in industry and explicitly prohibits workers under the age of 18 in the workshops. Workshop communities support welfare and health programmes to help ensure a better quality of life for their workers' families and to keep their underage children out of the workplace. Additionally, there are various registered non-profit organisations like 'Himalayan Health Initiative', 'Care and fair', 'Kaleen label Initiative', etc., to offer free education and health services to carpet workers and their families. The handmade carpet industry is moving towards greater social accountability through internationally recognised standards such as SA 8000 certification besides adopting other international quality systems which encourage training and improvement of skills.

In the early 1990s, intensive campaigns against the use of child labour led to a proposal to totally boycott the import of handmade carpets. A boycott would have led to disaster, with many families losing their earnings and would have further worsened the already severe problem of poverty in developing countries. To avoid such negative consequences RUGMARK, the initiative against the use of illegal child labour in the carpet industry, was begun in countries such as India in 1994 by carpet manufacturers and exporters along with UNICEF and leading non-governmental organisations (NGOs) under the guidance of IGEP.

The problem of child labour is linked with various socio-economic conditions. Poverty is considered its main cause, which leads to illiteracy, low productivity, poor health and low life expectancy. The problem of child labour is thus a vicious circle. To help resolve it, RUGMARK is trying its best to break this circle by helping poor children. It is spreading awareness among the people in the carpet belt about the abuse of child labour and trying to improve the basis for structural changes. With the experience of RUGMARK, IGEP is now working for the introduction of social standards on a voluntary basis in the Indian industry. The strategy is based on improvement, support and co-operation. The goal is to improve the basic social and environmental conditions rather than stopping business relations on account of unsatisfactory conditions at work sites. Meanwhile, progress in the leather and textiles sectors is being made with the support of several Indian associations. This has encouraged IGEP to start the ES Mark. 'E' stands for ecological and 'S' for social responsibility. The ES mark will certify that the company meets ambitious social and environmental conditions in sectors such as jewelry, handicrafts, sports goods and toys as well as carpet making.

6.14 Choosing and maintaining a handmade carpet

The purchase and installation of your carpet is a kind of investment. It needs also proper care to protect it against wear and tear and the other hazards of daily use.[22,23] There are a number of factors to consider in choosing a carpet, the first of which is to consider the right fibre. To pick the right fibre, consider how you live in each room. There are basically four types of fibre:

1. Nylon is the most durable and stain resistant carpet fibre available. It is the fibre of choice for homes with pets and children and for those who entertain a lot. It is perfect for heavy traffic in hallways and stairs.
2. Polyester is known for its luxurious look, feel and wonderful selection of colours and styles. It is good value for homes with a normal amount of traffic, although less durable and stain resistant than nylon.
3. Olefin offers good stain and moisture resistance, but scores below nylon and polyester for wearability. It can be a good choice in loop pile construction although its colours and styles are limited.

4. Wool, favoured for its natural beauty, has natural soil resistance quality, but is not inherently stain resistant. Wool looks good for a long time and is well constructed.

Here are some suggestions for maintaining carpets:

- Use a walk-off mat at each busy entrance to absorb soil and moisture. This mat should be cleaned regularly so that it does not become a soil source itself, especially in inclement weather.
- Rotate the carpet at least once a year to prevent bright sunlight damaging the dyes.
- Use a good quality underlay below the carpet. This will not only give better resilience underfoot, but prolong the life of your carpet. It also can prevent slipping leading to accidents.
- Vacuum your room frequently, at least once a week and more often in high traffic areas. The surface of your carpet should be vacuumed lightly in the direction of the pile.
- If you want to store your carpet for some time, first clean it and roll it in brown paper. Do not use plastic bags or leave it in a damp place as mildew will form and destroy its foundation.

If properly cleaned, your carpet will last for a long time:

- Professional cleaning every two or three years especially for silk carpets is recommended.
- How often the carpet should be cleaned will depend on the traffic and weather. Generally, carpets in light traffic areas should be cleaned once a year; in normal traffic areas once every six months and in heavy traffic areas probably once a month.
- In case of self-cleaning of a carpet, the most common problems are over wetting and excessive use of detergents.
- Therefore after cleaning, it is important to ensure that the carpet is dried within twelve hours, otherwise mould or mildew may grow on it.

Careful use of good ventilation, central heating and air conditioning systems will help the drying process. Exercise care with detergents as increasing quantities beyond the recommended solution levels will not enhance cleaning effectiveness while they may leave excess residues in the carpet which will lead to a rapid re-soiling.

How long your carpet will last depends on how well it is made. Quality construction will affect the durability, appearance and price of the carpet and is most influenced by a number of variables such as fibre performance, the twist and other parameters for yarn manufacturing, together with the density of the knots/tufts. Twist refers to how tightly the fibre (carpet yarn) has been twisted. This is especially important in cut pile carpet because the tips are exposed and can become untwisted, giving the carpet a matted and worn appearance. The tighter the yarn is twisted, the better the carpet will stand up to crushing and matting. Frieze carpet has the highest twist level at about 7–9 twists per inch (TPI), whereas most cut pile carpet styles have between 3 and 6 twists per inch. Density refers to both the amount, and how tightly packed together the fibres are within the carpet. The closer together the fibres are placed, the denser the carpet will be, and the better it will wear and perform. Ways to check for carpet density include trying to reach the carpet backing by pressing your fingers on the carpet fibres. The more difficult it is to reach the backing, the denser the carpet. Or with outward facing tufts, bend the carpet into a U-shape and look at how much of the carpet backing is visible. The less backing that shows, the denser the carpet.

There are various basic styles of carpet. Cut pile consists of yarns that are cut at the ends. The soft feel of cut pile carpet makes it a perfect choice for the most comfortable areas of your home – bedrooms, living rooms and family rooms. There are five basic styles of cut pile carpet: Velvet, Saxony, Frieze, Shag, and Cable, each provide a different look and texture. The primary difference among these styles is the amount of twist in the yarns that will ultimately influence the carpet's durability. Loop pile has yarns that are looped and uncut on the carpet surface. The pile height can vary from low, tightly constructed to a more luxurious high-level pile. Loop pile carpet has excellent durability, strength and soil-hiding capabilities. This style is ideal for heavy traffic areas. Berber is a popular style of loop pile carpet that can be constructed as a level-loop or multi-loop carpet. As the name suggests, a cut and loop pile carpet has some cut piles and some that are not, in order to create a different surface look and texture. Cut and loop carpets offer good performance but are slightly less durable than loop carpets.

The future potential of the handmade carpet sector has great potential given the quality of the product. There are a number of initiatives to take the sector forward in the 21st century.[24–26]

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Appendix: terminology relating to handmade carpets

A

Afghan-	A typical geometrical design associated with carpets from Afghanistan.
Asami-	Loom holder, a person in whose possession a carpet is woven.
Assan-	A small rug for sitting on.
Anga-	Waste cotton yarn.
Agarai-	Brown.
Addha-	Half-woven carpet.
Aaincha-	Uneven carpet from length to width.
Amphora print	A typical Indian 'motif'.

B

Baitha-	The unused colour of pile yarn commencing with a particular knot in design.
Baithoki-	The phera in the design from which the weaving of carpet is to commence in a convenient form; the beginning side of the design.
Bale-	A compressed packet containing wool, yarn, carpets, etc.
Balooch-	A typical geometrical design associated with carpet from Baloochistan.
Bana-	Weft yarn that is yarn used width-wise in a carpet.
Band-	Complete repeat of design.
Bandi-	Leasing cord.
Barbar-	Equal, when a carpet being woven is exactly equal to required size.
Barhotri-	A carpet being woven larger than the specified size.
Baya-	Arrangement of knitted cotton twine, for opening shed of loom in carpet weaving.
Bazru-	A term locally used in Uttar Pradesh for carpets made by weavers on their own without a specific order.
Benta-	Handle of knife.
BIDRI	A typical Indian 'motif'.
Bis-	Twenty consecutive warp threads.
Bokhara-	A group of typical geometric designs associated with the Turkoman area of central Asia.
Bujbun	a) Fluff of pile yarn fallen or clipped off from carpet during weaving. b) Waste after clipping of carpet.
Bundh	Rope which is used for tying the warp roller.
Bhattaha	Fewer design clauses in the rugs.
Bengal	Usually a design, not consisting of more than 4 colours.
Binkar/Binwaiya	Weaver.
Barkari-	A piece of jute-or-cotton cloth used by the weavers and loom holders in handling the ready carpet, or using as a mat for different purposes.
Bukani	Dyes.

C

Carpet Yarn Count	Yarn numbering in Indirect system, defined as No. of yards in 14.175 gm prevalent in Indian Carpet Industry in general and Bhadohi/Bikaner/Panipat carpet sectors in particular.
Carved carpet	A carpet with designs created by deeply embossing the appropriate parts of the pile.

Chintz	A typical Indian 'motif'.
Chala	A knot in one row on the right-hand side or a knot of the same colour in the preceding row.
Chalta naqsha	A running design, which repeats regularly.
Chand	Ornate medullation placed in the centre of a carpet design.
Chara	Fringes.
Chari-Utari Dam	A weave of carpet where the ground fabric is woven in 2/2-warp rib weave.
Chauthai	One-quarter, hence motif appearing at each of four corners of the part of a carpet bounded by the border.
Chharh	Iron rod used for attaching warp to beam of the loom.
Chhura	Knife used for cutting pile tufts while knotting.
Chin	Single row.
China	A carpet design of Chinese origin having typical motifs at two or more corners with or without central motifs.
Chowdhri	Master weaver.
Clipper	One who clips the carpet for cutting off the top of pile to make the surface even.
Chhurih	Bow-shaped knife.

D

Dam	Opening of warp shed for insertion of weft.
Dardan	Wooden roller used for winding the carpet.
Durrie	a) Pileless floor-covering fabric, made only with warp and weft, the warp being fully concealed by the weft, or b) The strip of dari-like fabric woven at commencement and termination of carpet.
Dehari	A day's work, nominally 6000 knots which a man is expected to tie in a working day.
Derh-Tapkia	A defect in a carpet caused by making one knot on three warp threads.
Dhari	A stripe, one knot or more in width, which separates matan from border, or border from bel or tasma, etc.
Dharu	Warp heald.
Do Dam	A weaver with two shots of weft, a tharri and a lachchhi, between adjacent pheras.
Do-Tapkia	Making knots on four warp threads in place of two warp threads as in the double knots.
Dukandar	Loom-holder.
Do-Tara	Same as double warp.
Design plate	A sheet of paper on which design of any particular carpet is drawn and painted.
Daura	Jamadars, visiting and taking report to different looms.

E

Ek-Chhorh Ek-Chhora	Alternate knots tied with yarn of two different colours or types.

F

Farsh	Pileless floor covering fabric, made only with warp and weft, the warp being fully concealed by the weft.
Full Moon	Circular carpet

G

Gachhai	Knotting of the fringes.
Gadda	A bale of wool or yarn.
Ganth	A knot in a thread; also a bale of wool, yarn, carpet, etc.
Gathiya	Bale.
Ghalicha	A small carpet or rug.
Ghalin Baff	Carpet worker.
Ghati Dalna	See Gachhai.
Ghatotri	A carpet being woven smaller than the specified size.
Gola	A circle rug.
Golla	Leasing Rod.
Goolna	Sewing the jute-cloth for packing purpose.
Gorevan	A group of typical designs with borders, medallions and corners, on fairly ornate matan, but with more or less simple, geometrical drawing.
Guchhi	A series of tufts or coloured pile yarn tied to a string showing the colours used in a design.
Guchhi System	A method of organisation of production where the Mahajan lays down the size, quality, design and colours of carpet and the Asami does all the rest.
Gulla	Harness.
Gultrash	Embossed or carved.

H

Half-moon	Semi-circular carpet.
Hashiya	Border.
Harez	See Gorevan.
Henna	A typical Indian 'motif'.
Hunar	A design motif.
Hunardar	Designed carpet.
Hunder	Design.
Hundaraha	The weaver who is expert in design weaving.
Hukk	A hook, a hook to handle yarn bale.
Hisab	Taking account of weaving charges after calculation.

I

India knot	A proprietary knotting effected by means of interlocking the warp pile yarns with the base warp, using doup healds.

J

Jai-Namaz	A prayer rug, usually with the design embodying an archway.
Jaipuri Puthha	A carpet in which two different types of weft stands are used, one being thick weft or untwisted cotton on the lower side and the other a twisted weft on the upper side to give the back of the carpet a resemblance of double fabric.
Jamadar	One who supervises the work of carpet weaving.
Jamdani	A typical Indian 'motif'.
Jhallar	Fringes.
Jheri	Wooden roller or rod used to protect the movement of the bottom roller and thus avoid unfolding of woven carpet on loom.
Jhol	Bulge.
Jut	Double knot.
Jute	The bast fibre from the plant Corchorus Capsularis.

Jharan	The loss of yarn either in weaving or embossing.

K

Kainchi	Pile height.
Kainchi Dalna	Trimming.
Kalava	Hank of three folded yarn.
Kalam Kari	A typical Indian 'motif'.
Kaleen	Carpet/floor covering.
Kam	Knots.
Kaman	Bow.
Kana Panda	A knot in a carpet having one of its legs shorter than the other.
Kani Tapka	Unwoven length of pile yarn.
Kangura	A narrow geometric border stripe with arch pattern in a design for a carpet.
Kanni	Edge, selvedge, border, corner motif in a design.
Kappan	A plain carpet.
Kashan	Richly ornamental design associated with high-class carpets from Kashan in Iran.
Kashmir Jamewar	A typical Indian 'motif'.
Kasida	A typical Indian 'motif'.
Katan	When two or more weavers weave the carpet sitting side by side and one has woven two or more rows of knots in advance, in that case the other weaver completes the gap, which gives an impression of joints called Katan.
Kath	Loom.
Kati	Yarn, particularly pile yarn.
Khamp	Customary excess size of carpet over the nominal size.
Khandki	Ball of one ply woollen yarn.
Khara Hashiya	Each of the two borders running along the length of carpet.
Khatti	First few picks of weft inserted into warp prior to commencement or knotting of pile of a carpet.
Khynchi	A pair of scissors.
Kichan	See (a) of Bujbun.
Kinara	(a) Edge (b) Border of a designed carpet.
Kinarapench	Selvedge.
Kiner Pench	Corded edge of a carpet.
Kolam	A typical Indian 'motif'.
Kooch	Stiff brush for cleaning a carpet.
Kowri	Harness.
Kukri	A cop or a conical ball of handspun woollen yarn.
Kunchimarna	Brushing.
Kappanaha	The weaver who is expert in weaving of plain carpets.
Kada Galicha	A carpet having perfect weight.
Katai	Spinning.
Kawali	Hank of woollen yarn.
Katan	The spare pieces of carpet-edges left after cutting the carpet for binding.
Konia	Corner of the rug or design.

L

Lachcha	Hank of yarn.
Lachhi	(a) Thin weft inserted slack in a carpet

	(b) Untwisted cotton of just strands.
Langri	(a) Fault in a carpet occasioned by one leg of a knot being shorter than the other. (b) Lame knot, or (c) A knot made on three warp threads.
Lapait	Rolling of carpet, particularly on beam of loom while weaving; one complete wind.
Larhi	See Guchhi.
Latia	Special hank with two small hanks at each end.
Laut Palat	The turning over of a design in a carpet, which creates symmetry.
Loom	The wooden frame on which a carpet is woven.
Loom holder	See Asami.
Look Sketch	See Naksha.
M	
Mahajan	An entrepreneur engaged in carpet weaving or its selling.
Mandna	A typical Indian 'motif'.
Maoo	Brown.
Metan	Design in the central portion of the carpet.
Mauri Bhokhara	Single wefted carpet
Mehrab	Arch, whence Bokara design, stylized arch motif in carpet, such as found at one end of Jai Namaz Carpets.
Mirzapuri Puthha	Back of the carpet in which equal number of twisted and untwisted cotton weft strands are used (see also Jaipuri Puttha).
N	
Nadhanni	The end of a carpet which is first woven.
Nadhna	Mounting of carpet warp on a loom and commencement of weaving.
Namuna	Design.
Napna	A graduated gauge to measure the pile height.
Naksha	Tying the warp.
Naksha-Navish	The designer.
P	
Pachhary	Scouring of woollen yarn.
Patola Gujarat	A typical Indian 'motif'.
Painting	Application of colour to woven carpet to rectify a defect of dyeing.
Paltha	Knot.
Panja	Comb, toothed equipment for beating down the weft during the weaving of a carpet.
Pankas	A device for stretching a carpet on the loom or on the floor.
Panna	Selvedge.
Panna Katarna	Selvedge scissoring.
Para Hashiya	Each of the two borders lying across the width of the carpet.
Partaha	Unevenly dyed or streaky yarn.
Patta	A plain stripe on outside edges of a designed carpet.
Paugazi	(a) One quarter yard, approximating in length to the span of a grown man's hand or (b) Number of woollen weft rows in 23 cm (9 in) length.
Pharahar	Widthwise spread of a design beyond specified size.
Phalua	The fringes at the ends of a carpet formed by the free ends of the warp threads.

Phanda	A pile knot tied into a carpet, sometimes used as a single knot as distinct from a double knot.
Phera	One horizontal row of knots in a carpet.
Phera Bolna	Reading out of design by reader to weavers.
Pichhe	In a carpet design, a direction signifying to the left.
Pile	The tufts of wool or other fibers knotted into the base fabric of a carpet or rug.
Pilav	Scouring of woollen yarn.
Pola	Hank of yarn.
Punja	See Panja.
Purmatan	(a) Matan when covered all over with pattern, or (b) Carpet with such matan.
Pusth Bandh	Bow supporter.
Puttha	Back of carpet.
Patti	A rug or carpet, which is, unusually, greater in length than width.
Penchani	The instrument used to rectify unevenness on back of the carpet.
Pistai	Green.
Phattahi	Blue.

Q

Qainchi	a) A pair of scissors, or b) The height of the pile of a carpet clear of base fabric.
Qalin	A carpet or a rug.
Qandil	Lantern, whence a stylist lantern motif frequently attached to the ends of medallion, or depicted from centre of mehrab in a Jai-namaz.
Quality	The fineness of a carpet as inferred from the closeness of weave, that is the number of knots per unit area.
Quachcha Bazar	The carpets which are inspected by manufacturers or their representatives, without clipping, etc.

R

Rafoo	Darning, hence darning of a damaged carpet.
Rok	An outline of distinct colour enclosing a motif in design.
Rug	A piece of thick, heavy fabric used for floor covering.
Rung cuta	Effect in carpet giving rise to streakiness caused by light and dark shades of the coloured pile yarn.
Runner	A narrow strip of carpet.
Report	This word used in terms of the loom survey and report be given about weavers/carpet under weaving by Jamadars.

S

Sastoon	Pillar on which loom rests.
Sehna knot	A type of knot common in India and Iran, where the pile tuft completely surrounds one warp thread and passes behind the other.
Serapi	See Gorevan.
Sidha Tana	Normal warp.
Sirhi	A narrow strip of carpet.
Snehabha	Patented system covering application of Snehabha polymeric sheet (SBPS) for backing thick fabric materials like tufted or loom-made carpet using Snehabha Carpet Backing machine (SBCB).
Suja	A stout needle such as used for dressing the back of a carpet.
Surmai	(a) Blue colour of medium depth, or

	(b) In Phera bolna the darker of the two or the middle one of three blue colours used in a design.
Surra	Total number of knots.
Soot	Cotton yarn to be used in weft.
Sust Galicha	A carpet having less weight than normal.
Sahal Hunder	The design, which is easier in weaving.
Siyahi	Black or dark blue.

T

Tahrir	See Rok.
Talim	Roks, also heliographic script describing a design for the benefit of a weaver.
Tana	Warp on which a carpet is woven.
Tang	Wooden roller for stretching the warp.
Tapka	(a) A knot of pile tied in a carpet, or (b) Double knotting the pile surface.
Tar Tar Mila Kar	One of each of two different types of yarn used together for making the knots in a carpet.
Tehra	Crooked, hence a carpet accidentally woven other than of the required shape.
Tharri	Thick weft inserted taut in a carpet.
That	Contraction of a design in a carpet below specified size.
Tim Dam	A weave of carpet with three shots of weft between adjacent rows of knots.
Toota	Broken or broken off, hence termination of a vertical line of a colour in a design.
Tosma	A narrow geometrical border stripe in a carpet design.
Tung	For tensioning the warp.
Tar	Cotton yarn used as warp.
Tinrangi	A design containing only three shades.
Teth Hunder	A design which is difficult in weaving.
Tejab	Acid.

U

Ulta Tana	Reverse warp.
Utarni	The end of a carpet which is last woven.
Ulta Dam	Jaipuri weaving.
Utiya	Camel colour.
Utarna	Completing the rug in weaving.

W

Weaver	One who weaves a carpet under a reader's direction.
Warlis	A typical Indian 'motif'.
Woon	Wool.

Z

Zamin	Background of a design motif, also the colour of such a background.
Zanzar	Border design, uniform shape.

Looms

Kath	Loom.
Sastoon	Pillar on which loom rests.
Tang	For stretching the warp.

Pata	Wooden bench on which weavers sit.
Jeri	Rod used to avoid unfolding of woven carpet on loom.

Instruments

Punja	Beate.
Kainchi	Scissor.
Chhura	Knife.
Napna	A graduated gauge to measure the pile height.
Dam	Changing the warp shed.
Gulla	Wooden or bamboo rod.
Kowri	

Dyeing

Kati Ranged	Dyeing of woollen yarn.
Partaha	Streaky.
Pitav	Scouring of woollen yarn.

Carpet constructions

Tana	Cotton warp.
Kati	Woollen yarn.
Kati Desi	Handspun woollen yarn.
Kati Mill	Mill-spun woollen yarn.
Bodh	Jute or cotton weft.
Bis	Number of warp in a yarn width.
Butan	Horizontal rows of knots in 9 inches length.
Kainchi	Pile height.
Khati	Kelim at the beginning of a carpet after which knots are put.
Chara	Fringes.
Tharri	Twisted weft in a strand.
Lachhi	Untwisted cotton or jute strands.
Galicha	Carpet.
Khukhari	Conical ball of handspun woollen yarn.
Aincha	One edge of the carpet projecting from the other end.

Weaving

Do Tapkia	Drawing the first even warp.
Langri	Lame knot.
Ulta Tana	Reverse warp.
Sidha Tana	Normal warp.
Card	Wrapping round the beam of woven length of the carpet.
Kani Tapar	Unwoven length of knotted yarn.
Nautath	Tying the warp.
Chin	Single knot.
Tapna	Double knotting of the pile surface.
Pola	Hank.
Latia	Special hank with two small hanks at each end.
Dehari	Work load of a day, namely 6000 knots.
Bujbun	Waste on clipping of carpets.
Kam	Knot.
Surra	Total numbers of knot.
Paugazi	Number of weft rows in 9″ length.
Mirzapuri Puthha	Back of the carpet in which equal number of twisted and untwisted cotton weft strands are used.

Jaipuri Puthha	Back of a carpet in which an unequal number of a cotton weft strands are inserted.
Hunder	Design.
Kappen	Plain.

Finishing

Gultrash	Raising the design by embossing.
Clipping	Smoothing of the surface pile.
Gachhai	Knotting of the fringes.
Jhol	Buckling, bulges.
Kinarpench	Selvedges.
Berai	Colours in the design separating.

Washing

Platform	Cemented plain floor for spreading a carpet.
Pani	Fresh water for wetting.
Bleaching Powder	Bleaching powder.
Kastic	Caustic soda.
Pharrua	Wooden sheet to scrub.
Peeth Jalana	Burning the back.
Stove	Stove.
Pani Nikalna	Rinsing excess water.
Dhulai	Washing.

7

Developments in handmade carpets: design and manufacture

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Abstract: This chapter reviews current design and manufacturing techniques for handmade carpets. It summarises different types of traditional carpet design. It then reviews the range of materials used in the manufacture of handmade carpets, from wool and silk to synthetic fibres. The chapter then describes current production methods such as weaving and dyeing. Finally, it considers quality issues such as eco-friendly carpet manufacture and colour quality.

Key words: handmade carpets, weaving, dyeing.

7.1 Introduction: key issues in design

The right combination of art, craft, technology and economics results in a product that is well-designed for its intended purpose. There are products that are known to be art and/or craft focused, but with today's modernised global outlook, technology is embedded with craft in many products. The intervention of technology has become of paramount importance in reducing the drudgery of artisans as well as in improving productivity and performance. In a cut-throat era of global competition, economic information also plays an important role, including market trends and feedback to inform the designer and manufacturers about customer preferences, pricing and productivity requirements. Products designed and produced in this way can survive in the market. Moreover, with constant upgrading of product feature(s) and/or appropriate pricing, a supplier can influence what is, in other respects, a buyers' market. Successful products have a balanced combination of art, craft, technology and economics. It may not be feasible for one person (e.g. a designer) to possess the required expertise in all these areas. An organisation must integrate the expertise of a number of people so that a product can be launched successfully in the market.

As well as being an indispensable item for interior decoration, carpets have long been used as a precious gift. Over time they have followed the routes of conquest and trade. This magical piece of craftwork has finally travelled through the ages to our times and, with its colours, its symbolic language and all its beauty, has become a subject of 'flying carpet' and other exotic tales. These masterpieces of art have migrated over the centuries from one country to another and from one district to another, interacting with local cultures on the way.

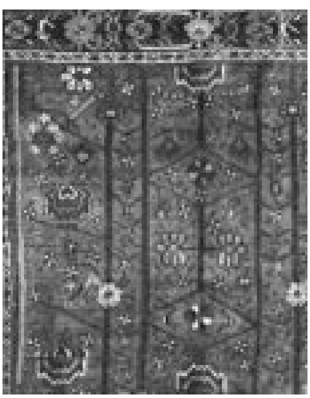
However, any attempt to determine the origins of many traditional carpet motifs, consisting of varied symbols from different places, which have overlapped in the course of their history, has understandably become a complex problem. Human beings, in the course of their own development over thousands of years, have reshaped their carpets, motifs and embroidery from one generation to another. Women today still weave their carpets with the same thoughts and emotions as their ancestors, but they no longer know the mysterious origins of particular motifs. Whilst it is remarkable to observe how patterns similar to motifs of Anatolian origin, dating as far as back 3000 BC, have been woven into later Turkish carpets, one also comes across new patterns and motifs. Women continue this long artistic and historical adventure by giving them new names and meanings relating to their present-day lives.

7.2 Traditional carpet designs

The following sections describe some popular traditional designs of handmade carpets (source: www.rugandcarpets.com and Internal documents; IICT 2000–08, Goswami KK, Karmakar R, Bajpai CS).

7.2.1 Afshar carpets

The Afshars are one of the great nomadic tribes in Iran. Afshar carpet patterns take the form of medallions. The typical tribal Afshar (Fig. 7.1) has geometric medallions with modified ones having floral medallions. Light red, light ivory and khaki are common colours in Afshar rugs and runners, all using natural dyes. Afshar carpets are famous for their typical tree design. Their size is generally less than 1.5 × 2.5 metres, woven tightly as a flat weave on a horizontal loom, making them suitable as runners and rugs. They are similar to Caucasian carpets in style and colour, and a common pattern consists of diamond-shaped medallions joined

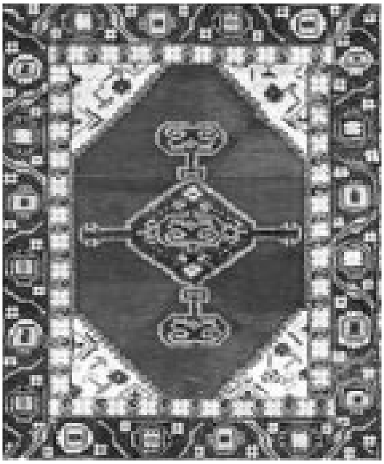


7.1 Afshar carpet.

together. The piles are woollen, although the base is cotton, and handspun wool is preferred to obtain the right texture. They have a symmetrical knotting pattern with a double weft, although a few may have a single weft and a unique type of knot. The patterns are usually woven from memory.

7.2.2 Bakhshaish carpets

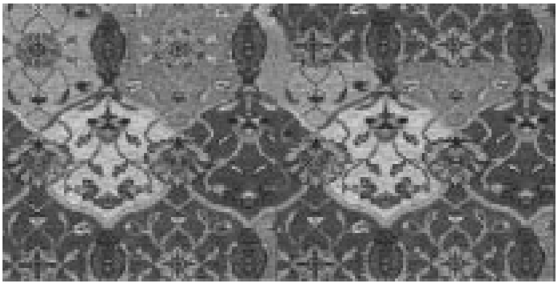
Bakhshaish is a small area in Iran known for large carpets with an inner medallion called the Herati pattern (Fig. 7.2). The geometrical patterns are brightly coloured with combinations including navy blue and red. A distinguishing factor is that the brightly coloured medallions are balanced on light-coloured background. The 'Tortoise' herati border is characteristic of the Bakhshaish carpets, which are known for their bold patterns and wide range of sizes. This quality increases their decorative value. Bakhshaish rugs are known for their tight knotting that makes them more durable. The patterns and style are similar to those of Heriz carpets. The base can be wool or cotton but the pile is mostly wool.



7.2 Bakhshaish carpet.

7.2.3 Bakhtiari carpets

The artisans from the Bakhtiari weaving area of Shahr-Kurd, south-east of Isfahan, are known for their artistic and technical skills. Bakhtiari carpets are called 'garden carpets' owing to the flower and curl motifs that fill the lattice designs (Fig. 7.3). This pattern style is called the 'Kheshti Design'. The main colours used in Bakhtiari carpets are shades of white and ivory, red and brown, green and yellow, with blue used sparingly. The pile is highly silky with a medium to high clipping. Natural dyes are used on the yarn and the pile is tied

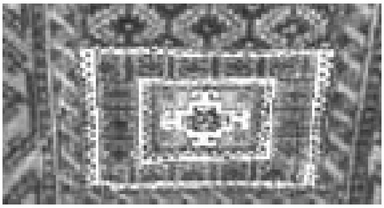


7.3 Bakhtiari carpet.

with a Turkish knot with changeable density. The warps and wefts are of cotton and the pile of wool, which may be dull to extremely silky. Amongst the differing types of carpet in this style, Hori carpets are of lower quality and Bibibaff, Chahal Shotur and Saman carpets are from medium to high quality.

7.2.4 Baluch carpets

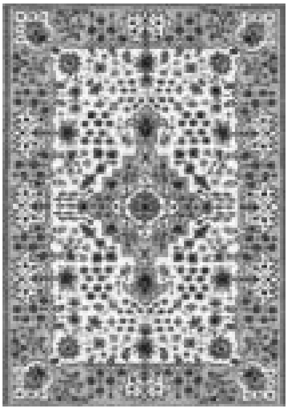
Typically, these are all dark woollen rugs of varying sizes (Fig. 7.4) made by the Baluchi tribal artisans of eastern Iran and Afghanistan, woven mainly in colours of rich burgundy and blue. They often have a tree of life or prayer rug pattern. The most prominent Baluch pattern is repetitions of camel's foot-shaped or pear-shaped medallions, surrounded by geometric borders on all sides. They are fairly small in size and more suited for use as rugs and throws. Dark red or blue colours are used with touches of white and yellow; blue in combination with ivory is often used. Women usually weave these carpets on a horizontal loom. The whole carpet is usually made from wool, even the warp and weft, although some Iranian Baluchi carpets may have a cotton foundation. Some include the seal of the weaver.



7.4 Baluch carpet.

7.2.5 Bidjar carpets

Bidjar carpets are very heavy and durable rugs usually woven by the Afshar weavers of Bidjar in Kurdistan (Fig. 7.5). The Herati motif is the one most commonly used in medallions as well as in all-over patterns. Other patterns are mostly geometric or curvilinear, or a combination of the two. The most typical

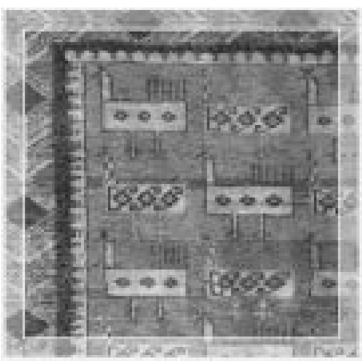


7.5 Bidjar carpet.

colours used are navy, cherry-red, brown, light blue, pink, yellow, orange, beige and ivory. Very high-quality wool is used for tying the symmetrical Turkish knots and, traditionally, even the base was woollen. The process of weaving Bidjar rugs involves extensive hammering of the knots against the wefts, thus making the carpet very tightly woven, and the pile height is greater than that of other carpet types. These two things make the carpets very tight and heavy. As a result of the hammering, the warp and wefts are so stressed that if the carpet is folded, the foundation threads may break. Therefore the Bidjar rugs should preferably only be rolled rather than folded.

7.2.6 Gabbeh carpets

The word Gabbeh means rough or unclipped in Persian. These are woollen hand-knotted carpets known for their tribal origin and bold-coloured tribal patterns, which are strongly influenced by the lifestyle of herdsmen and nomadic tribes (Fig. 7.6). The patterns are simple and neat with geometric representations of



7.6 Gabbeh carpet.

humans and animals, large fields, bold stripes or geometric shapes, or a combination of these. Owing to their design style and typical colour scheme, they suit the more abstract style of modern furnishings. The scenes of rolling hills and colourful flower fields depicted with little detail and in deep colours – crimson reds, cobalt blues, rust and olive green – are soothing to the eye. The carpet has a sturdy construction. Piles are made of hand-spun wool, preferably soft goat and sheep wool that is naturally coloured. They are made on horizontal as well as vertical looms, having warp yarn that is also dyed with natural colours.

7.2.7 Hamadan carpets

Hamadan carpets, made in the region of that name in Iran, are smaller-sized carpets, many of which are made as runners, and are known by their single weft medallion with a geometrically oriented pattern (Fig. 7.7). They are known for their brilliant colours, such as dark reds and deep blues, appearing in contrast with ivory. Besides these traditional colours, greens, blues and browns are also used in the patterns. The piles have Turkish knots and a taut weave. They can be easily identified by their fringe, which is only on one side as the weft thread is looped over the top bar. The carpet is created with soft wool and tight piles and is rather thin. The warps and weft are of cotton and the piles of sheep wool. The yarn is dyed in natural vegetable colours. Though primarily geometric, small animals or garden elements are often seen in designs. Hamadan rugs last a long time because the pile and colours maintain their appearance.

7.7 Hamadan carpet.

7.2.8 Heriz carpets

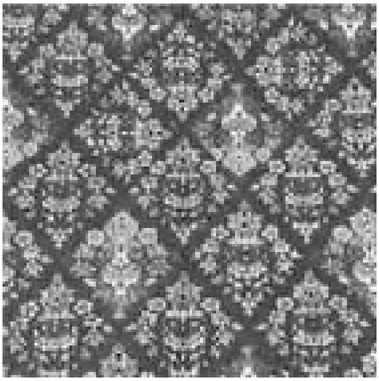
Heriz carpets from Iran range from coarse thick rugs with a heavy feel to finer rugs with a softer feel (Fig. 7.8). They usually have a large single medallion in

7.8 Heriz carpet.

the centre that has eight edges, with variations in size. Light red, brown and sky blue are the primary colours, with blue being used for contrast and contours. Brown, beige and turquoise shades are found in antique pieces. Primarily, Heriz carpets have a geometric pattern design complemented with flowers, garlands and vases. They are squarer than other Persian carpets and their massive size sets them apart for use only as furnishings. The warps of Heriz carpets are generally cotton but the weft is wool. The pile is always soft wool of medium thickness, tied in Turkish-type knots with a tight texture. The yarn is dyed with natural vegetable colours.

7.2.9 Isfahan carpets

Isfahan, a town in western central Iran, was the capital of Persia during 15th to 17th centuries when carpet craft was at its peak and Isfahan carpets are a symbol of quality even now. The structural design and the art of the era are reflected in these carpets (Fig. 7.9). A common approach is a central medallion surrounded

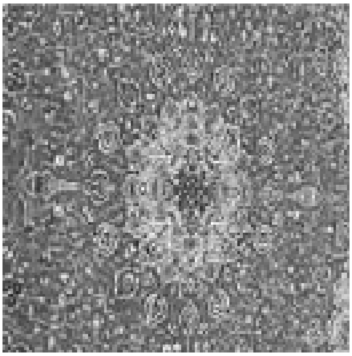


7.9 Isfahan carpet.

by floral garlands. The carpets have an ivory background with deep blue and red florals, and are very colourful, involving nearly 15 colours in a single carpet. Most designs have a prominent double outline of the patterns that brings an exclusive touch to even the most unadventurous carpets. The earlier material mix of cotton as warp and weft has changed. A combination of silk and wool or silk and cotton is often used. The tight pile is of soft wool with knots per square inch varying from 100 to more than 800.

7.2.10 Kashan carpets

The town of Kashan is situated between Tehran and Isfahan and is known for very high-quality wool, fine weaving and carpets with stunning colours and designs, which are among the finest of Persian carpets (Fig. 7.10). The designs have mostly central medallions with tendrils and vases. Shah Abbasi medallions are quite common. Kashan carpet colours are brick red and dark blue with ivory and green for the patterns. The asymmetric Persian knot is employed for piles, which are rather fine, ranging from 120 to 240 knots per square inch for woollen carpets to 240 to 550 knots per square inch for silk carpets, and the warp and weft are made of cotton or silk. They are governed by many rules regarding the colours and the design, resulting in a limited number of patterns.



7.10 Kashan carpet.

7.2.11 Kashmir carpets

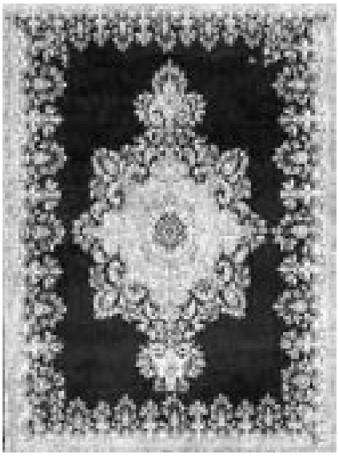
The Mughals brought carpet weaving to Kashmir in India, which today is the leading centre in India for quality rugs (Fig. 7.11). The patterns are Indo-Persian in origin. A typical Kashmiri Indian pattern is the tree of life. It is the colour of the carpet that helps distinguish it from others as the colours of Kashmiri carpets are more subtle and muted, with the yarn being dyed using vegetable colours. The yarn is either silk, wool or a combination of the two, but wool pile is more common. Woollen carpets always have a cotton base but silk carpets may have a

7.11 Kashmir carpet.

cotton or silk base. Woollen carpets are more common and affordable than silk ones although silk is used in woollen carpets for an exclusive look. Kashmiri carpets can be double-knotted and single-knotted. The single-knotted pile is fluffier than the double-knotted, and the pile of the double-knotted carpet is less resistant to touch and pressure.

7.2.12 Kerman carpets

Kerman lies in the east of Iran and is known for the quality of its carpets and particularly for their detailed patterns (Fig. 7.12). Kerman rugs generally have curvilinear floral and medallion motifs containing animal motifs and repetitive patterns; some have images that are said to be too realistic for a carpet. Kerman rugs are woven in a variety of intricate designs. The colours generally have softer hues: soft red, green, blue, yellow and ivory. The antique rugs have red and blue combinations but pastel colours like turquoise, orange, champagne and

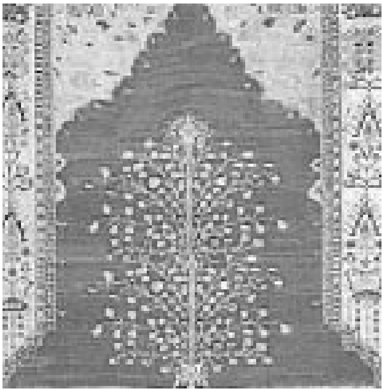


7.12 Kerman carpet.

beige have been introduced as they are more fashionable. The rugs are made of fine, lustrous wool with Persian knots, having a knot density that is medium to high (120 to 850 per square inch). The warp and weft are of cotton with a pile of wool. They are not very thick and have a soft texture, and are available in larger as well as smaller sizes.

7.2.13 Mahal carpets

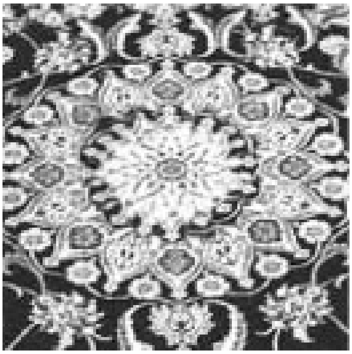
Mahal carpets, made in Mahallet in the Arak region of Iran, contain spacious patterns with bold floral designs and have a high decorative value (Fig. 7.13). They are medium quality carpets with prominent designs having patterns that may be all-over scrolling vines and large tribal or curvature palms. The yarn is dyed in pure natural shades of dark red, blue, soft green, gold and ivory. The warp and wefts are of cotton and the pile of soft wool, with a weave that is not tight but coarse, tied using Turkish knots. The wool used is soft and lustrous but the carpets are not very durable. The warp is usually cotton though the weft can be cotton or wool. They have double wefts and tight piles yet they are loosely woven with a knot count of around 100 knots per square inch. The colours commonly used are dark red, khaki and blue.



7.13 Mahal carpet.

7.2.14 Nain carpets

Nain is located in central Iran in the Isfahan region. Gradually the weavers there created their own identity by creating fine patterns and the Nain region now produces some of the finest carpets in Iran (Fig. 7.14). The colours of this type of rug are muted with white, ivory, beige, buff, light gray, light blue, turquoise, navy, light brown, camel, and burgundy among the most frequently used colours. Nain carpets have detailed curvilinear designs. They are similar to Isfahan rugs, but the animal and bird motifs are more prominent in the



7.14 Nain carpet.

background. The Islimi motif is also quite prominently used. Common designs consist of star medallions, Shah Abbasi and Islimi medallions. Nain rugs are woven with asymmetrical (Persian) knots. Most Nain rugs have either a wool pile, or a wool pile with silk highlights; all-silk Nain rugs are not common. The foundation can be either cotton or silk. Knots density varies from 120 to 840 psi.

7.2.15 Nepalese carpets

Before 1960, the few carpets that were produced in Nepal were for the domestic market and were not of particularly good quality. Tibetan refugees initiated the process of producing better-quality knotted carpets. The carpet belt is located in

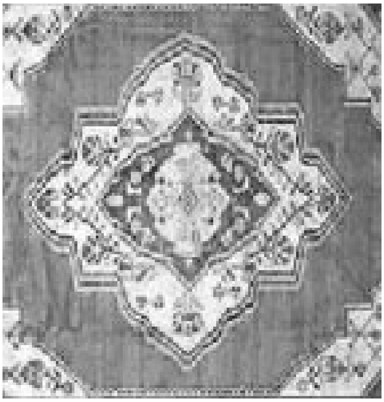
7.15 Nepalese carpet.

and around Katmandu. Buddhist arts and motifs have influenced the traditional patterns but in recent years, modern motifs have been included with the designs also being influenced by Chinese motifs (Fig. 7.15). The designs are first drawn on a graph and then mapped on the loom. Nepalese carpets are low to medium quality in terms of knot density, ranging from 60 to 120 knots per square inch. They use high-quality wool for the piles although the base may be cotton. Nepalese carpets have a distinct luster, similar to Tibetan carpets, because of their unique knotting style and their use of a different quality of wool than that used in Persian carpets. They are much more affordable than Persian carpets.

7.2.16 Oriental carpets

Knotted carpets and rugs manufactured anywhere in Asia are referred to as Oriental Carpets (Fig. 7.16). Knotted carpets are believed to have originated amongst the nomadic tribes of the so-called carpet belt, stretching from Turkey and Iran (Persia) as far as China. The development of the art of handmade rugs in these countries may be seen as an interaction between religious and ethnic structures. The most famous designs found in rugs today include numerous Persian designs, Turkoman all-over designs, geometric and plain tribal designs.

Rug weaving was introduced into India by the Mughals who had been exposed to the craft in Persia. Indian patterns are greatly influenced by Persian art with some Indian variations. The wool used in Indian rugs is generally coarser than that used in similar Persian rugs. Afghan rugs usually resemble Caucasian-style rugs and are similar to those made in Turkey. Caucasian rugs come from the region northwest of Iran and reflect its intricate ethnography, being very similar to Turkoman rugs. Iran and Turkey are historically known for the best quality knotted oriental rugs. The lifestyle of the nomadic tribes and villages where the rugs originate is reflected in their traditional patterns and designs. Chinese and Tibetan rugs look altogether different due to the

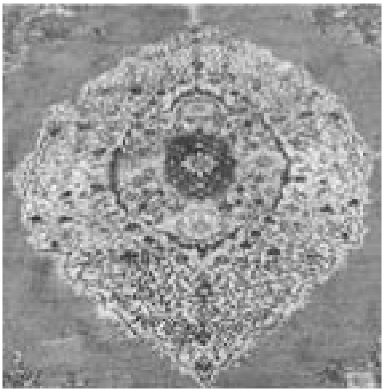


7.16 Oriental carpet.

differences in the wool quality, their knotting style, and the influences of Buddhism and Taoism in the motifs. In most cases the pile is mostly of wool. Silk is used for highlights if required. Silk carpets are not common as they take longer to finish. Cotton is most commonly used for the foundation.

7.2.17 Oushak carpets

Oushak, a small town in Anatolia, Turkey, is a place where carpets have been made commercially since the 15th century. They are highly decorated, having been influenced by Persian styles unlike other Turkish carpets (Fig. 7.17). They are made from the best Turkish wool coloured by natural dyes. These carpets gained access to international markets after being considered good enough to be used in Ottoman Palaces. They are 100% wool carpets and are still much in demand in the European markets.



7.17 Oushak carpet.

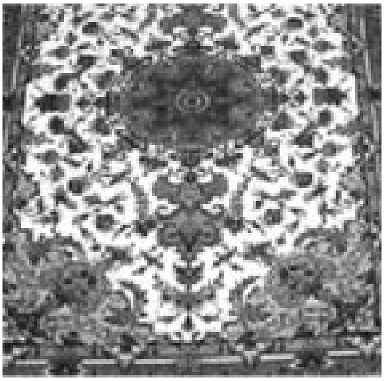
7.2.18 Sarough carpets

Sarouk is a small village in central Iran famous for producing knotted carpets with geometric patterns known as Sarough or Sarouk carpets (Fig. 7.18). The carpets are made of high-quality wool in workshops as well as on household looms. The traditional rug has herati and boteh patterns all over it or in a medallion layout of almost any geometric shape, the most common of which is a medallion and corner layout. After World War I, a branching type of medallion was introduced with the American markets specifically in mind. Customary colours are red, blue, burnt orange, ocher and champagne, with rich red and blue colours common in saroughs destined for America. Lighter shades of red, yellow and turquoise are used for outlines. The carpets are made using the best quality lustrous wool and are woven with a Turkish knot density from 120 to 500 kpsi. Originally the piles were cut very short but now they are preferred long.

7.18 Sarough carpet.

7.2.19 Tabriz carpets

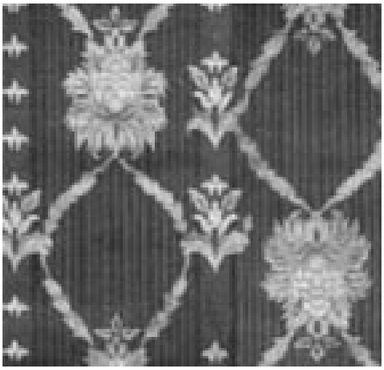
Tabriz, a town in the northwest of Iran, is famous for knotted woollen carpet weaving, which has been an integral part of its culture for centuries. The carpets are known for their durability, lush pile and curvature in the pattern (Fig. 7.19). The carpets usually have a central medallion surrounded and complemented by floral patterns and tendrils. Dark, heavy shades of blue and red are used in contrast with ivory. Pink, peach, camel and beige are popular for borders, and blue, green, yellow, orange and other pastels for the motifs. The pile is knotted using symmetrical knots. Wool yarn is used for piling and silk is used for accents and highlights. The warp is always cotton and the weft may be cotton or wool. They are generally medium-sized carpets (4 × 6 to 8 × 10 feet) but very large carpets up to (10 × 18 feet) are also made. They are medium- to high-quality rugs with 120 to 800 knots per square inch.



7.19 Tabriz carpet.

7.2.20 Tibetan carpets

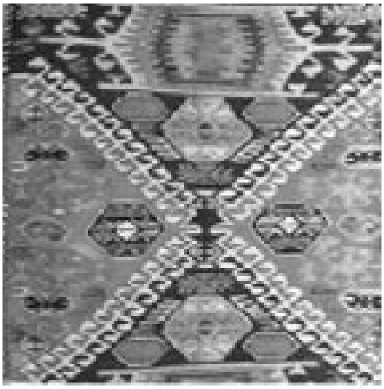
Tibetan carpets have existed for thousands of years but have only recently obtained international recognition through the efforts of certain non-governmental organisations (NGOs). The patterns and sizes of Tibetan rugs are versatile enough to be used as floor coverings as well as for wall hangings, accent rugs, runners and throws (Fig. 7.20). The carpets are unique in their structure and design, which have been developed separately from traditional Persian carpets. The designs are influenced by the Tibetan tribal culture, Buddhism and, to a lesser extent, Chinese culture. They are simple yet beautiful, complementing contemporary fashions. Wool is obtained from sheep and other animals bred by local tribes, the fleece of such local herds being long and lustrous, giving a good-quality yarn. The knotting style is different from that of the Persian and Turkish rugs. These differences give a rich and unique look to the carpets.



7.20 Tibetan carpet.

7.2.21 Turkish carpets

Turkey has a long tradition of weaving carpets of excellent quality and design. They can be knotted carpets, the better known or flat weaves being called kilims. Turkish carpets are both an expression of art for the Turks and a way of protecting people against the extreme temperature differences in the climate there (Fig. 7.21). Carpets in Turkey are a way of life and Turkish motifs are a complete language, being expressions of the weavers who are generally women. Though the motif arrangements may vary with the region, they speak the same language. The period they belong to is also reflected in the motifs and their placements. Knotted carpets are generally woollen on a cotton base. Silk carpets also exist but woollen ones are preferred. The foundation may be silk for silk pile carpets. The Turkish kilims are woollen flat weaves with bold patterns. A differently-coloured naturally dyed weaving yarn is introduced in the weft to

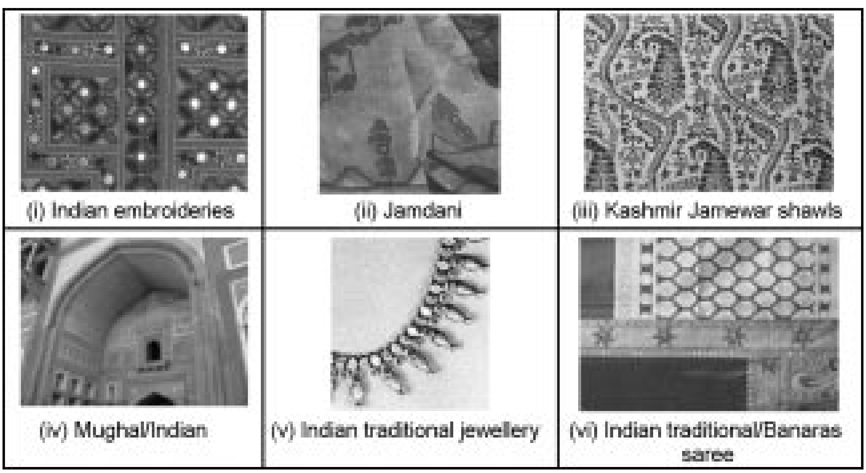


7.21 Turkish carpet.

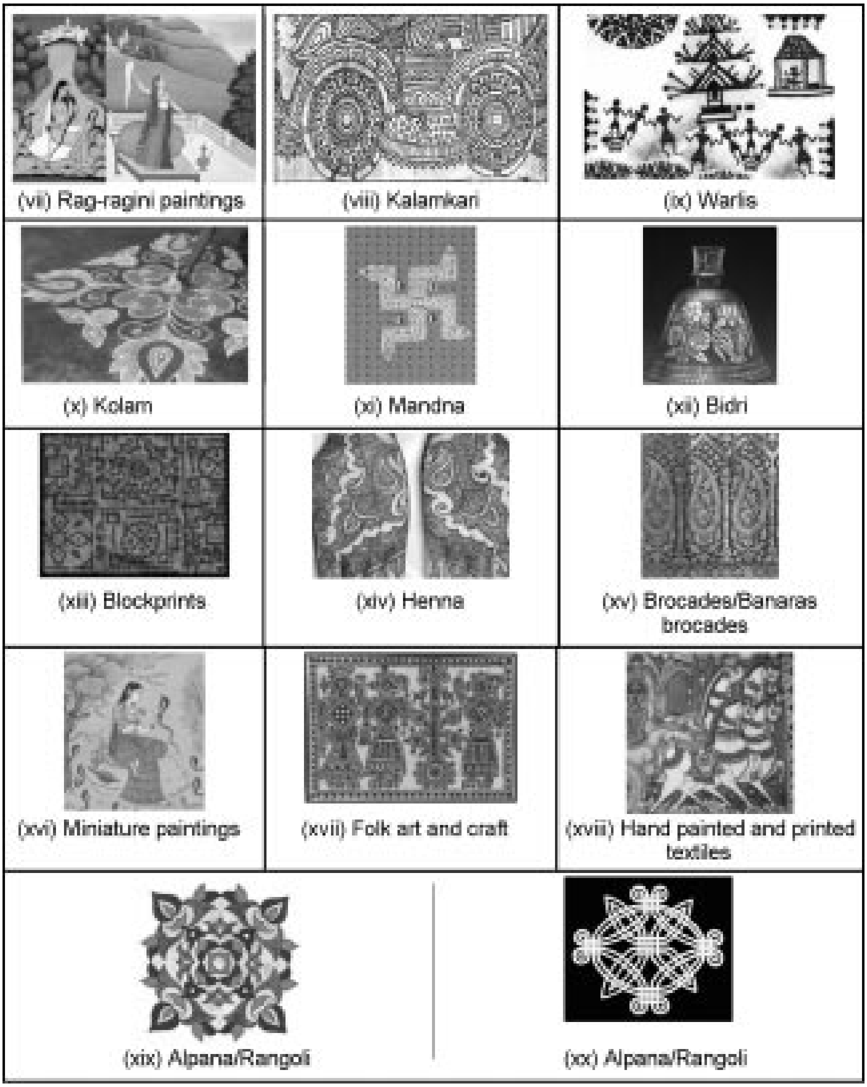
create the design. The two yarns are not joined thus creating slits where the different-coloured pattern begins and ends.

7.2.22 Indian carpets

Historically, most Indian designs have referred to Persian designs brought by the Mughals when they conquered India. The terminology, motifs, layout and colour combinations of Indian carpets remained for many years in the shadow of Persian carpet-making traditions. More recently Indian carpet makers have begun to look at the wealth of other Indian aesthetic traditions, motifs, styles and colour. The Indiya range of carpets reflects these broader influences drawn from Indian architecture, miniature painting, Rag-ragini painting, folk art, jewelry and textiles from different regions (Fig. 7.22). More recently, the Government of



7.22 Indian carpets.



7.22 Continued.

India (GOI) and United Nations Development Programme (UNDP) have provided investment in the areas of design and product development.

7.3 Key stages in design

In the field of product and industrial design, the best design is described by the phrase 'form follows function'. The design must have a functional dimension as well as a visual appeal. The form of a carpet can also include colour, lustre, texture, tones, etc. In the fields of visual design such as graphic design, textile design, and carpet design, visual appeal is the predominant feature. In the field of printed textile designs (surface designs), the visual appeal of the fabric is very important. However, as in carpets and floor coverings as well as woven textiles, the construction of the material plays an equally important role. For textiles and carpets, design is carried out at various levels.

7.3.1 Base material

The construction of the base material is of prime importance. This necessitates a thorough knowledge of the fabric structure The most commonly used materials include natural fibres such as cotton, wool, silk, linen and jute, and synthetic materials such as acrylic, nylon, polyester, viscose and rayon. Selection of materials must also take account of spinning and dyeing. In the field of fabric design, the structure, texture, lustre and finish of materials play an important role. The quality of a fabric includes the feel of the material, and its moisture absorbency, durability, wear-and-tear, washability and wash-and-wear qualities.

7.3.2 Surface design

Once base materials have been chosen, surface design techniques come into play. There are diverse techniques for designing the surfaces of floor coverings and textiles. Hand knotting is mostly used for the production of traditional carpets, which is followed by hand tufting or machine tufting. Several methods are used to translate the design onto the surface of textiles including printing, painting, embroidering, etc.

The design of a carpet is created in the form of artwork: an outline drawing or a sketch. It needs to be a graphic representation, with details of dimensions and a very detailed plan for construction or production. The basic components of a surface design include composition, colour schemes, forms, motifs or patterns. The design is first created on graph paper, whether the carpet is hand-knotted or tufted. The quality of the graph paper will vary, depending on the complexity of the design, particularly the number of knots or tufts per square inch. In hand-knotted carpets, the design on graph paper is what the weaver follows. In the case of hand-tufted carpets, a stencil is placed under the graph paper and holes are made in it. This stencil is placed on the backing cloth on which the tufting is to be done with indigo spread over it to transfer the pattern.

7.3.3 Repeats

An important aspect of designing textiles is working out how the repeat is going to be used across the entire surface. Simple repeat, half-step repeat, satin-based repeat and Ogee-based repeat are the most commonly used types. In the case of carpets, the entire design is first outlined. Traditionally, designs for carpets, especially the hand-knotted variety, have a formal outside border, an inside border, the middle area and a medallion. However, this layout or composition may vary depending on the size of the carpet and the design type. The middle area may have a medallion or it may contain repeats.

Traditional carpet designs have rigid formats which have always been sought after by customers all over the world for their ethnic value and appeal. However, like changing trends in fashion and design the world over, which have also greatly influenced carpets and floor coverings, the rigid formats for carpet design are breaking down, giving way to modern formats such as informal borders, merging borders, no borders and, particularly in hand-tufted carpets, very modern designs where almost free-flowing design formats are used.

7.4 Carpet materials

Carpets are made from materials such as sheep wool, cotton and silk. A summary of the performance of particular materials is shown in Table 7.1.

Table 7.1 Performance ratings of fibres widely used in carpet pile[1]

Quality parameters	Performance			
	Highest			Lowest
Resistance to abrasion	Nylon	Pp	Wool/ Acrylic	Viscose
Resilience and appearance retention	Wool	Acrylic	Nylon	Pp Viscose
Resistance to soiling	Wool Pp	Viscose	Acrylic	Nylon
Ease of cleaning	Acrylic Pp	Nylon	Wool	Viscose
Absence of static		Wool Viscose	Acrylic Pp	Nylon
Flame retardance	Wool		Nylon	Acrylic Pp
Ease of dyeing	Wool	Acrylic		Pp
Choice of colours	Nylon	Viscose		

7.5 Sheep wool

Wool is the most important fibre for use in hand-knotted carpets in particular (Table 7.2). Wool is an animal fibre forming a protective covering for sheep. It is an organised structure, growing from a root situated in the middle layer of sheep skin (Fig. 7.23).

Table 7.2 Wool usage in carpets

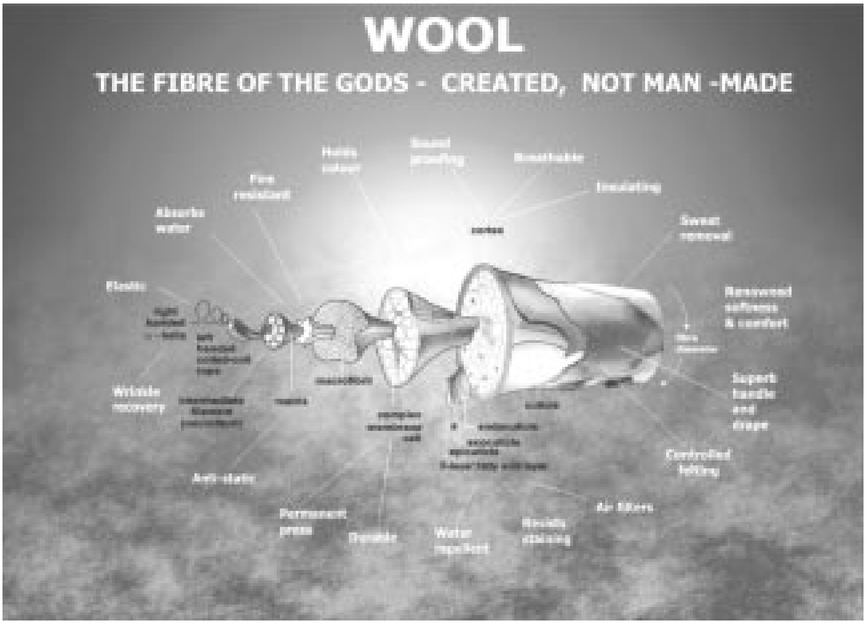
Carpet category	Total fibre (m.kg clean)	Virgin wool (m.kg clean)	% share of wool
Woven	106	56	53
Tufted	1158	74	6
Knotted	59	51	86
Others	167	2	1

The three main components of wool fibre are:

- Cuticle: The outer-most layer composed of flat, plate-like cells looking like scales.
- Cortex: Outer protective layer built with elongated cells lying parallel to the fibre axis.
- Medulla: Air-filled cell wall or hollow channel along the length of the fibre. Sometimes the medulla is not present in some coarser wool fibre.

Given its structure, wool has a number of important characteristics:

- it has a luxurious hand
- it is extremely durable
- it is naturally stain-resistant



7.23 Morphological structure of wool fibre. Source: www.iwto.org.

- it dyes easily and has good lustre
- it is flame-resistant
- it has good insulation properties
- it is less prone to generating static
- it is a renewable and biodegradable product.

Wool can be used in areas containing high levels of moisture. Its light-scattering qualities give it a lustrous look. As it is a natural fibre, the risk of allergies is reduced. Woollen pile carpets are a little more difficult to maintain than those with a flat weave, but depending upon the pile, they can even be used for high traffic areas with significant levels of wear. Wool is the most popular material for the piles of oriental rugs and carpets. They often have a cotton foundation which provides better strength but sometimes the weft may be of wool.

After shearing, sheep wool is processed to various levels of refinement. The quality of wool varies according to the climate, the breed of sheep and the time of year when the wool is sheered. Wool from sheep that live in warm and arid regions is normally dry and brittle, and since it breaks so easily, it ends up being short and feeling lifeless. Good-quality wool comes from healthy and well-fed sheep that are found in cold regions or at high elevations with good grazing lands and lots of water. In colder regions, sheep grow a full fleece to keep warm and their bodies store fat which then translates to a high lanolin content within the fibre, which can reach lengths of 10 cm and more. Such wool feels silky and smooth. Wool from cooler, higher elevations and from the spring sheering is considered to be the highest quality. Its performance characteristics are generally excellent. It is a good insulator and has good soil resistance. It comes in only a few natural colours, although it can be dyed. It is, however, subject to moth and UV light damage.

In handmade carpet production, wool is hand-spun, usually by women using traditional devices such as ‘kirmen’ (drop spindle) and spinning wheels. In hand-spun wool, the original length of the fibre stays the same throughout the spinning process; a fibre that measured 7 cm before spinning will still measure the same after spinning. It is a very versatile, high-quality fibre and blends well with synthetics so can also be industrially spun. However, the hard twisting of the fibres by the spinning machines tends to break some wool fibres during spinning. Although the broken bits and shorter fibres can be made to adhere together through the use of oils during the spinning process, the fibres will have lost some of their strength, which, in turn, will shorten the lifespan of the rugs woven from them.

7.5.1 Requirements for wool in carpets

An ideal wool carpet should be composed of wool fibre having the following properties:

- staple length of 75–170 mm for a semi-worsted system
- higher medullation, which causes a flattening effect and less resistance to wear in carpet; however, a small amount of medullation (2–5% in practice) improves certain functional properties
- 50–125 mm length for manufacturing woollen yarn
- fibre diametre of 30–35 micron to improve handling and bulkiness
- crimp: helical with high frequency for bulk and better resilience
- kemps: short, white hair-like fibres (normally medullated); no more than 4% by weight is considered to be the maximum limit
- contaminants: preferably should be free from vegetable matter and other impurities, but in any case should be < 1%
- colour, bulk and moisture characteristics: discussed below.

Colour measurement of grey wool fibre is essential to avoid repeated dyeing. Colour is expressed for brightness and yellowness in terms of Tristimulous values: X, Y and Z and yellowness (Y-Z) units. Standard values are shown in Table 7.3.

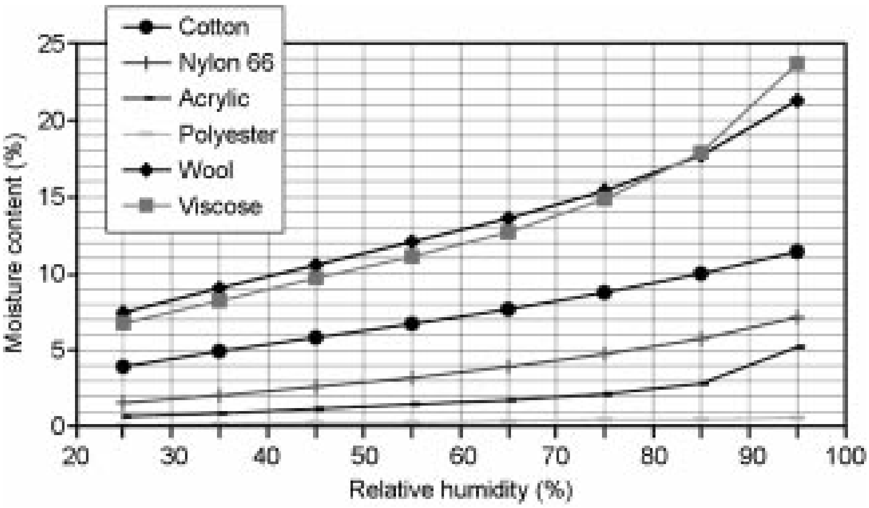
Bulk measurement of grey wool fibre is essential to attain the desired end properties in a carpet such as resilience, appearance and recovery after loading. Bulk is expressed as cm^3/gm. Standard values for some known sheep breeds/ wool type are shown in Table 7.4.

Table 7.3 Standard values of brightness and yellowness

	X	*Y*	*Z*	*Y-Z*
Good	60	62	59	3
Average	56	57	52	5
Poor	51	53	45	8

Table 7.4 Bulk standard values for sheep breeds

Breed/type	Bulk range (cc/gm)
Leicester, Lincoln	19–23
Romney	23–27
Perendale	24–32
Merino	27–33
Down-cross	32–37
Scottish	22–24
Cheviot	32–36
Bikaner (Chokla)	24–28
Magra	33–35
Kekri (Chokla)	26–30



7.24 Equilibrium moisture content of clean fibres.

Moisture content is another important characteristic of any fibre. Figure 7.24 highlights the ability of wool to hold more moisture than all the other major textile fibres over a wide range of levels of relative humidity. It can be seen that certain fibres such as acrylic and polyester absorb only 1–2% water before they begin to feel wet.

7.5.2 Wool production

According to data published by WoolPro in 2003, world wool production in 2001/2002 remained at 1.32 million tonnes, stable from the previous year. In recent years a downward trend in global wool production, which began at the start of the 1990s when the global wool clip peaked at 2.01 million tonnes clean, has been halted. In comparison with the previous year, production during 2001/2002 in:

- Australia, the world's largest producer, dropped 7% to 397 thousand tonnes;
- New Zealand, the second major producer, dropped 2% to 174 thousand tonnes;
- China, the third largest producer, is estimated to have increased 1% to 147 thousand tonnes;
- Commonwealth of Independent States (CIS), the fourth largest producer, is estimated to have remained constant at around 67 thousand tonnes.

Table 7.5 summarises production in the main wool-producing countries in 2001/02, with data from the 1991–92 seasons for comparison (in clean weights).

Table 7.5 World wool production

Country	Clean yield factor (%)	1991/92 (1000 tonnes clean)	2001/02 (1000 tonnes clean)	% change from prev. yr
Australia	65.1	569	397	−7
New Zealand	75.5	221	174	−2
China	50.0	120	147	1
CIS	52.0	228	67	0
United Kingdom	67.0	47	32	−22
Uruguay	71.0	62	37	−12
Argentina	53.0	64	32	−3
Turkey	50.0	40	35	0
South Africa	59.0	49	29	−3
India	48.0	28	28	0
Pakistan	42.0	20	17	6
Iran	45.0	20	33	0
Ireland	67.0	17	16	−6
Spain	45.0	16	15	0
Morocco	40.0	14	16	0
USA	53.3	21	12	−8
Other countries	–	243	230	−3
TOTAL	–	1779	1316	−3

7.5.3 Wool processing

Wool for handmade carpet production may come from a variety of sources, both local and imported. Imported wool varieties include: Tibetan, New Zealand, British, and Bikaneri Chokla wool varieties from India. In its raw form, wool requires careful sorting to pick out foreign matter such as vegetable materials. The wool is subsequently washed to remove dirt and grease, followed by drying in the sun for two to three days. Wool used for carpet making must be strong with a good fibre length, a good lustre and a high resilience value. Wool of 36 micron and 100 mm barb length has started becoming available on the market for carpet production.

The carding process aligns the fibres so that they flow smoothly when spinning. The carding process is also the stage when different wools can be blended if different varieties are to be combined. Traditionally, carding was performed by hand, though machine carding was introduced as the industry grew. However, hand-carded products are still available if a customer wants them.

Gilling is the blending together of card slivers with the direction of feed alternated to make a final sliver suitable for spinning. In worsted processing, three gilling operations are usually carried out prior to combing and two after combing. Combing is a process in which wool or other fibre is cleansed through an instrument that resembles a comb.

The following types of yarn spinning for wool carpets are used:

- Handspun yarn: the processed wool is spun into yarn by hand using a traditional device such as a charkha (spinning wheel). The thickness of the yarn depends on the quality of the carpet required; generally a 3-ply yarn is used.
- Woollen yarn: the processed wool is spun into yarn in the extended part of carding machine without any gilling and combing operation.
- Semi-worsted yarn: woollen fibre spun worsted is a ‘semi-worsted’ yarn. A semi-worsted yarn is spun from carefully selected high-quality fleeces (e.g., from Perendale or Hogget sheep breeds) to create a soft yet tough-wearing yarn. If one spins top or pin-carded roving worsted with either a long or a short draw (regardless of whether the shorter fibres were removed or not), ones get a semi-worsted yarn. The system includes gilling operation.
- Worsted yarn: worsted means that the individual fibres are roughly the same length and are running parallel to each other and only overlapping at the tips, leaving little to no space between the individual fibres. The system includes gilling and combing operation

Once it has been spun, wool yarn can be dyed. The traditional pot dyeing method has been largely replaced by machine dyeing in closed chambers. Dyes containing harmful substances such as benzidene are banned, and dye-stuffs from established international manufacturers are now widely used. These dyes have a high degree of fastness. The dyed yarn is dried, either in the sunlight for one to three days, depending on the weather, or in a drying chamber for a couple of hours. Pot-dyeing and vegetable (natural) dyeing are still being used by some manufacturers. The important issue is less about natural vs. aniline dyes, but more about whether the dyes used are of good quality, creating colours which are rich and lustrous, and whether the overall effect of the colour and design is pleasing and harmonious.

7.6 Silk

The finest silk comes from the first part of the amazingly long single thread with which a silk worm spins its cocoon. When unrolled, the thread from one silk cocoon can stretch up to 25 metres. Silk yarn is first dyed in the required colours, then the loom is set and each pile is hand knotted. After finishing, carpets are washed and dried.

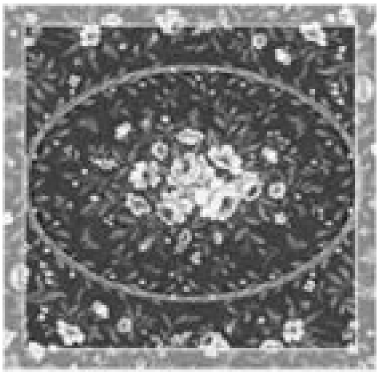
The finest hand-woven rugs in the world are Hereke silk rugs made in the village of Hereke, situated southeast of Istanbul in Turkey. A normal-quality silk Hereke should have 1 000 000 knots per square metre. Nowadays, with tremendous care and attention, some exceptional Hereke silk rugs are woven with 3 240 000 knots per square metre; that is 18 knots vertically on 1 cm and 18 knots horizontally on 1 cm. This indicates how finely the silk can be twisted and woven, as well as how strong and resistant these piles can be. As a result it allows particularly intricate designs. The number of knots per square centimetre or square inch defines the quality of a silk carpet. Bokhara carpets from Uzkebistan are some of the finest with about 125–500 knots in a square inch.

Silk has many important properties. It has high tensile strength and can be dyed easily to produce brilliant colours. Like wool, silk is a natural fibre and is neutral to skin. The fibre is so lustrous that weavers at times exploit the play of light in their patterns. As a result silk makes wonderful oriental carpets and is also used for highlights of the pattern in woollen carpets. Silk fibre is often used for the piling in a cotton or wool base but silk itself forms a fine warp and weft. Silk carpets are usually made on a cotton foundation but some may even have a silk foundation. Silk is, however, less durable than wool, making silk carpets suitable only for low to medium traffic areas. Silk carpets also require high maintenance and are easily spoiled by damp conditions.

As a raw material silk requires a great deal of handling and processing, which also makes it one of the most expensive fibres. Today, China is the leading silk producer in the world.

These are various kinds of silk:

- Mulberry: produced from domesticated silkworms, which consume mulberry leaves to produce silk. Like most natural fibres, fibre quality is measured using fibre fineness (micron), fibre length, fibre purity, fibre strength and fibre cleanness. This yarn is also called thrown silk, water-reeled silk or silk filament and is used in many applications such as weaving, knitting, needlework, carpet warp or weft, and scarf fringing. Mulberry silk can be easily blended in any yarn-making, such as wool blending and cotton spinning systems.
- Spun silk: yarn made from short-fibred silk and silk waste.
- Eri silk: a non-mulberry silk variety, extracted from domesticated silkworms, *philosamia rinini*, that feed mainly on tapioca and castor leaves. It has special thermal properties, which supplement the requirements of warm clothing to some extent.
- Artificial silk: staple/synthetic carpets are synthetic hand-knotted carpets with a silk feel (Fig. 7.25). They may be designed and patterned in the same way as a silk carpet and present the same aesthetic values. They may be finely knotted with 250 or more knots per square inch. For the purpose of making carpets, six types of synthetic yarn may be used. A short form of artificial silk is usually mercerised cotton, rayon or polyester that appears to be silk. Generally it is known as viscose. Viscose spun yarn is created by twisting together short man-made fibres, resulting in a good dyeability, colour fastness and luster, brightness and a soft feel. As a result, viscose is widely used in embroidery, knitting, decorative cloth and high-grade face fabrics, and can easily be used in handmade carpets.



7.25 Staple/synthetic carpet.

Cotton and wool are spun into yarns on spinning wheels or modern machines, but processing silk is a little more complex. The silkworm forms the raw silk as it forms its cocoon. While the insect is still in the pupae stage, the cocoon has to be plunged into boiling water to release the fibre. Workers plunge their hands into the hot water and pluck fibres from seven or eight cocoons and feed them onto a reeling machine to form a piece of single thread. Alternatively, the fibre can be spun by hand to make the silk threads. These fibres must be carefully selected, classified and combed and have all impurities removed before they are spun into thread.

7.7 Cotton

In rug and kilim weaving, cotton is used for the warp threads as well as the wefts. Compared to wool, cotton is generally considered to be a more resistant fibre and is less elastic, so tighter knots can be tied on to cotton warps as opposed to wool. If very tight knots are tied to wool warps, the fibre will break much more frequently than if the warps were of cotton. Consequently, woven pile rugs with high knotting density counts will normally have cotton warps.

Cotton is a soft fibre that grows around the seeds of the cotton plant. The fibre is most often spun into thread and used to make a soft, breathable textile. It is a valuable crop because only about 10% of the raw weight is lost in processing. Once traces of wax, protein, etc., are removed, the remainder is a natural polymer of pure cellulose. This cellulose is arranged in a way that gives cotton its unique properties of strength, durability and absorbency.

7.8 Other natural fibres

Jute is a glossy fibre that comes from the jute plant. It is seen most often in sacks, rope and twine, and as backing on carpeting. Jute fibres are particularly fine, have a soft texture and a natural sheen. Jute can be woven, knitted, twisted, corded, sewn, or braided. It can be piled or flat woven. Jute can also be bleached or dyed easily.

Jute rugs are one of the most economic investments. They were introduced at a late date into the carpet and rug sector but have created a niche due to jute's inherent qualities. They can be woven into beautiful patterns and weaves and are perfect area and accent rugs. The only problem that a jute rug may have is that it tends to stain and degrade in moist and damp conditions.

Linen is made from flax, a bast fibre taken from the stalk of the plant. The lustre comes from the natural wax content. Creamy white to light tan in colour, this fibre can be easily dyed and the colour does not fade when washed. Linen does wrinkle easily but also presses easily. Linen, like cotton, can also be boiled without damaging the fibre.

Ramie is similar to linen as a bast fibre from plants. It is naturally white in colour, has a high lustre and an unusual resistance to bacteria and moulds. Used in fabrics, and often mistaken for linen, it is extremely absorbent and dries quickly. Ramie has excellent abrasion resistance and has been shown to be three to five times stronger than cotton and twice as strong as flax. It is an inexpensive fibre and can easily be spun or woven into a fabric.

Nettle fibre is very similar to hemp or flax and for centuries was used for fine textiles, sail cloth, and rope in Europe. Its use as a fibre disappeared after the introduction of flax, but it was used again for army clothing during the flax shortages of World War I. The roots yield a yellow dye and the leaves yield a green dye which is used in countries such as Russia for dyeing woollens. Nettle fibre was widely used by many groups of North American Indians for thousands of years to make bowstrings, fishing nets and lines, snares, and rope. The Dakota, Ponca, and Winnebago tribes used it to weave special ceremonial cloth.

Hemp comes from the stems of the Cannabis Sativa plant. The stems are processed to dissolve the gum or pectin and separate the fibres, which are then processed again and woven into yarns and fabric. The finest fabric hemp is produced in Italy. Hemp fabric is similar to linen in both touch and appearance, and withstands water better than any other textile product. It wrinkles easily and should not be creased excessively to avoid wear and breakage of the fibres.

There are a range of other natural fibres. Banana fibre is collected from banana harvests, and then mixed with other materials to produce a fibre suitable for spinning. Sisal or sisal hemp is made from agave plants, and produces a stiff fibre used in making rope. It is not really a variety of hemp, but is so named because hemp was for centuries a major source of fibre, so other fibres were sometimes named after it. Coir fibre is a by-product of the coconut harvest, coir fibre. It holds ten times its weight in water and does not shed water like peat moss. It is an excellent potting medium for starting seeds and potting plants, but has also been processed as a fibre for spinning.

Grass may be woven or plaited to make rugs. The plaited varieties are often made of small rectangles, squares, circles, or ovals that are sewn together. Grass tiles, about 20 inches square, are also available. Grass floor coverings may be padded or laid flat on the floor. If the pad is permanently attached, the cost is about twice that of a non-padded grass rug. Grass fibre rugs can be cleaned with a mild detergent solution.

7.9 Synthetic fibres

Synthetic fibres are fibres made by chemical processes that do not occur naturally. There are two kinds of synthetic fibre. One is a regenerated synthetic fibre made from natural materials that have been chemically processed in some way. Rayon, for example, is made by processing the cellulose in wood pulp. The other type is a true synthetic fibre, made entirely from chemicals.

All synthetic carpet yarn is manufactured from either a staple or continuous filament fibre. Staple fibre is a series of short, 6- to 7-inch long strings spun together to form one continuous filament. Several of these are twisted together to form a strand of yarn. Continuous filaments are manufactured as one long string which are twisted and heat-set together to form a strand of yarn. These two processes create yarns that produce carpet products with distinctly different looks and characteristics.

Acrylic fibres are blended with other fibres such as wool to approximate the look and feel of natural wool for less cost. Acrylic fibres are resistant to moisture, mildew and fading in direct sunlight. Polyester has good colour clarity, colour-fastness, and resistance to water-soluble stains. In the synthetic family, of late polyester has emerged as a fibre for the sector. Thus, the available information and data base are useful for readers and widens the horizon for importers and exporters engaged for trading carpet, considering cost-effectiveness and availability. Use of polyester also can be seen in handmade and machine made carpets both. As usual one can analyse strength and weaknesses for considering the potential of this fibre in handmade carpet perspective. There is a scope to engineer polyester or such synthetic fibres incorporating hydrophilic group, flame and heat resistance property, antistatic and biodegradabality to make this or such fibres absolutely suitable for carpet

Polypropylene, also known as olefin, resists fading, generates low levels of static electricity, is reasonably priced, and can be manufactured for outdoor use. Owing to its manufacturing process, polypropylene is inherently stain-resistant. When used in carpet manufacture, this yarn will perform as well as most fibres. Olefin is preferred for outdoor use due to its resistance to water damage, pilling, and static. A wide variety of textures can be obtained but the manufacturing process has to be adjusted to produce the required resistance to pilling and shedding.

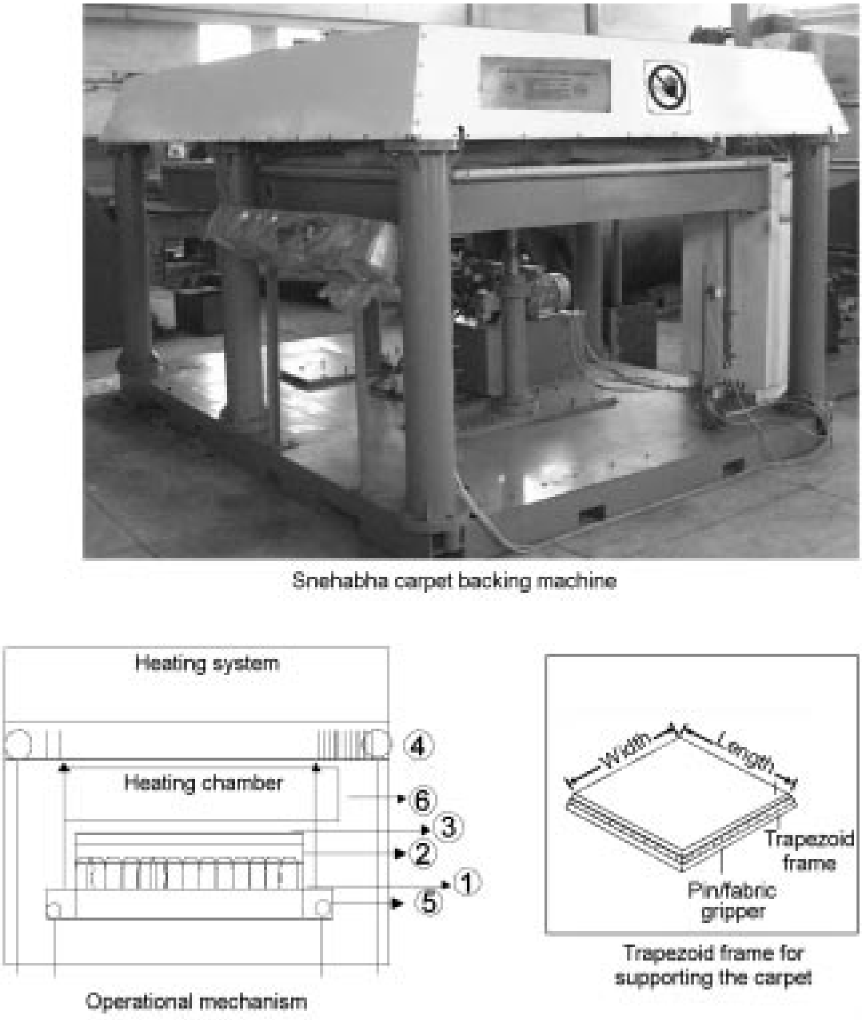
Nylon is the most popular and frequently used carpet fibre in residential and commercial applications due to its exceptional durability, versatility, resilience, ease of cleaning and low cost. It can be dyed in an endless variety of colours and made into numerous styles and textures. Nylon fibre arrives for mill processing in one of two yarn forms: BCF or Staple. BCF is an abbreviation for **B**ulked **C**ontinuous **F**ilament and refers to synthetic fibres in a continuous form, sometimes miles long, formed into yarn bundles of a given number of filaments and texturised to increase bulk and cover. Texturising changes the straight filaments into kinked or curled configurations. Since BCF already arrives as a single yarn, it is normally twisted with another yarn (two-ply) and bulked before being heat set.

Staple fibres are chopped up fibres in a natural, unprocessed undyed state that must be spun or twisted into yarn as opposed to a continuous filament. Staple fibres are available in fixed lengths or in variable cuts typically of 4–7 inches long. When staple fibres arrive at the carpet mill in bales, they are blended with other bales of staple fibres to ensure uniformity, and carded to make the fibres lie parallel to each other. A continuous yarn called a **s**liver, a large, soft, untwisted strand or rope of fibres, is formed. The slivers go to a pin-drafting machine that combs and stretches the fibres to the desired sliver weight. The yarn then goes to the spinning machine that stretches the sliver to the proper size and adds twist to improve the appearance of the finished product (the higher the twist the better). The single strands of yarn are usually twisted with others to make the final yarn.

Bulking is a process to make the yarn fluffy and bulky to give more coverage with the same weight. Bulking also adds to fibre resiliency. Crimping creates 'bulk' in individual filaments by creating a saw-tooth, zigzag, or random curl relative to the fibre. The yarns must be heat-set if used in cut-pile carpet (except plushes) but are often not heat-set if used in loop-pile constructions. There are three heat-setting methods: autoclave (steam and pressure in a batch process), superba (continuous steam and pressure), and suessen (dry heat). This allows the yarn to retain its shape and twist. The yarn then usually goes for tufting and carpet manufacture.

7.10 Backing materials

The primary backing is a particularly important material for tufted carpet since the tufts need to be inserted securely into it. It may be made of jute, cotton, woven or non-woven synthetics, but is normally cotton for handmade carpets and polypropylene for machine-made carpets. The secondary backing is a net-type (leno) open fabric used for reinforcing the backing of tufted carpets. A third type of tufted carpet backing is a mat or rib-type fabric, which comes into contact with the floor. The adhesive used for backing can be liquid, paste or other forms including Snehabha, a polymer sheet (SBPS) capable of pasting secondary and tertiary backing to a tufted carpet or other thick fabric using a Snehabna carpet backing machine (Indian Patents No. 211274 and 214269).[2] The diagrammatic view of the same is depicted in Fig. 7.26.



7.26 Snehabha carpet backing machine.

7.11 Manufacturing techniques

There are several ways to make carpet from yarn: tufting, weaving, knitting, braiding, needlefelt, fusion bonding, and flocking, as well as by hand. The global carpet market for domestic and industrial end use is dominated by three manufacturing processes:

1. weaving
2. tufting
3. needlefelting.

Weaving is the process of making a carpet (or rug) on a loom with face yarns held in place by intertwining them with warp and weft yarns. Warp refers to yarns running lengthwise and weft to yarns running across the warp. In weaving the carpet is produced on a loom similar to woven cloth. Normally many coloured yarns are used and this process is capable of producing intricate patterns from pre-determined designs. These carpets are normally the most expensive.

Over 95% of the carpet manufactured in the United States is tufted. A tufting machine is essentially a huge sewing machine, about twelve feet wide, with hundreds of needles that insert loops of yarn into the primary backing. Yarn is fed from a creel, one tube of yarn for each needle, and threaded through the needles. The tufting machine is set up to produce level loop, multi-level loop, cut pile, and cut and loop pile structures. The tufting machine's needles punch the yarn through the primary backing, which is fed into the machine from the rear. The looper forms the pile and determines the pile height. Loopers with a cutting knife attached are used to produce cut-pile or plush carpet. The carpet is manufactured 'fuzzy side down'. A loop-pile machine does not have those knives, leaving the loops uncut.

A carpet is produced on a tufting machine using a single coloured or sometimes non-coloured yarn. If non-coloured yarn is used, the carpet will be dyed or printed with a design as a separate process. Tufted carpets can be either cut pile, loop pile or a combination of both. Tufting machines produce many more metres of carpet per hour than weaving does and the carpets are normally priced at the low to medium end of the market. Modern tufting technology now enables the production of fairly basic geometric patterns.

Needlefelt carpets are more technologically advanced than other types. Needlefelts are produced by electrostatic attraction of individual synthetic fibres forming a unique carpet with extremely high durability. These carpets are normally found in the contract market such as hotels, etc., where there is a lot of traffic.

There is a range of other techniques: flocking is where short, chopped fibres or flock are stuck to a base fabric, usually by electrostatic processes, resulting in a very short pile material with a velvety texture resembling velour. Flocked carpets are resilient and crush-resistant. A secondary backing material is usually applied to this structure, adding body and dimensional stability. Some flocked carpets are made for bedrooms and bathrooms, but the majority of them are used in vehicles such as cars, planes, and buses.

Knitted carpet is made by a process similar to hand knitting. A coat of latex and secondary backing material is applied to the reverse of the fabric to provide dimensional stability and strength. Some variation in colour, pattern and texture is possible in knit carpet.

Needle-punched carpeting is made by barbed felting needles punching bating into a centre fabric. This forms a flat fabric like carpet that is mainly used for indoor-outdoor carpeting, artificial grass surfaces, and some carpet tiles. Needle-punched carpet can be printed, flocked or embossed. Different textural effects, such as corduroy, can be attained by mixing fibre deniers and angling the needle in various ways. A coating of weather-resistant latex or similar material is applied to the back.

The three most important machine-weaving methods for carpet are: Axminster, Velvet, and Wilton. In the Axminster method, the loom has control over each tuft of yarn making up the carpet. Axminster carpets usually have complicated designs and are always cut pile. The spools of yarn that feed the loom can hold different colours and even different kinds of yarn. In the Velvet loom method, the pile yarn loops are formed over 'wires', one wire for each row of tufts. The wires are then pulled out, leaving a row of tufts. A knife blade, similar to a razor blade, may be attached to the end of the wire, and as the wire is extracted, the tuft is cut to form a cut-pile carpet. If no blade is attached, the carpet remains a loop pile. The Wilton loom uses a mechanism to regulate the feeding of pile yarns into the loom to form a pattern, invented by Joseph Marie Jacquard in 1801. Sculptured carpets are made by controlling the pile height, and cutting, or not cutting, loops.

7.11.1 Handmade carpet production

The main varieties of handmade carpet and their major producers are:

- hand knotted – Iran, Turkey, India, Pakistan, China, Nepal
- Tibetan knot carpets – Nepal, India
- hand tufted – China, India
- broad loom – China, India
- kilim, dhurries – Turkey, India, Iran
- chain-stitch rugs – India
- India knot – India
- miscellaneous: shoumak and shaggy – India, Iran, China.

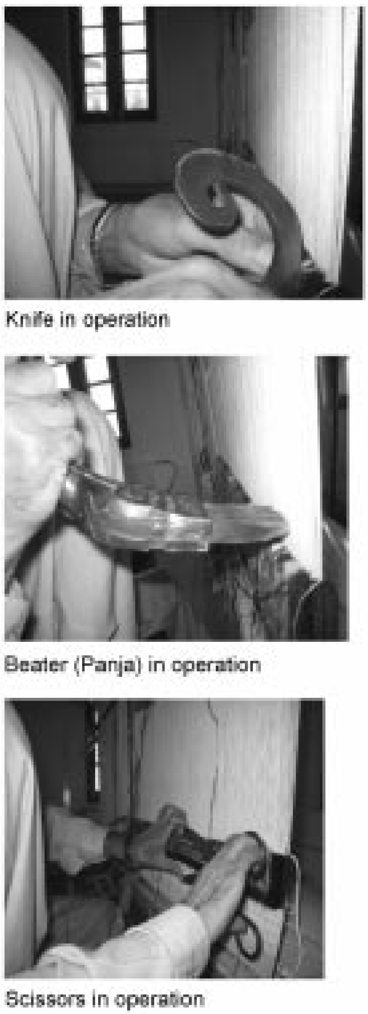
The tools that are used to produce handmade carpets vary across the various carpet-producing areas. The most commonly used tools are listed below:

- The design picture: before weaving a carpet, the weavers will first have a coloured drawing which will guide them in both designs and colours. The pictures are drawn by the designer, often on squared paper. The weaver must follow every intricate detail.
- The loom: a loom is a wooden frame which holds the carpet whilst it is being woven. There are two major kinds: the vertical loom and the horizontal loom. A vertical loom consists of four bars, two of which are horizontal – one at the top and one at the bottom – and two that go vertically from side to side, so that it looks like a standing frame. The warp yarns are fixed between the top

and bottom bars. A horizontal loom is simpler in structure. It is framed by four bars, looking like a quadrangle lying on the ground. The length of a carpet is determined by the distance between the top and bottom bars and the width by the two side bars and carpets woven on it are general smaller. In the same way as on a vertical loom, the warp yarns are fixed between the top and bottom bars.

- The comb: after the completion of a row of knots and one or several weft yarns, a special comb is used to press the weft and knots tightly together to make the carpet even and durable, and to secure the knots in place.

Other commonly used tools are scissors, knives for uses as depicted in Fig. 7.27.



7.27 Tools used in handmade carpet production.

In order to more easily describe the particular manufacturing processes/techniques for handmade carpets, it is necessary to identify the basic processes involved. Tana, known as warp in English, is the set of lengthwise threads attached to a loom before weaving begins. Each individual warp thread in a carpet is called a warp end. Warp means 'that which is thrown across'. Warp yarns are usually delivered to a weaving loom from a beam mounted on top of or behind the loom. The warp used for hand-knotted carpets is often cotton. The warping is done on the basis of the quality defined. For example, if the quality of the carpet is 12/60 then there will be 480 threads over a distance of 3 feet.

Hand-knotted carpets usually have one set of warp yarns, but loom-made woven carpets may have two or more sets, which may be wound on different loom beams. These include stuffer warp for lengthwise strength and stiffness, pile warp which forms the carpet's surface tufts, and chain warp which interlaces with fill yarn to lock the structure together.

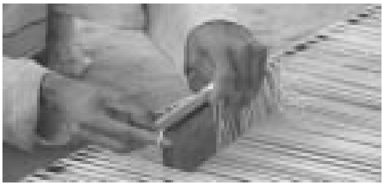
Tharry, or weft in English, are the cross-wise threads in a piece of carpet. These are the threads that are moved back and forth across the warp during weaving. The weft threads run across the width of a piece of carpet. There are two main types of weft: regular weft, which is thick and heavy; and thin weft, which is very small, strong, durable, and hard to detect. Thin weft threads and selvages (edges) are usually made of light, undyed woollen yarn.

The sequence of operations in handmade carpet manufacture is different for different varieties of carpet, whether hand-knotted, hand-tufted or made on a loom, for example. The typical sequence for hand-knotted woollen carpet manufacture is shown below: (Source: *a. Patodia Ravi, Patodia Pranay, Private communication 2007, Patodia Exports, Bhadohi, India; b. Mir Z A, Private communication 2007, Satellite centre of IICT Bhadohi, Srinagar, India; c. Chowdhury N K, Private communication 2007, Jaipur Rugs Co. Pvt. Ltd., Jaipur, India; d. Gupta Neeraj, Private communication 2007, Orient Carpets, Bhadohi, India.*)

- Preparation of the warp beam (Fig. 7.28) and mounting on the loom (Fig. 7.29) – the warp of hand-knotted carpets is first prepared on the ground and then transferred on to the loom. This is done to provide for two cross bindings between the two ends in order to allow criss-cross weft movement on the loom while weaving. The two ends are transferred on to iron rods which are mounted on the hooks on the inner grooves of the main rollers of the loom.
- Warp setting (Fig. 7.30) – a device which is traditionally called a 'gulla' ensures the equal distribution of warp in a given area as per the required quality. Warp setting relates to the requirement for even warping.
- Design picture (Fig. 7.31) – the designs for hand-knotted carpets are made on graph paper corresponding to the quality of the carpet required.
- Knot setting (Fig. 7.32) – the knot setting is as per the quality required and is already taken care of while making the warp. However, this only deals with

7.28 Warping.

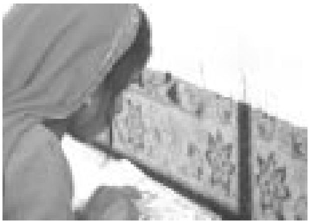
7.29 Preparation of the warp beam and mounting on the loom.



7.30 Warp setting.

7.31 Design picture.

7.32 Knot setting.



7.33 Knotting on the loom based on the design.

the horizontal knot setting; the vertical knot setting is done with the help of a beater.

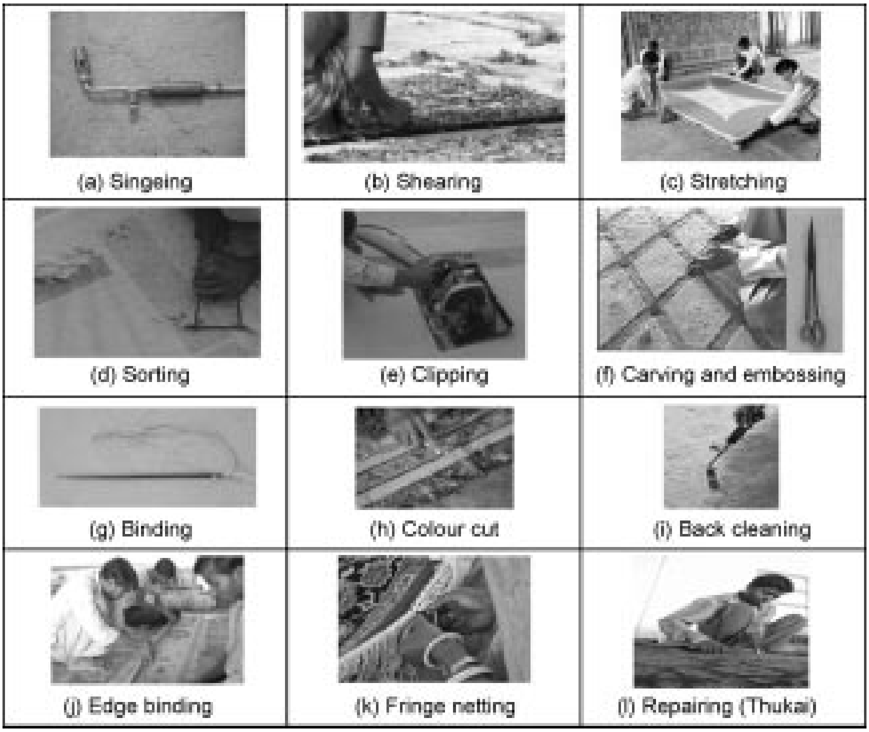
- Knotting on the loom based on the design (Fig. 7.33) – each graph box on the design paper refers to each knot in the carpet. This allows the weaver to decide the point where the colour has to be changed. As the weaving is done line by line, it is not possible to complete a single design motif on its own and then move to another one. A number must be worked on simultaneously.
- Measurement and control of pile height (Fig. 7.34), knot density, waste dimension, etc. – the pile height in knotted carpets is controlled by the weaver. While weaving the initial lines, the weaver uses a pile height gauge to check the required pile height. Once this is set, they simply weave the carpet following the previous height level.
- Binding (Fig. 7.35) and inspection (Fig. 7.36) – the lengthwise sides of the carpet are bound on the loom itself. The widthwise sides have fringes which are later finished by knotting the warps.
- Washing (Fig. 7.37) – carpet washing takes place on a washing platform, which is a often a cemented area with a water tank attached to it. There are three types of washing. Normal washing, which requires heavy rubbing, uses chemicals such as bleaching powder, caustic soda, acetic acid and softening paste. Herbal washing uses different natural products like henna and ritha. Antique washing, which gives a particular shine to the carpet, uses strong chemicals and heavy rubbing.
- Finishing (Fig. 7.38) – handmade carpets invariably undergo several finishing sequences which includes singeing and shearing, stretching, sorting, clipping,

7.34 Measurement of pile height.

7.35 Binding.

7.36 Inspection.

7.37 Carpet washing.



7.38 Finishing.

carving and embossing, binding, colour cut, back cleaning, repairing, fringe netting, edge binding, etc., to give an enhanced aesthetic appeal of the handmade carpets before it is ready for packing.

There are two major rug-weaving techniques: pile (or knotted) weave and flat weave. Pile weave or knotted weave is the method used in most rugs. In this technique the rug is woven by the creation of knots. A short piece of yarn is tied by hand around two neighbouring warp strands, creating a knot on the surface of the rug. After each row of knots is created, one or more strands of weft are passed through a complete set of warp strands. Then the knots and the weft strands are beaten with a comb, securing the knots in place. A rug can contain from 25 to over 1000 knots per square inch.

On a knotted pile carpet (technically described as a supplementary weft cut-loop pile carpet), the structural weft threads alternate with a supplementary weft that rises from the surface of the weave at a perpendicular angle. This supplementary weft is attached to the warp by one of three knot types (see below) to form the pile or nap of the carpet.

Flat weave refers to a technique of weaving where no knots are used and so the carpet surface looks flat. A flat weave carpet is created by interlocking warp (vertical) and weft (horizontal) threads. The warp strands are used as the foundation and the weft stands are used both as part of the foundation and for creating the patterns. The weft strands are simply passed through the warp strands. Types of oriental flatwoven carpet include kilim, soumak, plain weave, and tapestry weave. Types of European flatwoven carpets include Venetian, Dutch, damask, list, haircloth, and ingrain (double cloth or two-ply, triple cloth or three-ply).

Because they take less time to weave, flat weaves are generally less expensive than (knotted) rugs. The main difference between flat-weave kilims and pile rugs is that in kilims the weft strands create the colourful patterns, with no added rows of knots. The weft strands, unlike a pile rug, are discontinuous. They do not pass through the warp strands from selvage to selvage (edge to edge) but are passed through a few warp strands, then looped back around when they reach a section where a new colour weft is needed.

The Soumak weaving technique refers to a method of flat weaving where the wefts are passed over two or four warps and back under one or two warps. Brocade is also a form of flat weaving. Brocades already have a foundation (a warp and a weft). The foundation is patterned by additional coloured weft strands, which can be continuous or discontinuous, being passed through the already existing warp and weft strands.

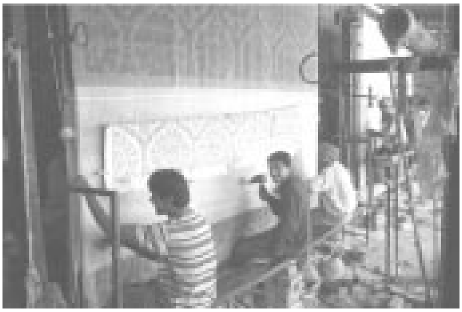
There are a number of other techniques in handmade carpet production. Shaggy is another type of pile carpet in which the piles are generally longer. This is woven using a flat horizontal weaving system installed just above the floor by one or more weavers, depending on the width, sitting on the floor. The pile height and spacing between the piles are normally greater than those of normal pile carpets. The weaving operation is depicted in Fig. 7.39.

Similarly some other existing handmade carpet manufacturing includes Tibetan, hand-tufting and hand-loom weaving techniques. The brief descriptions of operations providing relevant figures are as follows.

7.39 Weaving a shaggy pile carpet.

Tibetan technique (Fig. 7.40)

- Warping – the warp used for Tibetan carpets is cotton. The warping is done on the basis of the quality defined. For example, if the quality of the carpet is 9/25 then there will be 360 threads in a distance of 3 feet.
- Preparation of warp beam and mounting on the loom – the warping of the Tibetan carpet loom is done on the loom itself. Just before the lower beam, there is an iron rod. This rod is used to shift the warp down after the weaving point is out of reach. It works on a rolling mechanism.
- Warp setting – a device which is traditionally called 'gulla' takes care of equal distribution of warp in a given area as per required quality. Warp setting relates to the even warping requirement.
- Design picture – the design of Tibetan carpets is made on a graph paper corresponding to the quality of the loom.
- Knot setting – the knot setting is as per the quality required and is already taken care of while making the warp. However, this takes care only of the horizontal knot setting, the vertical knot setting is done with the help of a beater.
- Knotting on the loom on the basis of the design – each graph box in the design paper refers to each knot in the carpet. This allows the weaver to decide the point where he has to change the colour.
- Measurement and control of pile height, knot density, waste dimension, etc. – the pile height in a Tibetan carpet is controlled by the iron rod around which the weaver ties the knot. The diametre of the rod desides the pile height of the carpet. This allows a consistent pile throughout the carpet. Knot density is controlled by correct warping and beating during the process of weaving to ensure that the required number of knots is achieved horizontally as well as vertically.
- Chemical processing and finishing – similar to the process mentioned earlier for the other category of handmade carpets. However, all Tibetan carpets have cotton 'fringe' on the ends, this is the natural remaining ends of the weft threads once the carpet is cut off the loom. Since some customers prefer the



7.40 Tibetan carpet.

look and practicality of a clean edge, the fringe is often folded underneath the rug, covered with a strip of canvas, and hand bound.

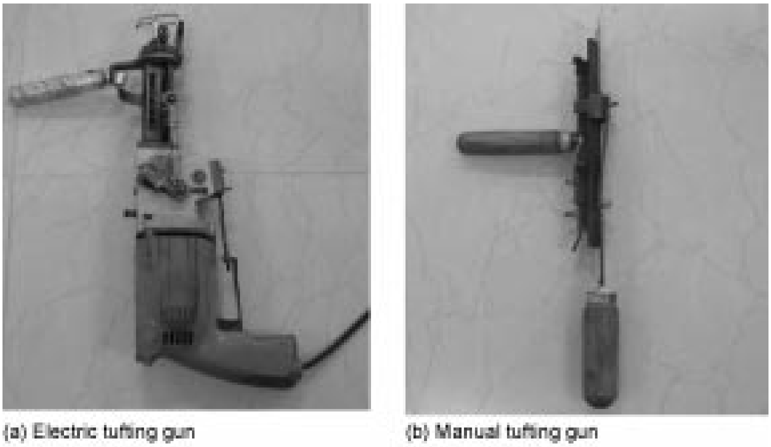
- Inspection and mending of the defects – the carpet is inspected from all angles, i.e knot density, pile height, design, straightness, etc. It is compared with the coloured graph to make sure that the colours are properly used. If any defects are found, they are corrected by expert menders. Otherwise the process is similar to that mentioned elsewhere for the other category of handmade carpets.

Hand tufting technique

Today, most of the world's carpet production utilises tufting technology. The action of a tufting machine is quite similar to that of a domestic sewing machine. Yarn bobbins feed yarn to needles which stitch through the anchor (or 'primary') backing to create loops. If a 'velvet' finish is desired, these loops are cut with a blade, and the finish is referred to as 'cut pile velvet'. For a 'loop pile' finish, the loops are left intact. 'Cut and loop' finishes, which mix the two techniques, are also popular. The tufted base is sealed with an adhesive, and the secondary base (of jute or synthetic) is then applied using latex-based glue. Designs may be created in two ways: by using pre-dyed yarns on graphic tuft, Hydrashift or cross-over tufting machines; or, by printing a design on a plain tufted carpet base. A variety of customised printing processes is available – Chromojet, Militron, or screen (flat or rotating) printing. Tufted carpets may be manufactured using 80% wool/20% nylon, 100% wool, 100% polyamide or any other manmade or natural fibre. Custom-made hand-tufted rugs and carpets begin their lives first as a design concept. Clients or designers usually specify anything from a simple sketch or a simple idea to a detailed specification regarding colours and rugs or carpets sizes. This will allow the supplier to submit samples and/or design picture for the customer's approval prior to the production process. When it comes to manufacturing and as the process name implies, this type of carpet is handmade and accordingly still produced by craftsmen who will first transfer the approved design at scale 1/1 on a canvas stretched on to a tufting frame which will become the rug or the carpet's primary backing.

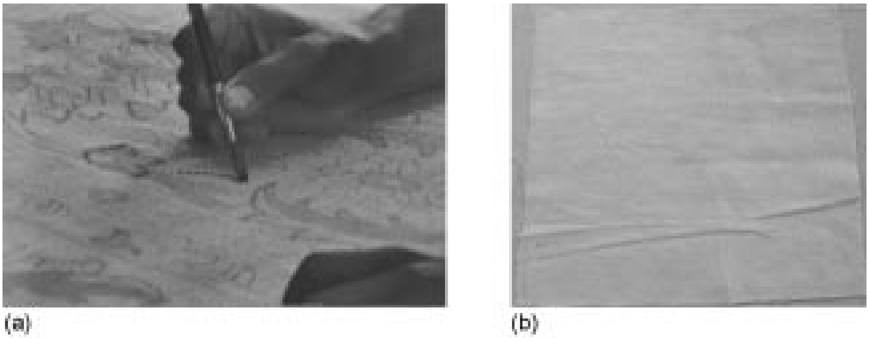
Flowchart of hand-tufted carpet manufacturing

- Framing of primary fabric – when the primary fabric is stretched on the loom it has to be stretched tightly. The cloth should be stable in order to withstand the force of the tufting gun. The cloth should be straight and the nails of the loom should penetrate the cloth in a straight row.
- Inspection and analysis of primary, secondary and tertiary backing fabric including yarn used for tufting – the process of analysis and inspection of raw material is possible only through a well-equipped lab, where all the technical parametres can be compared with the specific requirements.



7.41 (a) electric tufting gun; (b) manual tufting gun.

- Maintenance of tufting gun – there are mainly two types of tufting guns: manual gun and electric gun. The maintenance of the manual gun is simple and involves mainly the scissors and the pile height setting. The maintenance of the electric gun is complex and requires a qualified personal for the job. Electrical and manual tufting guns are depicted in Fig. 7.41.
- Tracing over primary fabric for design – the design is traced in the tracing paper and then all the lines are punctured with the help of needles. After this, the trace paper is aligned properly with the loom and the design is traced on the primary cloth with the help of a coloured solution which creates the impression of the design on the cloth. Make sure that the solution does not smudge (Fig. 7.42).
- Tufting over primary fabric – the tufting process is an art and has to be carried out by trained artisans. They have to make sure that the shots per square inch are consistent and the design is properly tufted. Hand tufted manual weaving operation is depicted in Fig. 7.43.



7.42 (a) Hand designing to be traced over; (b) Primary backing fabric.

7.43 Hand tufting operation.

Loom made carpets (broad loom technique)

- Warping outside the loom: warp preparation for base and pile: Beaming – the warping of a broadloom carpet is done on a beam which is detachable from the loom. The warp is 100% cotton. The cotton is first sorted out properly and transferred on to bobbins, and then the bobbins are fixed on a stand which transfers the cotton to a large wheel. Setting the range of the warp: once this is done the warp is finally transferred to the beam and the beam is placed behind the pile beam on the loom.
- Beam setting on the loom – the loom has three beams, one for the warp, one for the pile and the last beam is for the woven carpet. The warp beam and the pile beam are placed at the back of the loom and the carpet beam is placed at the front side. The warp beam is always placed behind the pile beam.
- Weft preparation – the weft of the broadloom carpet is either cotton or jute. A shuttle is used for putting weft between two knots.
- Design setting – the design in broadloom is set with the help of the pile beam and sometimes an additional beam.
- Weaving in broadloom – the weaving in broadloom is done in a cross weaving manner and iron rods are used to set the pile height. If we want to have a cut pile weaving then we have to cut the pile covering the rods with the help of a blade. If we want loop pile, then the rods are simply pulled out from the sides.
- Take-up of fabric and doting of desired length of woven carpet: dismantling of carpet from the loom is done following standard practice. Warping and weaving are shown in Fig. 7.44.
- Chemical processing, backing (optional), finishing, inspection and mending of defects, etc., are also applicable and as mentioned elsewhere.

Chain stitch rugs

Chain stitch rugs can be called the affordable rugs. They are much less expensive than the pure silk or wool carpets and equally beautiful. They vary in sizes and shapes and can be used as floor coverings, wall hangings, sofa throws or corner mats.

(a)


(b)


7.44 Loom-made carpets: (a) warping; (b) weaving.

- Technique – the base of the chain stitch carpets is usually Namda, which is felted wool and cotton. The base having 80% wool is considered best. The base may also be Hessian cloth and coarse wool or jute cloth. The chain stitch may be worked with silk wool or cotton threads. The stitches are done with a crochet hook instead of a needle. This hook is traditionally called ari. Hook work covers a much larger area than needle work in the same amount of time.
- Patterns – very fine Persian patterns can be created using chain stitch. The dense chain stitch filling allows continuous flow of patterns similar to the

7.45 A chain stitch carpet.

knotted carpets. Different floral and other motifs are worked with great precision. The stitch when performed on the cloth or jute appears same on both the right and the reverse side.

- Regions – chain stitch is the traditional kashida or hand embroidery of Kashmir of India. The finest chain stitch carpets are produced in Kashmir. The Bikaner–Udaipur belt of Rajasthan of India also has some areas where chain stitch rugs are made.

The typical view of a chain stitch rug is depicted in Fig. 7.45.

Carpet backing for hand-tufted/hand-loom carpet

- Analysis of latex and/or adhesive material – this operation includes the identification of the type of latex to be used. There are two types of latex used in the formulation in which synthetic latex and/or natural latex and chalk powder constitute major components (~400 gms/m^2 and ~1500 gms/m^2 respectively) to make overall addition to the extent of around 2200 gms/m^2 using various ingredients as per option which includes Glauber salt, zinc oxide, titanium oxide, Nonex S.P/Emolvan T, liquid ammonia, Dispersol F(ICI)/ BilauxT (BASF), sodium silicate, sodium hexa meta phosphate, carboxy methyl cellulose (CMC), sulphur.
- Analysis of backing fabrics – this operation includes the identification of the type of secondary backing to be used in the carpet while latexing. It is a mesh with approx. 2–3 mm squares which allow the latex to penetrate the mesh and reach the tufts. There are different types of secondary backing: (1) 100% cotton mesh, (2) 100% PP mesh and (3) cotton-PP mix. The role of the secondary backing is to provide body and dimensional stability to the carpet.
- Application of latex – a tufted carpet is tightened on a frame or on the ground, and then the design and size of the carpet is set with the help of hand tools. Thereupon the mesh is applied in the back side of the carpet and finally the

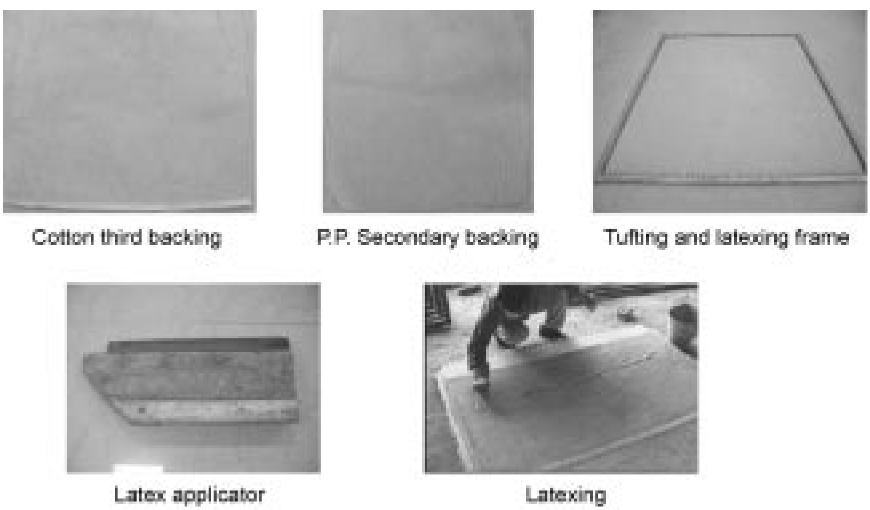
latex is applied. The application of latex can be of various types such as hand application (with the help of a spreader), spraying and roller application.

- Measurement and monitoring of drying and adhesion – the drying of carpets is generally in sunlight, this is the most cost-effective method of drying. Apart from this, latexed carpets are also dried in drying chambers and roller ovens. The latex should be properly dried before removing the carpet from the frame, otherwise the carpet will tend to lose its shape and it may develop mildew (fungus).
- Setting of backing process – process control with respect to delamiantion and tuft withdrawal force to ensure proper binding of the tuft. An optimum level of latex is mixed with fillers and tuft withdrawal force is tested with the help of proper equipment or in labs to make sure that the bonding is right.
- Inspection and mending of the defects – before the carpet is processed for finishing, it is inspected for various qualities such as weight, pile height, density, design execution, size and surface. Any defect found is mended by simply pulling out the tufts of the defective are and re-tufting that area in the correct manner.

The sequence of operations involved in the carpet backing is depicted in Fig. 7.46.

A hooked rug is a simple type of rug, handmade by pulling strips of cloth such as wool or cotton through the meshes of a sturdy fabric such as burlap. This type of rug is now generally made as a handicraft.

In the late 19th century, moquette came to mean wall-to-wall carpeting. However, its historical usage refers to supplementary warp cut or uncut loop pile made on a draw loom. These textiles have a low pile and are thinner than hand-



7.46 Backing of hand-tufted and hand-loom-made carpets knotted pile carpets. This form of carpeting, made as early as the 16th century, is constructed on a loom in the same way as velvet: the supplementary warps loop under the weft and are attached without forming a knot. Because of the loom structure, only five colours can be used to create the design. Moquette is woven in relatively narrow panels (usually 27″ or 36″). Larger works are composed of several stripes sewn together. Moquette carpets have been used on floors and tables, as furniture upholstery, and as wall coverings. Production was improved with the invention of the Jacquard loom in France in the early 19th century. The addition of steam power in the mid 19th century helped mechanise the process.

7.12 Key terms in manufacturing

To understand the manufacturing of carpet, it is necessary to be familiar with some of the technical terms used:

- gauge (carpet width)
- stitch rate (length)
- pile height (height)
- total pile weight
- stitch length
- pile or tuft density
- yarn count
- yarn ply
- yarn twist.

The three primary dimensions of a carpet are: gauge (width), stitch rate (length), and pile height (height):

- Gauge is the distance between the needles. For example, 1/8 gauge simply means there is 1/8″ between each needle, or there are 8 needles per inch.
- Stitch rate (or stitches per inch) defines the number of times per inch a stitch occurs, just as gauge expresses the frequency of tufts across the width. Stitch rate is the number of times an individual needle inserts a tuft into the primary backing as the primary backing moves one inch through the tufting machine. This is sometimes abbreviated as SPI. Therefore 8 stitches per inch means that as the primary backing moves through the tufting machine, a single needle forms 8 tufts or stitches.
- Pile height is the length (expressed in decimal parts of one inch) of the tuft from the primary backing to the tip. All other factors being equal, a carpet with a higher pile height will possess more yarn on the wearing surface and will essentially be more durable.

Other common measurements are:

- Denier or yarn denier: unit of weight for the size of a single filament or yarn bundle. The higher the denier, the heavier (coarser) the yarn and the more resilience it will offer. Denier is expressed as the weight in grams of 9000 metres of yarn. 9000 metres of 18 DPF (denier per filament) would weigh 18 grams and 9000 metres of a 1230/2-ply yarn would weigh 2460 grams. The higher the DPF, the greater the fibre's resilience and resistance to bending, but also the harsher it feels to touch. DuPont's Tactesse® has a denier of 12, which gives it a softer feel than the 15–18 denier more commonly used in carpet fibres.
- Density or pile density: the weight of a pile yarn (including its obscured parts) in a unit volume of carpet, which is expressed in grams per cubic metre, is also known as 'average pile yarn weight'. The closer the tufts are to each other, the denser the pile and the less weight each individual tuft has to support. Pile density is not only evaluated by the closeness of the tufts but also by the height and weight of the pile yarn. All other things being equal, the greater the pile density, the greater the expected durability of the carpet and thus the longer it is expected to last.
- Face (or pile) weight: the total weight of the face yarns (above and below the backing) in the carpet. The more grams per square metre, the denser the pile and, potentially, the greater the wearability of the carpet.
- Twist: is the process whereby two or more spun yarns are twisted together. Twist is counted by the number of turns per inch (TPI) of the yarn. The performance of cut-pile carpet is highly dependent on the rate of twist and twist retention. Heat setting helps stabilise yarn twist by subjecting the yarn to high-temperature steam under pressure. Most carpet yarns have 2.5 to 6.0 twists per inch. A higher twist level usually results in better texture retention and better resilience. A high twist will result in a frieze, a medium twist will produce a Saxony, and a low twist will result in a velour or Saxony plush style.
- Tuft bind: loop pile styles have closed loops, so twist is not a major factor but tuft bind is. Tuft bind is the relative strength of the attachment of the yarn loops to the backing of the carpet.
- Staple yarn size: the size of staple yarns is most often expressed in what is known as the cotton count system. In this system, a yarn count is an inverse system – i.e., the larger the numerator, the smaller the yarn – and is based on the number of 840-yard hanks required to weigh 1 pound. For example, a 1 cotton count (cc) yarn has 1 hank (840 yards) per 1 pound (453.6 gms), while a 2.5 cc yarn would require 2.5 hanks (2100 yards) to weigh 1 pound. The denominator represents the ply count of the yarn.

7.13 Weaving of handmade carpets

It is well known that a carpet consists of two parts: one is the foundation, which is formed by warp and weft yarns, and the other is the 'pile', which forms the designs and patterns and is, in effect, the 'working surface' of the completed carpet. The pile is the upright ends of strands, formed by knots (weft/pile thread tied with warp), that may be cut or looped.

Various fibres are used as foundation materials for different carpets, such as cotton, wool or silk. The threads used for the warp and the weft are undyed but those which will form the pile are dyed to match the colours required in the design of the carpet. These colours, as well as the design for the carpet, will have been decided by the designer and produced as a colour picture for the weaver to follow. Great care is taken to ensure that the threads match the precise colours stipulated by the designer and that the final carpet is a true representation of their artwork.

After all these preparations, the process of weaving begins. First, the warp yarns are fixed on the loom and, starting from the bottom, the weaving gets under way. The weaver takes a piece of carefully selected fibre, such as wool or silk, to form a knot on two warps, corresponding with the designs and colours in the picture, then the surplus fibre is cut off with a knife. After a row of knotting is completed, the weaver passes one or several weft yarns in between the front and back warps then uses a special comb to beat forcefully on the row of knots and weft in order to keep them tight and make the carpet even. As the work progresses, the weaver uses a knife or a pair of scissors to shear away unwanted fibres. These processes continue until the carpet is completed and finally, the carpet is washed in a special solution. After being dried, the carpet will appear elegant, splendid, and full of lustre.

The outline of a carpet loom looks like a wooden frame. Warp threads are vertically wound around the loom parallel to each other, depending on the type and the size of the carpet. After preparing the warp, a chain-like plait called a 'chiti' is woven, leaving a margin for fringes, and then a 2–4 cm wide kilim weaving is done so as to prevent the pile knots from shifting and dropping out. Upon completion of this procedure, the carpet is ready for weaving. The weaver hangs the coloured knotting threads wound into small balls, together with the carpet design drawn on a graph paper, somewhere within reach.

Each knot on the carpet corresponds to one square on the graph paper and its colour is shown by the paint covering the respective square. Sitting on a small stool, the weaver begins weaving the carpet from the bottom upwards. As the weaving progresses, the carpet is moved behind the loom. Upon completion of a row of knots, the weaver passes the horizontal thread, called the weft, through the warp threads (below and above) across the width of the carpet, and firmly presses on the knots with the shed stick. The ends of the knots, which are cut roughly with a knife at the time of knotting, are trimmed with a special pair of scissors to make them level with the face (pile) of the carpet. The two methods used in carpet weaving are double knot and single knot.

Although the single-knot method makes working with detailed motifs easier, the double-knot method produces extraordinary strength. Carpets woven with the double-knot method, therefore, are a better investment as over time they are better able to withstand wear and tear. Upon completion of the carpet, further weaving is done so as to fix the knots. Finally, a chain plait is woven and the carpet is cut loose from its warp to be taken out of the loom. It is washed with soapy water, to get rid of the dust and dirt collected during the course of weaving, and made ready for use.

Handmade carpets are made in three different ways: knotted weave, flat weave and tufting, of which knotted weave is the more widely used method. As its name suggests, in this technique knots are created. A strand is tied around two adjoining warp yarns, creating a knot. After a row of knots is completed, one or several weft yarns are woven through the warp yarns, and then a special comb is used to beat the knots and weft yarns tightly together. The weaving process begins at the bottom of the loom and as the knots and weft yarns are added, the carpet moves upwards until it is finished. Different weaving groups use different kinds of knots. Some are symmetric, some are asymmetric, while others are more complex. In the handmade carpet sector, hand-knotted carpet plays an important socio-economic role on one hand, and on the other demonstrates superb craftsmanship in terms of making unique knots.

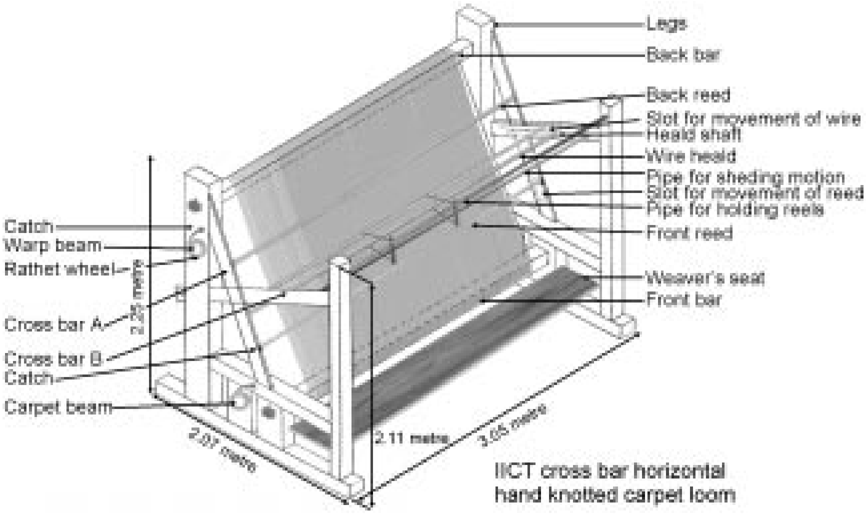
7.13.1 Developments in loom design

The traditional loom for hand-knotted carpet making has changed little over many centuries. However, recent research, using modern ergonomic principles, has been undertaken to improve loom design both to increase productivity and make working conditions easier for the weaver.[3] A new type of cross-bar horizontal hand-knotted carpet loom is shown in Figs 7.47 and 7.48.

The new design has a number of advantages:

- it remains a simple, reliable, easily transported technology suitable for rural conditions
- it provides a better sitting posture and improved visibility for the weaver, allowing the weaver to work longer and more accurately and safely whilst remaining comfortable
- it allows a longer length of carpet to be produced
- there is less time required for warp preparation
- it allows greater knot density and firmer, more uniform knotting
- it is flexible, being capable of producing hand-knotted, Tibetan, soumaik and shaggy styles of carpet on the same loom.

Over time, the new loom design is expected to significantly improve productivity, quality and working conditions within the handmade carpet industry.



7.47 Diagram of a cross-bar horizontal hand-knotted carpet loom.

7.48 A cross-bar horizontal hand-knotted carpet loom in use.

7.13.2 Carpet washing and finishing

Handmade carpets whether knotted, tufted or loom-made require washing using various chemicals. As such, hand-knotted carpets undergo severe mechanical agitation besides usage of chemical. The typical prevailing washing/chemical processing recipes of woollen and silk carpets are available in Tables 7.6 and 7.7.

Table 7.6 Washing/chemical processing of woollen carpet

Step no.	Name of chemicals and auxiliaries	Following parameters			
		Reporter 1	Reporter 2	Reporter 3	Reporter 4
1.	Water (normal water)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)
2.	Sulphuric acid + bleaching powder	100 gm/m^2 100 gm/m^2 (treated temperature 20 to 30 °C for 10 minutes)	100 gm/m^2 100 gm/m^2 (treated temperature 20 to 30 °C for 15 minutes)	Bleaching powder —2 to 4 °tw (temperature 20 to 30 °C for 20 minutes)	100 gm/m^2 100 gm/m^2 (treated temperature 20 to 30 °C for 30 minutes)
3.	Water (normal water)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)
4.	Caustic soda	100 gm/m^2 (treated temperature 20 to 30 °C for 10 minutes)	100 gm/m^2 (treated temperature 20 to 30 °C for 15 minutes)	Caustic soda -- 2 to 4 °tw (temperature 20 to 30 °C for 20 minutes)	100 gm/m^2 (treated temperature 20 to 30 °C for 30 minutes)
5.	Water (normal water)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)

6.	Sulphuric acid	50 gm/m^2 (treated for neutralisation, temperature 20 to 30 °C for 10 minutes)	50 gm/m^2 (treated for neutralisation, temperature 20 to 30 °C for 10 minutes)	Instead of acid neutralisation using acetic acid 50 to 100 gm/m^2 (treated for neutralisation, temperature 20 to 30 °C for 10 minutes)	50 gm/m^2 (treated for neutralisation, temperature 20 to 30 °C for 10 minutes)
7.	Water (normal water)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)	**Cold wash** (temperature 20 to 30 °C for 10 minutes)
8.	Silicon softner (like- Cirapon-PSLS, Ciba Soft)	**25 to 50 gm/m^2** for softening they are using with acetic acid for 10 minutes temperature 20 to 30 °C	**25 to 50 gm/m^2** for softening they are using with acetic acid for 10 minutes temperature 20 to 30 °C	**25 to 50 gm/m^2** for softening they are using with acetic acid for 10 minutes temperature 20 to 30 °C	**25 to 50 gm/m^2** for softening they are using with acetic acid for 10 minutes temperature 20 to 30 °C
9.	Hydro extraction	They are following manual procedure	They are using hydro extractor for 10 to 15 minutes	They are following manual procedure	They are following manual procedure
10.	Drying	Sunlight/dryer	Sunlight/dryer	Sunlight/dryer	Sunlight/dryer

Notes
1. Water proportion – 1: 50
2. Step no. 2 and 4 repeated according to the quality of carpet.

Table 7.7 Washing/chemical processing of silk carpets

Sr. no.	Name of chemicals/auxiliaries	Method/parameter
1.	Water (normal water)	Normal washing at room temperature for 10–15 minutes
2.	Paste	150 gms/sq. ft. Paste is mixed with water and then spread all over the carpet with the help of a scraper for a period of 10–15 minutes
3.	Water (normal water)	Washing at room temperature for 10 minutes
4.	Bleaching powder	100 gms./sq. ft. Bleaching powder is mixed with water at room temperature and the same is applied for 5–10 minutes
5.	Water (normal water)	Washing at room temperature for 5–10 minutes
6.	Detergent powder	100 gms./sq.ft. is treated with water at room temperature for 10 minutes
7.	Water (normal water)	Washing at room temperature for 5–10 minutes
8.	Drying	Carpet is allowed to dry through sunlight/ wooden stove
9.	Clipping	Once the carpet is completely dried the pile yarn is clipped with the help of clipping machines
10.	Drying	Sunlight/wooden stove
11.	Water (normal water)	Normal washing at room temperature for 10–15 minutes
12.	Bleaching powder	50 gms./sq. ft. mixed with water for 5–10 minutes
13.	Water (normal water)	Washing at room temperature for 5–10 minutes
14.	Detergent powder	50 gms./sq. ft. detergent powder is treated with water at room temperature for 10 minutes
15.	Water (normal water)	Washing at room temperature for 5–10 minutes
16.	Acetic acid + shiner	30 ml/sq. ft. + 100 gms./sq. ft. mixed with water and the mixture is applied to the carpet with the help of soft brushes for 10–15 minutes at room temperature
17.	Water (normal water)	Washing at room temperature for 5–10 minutes
18.	Paste	100 gms./sq. ft. treated at room temperature for 15 minutes
19.	Water (normal water)	Washing at room temperature for 5–10 minutes
20.	Tinopal powder	50 gms./sq. ft. Tinopal powder is sprayed on the top and bottom of thread/fringes of the carpet at room temperature for 5–10 minutes
21.	Water (normal water)	Washing at room temperature for 5–10 minutes
22.	Drying	Sunlight/wooden stove
23.	Final clipping	Final clipping is done with the help of clipping machines to ensure the uniform level of pile yarn.

Carpet finishing involves repairing defects and enhancing the appearance and properties of a carpet so that it can be delivered to the customer in excellent condition. The usual steps are: inspection and mending, shearing and back-coating. For tufted carpets the backcoating step converts the limp cloth delivered by the tufting machine into a firm, stable carpet with well-anchored tufts. Most cut-pile carpets are subject to a shearing process. The details are available in the manufacturing process.

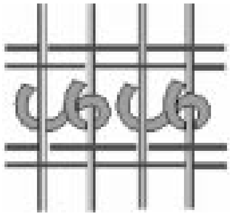
7.14 Carpet knots

Knotted pile carpets are the most durable handmade pile carpets. Tufted carpets with different types of piles or loops are also available but knotted are often considered the best. Usually, the quality of an Oriental rug is judged by the knots per square inch; the higher the count, the better the quality. The two most common types of knot used in an oriental carpet are the Persian knot and the Turkish knot.

7.14.1 Persian knot

This is an asymmetrical single knot, also called a Senneh knot or Farsibaff (Fig. 7.49). Here the thread forms only one loop around one of the two warps, so the pile threads vary in protruding between the adjacent warps.

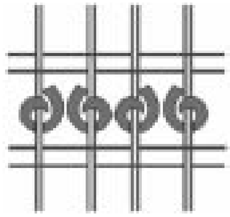
(a) Left-hand knot: warp on one level: one thread between each row.
(b) Right-hand knot: warp on one level: two weft threads between each row.
(c) Right-hand knot: warp on two levels: three weft threads between each row.



7.49 Persian knot.

7.14.2 Turkish knot

This is a symmetrical type of double knot, also called a Ghiordes (Fig. 7.50). Here the pile thread forms a loop around two warps, and both ends of the pile thread come out between both warps. There is another type called the Jufti knot. It can be symmetrical or asymmetrical and the difference is that it is formed over four warps.

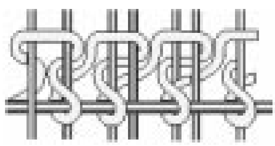


7.50 Turkish knot.

(a) Tied with the warp on one level and two weft threads between each row of knots.
(b) Tied with the warp on two levels, knots inclined to the left.
(c) Tied with warp on two levels, knots inclined to the right.

7.14.3 Tibetan knot

This uses a different approach (Fig. 7.51). A temporary rod, which establishes the length of pile, is put in front of the warp. A continuous yarn is looped around two warps and then once around the rod. Once the row is finished, the loops are cut to form the knot. According to the experts, no knot is better or worse than any other, they simply give a different texture to the carpet.



7.51 Tibetan knot.

7.14.4 India knot[4–6]

This type of knot is a recent innovation (Fig. 7.52). The process adopted with a hand loom for achieving such a knot uses two sets of warp yarns, each set supplied from a raised beam. The same threads are also drawn through the eyes

7.52 India knot.

of the doup-heald. The doup eyes are such that they allow lateral movement (right and left) as well as up and down movement so that the threads (meant for loops) can make two half circles over and under the base warp yarn. Thus, incorporating this douping system the alternative criss-crossing of the pile yarns over and under the ground warps results in interlocking in addition to simultaneous interlacement across the width forming the structure over which piles can erect with due stability as envisaged using the available formula as below.

$$T_{out} = T_{in}\, e^{\mu\theta}$$

where T_{in} = incoming tension
T_{out} = outgoing tension (in this particular case T_{out} is TWF)
μ = coefficient of friction
θ = angle of warp
e = 2.718

This knot is the product of academic concept of IICT since 2000–1 (source: 1st World Conference on Handmade Carpets, CEPC, 4–5 November 2003, New Delhi, India, pp. 75–77) and research being patented and trademarked that has been published.

7.14.5 Knot density

Knot density is an indicator of quality; the greater the number of knots per square inch (kpsi), the better the quality of the carpet. Eighty or fewer kpsi denotes poor quality and 120 to 330 medium to good, 330 or more kpsi denotes good to very good quality and carpets with more than that are classified as exclusively fine pieces.

To form a symmetric knot, a piece of strand is wrapped over two adjoining warp yarns and both ends of the strand are then pulled back together to surface between the two warp yarns, forming a cut. To form an asymmetric knot, a piece of strand is wrapped around one warp yarn and then passed under its adjoining warp yarn. The two ends are brought to the surface separately, creating better-looking designs, and each knot is tied by hand. A carpet may be made up using 25 to over 1000 knots per square inch (about 4 to 155 knots per square cm). If a weaver ties a knot in about ten seconds, this means about 360 knots per hour. Therefore it would take a skillful weaver 6480 hours to weave a 9 × 12-foot (2.7 × 3.7-metre) carpet with a density of 150 knots per square inch (23 knots per square cm). If we divide this number by 8 hours, it would take one weaver 810 days to weave a carpet of this size. A carpet as large as a 9 × 12-foot is usually woven by two or three weavers, so the above time can be reduced by a half or a third. A skillful weaver who can tie a knot in only 3 seconds can tie 1200 knots per hour.

7.15 Dyeing[7,8]

The use of colour in carpets demands a knowledge of colour in terms of design, matching and application methods. Recently there has been a revolutionary change with respect to its application and matching using a spectrophotometer which provides an objective and reliable way of measuring colour. The traditional method of dyeing now needs standardisation to cope with the customers' current requirements. Therefore, colour in today's context is not simply a matter of applying dye to yarn and using that dyed yarn for carpet manufacturing. There is a need for a scientific approach to getting perfectly dyed yarn which will then be suitable for carpets. As an example, new computer-assisted design tools can display around 90 basic colours combined in different combinations. Thousands of colour combinations can be previewed to see what they will look like, giving wider colour choices and innovative colour schemes which provide new ideas. Tint percentages can be obtained for every colour, ensuring correct reproduction.

7.16 Dyeing of wool

When a textile substrate like wool is dyed, the dyeing operation usually occurs in three stages:

1. Diffusion of dye through the aqueous dye bath to the fibre surface.
2. Transfer of dye across the fibre surface.
3. Diffusion of dye from the surface throughout the whole fibre.

Wool fibres are composed of two types of cell, namely cuticle cells and cortical cells. The cuticle cells form an outer sheath encasing the inner cortical cells. Whilst the cells of wool are mainly keratin, it has been shown that the non-keratinous proteins of wool are also important in dyeing. Increasing the keratin/non-keratin ratio, by partly removing the non-keratinous proteins, reduces the diffusion coefficients of acid dyes in the fibre, and diffusion of dyes becomes increasingly difficult as the non-keratinous protein content decreases.

The epicuticle of wool is strongly hydrophobic in character and forms a resistant barrier to the penetration of dyes; however, it is readily damaged by weathering and mechanical or chemical processes. When the epicuticle membrane has been damaged or is missing, dyes can penetrate the fibre more readily, especially at low temperatures. Chemical treatments such as chlorination cause extensive damage to the epicuticle and this process has often been used to facilitate wool dyeing. Differences in the surface properties of wool fibres probably account for the number of differences in the ease of penetration of dyes exhibited by wool fibres of the same type.

The remaining 90% of the wool fibre, the cortex, has a bilateral structure and can be further subdivided into two parts: the ortho cortex and the para cortex. The ortho cortex has a more open structure than the para cortex and is more accessible to dyes and more reactive chemically. The intercellular cement of the cell membrane complex in particular has been identified as providing not only the dye-binding site but also the channel system for dye diffusion.

Various groups within the protein structure are of importance for the dyeing of wool. Wool contains both dibasic and diacidic amino acids, which appear within the structure as basic and acidic side-chains. It is therefore amphoteric in character. The basic amino acid residues in wool are arginine, lysine and histidine. These basic groups are considered to be the predominant dye sites for the formation of covalent bonds between reactive dyes and wool.

When wool is dyed with acid dyes, the dye bath normally contains dye anions, hydrogen ions from the acid, electrolytes, sodium ions from the dye and the counter ions from the acid. When wool is immersed in the dye bath, the smallest and most rapidly diffusing ions would be expected to be absorbed quickly while the larger and more slowly diffusing dye anions would follow more slowly. When wool is immersed in water, the amino acid carboxyl groups will exist in the ionised or zwitterion form:

$$\underset{\text{Acid condition}}{H_3N^+\text{—WOOL—COOH}} \rightleftharpoons \underset{\text{Iso-electric condition}}{H_3N^+\text{—WOOL—COO}^-} \rightleftharpoons \underset{\text{Base condition}}{H_2N\text{—WOOL—COO}^-}$$

At the isoelectric point, the wool carries no net charge because there are equal numbers of positively charged ammonium groups and negatively charged carboxyl anions. As acid is added to the system, hydrogen ions from the acid react with the carboxylate anions to form carboxylic acid groups, leaving the positively charged ammonium groups available to act as ‘dye sites’ for acid dyes. Under alkaline conditions, on the other hand, hydrogen ions are abstracted from the positively charged amino groups. The carboxyl anions then confer a negative charge on the substrate.

7.16.1 Wool dyes

Wool dyestuffs vary in terms of molecular size and the polarity of the molecule. Most dyestuffs contain ionic solubilising groups that are based on the sodium salts of either sulfonic or carboxylic acid groups. The number of solubilising groups present within the dye molecule influences the solubility, dyeing properties, and wet fastness. Acid, chrome, metal-complex and reactive dyes are used for the dyeing of wool. The great majority of acid dyes are the sodium salts of aromatic sulfonic acids, some of which contain carboxyl and phenolic groups.

7.16.2 Mordant dyes

The use of mordant dyes has been adopted to improve the wash fastness of dyed wool. These dyes are marketed as chrome dyes or mordant dyes. Mordant dyes may be applied using:

- chrome-mordant process
- metachrome process
- after-chrome process.

In each case, an excess of potassium dichromate or sodium dichromate is added before, during or after the application of dyestuff. Methods of fixing the dye/chromium complex in wool have been put forward for both 1:1 metal complex and 1:2 metal complex formations. It is generally accepted that only with 1:1 metal complexes could there be a coordinate linkage between the oxygen or nitrogen groups of wool fibre. For 1:2 metal complexes, the wet fastness of chrome dyes has been attributed to van der Waals forces, which are greater for large dye molecules than small ones. Hydrogen bonding between the dye complex and the fibre is also the reason for improving the wash fastness of chrome dyes.

Metachrome dyes are the easier to apply as they only require a single application procedure, but some dyes have a tendency to exhibit poor rubbing fastness due to the precipitation of complexed dyestuff in the dye bath, some of which is subsequently deposited on the wool fibre surface. The after-chrome process is the most widely used because it gives the highest wet fastness properties and the best levelling properties.

In the chrome-mordant process, chroming and dyeing are carried out simultaneously. The disadvantages of this method are:

- limited number of suitable dyes
- inability to achieve heavy shades because of limited exhaustion at neutral pH
- high residual level of chromium resulting from less than optimum dye bath exhaustion of the mordant at neutral pH.

A typical dyeing method using the after-chrome process is described below. A typical dye formulation is:

- Omega chrome dye: X%
- Glauber's salt calc: 5–10%
- Lyogen SMKI liquid: 1–2%
- Acetic acid 40%: 2–4%

Immerse the wool fibre at 50 ºC, then raise the temperature of the dye bath to boiling point over a period of 30–40 minutes and boil for 30 minutes. Add 1–2% of formic acid (85%) for exhaustion and continue boiling for a further 15 minutes. Cool to 75 ºC and add 0.2 to 2.0% potassium dichromate. Raise the temperature of the dye bath to boiling point over a period of 20 minutes and boil for 45 minutes. Rinse and dry.

- Acetic acid (80%): 1.2%
- Chrome fast dye: X%
- Potassium dichromate (0.2% + 15% of the total amount of dye): Y%
- Formic acid (85%) pH 3.5–3.8: 2–3%

The disadvantage of the after-chrome process is the difficulty in shade matching since the final colour does not develop until the chroming stage. For this reason, 1:2 metal complex dyes are used to obtain shades.

The amount of potassium dichromate constitutes half of the total dye used and should not be more than 2% and less than 0.5% for mordanting. If excess chromium salt is used for a prolonged period, it causes damage to the wool fibre. This damage can be minimised, while maintaining fastness and shade, using a reduced amount of dichromate at a low temperature (below boiling).

Chromium, the heavy metal residual, causes waste disposal problems. To reduce the amount of effluent, the Clariant process has been developed that uses a reduced amount of chromium. In this process Lyocol CR (Clariant) is added during chroming at a concentration that is one quarter of the amount of dichromate. This acts by reducing any residual hexavalent chromium to trivalent chromium ions with which it then forms a complex, which is absorbed by the wool.

7.16.3 Acid dyes

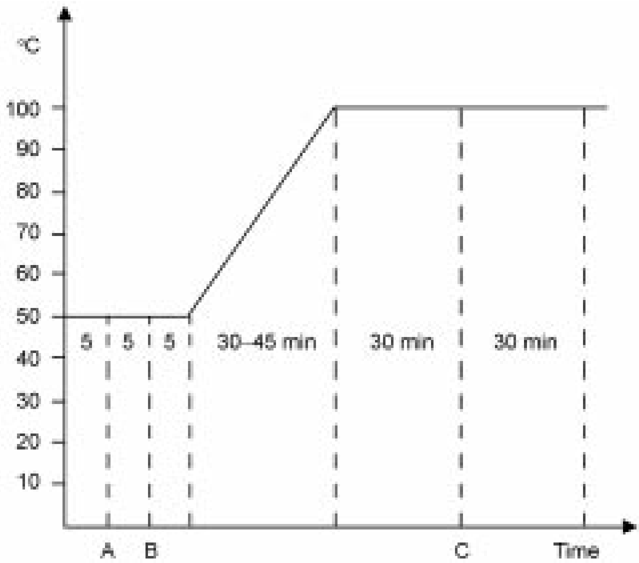
Acid dyes are sodium salts of sulfonic acids, which are Azo, anthraquinon, Xanthene, and Tri-phenyl methane dyes. These are planar in structure. While dyes may be synthesised from many different chemical groups, they are usually classified into three groups on the basis of their technical properties such as dyeing method, levelling properties and wash fastness.

Acid levelling dyes have relative molecular mass (rmm) values of around 300–600. The dye molecules rapidly diffuse into the wool fibre and, although exhaustion can be so rapid as to be initially unlevel, the dyes readily migrate at boiling point to give a level appearance. This type of dyestuff has very good levelling properties because during dyeing at boiling point, an equilibrium level of exhaustion exists. The degree to which this equilibrium favours the fibre or the solution phase is determined by the pH, the temperature, the amount of anionic sulfate ions added in the form of Glauber's salt, and the number of solubilising groups on the dye molecule. This class of dyestuff is ideally suited for use on fabrics and yarns where levelness is paramount. They exhibit moderate wet-fastness but are not fast for either hand or machine washing. They are used for dyeing pale to medium depth shades on wool. Acid levelling dyes are applied using an acidic bath at around pH 2–3 in the presence of 10% sodium sulfate. The sulfate anions compete with the dye anions for the protonated cationic sites on the wool.

Typical dyeing procedures are shown in Fig. 7.53.

Method 1:

- At **A** set bath at 50 with: 4% sulfuric acid (96%) 5% Glauber's salt anhydrous, pH 2.5 to 3.5
- At **B** add required amount of dyestuff.



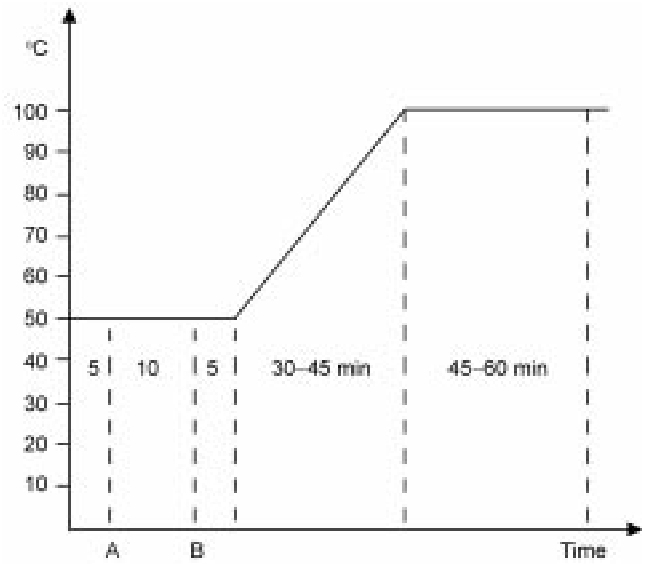
7.53 Acid dyeing process.

Method 2:

- At **A** set bath at 50 with: 2% formic acid (85%) 5% Glauber's salt anhydrous, pH 3.5 to 4.5
- At **B** add required amount of dye.
- At **C** add 2% sulfuric acid (96%) or 2% formic acid (85%).
- Thoroughly rinse after dyeing to remove loose colour.

Fast acid dyes have a higher relative molecular mass (500–700) than acid levelling dyes and hence exhibit improved levels of wet contact fastness. They are applied to wool fabric and yarn in medium to deep shades. Their migration properties are lower than those of levelling dyes and dyeing is carried out using acetic acid at around pH 5.2–6.2. This type of dye has excellent migration properties relative to the molecular size because levelling properties are greatly enhanced by the addition of a mildly cationic substantive dye levelling agent. The dye-levelling agent complex acts to reduce the rate of dye uptake during the heating phase and promotes migration during the boiling phase. This type of dye is widely used for producing brilliant and trichromatic combination shades on wool fabrics and carpet yarns. A typical dyeing procedure is shown in Fig. 7.54:

- Set bath at 50.
- At **A** add 5% Glauber's salt anhydrous and 1–3% acetic acid 80%, pH 5–6 and levelling agent if required (Lyogen SMKI 1%)
- At **B** add dissolved dye. Follow cycle profile indicated. Thoroughly rinse after dyeing to remove loose dye.



7.54 Fast acid dyeing process.

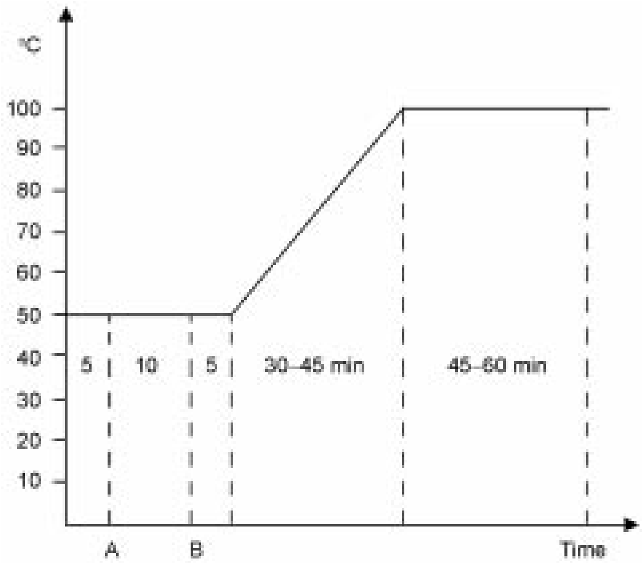
7.16.4 Acid milling dyes

These are larger dye molecules with relative molecular mass (rmm) values of 600–1000. Owing to the higher rmm, two or more solubilising groups are often used to give enough solubility. Some dyes in this group also have an additional hydrophobic alkyl chain that further increases the molecular weight and provides additional fibre attraction in the form of van der Waals forces. This class of dyestuff has limited levels of migration but extremely high wet fastness properties. Loose fibre dyeing is normally carried out at a fixed pH in the range of 4 to 6, with a weakly cationic leveling auxiliary (see Fig. 7.55). A typical dyeing procedure is:

- Set bath at 50 and immerse wool for five minutes
- At **A** add 5% Glauber's salt anhydrous 1–2% acetic acid 80%
- 0.3–0.8% neutrasol LAM **pH 5–6**
- At **B** add dissolved dye. Follow cycle profile indicated. Thoroughly rinse after dyeing to remove loose dye.

7.16.5 1:1 Metal complex dyes

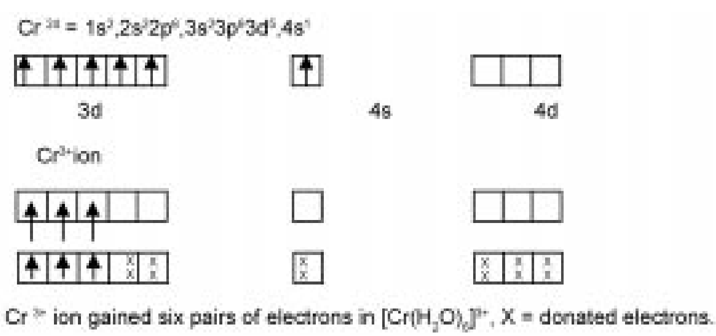
The electronic configuration of Cr^{III} gives stability to the complex formed by dye molecules. The stability of the complex is such that it resists demetallisation during dyeing or subsequent processing and use. In chromium, 3d orbitals and 4s orbital are filled with single electrons. It becomes a $\mathbf{Cr^{3+}}$ ion by releasing three electrons and can then form a complex with a dye molecule and water.



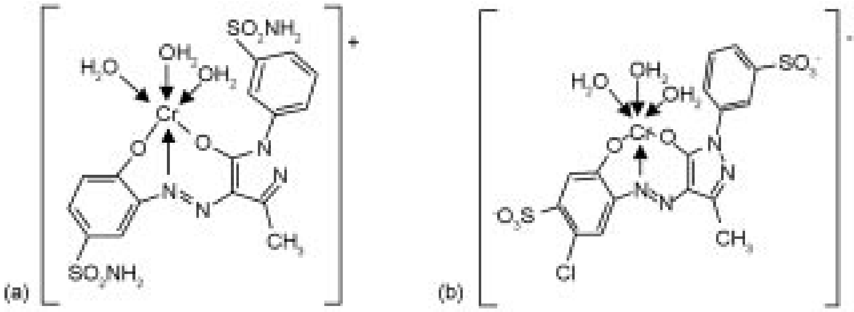
7.55 Acid milling dyeing process.

In a 1:1 metal complex dye, the metal ion Cr^{3+} matches with a single monoazo dye ligand and three other ligands, usually water or colourless hexafluorosilicate ligands (Fig. 7.56). Solubility in water is conferred by the presence of one or more sulfonic acid groups, although CI acid orange 76 (Fig. 7.57a) contains the non-ionic aminosulfone ($-SO_2NH_2$) group as a solubilising aid. Depending on the nature and number of the solubilising groups and the nature of monodentate ligands present, the dyes are either effectively uncharged or carry an overall negative charge (because of the presence of Cr^{III}) as in C.I. Acid Red 183 dyes; dyes that contain no solubilising groups (Acid Orange 76) have an overall positive charge.

These dyes exhibit good even dyeing, good penetration characteristics, are suitable for acid milled wool, cover irregularities in substrate and produce



7.56 Chromium reaction in 1:1 metal complex dye.



7.57 (a) C.I. acid Orange 76; (b) C.I. acid Red 183.

uniform shade, and have very good light fastness and moderate to good wet fastness.

1:1 Metal complex dyes are commonly applied to wool using a strongly acidic (pH = 2) dye bath (hence dyes are sometimes referred as 'acid dyeing metal complex dyes'). Under these conditions, the dyes possess excellent transference and thus are good levellers. Since wool absorbs approx. 4% W.O.W. of H_2SO_4 (96%), excess acid is required to maintain the pH. The amount of acid depends upon the liquour ratio and dyeing method used as shown in Table 7.8.

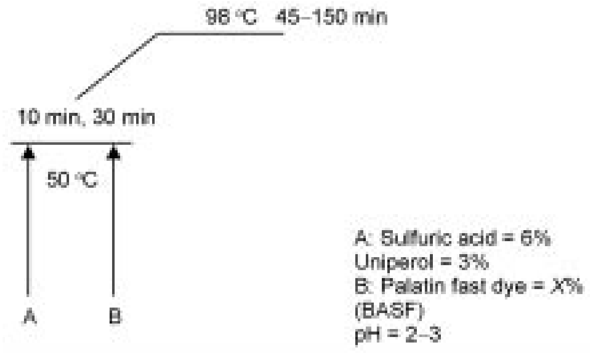
Dyeing with 1:1 metal complex dyes is started at 50 ºC with auxiliaries and after 10 minutes the dye solution is added, still at 50 ºC. The temperature is then raised to 98 ºC over a period of 30 minutes and dyeing continues for a further 45 to 150 minutes. After draining off the liquid, the dyed material is rinsed and washed with soap at 60 ºC for 20 minutes. A typical recipe is (Fig. 7.58):

- Sulfuric acid: 6%
- Uniperol 5700 (BASF): 2%
- Na_2SO_4: 5%
- Palatin (BASF) Fast Dye: X%

Ciba Geigy (Neolan P) has developed 1:1 metal complex dyes that are complexes of sulfonated azo dyes with colourless hexafluorosilicate ligands. These dyes are applied in the pH range 3.5–4.0 in conjunction with Albegal plus

Table 7.8 Excess H_2SO_4 used (%wt)

L:M	< 1% dye o.w.m.	>1% dye o.w.m.
10:1	0.7	1
20:1	1.4	2
30:1	2.1	3
40:1	2.8	4
50:1	3.5	5

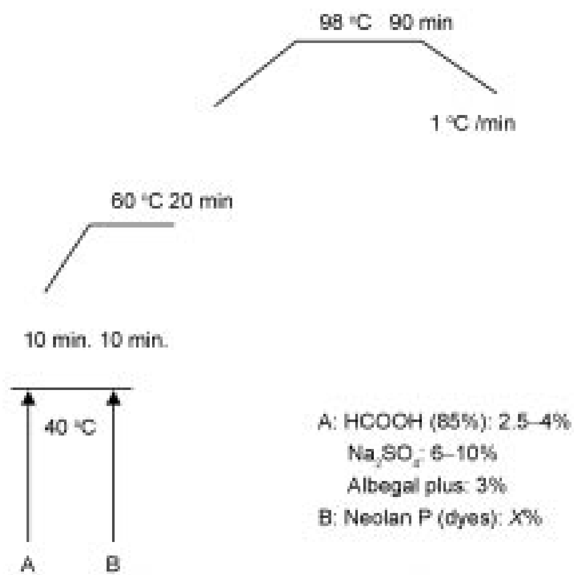


7.58 Dyeing with Palatin Fast Dye.

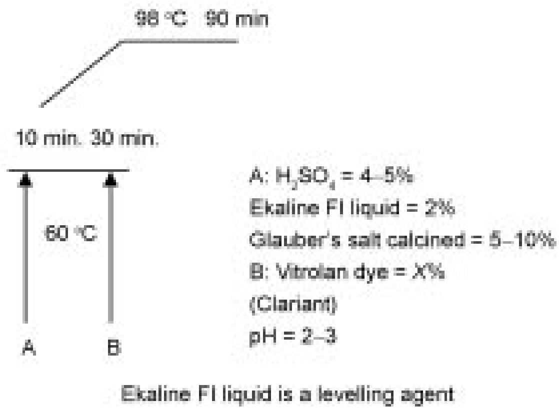
(CIBA), an amphoteric auxiliary that contains ethoxylated fatty amine and ammonium hexafluorosilicate [$(NH_4)_2SiF_6$].

Dyeing with Neolan P dyes (Fig. 7.59) is started at 40 ºC with auxiliary (A) and after 10 minutes the dye solution is added at 50 ºC. The temperature is then raised to 60 ºC over a period of 10 minutes and dyeing is continued for 20 minutes at this temperature. After that, temperature is raised to 98 ºC at the rate of 1 ºC per minute and dyeing continues for a further 90 minutes at this temperature. After draining off the liquid, the dyed material is rinsed and washed with soap at 60 ºC for 20 minutes.

Dyeing with Vitrolan dyes (Clariant) (Fig. 7.60) is started at 60 ºC with auxiliary (A). The temperature is raised to boiling over a period of 30–45



7.59 Dyeing with Neolan P.

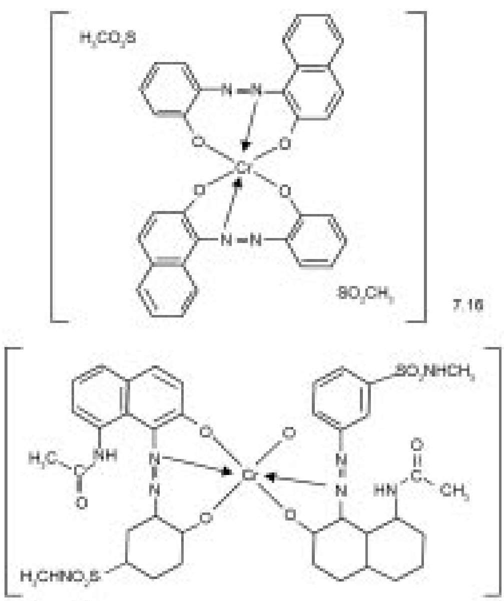


7.60 Dyeing with Vitrolan dyes.

minutes and dyeing continues for a further 90 minutes. The dyed material is then rinsed and dried.

7.16.6 1:2 Metal complex dyes

Metal complex dye shades are dull in comparison to acid dyes. 1:2 metal complex dyestuffs are formed by the complex formation of a metallic atom such as chromium or cobalt with two dye molecules (Fig. 7.61). The resultant dye



7.16

7.17

7.61 1:2 metal complex dyes.

Table 7.9 1:2 metal complex dyes and their trade names

Trade name	Manufacturer
Lanasyn	CLARIANT
Amichrome	ICI
Irgalan	CIBA
Isolan	BAYER
Ortolan	BASF

molecule can form strong links with the fibre and so the dyes tend to have low migration properties. There are three distinct types of 1:2 metal complex dyes: unsulfonated, monosulfonated and disulfonated. The disulfonated dyes are the most soluble and the dyeing behaviour has a greater dependence on pH.

The polarity of dye molecules depends on the presence of strong and weak polar groups. Dyes which are free of strongly polar, ionic solubilising groups (i.e., $-SO_3H$, or –COOH) are known as weakly polar 1:2 metal complex dyes. Water solubility is conferred by the anionocity of the dye complex. These 1:2 metal complex dyes are available as the trade names shown in Table 7.9.

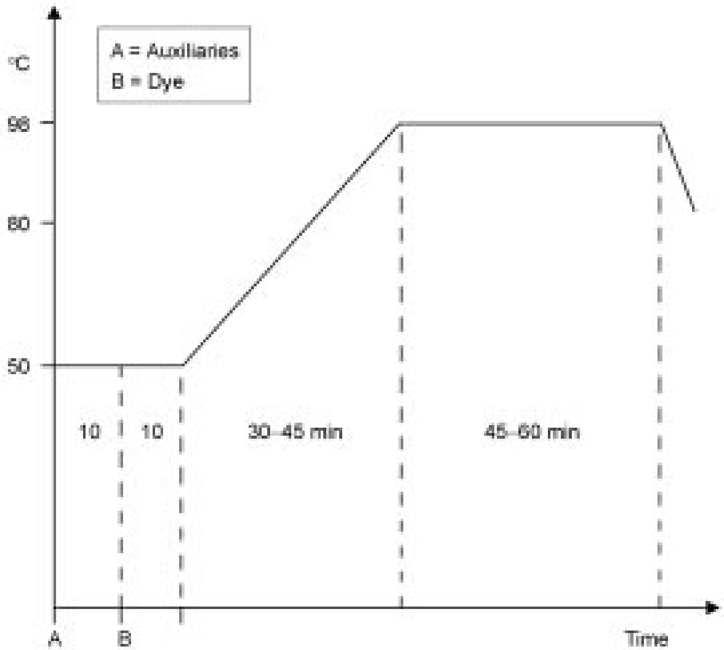
These dyes display very good to excellent light fastness and very good fastness to wet treatment on wool in pale to medium shades. The dyes exhibit good levelling and penetration properties and typically yield non-skittery dyeings. They are used on loose stock, slubbing, and yarn for men's and women's outerwear, carpet and knitting yarns and knitted goods; owing to their tendency to accentuate barre dyeing, they are less widely used on woven goods.

Dyeing with weakly polar 1:2 metal complex dyes (Fig. 7.62) is started at 50 ºC with auxiliaries. After 10 minutes the dye solution is added at 50 ºC. After 10 minutes the temperature of the dye bath is increased to boiling over a period of 30–45 minutes and dyeing continues at boiling for 45–60 minutes. The wool is then rinsed and dried. A typical recipe is:

- Lanasyn dye: X%
- Ammonium Sulfate pH 6–6.5: 2–5%
- Glauber's salt calcined: 5–10%
- Lyogen SMKI liquid: 1–2%
- Lyogen SMKI liquid: used as a levelling agent.

Strongly polar 1:2 metal complex dyes exhibit strong polarity due to the presence of strong polar groups such as SO_3H, or –COOH groups. Table 7.10 shows the monosulfonated range of 1:2 metal complex dyes.

Generally, strongly polar 1:2 metal complex dyes exhibit very good build-up characteristics, have very good to excellent light fastness and very good fastness to wet treatments on wool. Generally, they display a higher fastness to wet treatments on wool than their weakly polar counterparts and are therefore generally suitable for those applications where mordant dyes are used, as well as



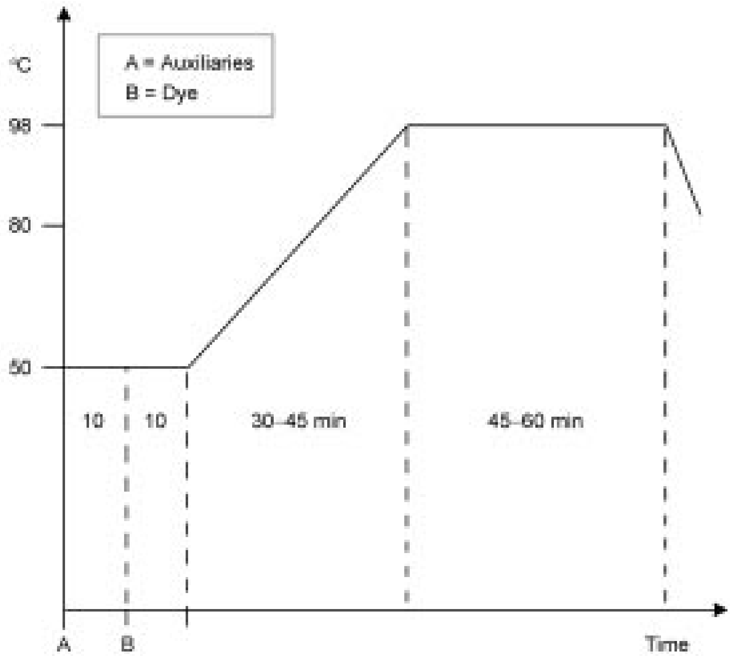
7.62 Dyeing with weakly polar 1:2 metal complex dyes.

Table 7.10 Monosulfonated range of 1:2 metal complex dyes

Trade name	Manufacturer
Lanasyn S	CLARIANT
Neutrichrome S	ICI
Lanacron S	CIBA
Isolan S	BAYER

those for which mordant dyes cannot be employed because of the prolonged dyeing time required. They are used principally on loose stock, slubbing and yarn for women's and men's outerwear, furnishings and floor coverings, knitting yarn and knitted goods. The dyes possess a lower levelling ability than their weakly polar counterparts and have a greater tendency to skittery dyeings; the disulfonated variants possess the lowest levelling characteristics and are therefore rarely used on woven fabrics.

Dyeing with strongly polar 1:2 metal complex dyes (Fig. 7.63) is started at 50 °C with auxiliaries. After 10 minutes the dye solution is added at 50 °C. After 10 minutes the temperature of the dye bath is raised to boiling over a period of 30–45 minutes and dyeing continues at boiling for 45–60 minutes. The wool is then rinsed and dried. A typical recipe is:



7.63 Dyeing with strongly polar 1:2 metal complex dyes.

- Lanasyn S dye: X%
- Sodium acetate: 3%
- Acetic acid: 4–6%
- Glauber's salt calcined: 5–10%
- Lyogen SMKI liquid: 1–2%
- Lyogen SMKI liquid is used as a levelling agent.

7.17 Chemical processing and dyeing of silk

Silk is a lustrous protein fibre obtained from *Bombyx mori*, cultivated mainly in China, India, Japan, Thailand, Italy and Korea. The collective term 'silk' is applied to protein-containing secretions which are exuded as filaments by the glands of the larva of different species of moth. There are differences between the two types of silkworm, *Bombyx mori* and *Antheraea*, and the silk they produce.

In the raw state, the silk filaments look dull and harsh due to the presence of sericin. After removal of the sericin, the elegant lustre and softness is obtained. Raw silk is available in many shades ranging from white to yellow, and greenish to brownish.

Degumming of silk is carried out in different ways, but the most widely used process is to boil it with Marseilles soap for several hours. Generally, 8–10 g/l

Marseilles soap is used, boiling it for 2–6 hours at pH 9.5. Enzymes, acids and alkalis may also be used for degumming. Loss is an important factor in degumming, varying from 25% to 30%. More degumming loss means there is degradation of fibroin and less loss means residual sericin is present.

As a natural polyamide, silk fibroin exhibits not only free carboxyl and amino groups but also phenolic substituents with accessible –OH groups. Silk can be dyed with acid dyes, chrome dyes, metal complex dyes, vat dyes, reactive dyes, etc. The decisive factors influencing the uptake of these dyes on silk fibre are the following:

- pH of the dyeing system
- dyeing temperature
- dyeing time
- chemicals used (fibre and dye-substantive levelling agents).

Based on their dyeing behaviour and ever-increasing fastness requirements, the large molecule Sandolan N/Millng N or Nylosan F products are now the dyes of choice for obtaining brilliant shades on silk, while Lanasyn and Lanasyn S dyes are preferred for more muted tones.

Sandolan MF/Nylosan N dyes are primarily suited for pale to medium combination shades on 100% silk yarn and goods by reason of their:

- good levelling power
- good combinability
- adequate wet fastness, depending on the depth, which can be further improved, particularly the rubbing fastness, by an after treatment with Sandofix WES powder.

Sandolan N, Sandolan milling N and Nylosan F dyes are suited for full, brilliant shades in piece goods and yarn dyeing. The advantages of these dyes are as follows:

- high wet fastness
- best possible brightness of shade
- preferred application as straight colours with shading elements
- applicability in combination with Lanasyn/Lanasyn S dyes
- they produce good levelness and excellent fastness properties in weighted silk.

Lanasyn/Lanasyn S Dyes are often used for pale to deep shades on piece goods and yarn dyeing. The advantages of these dyes are:

- good combinability with one another and with selected Sandolan Milling N dyes
- high wet fastness properties, even in the deepest shades, which can further be improved by an after-treatment with Sandofix WES powder
- high light fastness.

7.17.1 Dyeing methods for silk (Fig. 7.64)

Additions to the dye bath for dyeing in the weakly acid region using Sandolan or Nylosan dyes can be made in the following proportions:

- X%: Sandolan or Nylosan dye
- 0.5–1.5%: Lyogen MF liquid (levelling agent)
- 1–2 g/l: Sodium acetate
- 1–2g/l: Acetic acid for maintaining pH 4.5–7.0 depending on depth

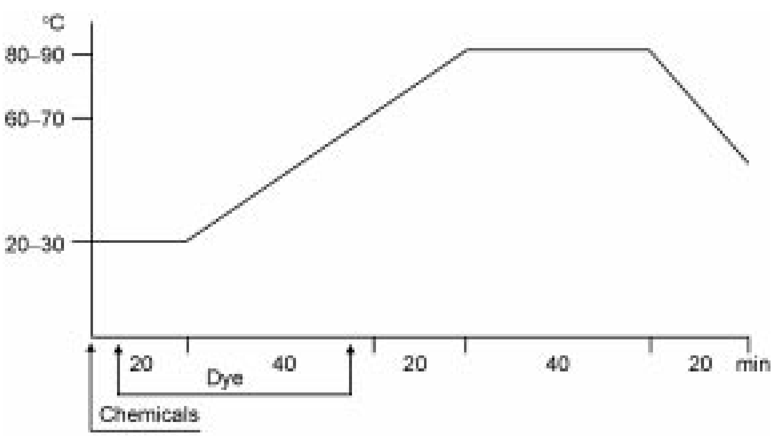
Additions to the dye bath for dyeing in the weakly acid region with metal complex dyes (Lanasyn/Lanasyn S dyes) can be made in the following proportions:

- X%: Lanasyn/Lanasyn S dye
- 0.5–1.5%: Lyogen SU liquid
- 1–2 g/L: Sodium acetate
- 1–2g/l: Acetic acid for pH 4.5–7.0 depending on depth

The silk is placed in the dye bath at 20–30 ºC, then the temperature is raised to 80–90 ºC over a period of 40–60 minutes. It is dyed at this temperature for 40 minutes, then cooled to 50 ºC and drained. It is then rinsed and washed with 0.5 g/l soap (Sandopan DTC) at 60 ºC for 15 minutes.

Reactive dyes can also form covalent, highly wet-fast bonds with silk fibre just as they can with wool or cellulosic fibres. Their most popular applications are in the yarn sector for coloured woven and special effect yarns, where good boiling-off and overdyeing stability are required.

In the second phase, after remaining at dyeing temperature for about 20–40 minutes, the dyes are fixed by adding 2–5 g/l sodium bicarbonate in two portions. Further dyeing takes place at the appropriate dyeing temperature for



7.64 Dyeing silk.

30–60 minutes and then it is cooled. To maximise dye fixation, a dyeing temperature of about 60–70 ºC, depending on the substrate structure, is recommended for Drimalan F and selected Drimarene K dyes.

Additions to the dye-bath for Drimalan F or Drimarene K dyes can be made in the following proportions:

- X%: Drimalan F or Drimarene K dye
- 20–60 g/l: Glauber's salt calc.
- 2–5 g/l: Sodium bicarbonate

The silk is placed in the dye bath at 20–30 ºC, then the temperature is raised to 60–70 ºC over a period of 40 minutes. It is dyed at this temperature for 60 minutes, then cooled to 40–50 ºC and drained. It is then rinsed and washed with detergent and sodium carbonate for 30 minutes at 70 ºC, the washing being an absolute requirement for perfect wet fastness properties. A typical washing process involves:

- 0.5 g/l soap (Sandopan DTC) at 70 ºC for 30 minutes.
- 1 g/l soda ash.

The characteristic 'scroopy' feel of silk is restored at the final stage of processing. It is treated with 2–4 g/l formic/acetic acid for 15–20 minutes at room temperature, then hydroextracted and dried.

There can be a number of potential faults in silk dyeing. Chafe marks are not only caused during dyeing but may also originate during boiling off (degumming) and then, of course, only show up after colouring. The cause of this in most cases is chafing of the fabric surface against a harder surface (the material itself), rough places in the machine, etc. Light chafe marks look as if the material has been sprinkled with a white powder or flour, which is why they are known by the French term farinage, from farine (flour). Severe chafe marks are called blanched places.

7.18 Natural colours for wool and silk carpets[9–12]

The use of natural dyes for colouring textiles has been known for centuries. The raw material for the production of natural dyes is usually from vegetable sources such as seeds, roots, leaves and bark. Some sources of dyes are listed in Table 7.11. The use of natural dyes has renewed importance because of environmental concerns. The advantages of natural dyes are:

- they are from renewable sources
- they are usually non-toxic
- they do not require significant use of chemicals in their preparation
- they are biodegradable and can be recycled or disposed of safely after use
- they provide a more natural look

Table 7.11 Specifications of some purified natural dye powders

S. no.	Botanical name	Common name	Part of the plant	C.I. number	Moisture (%)	Water soluble matter (%)	pH of 1% solution	Trade name*	Ash (%)
1.	*Acacia catechu*	Cutch	Heartwood	C.I. Natural Brown 3	6.0 + 0.2	95.0 + 2.0	6.0 + 0.4	Thar	7.0 + 1.0
2.	*Acacia nilotica*	Acacia	Bark	—	3.0 + 1.0	95.0 + 2.0	7.5 + 1.0	Caspian	27.0 + 2.0
3.	*Mallotus philippinensis*	Kamala	Flower deposits	C.I. Natural Yellow 2	4.0 + 1.0	10.4 + 4.0	6.3 + 0.3	Basant	5.0 + 3.0
4.	*Pterocarpus santalinus*	Red Sandal wood	Heartwood	C.I. Natural Red 22	5.0 + 2.0	29.0 + 2.0	6.0 + 1.0	Garden	11.0 + 2.0
5.	*Punica granatum*	Pomegranate fruit rind	Pomegranate fruit rind	C.I. Natural Yellow 7	6.0 + 2.0	95.0 + 3.0	4.3 + 0.2	Pacific	11.0 + 2.0
6.	*Quercus infectoria*	Gall Nuts	Gall Nuts	—	5.0 + 1.0	96.0 + 2.0	4.0 + 0.2	Amber M	6.0 + 1.0

7.	*Rheum emodi*	Himalayan rhubarb	Roots	C.I. Natural Yellow 23	5.0 + 1.5	30.0 + 5.0	3.0 + 1.0	Desert	5.0 + 3.0
8.	*Rubia cordifolia*	Indian Madder	Wood, roots	C.I. Natural Red 6	5.0 + 2.0	95.0 + 2.0	8.0 + 0.2	Indus	35.0 + 5.0
9.	*Rumex maritmus*	Golden Dock	Seeds	—	12 + 1.5	14.0 + 3.0	3.0 + 1.0	Sahara	3.0 + 1.0
10.	*Terminalia chebula*	Myrobalan	Fruit	C.I. Natural Brown 6	5.0 + 1.0	97.0 + 2.0	3.5 + 0.5	Kango	7.0 + 2.0
11.	*Indigofera tinctoria*	Indigo	Leaves	C.I. Natural Blue 3	5.0 + 1.0	4.0 + 2.0	5.0 + 1.0	Nile	63.0 + 7.0
12.	*Caesalpinia sappan*	Sappan	Heartwood	—					
13.	*Luccifer lacca*	Lac	Insect Secretation	C.I. Natural Red 25					
14.	*Berberis aristata*	Berberry	Root	—					
15.	*Butea frondosa*	Tesu	Flower	—					

* Trade name of Alps Industries Ltd., Shahibabad, India

- some customers prefer the use of natural dyes as more environmentally friendly and as giving handmade carpets a more authentic, traditional appearance.

The disadvantages of natural dyes are:

- labour-intensive methods of preparation, which can increase costs
- a more limited range of shades and colours, restricted by the raw materials available
- poor reproducibility and repeatability: it is very difficult to eradicate differences in hue and quality between different batches of the same dye
- colour matching is difficult
- poor fastness properties.

The quality and exact hue of a dye is dependent on the raw materials from which it is made. These are, in turn, affected by such variables as climate, harvesting season and horticultural practice. These variables make it hard to ensure a batch matches a particular colour required or that different batches produce exactly the same hue each time. Natural dyes in powdered form overcome some of these disadvantages since they allow stockpiling of dyes produced from raw materials from the same source and time of harvesting. They also tend to have better fastness properties.

In some respects, the lack of uniformity in natural dyes can be one of their advantages. Looking through an electron microscope, a wool fibre dyed with natural dyes has more of a speckled than a uniformly coloured appearance. As a result of these microscopic differences, the human eye perceives the colours of the fabric as soft and muted. A dye, whether synthetic or natural, absorbs certain wavelengths of light and reflects others. Because natural dyes contain more impurities than synthetic dyes, which can be more precisely formulated and distilled, they reflect a wider range of wavelengths. As a result they rarely appear as a single hue. A natural red will appear, for example, as reddish-yellow or reddish-blue. The breadth or narrowness of the range of wavelengths reflected by dyes is an important factor in how readily different colours harmonise. If, for example, three strands of fabric synthetically dyed red, blue and yellow are placed side by side, the individual colours, each reflecting a narrow range of wavelengths, can be seem as clashing with each other because each colour is too strong. In contrast, three strands dyed with natural dyes such as indigo blue, madder red and milkweed blue, will produce a more harmonious effect.

The essential rules for using natural dyes are:

- make designs according to the availability of colours
- avoid designs using shades
- use standard dyes
- use soft water in the dyeing process

- avoid using excessive amounts of mordant during dyeing as coloured mordant alters the shade of a dye
- wash natural-dyed carpets with neutral soaps; avoid strong acid or alkali chemicals which can alter shades
- dry carpets in the shade, preferably laid flat; avoid direct sunlight which will bleach natural dyes
- iron carpets at temperatures below 150 ºC.

7.19 Eco-friendly and organic carpet manufacture

The carpet industry consumes large amounts of chemicals, including dyes, auxiliaries, acids, alkalis and finishing chemicals to improve qualities such as insect, stain or fire resistance. It is also affected by contaminants such as pesticides and heavy metals in raw materials such as wool and cotton, or in natural dyes, for example, as a result of poor agricultural practices. Water quality can also be a major problem in an industry which consumes large quantities of water during processing. As a result, even handmade carpet production faces significant environmental problems.

Environmental issues are increasingly important to consumers and are now the subject of legislation governing imported products in such markets as the European Union. The need to conform to environmental standards in production is also increasingly part of the quality specifications required by many buyers in Europe, North America and elsewhere. The major challenges facing the carpet industry in countries such as India is the use of chemicals during wet processing in particular. The use of chemicals in processing is not just an environmental issue. Some chemicals are toxic or carcinogenic and may cause dermatological or allergenic problems. As an example, Benzidine-based dyes and dyes containing Aryl amines are banned on safety grounds. Latex-containing styrene-butadiene, which emits harmful volatile organic compounds (VOCs), has been replaced as a backing material by ethylvinyl acetate (EVA) which meets consumer safety regulations in Europe and elsewhere.

In response to environmental concerns from markets such as Germany, eco-friendly or bio-carpets are starting to be made in India and other centres of handmade carpet production. These carpets are designed to be biodegradable through use of natural materials throughout production and the elimination of synthetic chemicals in such areas as coatings for insect and flame resistance. Backing materials are made from natural materials such as jute. Treatment of water with demineralisers reduces the need for heavy use of water treatment chemicals.

As well as bio-carpets, there is an increasing demand for organically produced carpets. This requires ensuring that all raw materials and chemicals used in production are from organic sources. To ensure this, and provide appropriate evidence to a potential buyer, it may be necessary to use a third-party certification organisation to verify that organic producers have used approved materials and methods of production. Since wool is the most widely used material in handmade carpet manufacture, manufacturers need to be aware of the particular requirements for organic production. These include the following:

- feed and forage given to animals must be certified organic for a specified period before shearing
- grazing land must be free of pesticides and insecticides
- the use of synthetic veterinary chemicals such as antibiotics and growth hormones is prohibited
- producers must ensure good animal health through good agricultural practices in such areas as housing and grazing.

Following these requirements opens up an important new niche market for carpet manufactures supplying carpets to consumers in developed countries in particular.

7.20 Colour matching

In traditional systems, matching the colour is performed visually. The inaccuracies inherent in this may lead to rejection by importers who require most consistent quality (Table 7.12). There is plenty of opportunity to make dyeing woollen yarn for carpets cost-effective using a computerised colour matching (CCM) system (Table 7.12). Nevertheless, CCM alone cannot make the job cost-effective until and unless there is standardisation of the variables in the dyeing process which may affect colouration, such as raw materials, dyes and chemicals, dosage, dyeing profile, etc. The method of application standardisation used for wool in the carpet sector is equally applicable to silk. To understand the dyeing process better, further reference may be made to standard available literature.

Table 7.12 Computerised colour matching (ccm) vs. visual matching

Visual/human memory	Spectrophotometer/computerised
o Traditional methodology	o Scientific tool
o Biased	o Unbiased
o Inaccurate	o Accurate
o Unauthentic/non-evidential	o Authentic/evidential
o Memory loss is likely	o Memory loss is unlikely
HIGH FAILURE COST	LOW FAILURE COST
o **Design unfriendly**	o **Design friendly**
o No control of external failure	o Generated control of external failure
o Possible customer dissatisfaction	o Possible customer delight

7.21 Quality issues

Buyers need to be sure about the quality of the final product. Carpet quality can be judged subjectively, i.e. on a visual and touch basis, which includes:

- appeal of the design/motif
- colour combination in the design
- finishing in terms of how it feels to touch
- comfort in terms of feeling good under foot.

However, certain objective parameters are also judged, which include:

- knot density (construction)
- colour fastness (to cleaning, rubbing and exposure to light)
- abrasion resistance (durability)
- static and dynamic loading (prediction of load resistance)
- tuft withdrawal force (knot/pile retention strength)
- compressibility and resilience (durability).

The test methods (TM) of organisations like The Wool Mark Company,[13] the specifications of buyers for companies like IKEA, and standardisation bodies like the British Standards Institution (BSI), Bureau of Indian Standards (BIS) and American Society for Testing and Materials (ASTM), which have either test methods and or acceptance criteria (pass level), serve as quality assurance from the buyer's point of view. Some pertinent information is reproduced in Tables 7.13 to 7.16.

The durability of carpet has, for example, been specified by The Wool Mark Company in terms of pile density (p) and thickness (t). In their specifications, the requirement for heavy traffic areas is 70 000. However, the minimum requirement for p and t is 600 and 12 respectively. It is pertinent to mention that in spite of the existence of such specifications, carpet durability is also related to the carpet structure, irrespective of its fibre content and weight. Carpet durability can also be accurately and reliably measured by means of testing it under actual foot traffic. It is further reported that the 20 000-step contract walker test is a proven,[14] quantitative measure of the durability of a particular carpet style under virtually real-world conditions. In this test, the following ratings are given: 1–2 for light traffic, 3 for normal traffic, 4 for heavy traffic, which essentially describes the carpet's durability or appearance retention after 20 000 foot falls. The report also mentions that it is impractical to associate years of use with any level of durability since there are many variables which can determine the ultimate appearance of any carpet and what might be considered as three years of acceptable performance of one carpet compared to a lifetime of another. Thus one has to think of prolonging the life of a particular carpet, for which certain salient guidelines are available[15] such as:

- buying a carpet using carpet specifications that identify important carpet

Table 7.13 Mandatory requirements

Property	Woolmark test method (ISO/ EN test method)	Pass level	
		Woolmark	Woolmark blend
Fibre content of pile/use surface	155 (ISO 1833) (BS 407)	Pure new wool (see specification sheet E1, E2, E3 or E4 for details as appropriate)	80% new wool (min) 20 new non-wool (max) • Polyamide • Polyamide/polyester • Polypropylene • Other natural fibre
Durability (pile weight density p^2/t: 000's minimum)	216	70	
Tuft/yarn withdrawal force (N: minimum)	202 (ISO 4919)	Woven pile products: Tufted products:	3.5 Cut pile: 10.0 Loop pile: 20.0
Delamination of backing fabric (N: minimum) Contract products only	264 (ISO 11857)	25	
Abrasion weight loss (mg/1000 rubs: max)	283 (ISO 17504)	70	See advisory requirements

Appearance retention • Hexapod (grade: min)	247/251 (ISO 10361: Hexapod Assessment) (EN1471)	Depends on end-use location	
• Usometer (Grade: min) loop pile products only	253/251	Fuzzing and piling: 3	Woolmark blend applicable to loop pile products only on an individual (case-by-case) basis.
Soiling • DCM Extractable matter (%: max) See Note 5 below	136	Woolmark: 10 Woolmark blend including polyamide or non-wool natural fibres: 1.0 Woolmark blend including polyester and/or polypropylene: See Advisory requirements.	
• Direct soiling test Blends containing polypropylene only	267 (ISO 11378 1)	Pass	
Insect resistance	27 & 28	Specification sheet E10 may be referred for more detail.	

Table 7.14 Location specification

Suitability	Durability (Pile weight density: p^2/t: 000s min) Woolmark test method 216	Overall appearance Retention (grade: minimum) Woolmark test method 247 and 251
Medium duty domestic	70–89	2–3
Heavy duty domestic	90–124	3
Extra heavy duty domestic	> 125	3–4
Light duty contract	80–114	3
Medium duty contract	115–149	3
Heavy duty contract	150–199	3–4
Extra heavy duty contract	> 200	3–4

Table 7.15 Location specification

Property	Woolmark test method (ISO/BS test method)	Pass level	
Tuft withdrawal force (N: minimum)	202 (ISO 4919)	Woven products:	Cut pile: 5 Loop pile: 10
		Tufted products:	Cut pile: 15 Loop pile: 30
Gauge (tufted)/ Pitch (woven) (Tufts/10 cm: minimum)	140 (ISO 1763)	25	
Pile height	20 (ISO 10834)	12	
Visual assessment	500	Does not display base fabric when bent through 90º over 2.5 cm diameter stair nosing	

characteristics like mass (gm/sq. metre), knot/tuft density, pile height, durability retention rating, etc.

- use of walk-off mats to protect cloths from soiling
- maintaining and cleaning a carpet as set out in the guidelines given by supplier.

7.22 Customer attitudes to quality

A report on the sales of handmade carpets by OTF (Courtesy: Aref Adamali, Presentation to the World Bank's AFTPS Group, 29 November 2006 by OTF Group) looked at various types of carpet, including:

Table 7.16 Typical specification II

Property	Test method	Synthetic carpet	Natural carpet	Rag rug	Cotton carpet	Bathroom rug
Deviation from size	ISO 3932	± 3	± 3	± 3	± 3	± 3
Deviation from indicated weight	ISO 3801	± 5	± 5	± 5	± 5	± 5
Construction yarn count	ISO 7211-5	± 5	± 5			
Construction density	ISO 7211-2	± 5	± 5			
Deviation of fibre content in mixed compositions	ISO 1833	± 3	± 3	± 3	± 3	± 3
Formaldehyde	ISO 14184-1	300	300	300	300	100
Flammability, carpet 16 CFR 1630	16 CFR 1630	Pass	Pass	Pass	Pass	Pass
Flammability, carpet 16 CFR 1631	16 CFR 1631	Pass	Pass	Pass	Pass	Pass
Colour fastness						
Light rubbing	ISO 105-B02	5–6	5	4–5	5	5
Dry staining	ISO 105-X12	4	3–4	3–4	3–4	4
Dry colour change	ISO 105-X12	4	3–4	3–4	3–4	—
Wet staining	ISO 105-X12	3–4	2–3	2–3	2–3	3–4
Wet colour change	ISO 105-X12	3–4	2–3	3	3	—
Washing, staining	ISO 105-C06	3–4	—	—	—	—
Washing, colour change	ISO 105-C06	3–4	3–4	3–4	3–4	—
Water spotting carpets	SIS 83 25 28	3–4				
Migration	ISO 105-X10	4	4	4	4	4
Water	ISO 105-E01	—	—	—	—	4-5

- Traditional carpets, developed mainly in Northern Afghanistan by Turkmen tribes, depicting geometric designs that are often repeated, usually on a dark red or burgundy base, using both chemical and natural dyes.
- Chob Rung carpets, developed over the past decade mainly in Afghan refugee camps in Pakistan, depicting 'Indo-Persian' floral designs in pastel colours. Predominantly woven with natural dyes, they have dominated Afghan and Pakistani exports in recent years.

The OTF report concluded that:

- The market for high-quality, traditional Afghan carpets is more stable. However, it has been marred by a limited range of designs and colours, as well as poor quality (such as the use of non-fast chemical dyes and unevenness of carpet and borders).
- Chob Rung designs have done well over the past 10 years, but may be nearing the end of their cycle. Kabul-based producers of Chob Rung carpets surveyed by OTF reported an average decline in sales of 25% over the past few years.
- There may be good growth opportunities in the area of 'soft contemporary' designs, such as Nepali/Tibetan carpets (which experienced over 250% import growth into the USA between 1995 and 2004).

Table 7.17 shows the attitudes of US and German customers to differing carpet attributes. Colour, design, type of fibre, and price are the most important product attributes in both the USA and Germany. Carpet size matters more in the USA while price and quality of weave matter more in Germany. Despite commonality in many areas (highlighted in the table), there are some important differences between the US and German markets:

- Size is the 3rd most important attribute in the USA, but 9th in Germany.
- Quality of weave ranks 5th in Germany, but 9th in the USA.
- Durability ranks 6th in Germany, but 9th in the USA.

It is common in the USA for identical carpets to be produced in many different sizes, referred to as 'programmed carpets'. They are therefore sold not as unique products, but as standardised interior items. Germany's emphasis on weave and uniformity, as opposed to size, indicates that oriental carpets are still purchased as original artisan products, valued for the quality of the workmanship. However, this is changing: carpets are becoming more of a fashion item and are not regarded as a traditional ethnic product anymore.

Buyer (USA, Germany and average) perceptions were surveyed of handmade carpet supplier countries (8 studied) to understand which country comes closest to being the ideal carpet supplier. The popularity of supplier countries in descending order was: India, Nepal, China, Pakistan, Afghanistan, Egypt and Turkey. In the US market, India is the most popular supplier, leaving China far behind as the second-most ideal carpet supplier. In the German market, Nepal is

Table 7.17 Product attributes overview

Product attributes	USA	Germany
Not relevant		
Country of origin	2.10	2.60
Quality guarantee	2.70	2.70
Green production	2.80	3.75
Labour conditions	3.20	4.00
Brand attributes		
Type of dye	3.40	4.00
Durability	3.90	3.60
Size	4.10	3.80
Uniformity	3.70	4.50
Weave quality	3.80	4.50
Highly relevant		
Price	3.90	4.90
Type of fibre	4.10	4.80
Design	4.40	4.60
Colours	4.80	5.00
Colour		
Earth/natural	4.20	4.00
Range	3.70	3.00
Pastels	3.00	3.00
Dark	2.90	2.50
Bright	2.80	4.70
Design		
Geometric/tribals	3.80	3.10
Modern/country	3.70	4.30
Floral (bold/simple)	3.70	4.10
Floral/intricate	3.30	2.30

Rank: 1 to 5, 1 = Not important, 5 = Very important

the most popular supplier, followed by Iran as the second and India and China jointly in third place. Overall, for the US and German markets combined, India ranks No. 1 followed by Nepal, Iran, China, Pakistan, Afghanistan, Egypt and Turkey.

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8
Reducing static electricity in carpets

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Abstract: Static electricity nuisance shocks have become prevalent since floor covering and shoe sole materials have been increasingly made from highly insulating materials such as polymers. This chapter describes how static electricity is generated and can give rise to shocks to personnel walking on a floor covering. The link between floor electrical resistance and static charge build-up, and the role of atmospheric humidity, is explained. Test methods and some important standards are given. Methods of reducing static electricity by use of treatments or incorporation of conductive fibres in the carpet are described, and the requirements and application of static electricity reduction in electronics manufacturing, flammable atmosphere hazard areas and office, retail and domestic environments are discussed.

Keywords: static electricity, electrostatic, carpet.

8.1 Introduction

The phenomenon of static electricity has been known since ancient times (Cross 1987). More than 2000 years ago, Thales found that a piece of amber rubbed on silk could then pick up small pieces of paper. Understanding of the phenomenon did not, of course come until much later, with the discovery of the electron in the 20th century leading to the understanding of electrical charge.

In the context of flooring materials, static electricity has become particularly relevant since the use of polymer materials became common in footwear, furnishing and floor covering materials including carpets. People walking on such floor covering have found that they may experience shocks when they touch a metal door knob, metal equipment or furniture (e.g., filing cabinets) or other people. During the author's schooldays in the mid 1970s when carpet was first fitted, boys found to their delight that they could shuffle along one corridor and draw sparks about 10 mm long on touching a fellow pupil, who then cried out in surprise, to their colleague's merriment! Considering that it requires a voltage of about 3000 V to cross a 1 mm air gap, the voltages built up on the children's bodies must have been of the order of 30 000 V.

Even these days when flooring is often treated to reduce static charge build-up on personnel, most people experience shocks on a regular basis. A voltage of about 3000–4000 V is required on the body before a shock is felt on discharge. In the author's experience, body voltages up to 5000 V are everyday phenomena in the average working or domestic environment especially under dry air conditions, where polymer materials are used in floor coverings. Body voltages up to 35 000 V have been reported (Department of Defense 1994). It is not only polymer materials that can give rise to static shocks – other materials such as wool may be involved.

8.2 Principles of static electricity in carpeted environments

8.2.1 Some basic principles and terminology

At the root of all static electricity are electrical charges. These are of two types – positive and negative. These electrical charges are part of the atoms which make up all materials, and have a positively charged nucleus and negatively charged electrons around the nucleus. These charges are normally present in nearly equal numbers, and if so, their electrical effects cancel. In some situations a material can have a small excess of positive or negative charges, and in this case we say they are charged, and static electrical effects may be noticed.

These charges that are present in all materials may be separated by a process called triboelectrification, or contact and frictional charging. When any two materials are brought into contact, a small number of electrons move from one material to the other. If the materials are then separated, each will take that imbalance of charge with it. One material will have excess positive charge, and the other an equal amount of negative charge, and the materials are charged. The amount of excess charge which is required to give strong static electricity effects is very small, only 8 atoms per million on the surface to give the maximum charge density of a surface, limited by the breakdown field strength of air (Cross 1987).

Like polarity charges repel each other, and unlike charges attract, and so the excess charges will always try to move to recombine if they can. Often, if the materials allow the charges to move, they will migrate away following a path through the local materials, often to earth.

The process of electrostatic charging can be thought analogous to the filling of a basin with water. If the basin has a sufficiently large plug hole and pipe to the drain, and the flow of water from the tap is small, then the water just flows out of the basin and it never fills. If the plughole is small and the water cannot escape as quickly as it flows in, then the water level in the basin can build up. If the plug is in the plughole, or the drain is blocked, the water level can build up quickly.

Similarly in static electricity if the charge can escape faster than it is generated, static electricity does not build up. If it is generated faster than it can escape, then static electricity will build up over some time period. If prevented from escaping by an insulating material, then static charge can build up quickly.

In the water analogy, the level of the water can be thought analogous to static electricity voltage. Given a certain amount of water (charge), the level in the basin (voltage) can be high or low depending on the basin size and shape. Basin capacity and shape is analogous to capacitance in static electricity. Capacitance describes charge storage, and is related to the size of the object on which charge is stored, and the properties of the materials present. Just as a large wide basin gives a low level for a given amount of water, a large capacitance gives a low voltage for a given amount of charge. A small basin (small capacitance) would give higher water level (voltage) for the same amount of water (charge).

Given that static charge is generated whenever two materials are in contact and then separated, it is not surprising that static electricity is a common phenomenon. It is perhaps more surprising that electrostatic effects are not noticed more often. When excess static charges build up they always try to recombine, or escape (often to earth).[1] Materials which allow the charge to move away are called conductors or dissipative materials. Some materials do not conduct charge well and effectively prevent the charge moving away – these are insulating materials. The ease by which the charge can move can be measured as the electrical resistivity of the material. Metals and water are common conductors. Metals have very low electrical resistance, but from an electrostatic point of view, materials of a wide range of resistivity may be conductive enough to move charge away in the timescales of interest. Higher resistivity materials (between about 10^5 and $10^{11}\,\Omega$, which allow charge to move around more slowly, are often called 'dissipative' in electrostatics work. The range of resistivity that is considered conductive, dissipative or insulating may vary with different applications. Using the water basin analogy again, a highly conductive material acts like a large diameter drain fitted to the basin. A dissipative material acts like a small diameter drain. An insulating material acts like a plug in the drain.

If we consider the case of the conductive material (large diameter drain) we can see that a very high flow of water into the basin would be needed to give any appreciable rise in water level. Similarly for highly conducting materials in a ground path, even high charge generation levels may not generate high voltages. For a small diameter drain, the water level in the basin may rise if the tap is full on, but drop if water flow is reduced to a trickle. Similarly for dissipative materials the voltage may rise if high charge generation occurs, but will reduce near zero if the charge generation rate is sufficiently small. In summary, static voltages will build up if the rate of charge generation is greater than the rate at which charge can escape (dissipate). If the charge can dissipate faster than it is generated, little electrostatic voltage is developed.

1. Connecting a conductive item to earth or ground via a conductive or dissipative material allows the charge to flow away and prevents static voltage build up. This is known as 'earthing' or 'grounding' the item. The terms 'earth' and 'ground' are used synonymously in this work, as is general practice in electrostatics.

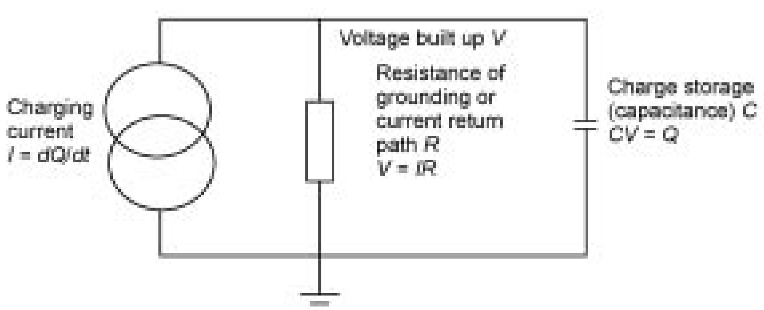
8.2.2 A simple electronic model of electrostatic charging

The principles of simple electrostatic situations can be modelled using a simple electronic model (Fig. 8.1). The charge generation process can appear as a charging current I which then tries to find its return path through a resistance R which is generally the resistance of the materials in the system. The system is often grounded, but it does not need to be so.

If we first ignore the effect of charge storage (capacitance C), to a first approximation the electrostatic voltage V built up is $V = IR$ due to Ohm's law relating the charging current I and the resistance of the discharge path R. If the charge generation rates remain the same the voltage built up can vary by orders of magnitude in response to the resistance – a charging current of 10^{-8} A will produce a voltage of 0.1 V in a discharge path of $10^7\,\Omega$, or 10 V in a discharge path of $10^9\,\Omega$, but will produce 10 kV over a discharge path of $10^{12}\,\Omega$. The resistance of floor materials certainly varies over this range, with bare concrete often being $10^7\,\Omega$ or lower, and asphalt, polymer coverings and epoxy coatings exceeding $10^{12}\,\Omega$.

In many situations where charge storage has significant effect the effective capacitance C is important. We can see the effect of this if we ignore for the moment the discharge path resistance. The voltage built up is then related to the effective capacitance C and the charge stored $Q = CV$. The effective capacitance is often variable, and for a given charge voltage is increased as capacitance is reduced. If 10^{-6} C charge is stored on a capacitance of 10^{-7} F (100 nF) only 10 V is observed. If the capacitance is reduced to 10^{-10} F (100 pF) the voltage can rise to 10 kV.

When both charge storage and dissipation are considered, the circuit is found to have a characteristic decay time $\tau = RC$. With no charge being generated and no change to capacitance or resistance, an initial voltage on the capacitor will reduce to 40% of its initial value in a decay time τ. For sufficiently small RC the charge is dissipated quickly and no static charge build-up may be noticed by the casual observer. For example if $R = 10^7\,\Omega$ and $C = 100$ pF (possible values for a



8.1 A simple electrical model of static electric charge build-up, storage and dissipation.

human standing on a concrete floor) $\tau = 10^{-3}$ seconds. A static charge present for this time would not be noticed by the subject. If, however, the floor covering resistance is raised to $10^{12}\,\Omega$ (often exceeded by untreated polymer coverings) then $\tau = 100$ seconds. A charge generated in this circumstance can be held for appreciable time and the subject could get shocks on touching a metallic object or another person.

8.2.3 The role of materials in charge generation

Charge generation is affected by the types of materials in contact. A guide to this is given in a triboelectric series (Table 8.1) (Cross 1987, Kessler and Fisher 2007) where materials are ranked according to how they have been experimentally found to charge against each other.

If a material in the series (e.g. wool) is rubbed against a material lower in the series (e.g. rubber) the higher material (wool) normally charges positive, and the lower material (rubber) charges negative. The further the materials are apart in the table, the stronger the charging action is expected to be. So polyurethane (a common shoe sole material) in contact with glass (sometimes used as a floor) is likely to give strong charge generation. Contact of PU with PVC, which are neighbours in the table, might be expected to give lower charge generation.

In practice, triboelectrification is an extremely variable and unreliable phenomenon and it is hard to make any reliable predictions of strength and polarity of charging. Triboelectrification is a surface process and highly dependent on surface contaminants and conditions, and atmospheric humidity.

Table 8.1 A triboelectric series of materials

Rabbit fur	More positive ↑
Glass	
Human hair	
Polyamide (nylon)	
Wool	
Fur	
Silk	
Aluminium	
Paper	
Cotton	
Steel	
Wood	
Rubber	
Acetate rayon	
Polyethylene (PE) and polypropylene (PP)	
PET	
PVC	
Polyurethane (PU)	
PTFE	↓ More negative

Some shoe sole materials are commonly materials such as rubber and polyurethane (PU) which are much lower in the table than wool and nylon which are high in the table. If a PU shoe is worn walking on a wool/nylon mix carpet, high charge generation is expected. Conversely if a PU shoe sole is walked on a polymer carpet or tile (such as PET or PVC) much lower charge generation is likely to occur. However, in both cases charge could build up under particular conditions.

8.2.4 The effect of atmospheric humidity

Experiences of shocks can be seasonal, and vary with the weather or air conditioning settings due to air humidity. Typically in the UK shocks are most often felt during the winter months January to March. This is because cold air from the outside is heated for indoor comfort and becomes very dry, enhancing static charge build-up. Often these problems disappear on a rainy day or when the weather warms from April onwards. A building commissioned in summer or autumn may be used for several months without any apparent static shock problems, and these may then appear in the cold winter months. To the average person this can make static electricity seem inexplicably unpredictable.

The atmosphere has variable moisture content. The amount of moisture that the air can hold varies with temperature, increasing strongly as temperature increases. Often the air holds less moisture than the maximum that it could hold at that temperature. The ratio of the amount of moisture in the air, to the maximum amount it could hold at that temperature, is expressed as a percentage as the relative humidity (r.h.) of the atmosphere. It is well known that when the air humidity is less than about 30% r.h. any tendency for electrostatic charge build-up is strongly enhanced.

If the moisture content of air remains constant, the relative humidity is strongly increased as temperature is decreased, and vice versa. Under dry external conditions the atmosphere in a building can become even drier and electrostatic charge build-up can be far worse. In the UK the worst case is often in winter (January to March) when cold and dry external air is warmed and brought into the building leading to very dry internal atmospheric conditions. A 10 degree rise in temperature can approximately halve the relative humidity of air. If external winter at, say, 5 ºC and 50% r.h. is brought indoors and heated to over 15 ºC, the relative humidity can be expected to drop below 25% r.h. unless moisture is added.

As previously mentioned, water is a good electrical conductor. The electrical properties of materials are often highly dependent on the bulk or surface water content of the material. Some materials, especially natural materials such as cotton and wool, absorb water into the bulk of the material. Others, such as common plastics, absorb less water to the bulk, but can adsorb water molecules to the surface of the material. Some materials (such as PTFE) absorb or adsorb relatively little moisture to their surface and bulk.

As atmospheric relative humidity is reduced, the amount of water absorbed or adsorbed by a material changes strongly. This can result in a change in the surface or bulk electrical resistance of several orders of magnitude over the 0–100% range of relative humidity, increasing as relative humidity is reduced and the atmosphere becomes drier. For materials that have an adsorbed water layer, the decrease in surface resistance is due to the presence of a continuous surface moisture layer. If atmospheric relative humidity reduces below about 25% r.h, this water layer may become discontinuous, and the surface resistance is correspondingly increased. It is this increase in resistance that reduces the rate at which charge can escape, and encourages static charge build-up.

8.2.5 Static charge build-up on walking personnel

Charge can often build up on people as they walk or move around in their everyday environment and can reach levels that give uncomfortable shocks. Shocks are felt by people when they touch a discharge path (e.g., metal frame or another person), if the voltage on their body exceeds about 3 kV (3000 V). Personnel who have acquired an electrostatic charge can experience shocks and present an ignition hazard to flammable atmospheres such as solvent vapours and gases.

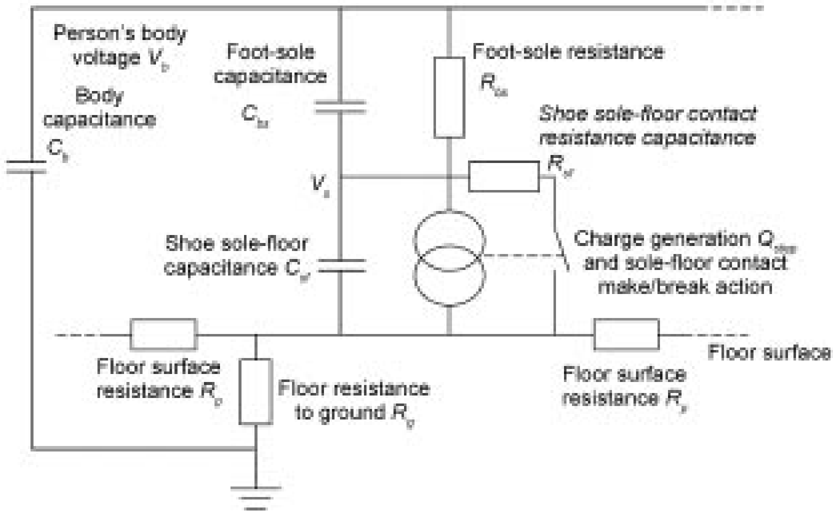
There is a wide range of factors that can affect the amount of electrostatic charge that can build up as a voltage on walking personnel. The main common factors include:

- the floor material and its electrical resistance, and resistance-to-ground
- personal footwear, especially the materials of the shoe sole and its electrical resistance
- atmospheric humidity
- the manner in which a person walks, e.g. scuffing and friction of the shoes against the floor
- actions of brushing against furniture, sitting and rising from seats.

Static electric charges are separated whenever two materials make and break contact. This occurs with regularity between the shoe sole and floor material during walking action. Charge cannot dissipate or recombine where it is prevented from moving by insulating floor and shoe sole materials. Charge builds up if the charge is generated faster than it can dissipate, and a high voltage can quickly result.

It is not within the scope of this work to analyse in depth an electronic model of a person walking, which is rather complex. Nevertheless the basic principles apply, and some parameters that affect charging are discussed here (Fig. 8.2).

Shocks are felt because the person's body capacitance C_b reaches a high voltage V_b of around 3kV or more. However the person's body is not charged directly. When walking, most of the charge generated is by contact of the floor surface and shoe sole by triboelectrification. The relationship between these



8.2 Electrical model illustrating some factors at play in the charging of a person by step action. Only one foot-floor contact is shown.

materials in the triboelectric series, modified by surface contaminants and influenced by contact forces, rubbing action, humidity and other factors, plays a large part in determining the charge generated Q_{step}. The charge is generated when the shoe sole is in contact with the floor, and has at that point a large effective capacitance to the floor C_{sf}. When the foot is lifted, several things happen simultaneously. Firstly the contact between the shoe sole and floor is lost – modelled here by a simple opening of a switch. In practice this would be likely to be a progressive action, rather than a sudden one. Secondly the capacitance C_{sf} reduces from a high value to a much lower one as charges are separated. A correspondingly high voltage $V_s = Q_{step}/C_{sf}$ appears at the shoe sole. This voltage induces the body voltage V_b by capacitive action through the foot-sole capacitance C_{bs}.

When the foot is again placed on the floor, the charge stored on the shoe sole can start to dissipate via the sole-floor contact resistance R_{sf}. The body capacitance C_b can also start to discharge via the foot-sole resistance R_{bs}, the sole-floor contact resistance R_{sf} and the floor-ground resistance R_{fg}. The voltage decay time is given by C_b (R_{bs}+ R_{sf} + R_{fg}). If any of these resistances are high, the decay time will be long. If it is longer than a few seconds, static charge will accumulate on the body with each successive step. In practice if R_{bs} and R_{fg} are low then R_{sf} will normally also be low, and vice versa.

So, the person's shoes and flooring materials both perform a very important part in charging and discharging the body. For insulating materials, (R_{bs}+ R_{sf} + R_{fg}) is very high and charge accumulates on the shoe sole in increasing amounts with each step. Most modern shoes have polymer soles, and many floors are also surfaced with insulating covering materials, and the combination can cause charge to build up and remain on the body for a significant time unless another discharge path is found. If we wish to avoid the electrostatic charging we can estimate the maximum resistance that we would wish to have in the circuit. If $C_b \approx 10^{-10}$ F , to get a voltage decay time less than 1 second, (R_{bs}+ R_{sf} + R_{fg}) should be < 10^{10} Ω. In practice it is the shoe sole resistance R_{bs} and the floor resistance to ground R_{fg} which we can control through choice of materials used in footwear and flooring.

Floor surface resistance R_s also plays a role in controlling body voltage. This is because if the resistance is sufficiently low, charges can move to the part of the floor immediately under the foot (or feet) placed in contact with the floor. These charges can neutralize the charge on the shoe sole. From this analysis it can be seen that the shoe sole resistance and floor resistance both should be kept below a certain level to reliably achieve voltage limitation. Nevertheless some benefit can be achieved by controlling either one of these alone. This is discussed further in Section 8.5.

8.2.6 Measurements made on floor materials

The floor resistance-to-ground (R_g) is one of the most frequent measurements made on installed floors. This gives a measure of how easily charge can dissipate to earth. Point-to-point resistance (R_p) measurements are made between two electrodes placed on and installed floor surface. This gives a measure of how easily electrostatic charge can move across the floor surface. Resistance values R_g and R_p above about 10^{10} Ω can be expected to promote electrostatic charge build-up on people, vehicles, trolleys or other items moving about in contact with the surface.

Point-to-point resistance or surface resistance

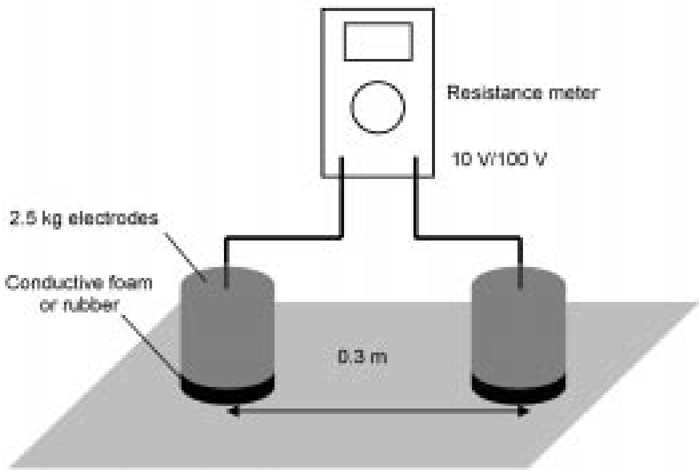
The point-to-point resistance (61340-4-1) or surface resistance (ISO 10965) is the resistance measured between two electrodes placed on the floor a certain distance apart (Fig. 8.3). This measurement indicates how easily charges may move along the floor surface.

In the 61340-4-1 standard, this measurement is done on installed floors or samples in the laboratory. In ISO 10965, it is done on pre-conditioned samples under controlled atmosphere conditions in the laboratory.

In ISO 10965, the sample is placed on an insulating plate which is itself placed on an earthed metal plate. The test electrodes are then placed on the sample for measurement. The resistance between the electrodes is measured.

Resistance-to-ground

The resistance-to-ground (IEC 61340-4-1) is measured between an electrode placed on the floor surface, and an earth reference point (Fig. 8.4). It is common

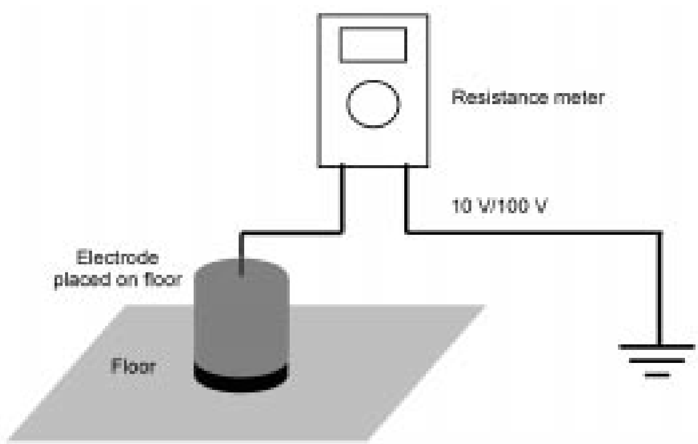


8.3 Measurement of point-to-point resistance.

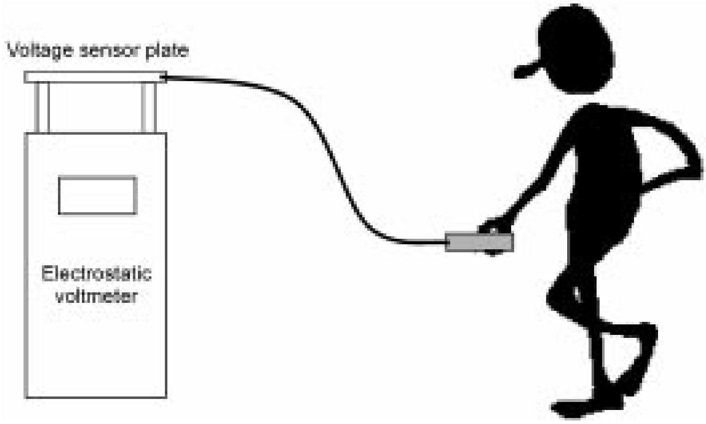
practice to use mains electrical earth as the earth reference. This test is commonly done on an installed floor. A similar test may be done in the laboratory, in which a simulated ground point (groundable point) is affixed to the floor material sample. The 'resistance-to-groundable point' is then measured between the sample surface and the groundable point.

Vertical resistance

Vertical resistance (ISO 10965) is a method of measuring the resistance vertically through a sample under laboratory conditions. The sample is placed on an earthed metal plate, which is itself placed on an insulating plate. An electrode



8.4 Measurement of resistance-to-ground.



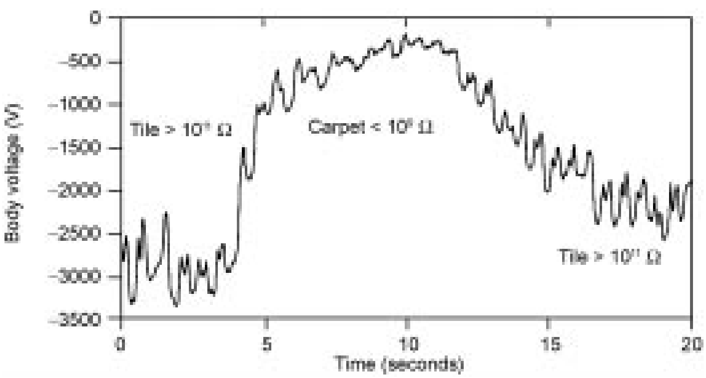
8.5 Measurement of body voltage of personnel.

is placed on the sample. The resistance between the electrode and the earthed metal plate is measured.

Human body voltage (walking test)

Body voltage measurements (IEC 61340-4-5, EN 1815) are made as a means of direct measurement of electrostatic voltages arising as people walk on a floor surface. These measurements may be made of on an installed floor or on a sample floor material under laboratory conditions.

The subject is typically given a hand-held electrode that connects them via a wire to an electrostatic voltmeter (Fig. 8.5). The electrostatic voltage accumulated on their body is then directly read from the electrostatic voltmeter. A typical voltage recording from a walk test in an office environment is shown in Fig. 8.6.



8.6 Body voltage of subject walking first on a white synthetic tile floor (resistance $> 10^{11}\Omega$), then onto green carpet (resistance $< 10^{9}\Omega$), and then back onto the white tile (25 °C 35% r.h.).

8.3 Methods of reducing static electricity in carpet materials

Electrostatic voltages on the body can theoretically be controlled by two methods. Firstly, the charge generated can sometimes be controlled by choice of materials or by surface treatment. Secondly, the voltage built up can be controlled by using lower resistance materials. Lowell and McIntyre (1978) provided an interesting demonstration of the influence of floor and shoe materials, testing wool, polyamide polypropylene and polystyrene carpet materials with leather, PVC, polyurethane and rubber shoes. Whilst confirming that low carpet resistances $< 10^8\,\Omega$ would indicate low charging of personnel walking on the carpet, it was not necessarily true that high resistances would indicate high charging and that the carpet would be static prone.

8.3.1 Choice of materials

In principle, the choice of material can directly affect charge generation in contact with shoe sole materials according to the triboelectric series. Unfortunately in practice, shoe sole materials are quite variable. A floor material selected to minimize charging against one shoe sole material could show high charge generation against another. Nevertheless a material from the middle of the triboelectric series (e.g. wood or rubber) may give less charging in general than one from the extremes (e.g. glass).

There are two main technologies that are used to control static electricity – conductive fibres and topical finishes. Conductive fibres give a long-term solution to the problem of static charge build-up. Topical finishes tend to give a temporary solution, and may not be effective in low atmospheric humidity.

Conductive fibres

Conductive fibres are mainly carbon based although stainless steel and silver coated fibres have also been used. The latter also has the advantage of being antimicrobial, which has benefits in healthcare environments and schools, and can help reduce unpleasant odours from carpets. Carbon conductive fibres may have the conductive material incorporated as one or more stripes on the outside of the fibre, or buried within the fibre core. The percentage of conductive fibre required may be quite low, as little as 1%.

The conductive fibres may be incorporated into the pile, the primary backing or both. For application where a low resistance to ground is required, the secondary backing may also include some form of static protection. In the case of bitumen or vinyl backed carpeting, this will usually take the form of carbon black added to the backing compound.

Kessler and Fisher (1997) and Lowell and McIntyre (1978) have showed that incorporation of conductive fibres in the carpet reduced static charge build up in walking tests not just by conduction and lowered resistivity, but also by corona discharge.

Corona discharge is a low level electrostatic discharge in which a high electrostatic field causes limited electrical breakdown of the air around sharp edges of an electrode, at voltages far less than that required for spark breakdown of an air gap (Cross 1987). The effect is to spray charged ions into the air around the electrode. These ions are attracted to opposite polarity charges and can neutralize them. So, ions formed by corona discharge from the sharp end of a fibre can migrate to a nearby charged shoe sole, neutralizing some of the charge on the sole and reducing the voltage built up. Corona discharge requires a threshold voltage for inception, and this inception voltage is dependent on the conductive fibre geometry. This threshold may be of the order of a few thousand volts, and so the corona mechanism limits personal body voltage to around 4000–6000 V (Kessler and Fisher 1997) for carpets where there is no conductive contact between the fibres. Adding conductive latex to the backing provides electrical contact between the conductive fibres and improves both corona discharge and conductive charge reduction.

The corona discharge mechanism was found to be more effective for level loop carpets than for cut pile carpets. Best results were obtained with carpets having a conductive latex backing.

Topical finishes

Topical finishes contain ionic or cationic surfactants or quaternary ammonium compounds and may be applied to pile and/or backing yarns during manufacture or to finished carpets prior to dispatch from the factory. They may also be applied to carpets after installation. In general, topical finishes are used only to control nuisance effects of static electricity. More critical applications, e.g. computer rooms or electronics manufacturing and handling areas, will usually require conductive fibres.

8.4 Test methods and standards

8.4.1 Standard organizations

Standards are developed by many different organizations for their various purposes. These standards organizations may have international, national, or industrial scope. This review focuses on some important international standards developed by Technical Committees of the International Electrotechnical Commission (IEC), International Standardization Organization (ISO) and the European Committee for Standardization (CEN). IEC and ISO are worldwide international standardization bodies mandated by the World Trade Organization (WTO) under the Technical Barriers to Trade Agreement to ensure that standardization bodies in the signatory countries comply with the WTO Code of Good Practice for the Preparation, Adoption and Application of Standards. IEC and ISO have complementary scopes and expertise and provide standardization in support of this agreement. IEC covers electrotechnologies and associated terminology and symbols, electromagnetic compatibility, measurement and performance, safety and the environment. ISO covers nearly all other technical fields (except for telecommunications) and management systems. CEN develops standards for the use within the European Community. Standards published by CEN often support European Directives such as the Construction Products Directive.

There have also been many other standards developed over the years by individual countries, commercial organizations or trade organizations such as the American Association of Textile Chemists and Colorists, or the ESD Association, but these are not discussed here.

8.4.2 Comparison of methods for measuring resistance

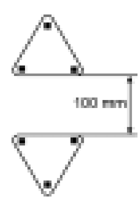
A comparison between the flooring test methods specified in IEC 61340-4-1:2003, ISO 10965:1998 and EN 1081:1998 is shown in Table 8.2. ISO10965 is intended for use only with textile floor coverings, whereas IEC 61340-4-1 is generally applicable. EN1081 is intended for use with resilient floor coverings but is included here for comparison.

The design of electrodes is a key element of any resistance test method. The two most widely used designs are those specified in ISO 10965 and the '5 lb/2½ in.' electrode used extensively in the electronics and computing industries in North America and Asia and included in a number of commonly used standards. The electrode specification written into the second edition of IEC 61340-4-1 encompassed both ISO 10965 and '5 lb/2½ in.' electrode designs. For hard surfaces a 2.5 kg electrode was specified with a conformable conductive rubber contact pad to ensure good electrical contact between electrode and the product under test. For textile floor coverings where conductive fibres may be positioned within the pile or backing, a heavier electrode of 5 kg was considered more suitable.

The applied test voltage is an important parameter in resistance measurements. Measurements made with different test voltages often give different measurement results. In general a high voltage is needed for high resistance measurements, whereas a lower voltage is used for low resistance measurements. Ordinary 'multimeter' equipment does not have a sufficiently high test voltage for measurement of resistance of flooring materials.

The applied voltages specified in IEC 61340-4-1:2003 is common to the IEC 61340 standard series. For resistances below $10^6\,\Omega$, a test voltage of 10 V is used. Use of a higher voltage would produce too high an electrical current for during the test. Above $10^6\,\Omega$, resistance measurements can become unstable if

Table 8.2 Comparison between the test methods specified in IEC 61340-4-1:2003, ISO 10965:1998 and EN 1081:1998

Parameter	IEC 61340-4-1:2004	ISO 10965:1998	EN 1081:1998
Application	Universal, laboratory or installed floors	Textile material only, laboratory	Resilient material only, laboratory or installed floors
Resistance-to-ground	Yes	No	Yes
Point-to-point, horizontal, surface resistance	Point-to-point	Horizontal	Surface
Vertical resistance	Yes	Yes	Yes
Electrode diameter	65 mm $\pm$ 5 mm	60 mm $\pm$ 5 mm	Tripod electrode 3 $\times$ 39 mm o.d.with centres located at vertices of an equilateral triangle of 180 mm side length
Electrode mass	2.5 $\pm$ 0.25 kg (hard surfaces) 5.0 $\pm$ 0.25 kg (other surfaces)	5.0 $\pm$ 0.1 kg	$>$ 30 kg (specified as load $>$ 300 N)
Electrode contact	Conductive pad mandatory for hard surfaces	Conductive pad optional	Conductive rubber (colloidal graphite coating applied to underside of test specimens for vertical resistance measurements)
Test voltage	$< 10^6\ \Omega$: 10 V $10^6\ \Omega$ to $10^{11}\ \Omega$: 100 V $> 10^{11}\ \Omega$: 500 V	$< 10^8\ \Omega$: 100 V $> 10^8\ \Omega$: 500 V	$< 10^6\ \Omega$: 100 V $> 10^6$ ohm: 500 V
Conditioning	48 h. at (23 $\pm$ 2) °C & (12 $\pm$ 3) % r.h. (Pre-condition textiles for 24 h at (20 $\pm$ 2) °C & (65 $\pm$ 3) % r.h.)	Pre-condition for 24 h at (23 $\pm$ 2) °C & (50 $\pm$ 5) % r.h. D: 7days at (23 $\pm$ 2) °C & (25 $\pm$ 2) % r.h. N: 7 days at (23 $\pm$ 2) °C & (50 $\pm$ 5) % r.h.	48 h. at (23 $\pm$ 2) °C & (50 $\pm$ 5) % r.h.
Sample size	For point-to-point & resistance to ground: (1200 $\pm$ 50) mm $\times$ (500 $\pm$ 50) mm For vertical resistance: (500 $\pm$ 50) mm $\times$ (500 $\pm$ 50) mm	(500 $\pm$ 50) mm $\times$ (500 $\pm$ 50) mm	Tile size or ($\geq$ 400) mm $\times$ ($\geq$ 400) mm
Electrode centres for point-to-point, horizontal or surface resistance measurement	Electrodes placed rectilinear (300 $\pm$ 10) mm apart	Electrodes placed on the diagonal (500 $\pm$ 5) mm apart (Rectilinear placement is optional)	100 mm 

the applied voltage is too low because the measurement of the very small currents involved is affected by stray capacitance and noise. Where accurate measurement above $10^{11}\,\Omega$ is required, a test voltage of 500 V is more appropriate. For measurements in Electrostatic discharge Protected Areas (EPA) defined for the electronics industry, applied voltage must not be greater than 100 V. However, as the maximum resistance specified for flooring in this application is $10^{9}\,\Omega$ (IEC 61340-5-1), there is really no need to make accurate measurements above $10^{11}\,\Omega$.

Atmospheric test conditions (i.e. temperature and relative humidity) can be an important point of difference between test methods. IEC 61340-4-1:2003 specified the worst case practical conditions as far as dissipation of static electricity is concerned, namely low humidity conditions. In the absence of other specifications, a test conducted in accordance with IEC 61340-4-1:2003 would then at least confirm if the product is suitable for all practical conditions. Of course, it is acknowledged that for specific applications less extreme conditions may be more appropriate. In these cases it is left to specific product or system standards to include the test conditions in their respective performance and/or design requirements.

8.4.3 Comparison of methods for walking tests

The three standards that specify methods for walking tests, IEC 61340-4-5:2004, ISO 6356:2000 and EN 1815:1997 are in many ways very similar. The main difference is the use of standard conductive BAM-rubber soled sandals in EN 1815, and Neolite soled test sandals in ISO 6356. In contrast IEC 61340-4-5 uses footwear specified by the user for use with the floor under test, to achieve a footwear-flooring system test. Unlike ISO 6356 and EN 1815 which are intended as test methods used to classify floor coverings, IEC 61340-4-5 is intended to evaluate the user-specified footwear and flooring system as a whole, as this is an important approach used in electronics industry applications. Apart from the use of standard footwear, the test procedures of IEC 61340-4-5 and ISO 6356 are almost identical.

8.4.4 Performance requirements for floor coverings

The specification of performance requirements by IEC for application in electronics industry ESD Protected Areas (EPA) and is published in IEC 61340-5-1.

While ISO has mainly produced test method standards, CEN has developed a number of product standards for floor coverings, including EN 14041. A comparison between the classification and performance requirements of IEC 61340-5-1:2007 and prEN 14041:2007 is shown in Table 8.3.

If we assume that floor coverings classified as 'static dissipative', 'conductive' or 'antistatic' in accordance with EN 14041 could be used in an

Table 8.3 Comparison between classification and requirements of IEC 61340-5-1:2007 and prEN 14041:2007

	IEC 61340-5-1:2007	prEN 14041	
		Resilient & Laminate	Textile
Resistance test method	IEC 61340-4-1	EN 1081	ISO 10965
Relative humidity for resistance test	12%	$50 \pm 4\%$	$25 \pm 4\%$
Upper resistance limit	Resistance-to-ground $< 10^9\,\Omega$	Static dissipative: vertical resistance $< 10^9\,\Omega$ Conductive: vertical resistance $< 10^6\,\Omega$	
Walking test method	IEC 61340-4-5	EN 1815	ISO 6356
Relative humidity for walking test	12%	$25 \pm 4\%$	
Maximum body voltage	100 V	Antistatic[a]: < 2000 V Class AS1: the floor covering is antistatic when used on any surface Class AS2: the floor covering is antistatic when used on a surface having resistance to earth $< 10^9\,\Omega$	

[a] In IEC 61340 series standards, the term 'antistatic' is deprecated because it can have many different meanings in common usage and can lead to confusion.

EPA set up in accordance with IEC 61340-5-1, then some problems are highlighted by this comparison. The resistance limits alone suggest that a 'static dissipative' or 'conductive' floor covering may be acceptable in an EPA, but as EN14041 tests are conducted at much higher humidity and higher test voltages than specified in IEC standards, lower resistance results would be expected than in 'worst case' measurements at low humidity conditions specified by IEC. It is questionable whether 'static dissipative' or 'conductive' floor coverings tested by EN 14041 would be suitable for use in EPAs, resulting in possible confusion or specification of unsuitable materials.

The specification in prEN 14041 for 'antistatic' floor coverings (i.e., body voltage less than 2 kV) would exclude their use in and electronics industry EPA. However, ISO and CEN walking tests are done using specified standard soled sandals, whereas the IEC walking test is done using the footwear and floor covering specific to the application in question. It is possible that with careful choice of dissipative or conductive footwear, some carpet tested to EN14041 might give the performance required in electronics industry EPAs, but this performance could only be revealed by testing according to IEC 61340-4-5.

8.5 Applications

8.5.1 Electronics industry

Perhaps the most demanding application is the electronics industry, where personnel body voltage must be kept reliably below 100 V within an ESD Protected Area (EPA) when handling sensitive electronic components and the circuit resistance from an operator's body to ground must be continuously kept below 35 MΩ. These limits are set in industry standards such as IEC 61340-5-1:2007 and ANSI/ESD S20:20-2007. In some manufacturing areas, the body voltage requirement may be even lower and resistance-to-ground limits correspondingly reduced. Conductive or dissipative footwear are issued to personnel working in static safe areas, and the floor resistance-to-ground is specified before installation.

In IEC 61340-5-1:2007, the requirements given are that the floor must have resistance to ground less than $10^9\,\Omega$ and

- EITHER the total resistance from the person's body to ground is less than $3.5 \times 10^7\,\Omega$
- OR the maximum voltage generated on the person's body must be less than 100 V.

These criteria may be met using a grounded wrist strap or a conducting footwear-flooring system. It is found that the body voltage and the resistance to ground achieved using a footwear-flooring system cannot be reliably predicted from separate footwear and flooring measurements. It is necessary to measure the performance as a system, and changing the type of footwear can give a widely different performance from that expected. The method for measuring body voltage and resistance from body to ground for a footwear-flooring system is given in IEC 61340-4-5. The test method for measurement of resistance to ground of flooring is given in IEC 61340-4-1, and for ESD footwear in IEC 61340-4-3.

To meet the requirement of a total resistance from the person's body to ground less than $3.5 \times 10^7\ \Omega$ using a footwear-flooring solution, the resistance to ground of the floor must usually be of the order $10^7\ \Omega$ or less. Carpeting for ESD Protected Areas (EPAs) is available in resistance range from 2.5×10^4 to $10^9\ \Omega$ (IEC 61340-5-2: 2007)

Contamination inevitably changes the performance of both ESD footwear and flooring. In order to maintain the performance of flooring a cleaning regime and materials must be used which do not impair the properties of the floor covering material. Footwear may be contaminated by wearing outside the EPA, for example by asphalt or oil contamination. In wet weather, wetting of footwear may reduce its electrical resistance below levels considered safe for some applications where mains electricity or high voltages may be encountered.

8.5.2 Environments where flammable atmospheres may be present

Many flammable solvent vapours are easily ignited by ElectroStatic Discharges (ESD). One possible source of ESD is the charged body of an operator who may be handling the solvent. When this may be a risk, the operator must be grounded (earthed) to prevent charge build-up on their body. The usual way of achieving this is for the operator to wear static dissipative or conducting footwear and stand on a conducting floor surface (CENELEC 2003, HSE 1996). The CENELEC CLC/TR50404 (CENELEC 2003) defines dissipative footwear 'that ensures that a person standing on a conducting or dissipative floor has a resistance to earth of more than $10^5\,\Omega$ but less than $10^8\,\Omega$'. It also defines conducting footwear 'ensuring a resistance to earth typically of less than $10^5\,\Omega$'. In doing so it implies that the flooring will need to have a resistance to ground (earth) less than $10^8\,\Omega$ and $10^5\,\Omega$ respectively in these circumstances, in order for these system resistances to be achieved. At the time of writing this document is being reviewed by IEC TC31 JWG39 for likely adoption as an IEC standard, which would replace the current CLC/TR50404. It is likely that in the IEC document, fixed limits will be recommended for flooring used to ground personnel handling flammable materials.

Conductive and dissipative flooring in flammable atmosphere areas may also have the task of grounding vehicles such as fork trucks and equipment such as trolleys.

8.5.3 Offices, retail and domestic environments

From the above analysis, it may be thought that if the shoe sole material is insulating, there is little benefit in reducing only the floor resistance. In practice this may not be true, for two reasons. Firstly, if the floor is sufficiently conductive, each time the shoe sole is in contact with the floor, charge may migrate to the floor surface to partially neutralize charge on the shoe sole material surface. This neutralization may help to reduce the sole voltage and hence the body voltage. Secondly, with a dissipative or conductive floor material some charge may be conducted away from the shoe sole when in contact with the floor, also reducing the sole charge and voltage and hence body voltage. So, in situations such as domestic and office environments where the shoe sole material is not within our control, we may still reduce body voltage build-up by controlling floor surface resistance and resistance-to-ground.

Furthermore, use of conductive fibres in carpets has been shown to help reduce static electricity by corona discharge as discussed above. This mechanism may not, however, in itself reduce voltages on personnel walking on carpets to less than the threshold for shocks (about 4000 V). This author would recommend that carpets should have surface point-to-point resistance less than $10^{10}\,\Omega$ (or preferably $< 10^9\,\Omega$) to avoid shocks to personnel. Ideally the installed resistance-to-ground should also be of this order. A typical voltage recording from a walk test in an office environment is shown in Fig. 8.6. The recording shows typical fluctuations in voltage caused by capacitance changes and foot-floor contact during walking movements. The subject walked first on a highly insulating tile floor (resistance $>10^{11}\,\Omega$), then onto a carpet (resistance $< 10^9\,\Omega$), and then back onto the tile floor. It can be clearly seen how the body voltage was much higher when walking on the insulating tile compared to the carpet, although on the day of the test the atmospheric humidity was sufficiently high (35% r.h.) to reduce body voltages to below the threshold for shocks. On drier days, personnel reported experiencing shocks on a regular basis.

Unfortunately there are no standards to the author's knowledge currently specifying requirements for electrostatic behaviour and characteristics of flooring in domestic and office environments.

8.6 Future trends

With the continuing usage of polymeric materials in carpets and other flooring materials, shoe soles and furnishing materials, static electricity can be expected to be a continuing source of discomfort and risk to personnel in working and domestic environments. This can only be reduced and averted if designers and manufacturers of these materials incorporate static electricity reduction technologies in design and specification of future materials. Although techniques are available to carpet manufacturers for this, development of new techniques materials and treatments for low cost reduction of material resistance and static charge generation would no doubt assist this.

It is likely that in future requirements will be placed on the resistance of flooring materials used in flammable atmosphere hazard zones. This type of requirement has for a long time been in place in electronics industry EPAs.

It is to be hoped that the rather confusing range of test methods produced by various standards organizations may be harmonized and simplified in the future, although there is little sign of this at present.

8.7 Sources of further information and advice

There are few sources of information available in this field. The materials listed in the references and further reading section give further details of many of the topics discussed here.

Some conference articles such as Fromm *et al.* (1997) covering the electronics industry application area are available from the ESD Association EOS/ESD Symposium proceedings. The various textile-related conferences may also from time to time carry papers on the subject. The Electrostatic and Electromagnetic fields New Materials and Technologies (El-tex) Symposium has been organized by the Textile Research Institute of Poland (Brzeziñska 5/15, 92-103 Lódz, Poland) since 1994.

The *Journal of Electrostatics* has from time to time published articles on static electricity and carpets such as Kessler and Fisher (1997), Nowikow (1982) and Lowell and McIntyre (1978). Other journals that have published articles include *Textile Industries*, *Textile Research Journal*, and the *Journal of the Textile Institute*.

These days the internet is a useful research medium on most topics. For example, various patents relating to the subject may be found by internet search using key terms such as 'conductive' 'fibre' and 'carpet'. Some useful web addresses current at the time of writing are included below.

- International Electrotechnical Commission http://www.iec.ch
- World Trade Organisation (WTO) http://www.wto.org/
- International Standardisation Organisation (ISO) http://www.iso.org
- European Committee for Standardization (CEN) http://www.cen.eu
- European Committee for Electrotechnical Standardization (CENELEC) http://www.cenelec.org
- ESD Association www.esda.org
- American Association of Textile Chemists and Colorists. http://www.aatcc.org

8.8 Acknowledgement

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9

Developments in the thermal processing of carpets

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Abstract: During carpet manufacturing, yarn twist setting, wet processing (dyeing, printing, washing, finishing and drying) and backcoating (drying/curing) utilize predominately thermal energy. These processes for tufted carpet along with energy requirements are discussed in this chapter. Energy management of tufted carpet manufacturing processes and the future in thermal energy conservation are also presented.

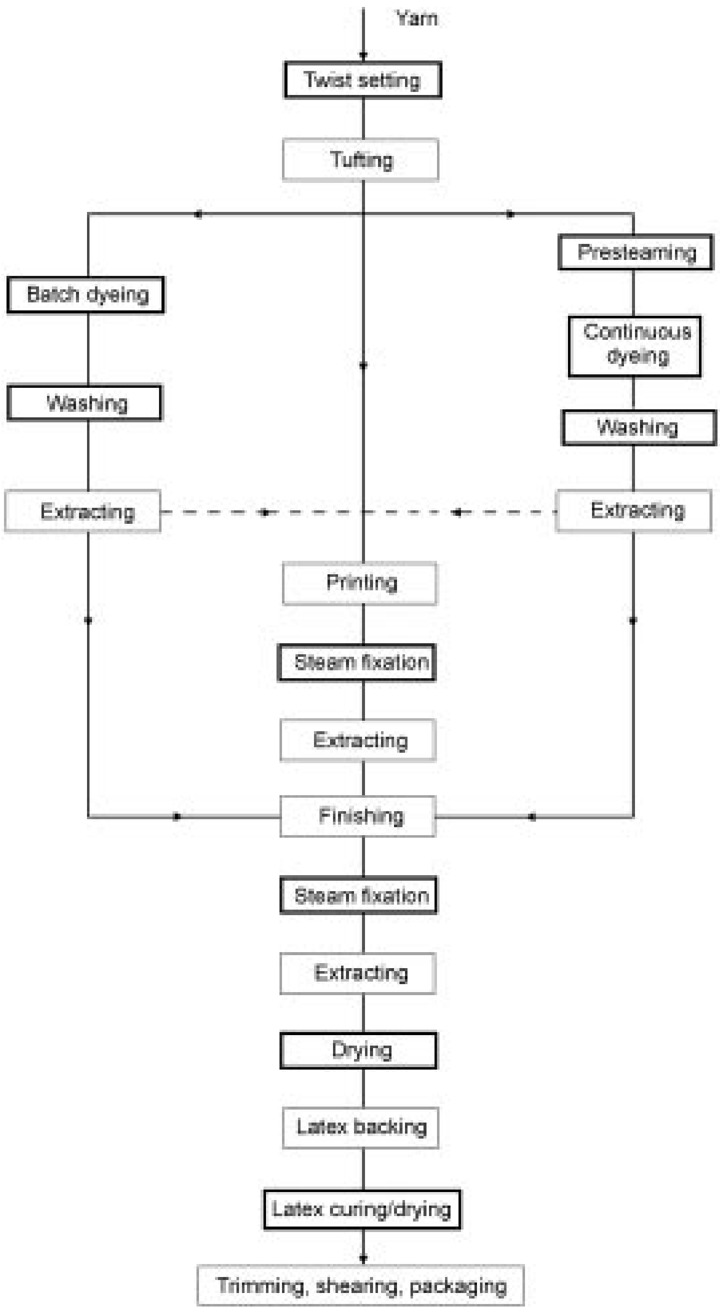
Key words: energy consumption, tufted carpet, twist setting, wet processes.

9.1 Introduction

Thermal science, which is the combined study of thermodynamics, fluid mechanics, and heat transfer, is important in several tufted carpet manufacturing processes. Thermodynamics deals with energy transformation between the end states within a system, but cannot predict how fast these changes will occur. The science of heat transfer supplements the laws of thermodynamics by providing analysis methods that can be used to predict the rate of energy transfer.[1] In heat transfer analysis, three different mechanisms may be involved: conduction, convection, and radiation.

Yarn twist setting, wet processing (dyeing, printing, washing, finishing and drying) and backcoating drying/curing utilize predominately thermal energy. These processes for tufted carpet (see Fig. 9.1) along with energy requirements will be discussed in this chapter. The equipment used in these processes includes boilers, heat setting devices, dryers, steamers, and dyeing/finishing machinery.

We begin, in Section 9.2, with a discussion of carpet yarn twist setting. The processes commonly used for tufted carpet yarn twist setting will be covered. In Section 9.3, thermal processes involved in carpet dyeing and finishing, including steaming and washing, will be discussed for both batch and continuous processes. Then carpet drying approaches and mechanisms will be covered in Section 9.4. The backcoating drying/curing process will be presented in Section 9.5. Finally we summarize the energy consumption and management of tufted carpet manufacturing processes in Section 9.6, and describe the future trends in thermal energy conservation of the carpet industry in Section 9.7.



9.1 Tufted carpet process flow diagram. (Major thermal energy consuming processes are shown in bold frame, and dashed lines indicate alternative steps.)

9.2 Carpet yarn twist setting

9.2.1 Fundamentals of twist setting

Twist setting is applied to carpet yarns to prevent their cut ends from untwisting and to enable yarns to retain bulk, crimp, and mechanical characteristics for improving dimensional stability, resilience and resistance to wear. Twist setting is essential for cut pile carpets. This is typically achieved by twisting the yarn in the desired configuration, followed by heating and then cooling it in the twisted state. Synthetic yarns, such as nylon, polypropylene and polyester, can be twist set using only heat; however, steam is usually the heating medium. Heat setting of wool requires the presence of water as well as heat. Here, we will focus on twist setting of synthetic fibers. The batch (autoclave) heat setting process is sometimes used; however, continuous (Superba and Suessen) processes are primarily utilized.

The properties of twist set carpet yarns depend on the processing conditions, such as temperature, yarn tension, moisture condition, heating and cooling times, pressure, and yarn chemical structure. The temperature of twist setting is very important. At room temperature, twisting produces recoverable deformation of carpet yarn. However, if the fiber temperature rises above the glass transition temperature, polymer microstructure changes. In the amorphous regions, molecules move and rearrange, relaxing stresses induced during twisting. Crystallization takes place through polymer chain folding and other mechanisms, and new crystalline regions can form and grow. If the structure is then cooled below the glass transition temperature, the molecules stay in the new ordered conformation, thus setting the twist.[2] Since fiber microstructure rearrangement is a time-dependent process, the time in which fibers are kept at the setting temperature is also important in twist setting.

Steam is widely used as a setting agent in twist setting. Some synthetic yarns, such as nylon and polyester carpet yarn, can be twist set at much lower temperature with steam than with dry heat. This is because moisture lowers the glass transition temperature and swells the fiber, thus enhancing the effect of temperature. Mobility of polymer chains in amorphous regions of nylon and polyester is increased because water molecules assist in breaking bonds. As a result, crystal growth is favored over nucleation and more perfect crystalline regions are formed. The specific heat of steam is about twice that of hot air (see Table 9.1), which improves the rate of heating. Steam acts as a protective gas, preventing oxidation at high temperatures.

9.2.2 Autoclave

The autoclave was the original method of heat setting of twisted yarns. Its use has declined significantly since 1970s because it is a batch process, requiring more labor, time and energy than continuous processes. Skeins of yarn are first

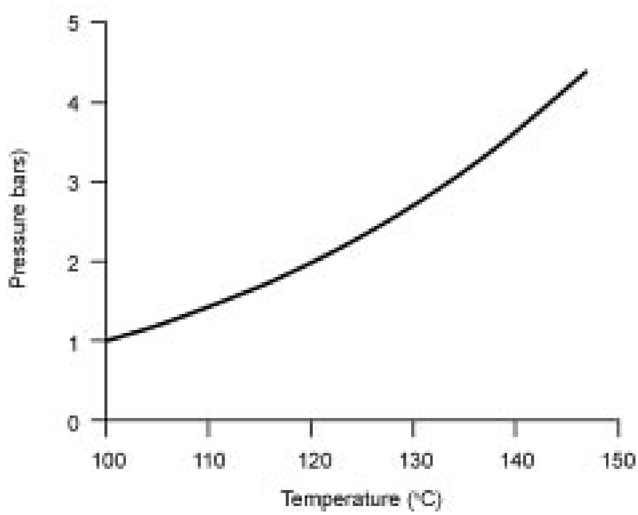
Table 9.1 Thermal properties of materials used in carpet processing[1,3]

Material	Density (g/cm^3)	Specific heat (kJ/kg·K)	Thermal conductivity[a] (W/m·K)
Wool	1.34	1.34	
Wool bats	0.5	0.5	0.054
Nylon	1.14	1.42	0.25
Polypropylene	0.93	1.79	0.12
Polyester	1.18	1.29	0.14
Acrylic	1.4	1.10	0.20
Water at 300 K	1.00	4.18	0.61
Air at 373 K	0.00094	1.00	0.026
Steam[b] at 373 K	0.00060	2.03	0.025

[a] The values for thermal conductivity are meant to be guidelines only since molecular orientation can affect thermal conductivity.
[b] Latent heat of evaporation of water at 373 K is 2257 kJ/kg.

tumbled in the presence of steam to fluff the yarn. Then the twist in the yarns is set in the autoclave unit with saturated steam, usually at a temperature up to 140 ºC. The temperature of the saturated steam is controlled via pressure (see Fig. 9.2).

Steam temperature has a significant effect on yarn properties and the variation in steaming temperature may result in different microstructures. Typical process temperatures used for several types of carpet fibers are given in Table 9.2. As the steam temperature increases, more open micro structures are



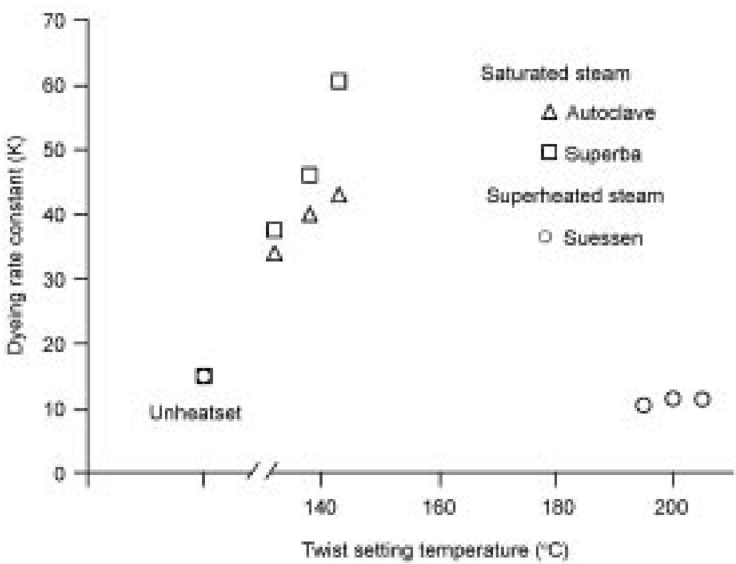
9.2 Pressure versus temperature for saturated steam.

Table 9.2 Process parameters for three carpet yarn twist setting methods[4,5]

	Saturated steam		Superheated steam Sussen GVA
	Autoclave	Superba	
Setting time	5–30 min	~ 1–3 min	45–60 sec
	Temperature (°C)		
Fibers	T_{db} and T_{dp} [a]		T_{db} (T_{dp})
Wool	105		[b]
Nylon 66	130		200–212 (88–96)
Nylon 6	120		185–202 (88–96)
Polypropylene	120		140–150 (88)
Polyester	140		185 (90)
Acrylic	105		104–150 (92)

[a] T_{db}: dry bulb temperature
T_{dp}: dew point temperature
[b] Unsuitable for twist setting wool yarns

formed in nylon fibers, thus increasing dye diffusion rates after heat setting (see Fig. 9.3). In the dyeing process, the yarn twist set at 140 °C, therefore, would dye faster than yarn set at 135 °C. If carpet tufted using these two yarns is dyed, streaks may be seen in the dyed carpet due to difference of dye uptake of the two yarns.



9.3 Effect of heat setting process on dyeing rate of nylon carpet yarn.[6]

Autoclaved yarns tend to be more bulky than yarns set using the two continuous processes; however, variations in the tumbling step may cause the appearance of streaks in the carpet after the dyeing step. Skein conditions (configurations, moisture, air) influence steam penetration and heat transfer into the skein, impairing the uniformity of the setting treatment. As a result, different bulkiness and microstructures may vary with position in the skeins. Alternating vacuuming and steaming may be used to remove the entrapped air inside the skein to achieve a uniform treatment.

9.2.3 Superba

Superba twist setting is a continuous process where carpet yarns on a moving belt pass continuously through setting equipments. The yarns are first pre-steamed in a chamber with the saturated steam at atmospheric pressure, and then transported into the set chamber containing pressurized steam at the required temperature. Because the Superba process uses saturated steam, it is very similar to autoclaving in its heat setting effects on the fiber structure and properties. However, the steam is forced circulated in the setting chamber, providing a faster steam penetration and heat transfer. As a result, the dwell time is much shorter (approximately one minute) than in the autoclaving process. The effect of the Superba process on the dyeing rate of the yarn is similar to that of the autoclave (see Fig. 9.3). Dwell time in the Superba affects the dyeability of nylon yarns.[5] Increase in Superba dwell time results in an additional opening in the fiber structure and an increase in dyeing rate. However, if dwell time is increased to 10–15 minutes, the structure may begin to close, leading to decrease in dyeing rate.

9.2.4 Suessen

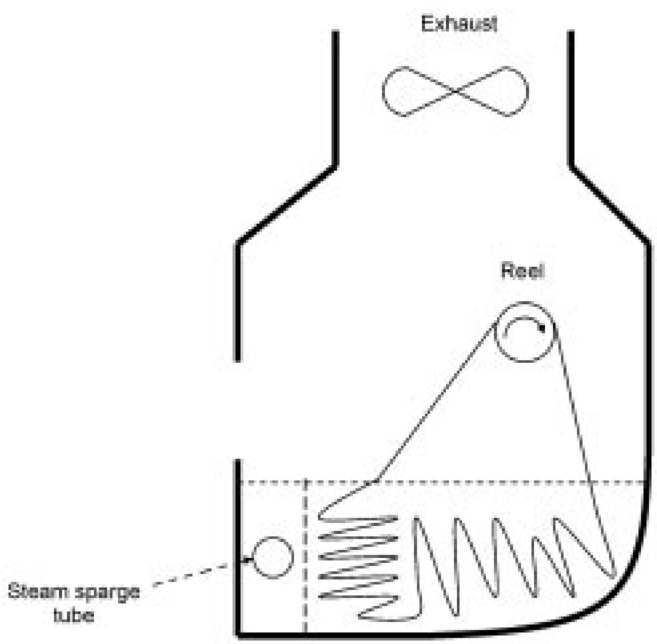
Suessen twist setting is a dry heat setting process. It is also referred to as the superheated steam method. In contrast to the Superba or autoclave processes, the Suessen system operates using a steam-air mixture at atmospheric pressure. Steam may be injected to pre-bulk the yarn and a small amount (about 2.5 psig) steam is also used in the setting chamber. The temperatures in setting chamber can be over 200 ºC, which allows a shorter dwell time (about one minutes) and higher process speed. The variables which affect twist settings include chamber temperature, belt speed or dwell time, and steam content. As shown in Fig. 9.3, the dyeing rates of nylon yarns for Sussen twist setting are much lower than those for saturated steam twist setting processes. They are also slightly lower than dyeing rates for yarn that has not been heat set.[6]

9.3 Carpet dyeing and finishing

Carpet dye fixation is carried out at elevated temperature so that dye molecules can penetrate into and be fixed in fibers, allowing optimum dyeing rate and quality to be achieved. Owing to the large amount of water used, a much larger amount of thermal energy is needed in dyeing than in carpet twist setting (see Table 9.1). Carpet may be dyed using batch or continuous dyeing processes. Continuous dyeing process is favored over batch dyeing due to the lower costs of energy, water, and labor. However, batch dyeing typically gives better dyeing quality and may have an advantage when short-run production is required. Finishing of both batch-dyed and continuous-dyed carpet is usually carried out just prior to the drying. Finishes are applied to carpet to enhance carpet properties, such as stain resistance to reduce staining by acid colorants found in food and drink, and soil resistance to repel water-and oil-based stains. Other finishes may include antistatics, antimicrobials, and softeners. The thermal energy requirements of finishing are much smaller than those for dyeing because the wet pickup of the carpet is much smaller, thus requiring less energy for heating.

9.3.1 Batch dyeing – atmospheric dye beck

Atmospheric dye becks (see Fig. 9.4) are often used for batch dyeing of carpet. The carpet is loaded in the beck and looped around the reel. The beck is filled



9.4 Schematic of atmospheric dye beck.

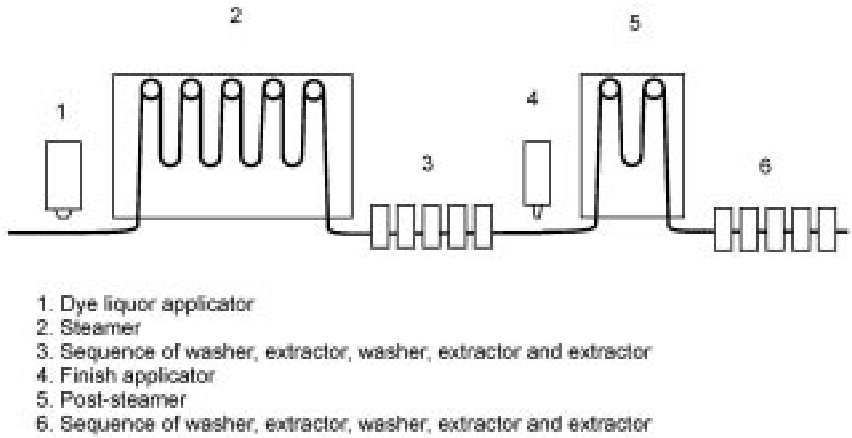
with water, and auxiliary chemicals (for controlling pH, antifoaming, leveling, etc.) are added from a separate tank. Dyestuff is added slowly according to production dye recipe.

Dye liquor ratio (water plus dyes and chemicals) to dye carpet is typically about 20 : 1 in beck dyeing. The dye bath is heated by direct injection (sparging) of steam into the beck. The dye liquor temperature is usually raised at a rate of approximately 1 to 2 ºC per minute for nylon carpet. Once the temperature reaches the operational value, it is held there for approximately one hour to allow dye molecules to migrate from the dye liquor to the carpet. During the process, continuous agitation is provided by the action of the carpet being pulled out of the water by the reel. To achieve uniform dyeing, several operational conditions should be well controlled, including rate of temperature increase, temperature uniformity throughout the beck, and uniformity of dye and chemical concentration. Direct contact of steam with the carpet should be avoided throughout the dyeing process. Once an acceptable color match is achieved, the dyeing batch is dropped. Normally the carpet is rinsed in warm water for approximately 10 minutes. The rinse batch is dropped, and the carpet is removed and taken to a dryer.

Owing to the large volume of water that must be heated to boil, the thermal energy requirements for batch dyeing are much higher than for continuous dyeing. Thermal energy requirements can vary widely in atmospheric dye beck dyeing due to a number of variables, such as dye liquor/carpet ratio, hold time at dye fixation temperature, number of adds and redyes, type of materials being dyed, and class of dye used. The average energy requirement for dyeing carpet in atmospheric dye becks is approximately 31 700 kJ/kg consisting of 30 900 kJ/kg thermal energy and 0.8 kJ/kg electrical energy.[7]

9.3.2 Continuous dyeing

In the tufted carpet industry, continuous ranges where carpet is dyed, finished and dried open-width are prevalent. Figure 9.5 shows an example of continuous dyeing and finishing line for tufted carpet. Rolls of greige carpet are sewed together end-to-end and then feed into a J-box located at the input end of the range. After moving through the J-box, the carpet passes through a guider which removes folds from the carpet and ensures that the carpet is properly centered as it enters the presteamer. The presteamer may be used to apply steam to the carpet to remove creases from the carpet and to bulk up the fibers for dye application. Presteaming consumes only a very small part of the total thermal energy required for continuous dyeing.[7] After passing through the presteamer, the carpet moves through the dye applicator where dye liquor is applied at a wet pickup typically ranging from 350 to 450%. Next the carpet passes through a steamer which raises the temperature of the carpet and dye liquor. Condensing steam rapidly raises the temperature of the carpet and the dye liquor. The carpet



9.5 Schematic of continuous dyeing and finishing line.

is carried through large vertical loops by powered rolls as it moves through the steamer. Ideally air-free saturated steam should be used so that the carpet temperature across the surface will be uniform. Owing to the higher density of air, steam rises to the upper part of the steamer, forming a steam cloud above the air. It is believed that the carpet should stay in the steam cloud during dye fixation to obtain good dyeing quality. The retention time in the steam environment must be sufficient to fix the dye to the carpet fiber, about 2–5 minutes for nylon carpet. Steaming after dye application is a highly energy-intensive process due to the amount of dye liquor that must be heated up along with the carpet. The rate of thermal energy consumption, p, for continuous dyeing can be estimated using the following equation:

$$p = \Delta T(c_f + c_w n)vwm\eta \qquad 9.1$$

where ΔT is the difference between dyeing temperature and room temperature, c_f is the specific heat of carpet, c_w is the specific heat of dye liquor, n is the dye liquor pick up ratio, v is the line speed, w is the carpet width, m is the carpet weight (areal density) and η is the efficiency of steaming system.

Table 9.3 gives the theoretical values of thermal energy and steam consumption for three different weights of nylon carpets for the following processing conditions: production speed of 40 m/min, carpet width of 4 m; temperature difference of 80 ºC. Wet pickup and carpet weight significantly influence the thermal energy consumption of the dyeing range. The steaming step is often the bottleneck for the continuous dyeing process for heavy weight carpets due to the high energy requirements. The actual production speed for heavy weight carpets is usually much lower than 40 m/min. Several techniques have been tested in an effort to decrease dye liquor pickup ratio, but have not been utilized because it is believed that a high dye liquor pickup ratio is needed for good dyeing quality.

Table 9.3 Theoretical steam consumption and thermal energy for continuous dyeing of nylon carpet[a]

	Wet pickup (%)	Carpet area density, kg/m^2 (oz/yd^2)		
		1.0 (30)	1.5 (45)	3.0[b] (60)
	350			
Steam (kg/hr)		6 800	10 200	13 600
Thermal energy (kW)		3 500	5 200	7 000
	450			
Steam (kg/hr)		8 500	13 000	17 000
Thermal energy (kW)		4 400	6 600	8 800

[a] Assumption: boiler efficiency is 82%; processing speed is 40 m/min, carpet width is 4 m, and carpet temperature increase in steamer is 80 °C.
[b] The actual production speed for heavy weight carpets is usually much lower than 40 m/min.

After exiting the steamer, the carpet is washed in a series of wash boxes to remove the unfixed dye. The energy brought into the wash boxes by the hot and wet carpet is often sufficient to maintain the wash box at an acceptable temperature.

9.3.3 Carpet finishing

Prior to drying, finishes such as stain resistance, stain blockers, antistatics, softeners, and antimicrobials, are applied to carpet and require thermal energy provided by steam for setting. After dyeing and washing, the moisture content of the carpet is reduced using mechanical devices, usually squeeze rollers followed by vacuum extractors, to typically 35 to 50%. Then the finishing agent formulations are applied to the carpet using either spray or foam applicators. Added wet pickup is typically about 10%. The carpet passes through a steamer for 1–2 minutes to fix the finishes. The rate of thermal energy consumption, p, for continuous finishing can be estimated using equation 9.1. Since the total wet pickup (45 to 60%) after the application of finish agent formulation is much lower than the value (350 to 450%) following dye application, the energy requirements for steaming associated with finishing are much lower than those for dyeing.

Also, the steaming temperature (often less than 80 °C) is typically lower than that needed in the dyeing process. Wet pickup ratio of finishing solution, steaming time and temperature are key parameters associated with energy consumption and production quality.

9.4 Carpet drying after dyeing and finishing

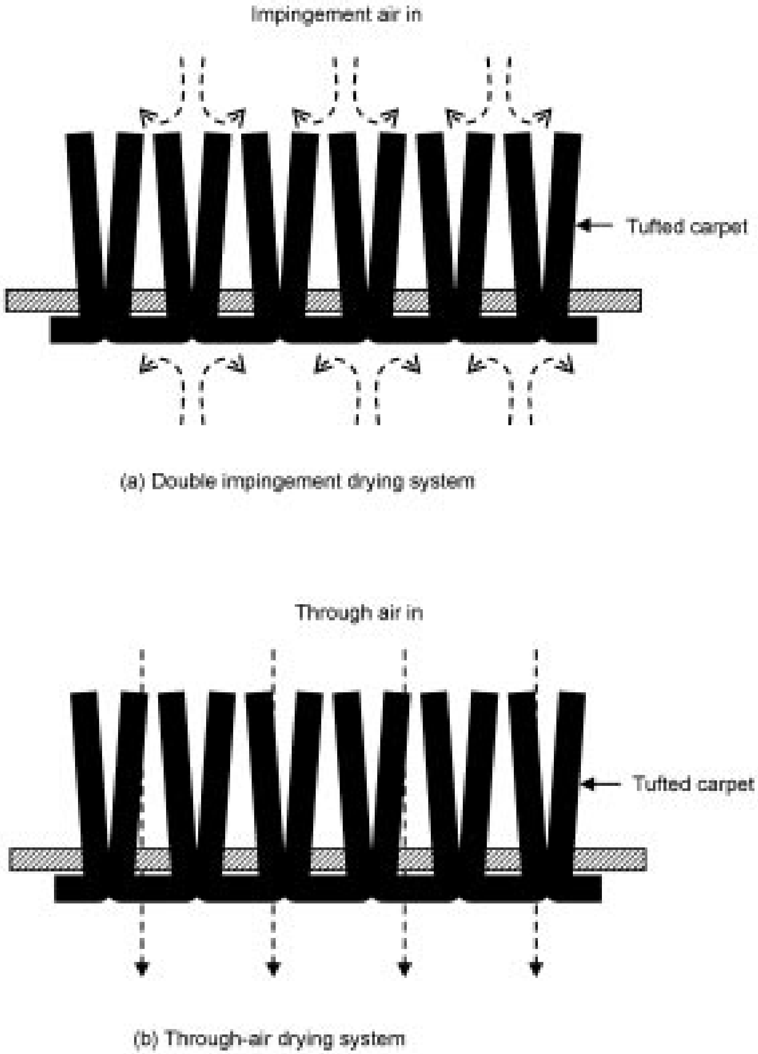
The process which carpets generally go through after dyeing, washing and finish application is drying. For batch dyeing, the carpet is sewn end to end and passed through a continuous dryer. For the continuous dyeing, the dryer is typically part of the dyeing range.

The purpose of drying is to remove moisture from the carpet to an acceptable level. Since vaporization of water is thermal energy intensive, moisture is first removed by mechanical methods – squeeze rollers followed by vacuum extraction. Mechanical water removal requires only approximately 3% of the energy required for removal by a phase change of water.[8] However, the moisture removal via mechanical means is limited, and the moisture content (dry basis) leaving the mechanical devices is usually between 35 and 50%. The remaining moisture is typically removed in a convection oven using hot air heated by natural gas.

The most common dryers for carpets are the double impingement dryer with a fairly high velocity and the through-air dryer. Most dryers have temperature controllers and exhaust ducts in each of several zones coupled to individual burner. Figure 9.6 shows the difference in mechanisms between a double impingement system and a through-flow system.[9] In a double impingement system, air is forced through ducts feeding high velocity discharge nozzles above and below the carpet, and then air leaves the ducts at high velocity and strikes the carpet. The design reduces the dead air space surrounding the evaporative surfaces, but the air does not penetrate through the carpet. On the other hand, air in a through-flow system flows around the individual yarn surfaces. This minimizes shielding so as to increase the evaporation rate. Consequently, the through-air dryer gives a significant reduction in drying time and increases the drying rate relatively to the double impingement system. Thus, the through-air drying system has been widely used in carpet industry.

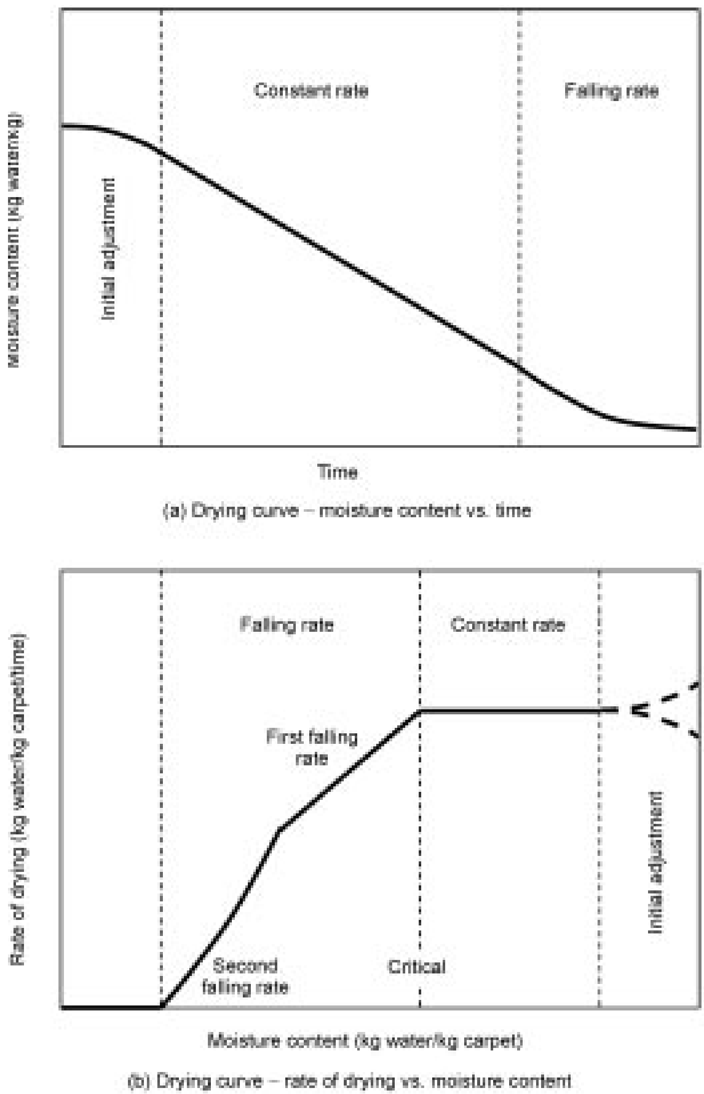
9.4.1 Fundamentals of drying mechanisms

A typical drying curve is plotted in Fig. 9.7a.[9] The absolute value of the slope is the so-called drying rate, the evaporation rate, or the moisture removal rate. It is an important parameter in the drying process. In Fig. 9.7b, drying rate versus moisture content (dry basis) is plotted. As shown in the Fig. 9.7a, the curve starts with an initial adjustment period. In this period, the drying rate is low because a significant amount of heat transfer to wet material is used to raise the temperature of the material. As the material is heated, the drying rate increases to a peak value and then holds constant. In the constant drying rate period, a balance between heat transfer and mass transfer occurs, resulting in constant temperature and vapor pressure at the surface of the material. Since the vapor pressure of the wet material equals that of liquid water, moisture at the surface of the solid is called the free moisture. The removal of water depends on conditions



9.6 Schematics of two drying systems.

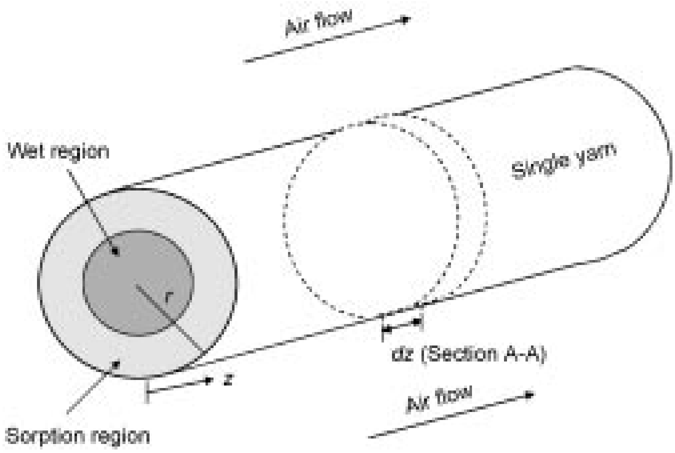
of the gas stream such as temperature, relative humidity, and flow rate, as well as exposed surface area of the material. This period will not end until moisture content of the material reaches a critical value, called critical moisture content, where most of unbound moisture has been removed. The first falling rate period begins as the moisture film at the surface of the material becomes unsaturated and ends as the surface moisture is completely removed. In the second falling rate period, bound moisture diffuses from within the solid toward the surface of the solid. Evaporation occurs mostly at the receding evaporation front until the material has been dried out.



9.7 Typical carpet drying curves.[9]

9.4.2 Drying model

Numerous simultaneous heat and mass transfer models have been proposed for convectively drying all kinds of moist porous materials such as agricultural, ceramic, food, pharmaceutical, pulp and paper, mineral, polymer and textile products. Lee *et al.*[10] proposed a simplified transient two-dimensional mathematical model has to simulate the through-air drying process for an unbacked tufted carpet. In their model, the carpet yarn geometry is simplified by



9.8 Schematic of the unit cell: the yarn and its surrounding space.[9]

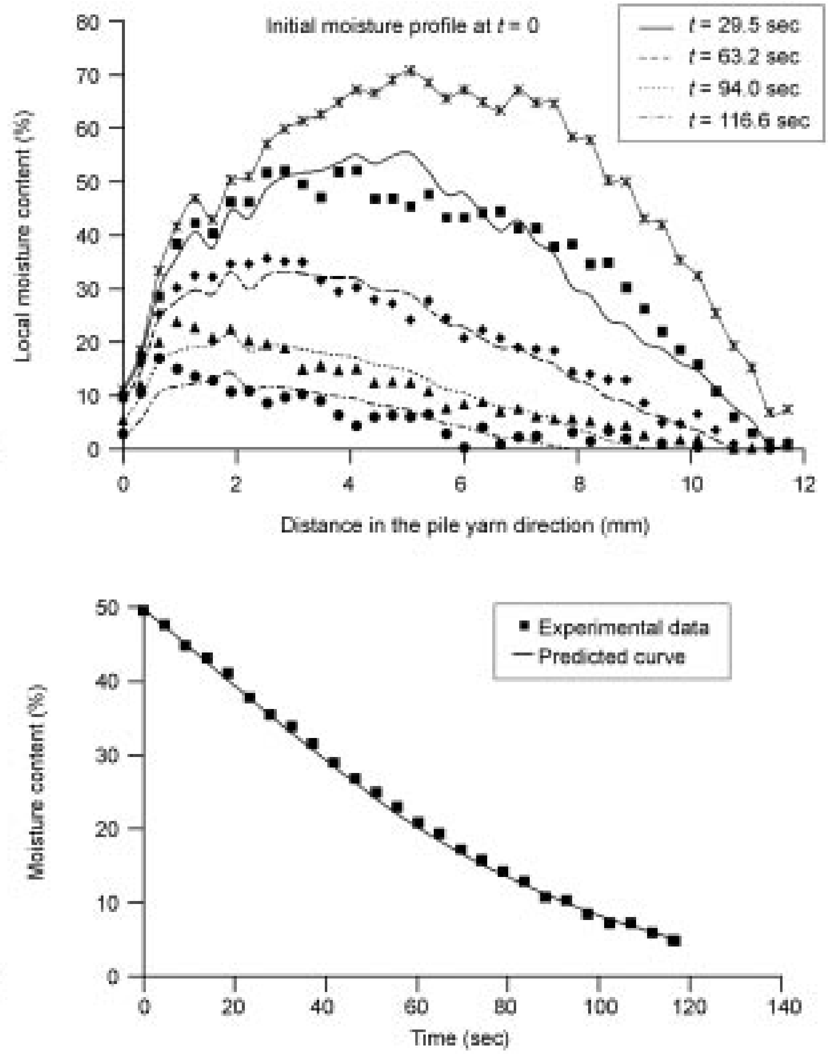
adding the length of the yarn on the backside to the length of face yarn since the length of the yarn on the backside is small compared to the length of the face yarn. The yarn was considered to be a porous circular cylinder. Since the primary backing is usually made of polypropylene and holds little moisture, it is neglected in the model. As a result, they selected the unit cell (see Fig. 9.8) that is a yarn running perpendicular to the backing and surrounding space through which air flows parallel to the yarn.[9]

As shown in Fig. 9.8, the entire moist porous solid generally consists of the wet region at the beginning of drying. The wet region contains unbound (free) moisture, and capillary flow governs the liquid moisture transport in this region. The sorption region emerges when the moisture regain (moisture content on dry basis) falls below the maximum sorption value. In this region containing bound moisture, the liquid-phase moisture transport and gas-phase moisture transport are governed by bound moisture flow and water vapor diffusion, respectively. A moving front divides the porous medium into the sorption region and the wet region. The front will recede until the wet region disappears; i.e. the entire porous solid consists of the sorption region.

The drying model consists of two parts: the first is a model for heat and mass transfer in the yarn, and the second is a model for heat and mass transfer in airflow. Though the model was simplified so that fewer physical and transport properties are required for industrial application, it gave solutions that closely agree with experimental results. Figure 9.9(a) shows that predicted variations of one-dimensional moisture distributions within carpet versus drying time agree well with profiles obtained using the magnetic resonance imaging system.[10,11]

This simplified but accurate mathematical drying model has great potential to be used to assist carpet manufacturers in controlling and/or optimizing their current operations, increasing production rate and decreasing energy cost.

(a)



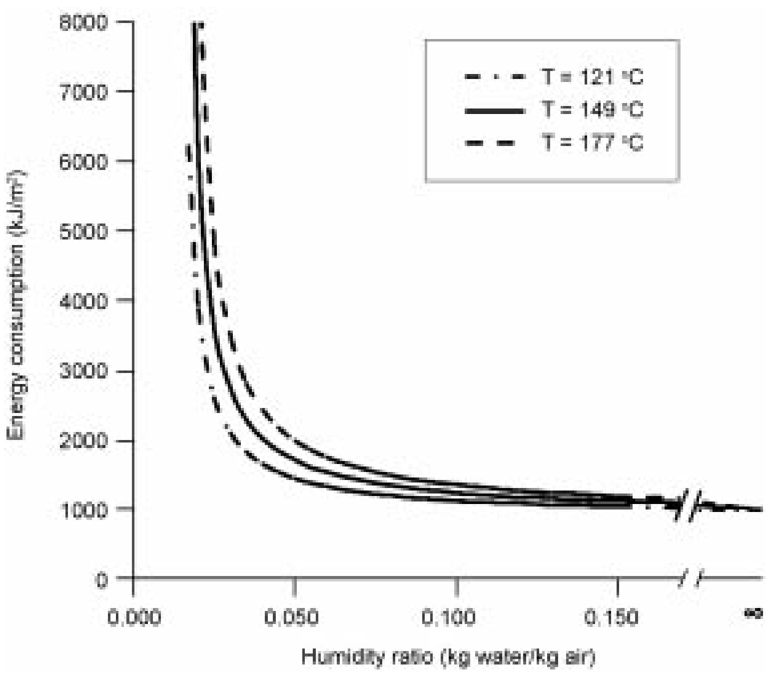
(b)

9.9 Through-air drying model predictions compared with experimental results for airflow rate of 20 m/min and an air temperature of 80 °C.[11]

9.5 Latex curing

In the process of tufting, face yarns are inserted through a primary backing, but are not locked in. After dyeing and finishing, backcoating is applied to bind the piles and to improve the dimensional stability of the carpet. During the typical backcoating process, a layer of latex adhesive, which consists of a colloidal dispersion of polymer spheres in water, is applied on the backside of the carpet. The coated carpet is then laminated with a thin secondary backing, usually polypropylene. The latex backing must be dried sufficiently so that its mechanical properties are developed properly. A tenter frame transports the backed carpet through a convection oven which utilizes heated air to remove water and cure the latex backing.

The most common dryer for drying/curing latex backing on carpet is an impingement dryer with high velocity air impinging on the backing. These dryers are typically large consumers of energy because large volumes of process air are exhausted, requiring copious amounts of make-up air. In addition to the air velocity, oven temperature and humidity ratio of the hot air are important parameters in the process.[12] Required drying time decreases significantly as oven temperature is increased. The effect of humidity ratio greatly depends on oven temperature. At a lower temperature, drying time increases with increasing humidity ratio; however, for a higher oven temperature, the effect of humidity ratio is small. Energy requirements are significantly greater for dryers operated at low humidity ratio because very high rates of make-up air are required (see Fig. 9.10).[13] Thus, from an energy conservation standpoint, backcoating dryers should be operated at the highest feasible temperature consistent with good product quality and at the highest humidity ratio consistent with acceptable productivity.



9.10 Effect of humidity and temperature on energy consumption to dry/cure latex backing (0.88 kg/m^2 nylon carpet with 0.95 kg/m^2 latex backing).[13]

9.6 Energy consumption and management

9.6.1 Energy consumption

Table 9.4 lists the typical energy consumption of tufted carpet processes. The equipment in dry processes (such as climate control systems and tufting machine) utilizes energy mostly in the form of electricity, requiring extensive and costly engineering modifications to significantly reduce energy consumption. On the other hand, wet processes (dyeing, steaming, finishing, and drying) utilize predominately thermal energy, which is usually in the form of steam (heat dyeing) or heated air (drying). The steam and heated-air systems account for a significant amount of the energy used in carpet production, and there are a number of opportunities for reducing energy consumption in these systems.

9.6.2 Control measures and energy management

Boilers are used in carpet mills to provide steam for dye line and pre- or post-treatments. Optimization of boiler operations, including optimizing boiler sequencing, installing economizers and oxygen trim, and de-scaling boiler tubes, can achieve a significant energy saving. A case study showed that boiler sequencing leads to higher steam generation efficiency, saving more than $299 000 annually.[15] Boiler operated with excess gas oxygen levels results in the heat loss and higher fuel consumption, and a cost saving from installing a oxygen trim controller was estimated at about $40 000 annually in that study. A waste water heat exchanger was also installed to capture the excess heat from Kuster dye line and heat process water for dyeing, which can yield annual energy savings of more than $786 000.

Table 9.4 Typical energy consumption for tufted carpet processes[14]

Process	Total energy consumption[a] (kJ/kg carpet processed)
Twisting	10 500
Twist setting	7 000
Tufting	2 400
Continuous dyeing	22 800
Finishing	8 000
Drying	10 100
Latex curing	2 700[12]

[a] The values of energy consumed in production are based on an energy intensity of 10 500 Btu/kWh-electric as opposed to the direct conversion factor of 3412 Btu/kWh-thermal.

9.6.3 Low wet pickup dyeing

The equation in Section 9.3 for calculating the rate of energy consumption for steaming carpet indicates that energy consumption increases directly with increasing wet pickup. Thus wet pickup during continuous dyeing and finishing should be kept as low as possible to minimize the energy requirements of steaming. Wet pickup during finishing (45 to 60%) is much lower than in dyeing (350 to 450%). Thus reduction in wet pickup during dyeing and printing represents a large potential for energy reduction in processing carpet. However, high wet pickup in dyeing and printing is used to achieve the required penetration of the dye in the carpet pile and coloration quality. Continuous foam dyeing of tufted carpet, which allows dyeing at low wet pickup, was explored in the early 1980s. Air blended with foam liquid serves as a diluent, allowing uniform distribution of dyes and chemicals over the substrate at much lower wet pickup than required in the standard dyeing process. Keller[16] summarized the potential advantages of a foam dyeing process for tufted carpets as follows:

1. Wet pickup may be 30–50% rather than the conventional 300–500%.
2. Greater throughput rates during steam fixation since heat-up and fixation rates are higher.
3. Reduction in thickening agent usage, with associated reduction in cost and effluent loading.
4. In certain cases, no washing after steaming is required, with reduction in water usage.

Although foam dyeing had many potential advantages, it was abandoned when energy prices fell in the mid 1980s. With the rapidly rising energy costs, further study of foam dyeing of carpet may be warranted.

Drying is an energy-intensive process, and can often be the bottleneck in the speed of the dyeing and finishing range. A large percentage (up to 80%) of heating value of the fuel consumed in the burner may end up as waste energy in the dryer exhaust.[17] With multiple dryers at a single site, it is not uncommon to have fuel costs in the million dollar range. Thus a modest improvement of 20% in energy efficiency would save several hundred thousand dollars at a single site. Agrawal suggests two approaches to reducing energy consumption in drying:[17]

1. Eliminate overdrying by measurement and control of product moisture content at dryer exit; and
2. Operate dryer at the highest humidity ratio consistent without impacting productivity.

With the present state of art, on-line moisture measurement and control is not an economically viable option; however, technology is currently available for measuring and controlling humidity ratio in exhaust stacks.[13] Many latex-back coaters consume more than $400 000/year in fuel, and increasing humidity ratio to 0.1 kg_w/kg_a can reasonably be expected to obtain 10–20% savings. After the investment in the humidity controls, the changes in operating parameters do not require a capital investment. The investment in humidity controls is reasonable at $2500 per sensor plus installation and programming. This method of energy conservation is very cost effective.

9.7 Future trends

Energy consumption, sustainability and environmental management are critical issues for the carpet industry. Wet processes offer opportunities for reduction in energy and water consumption, as well as reduction in effluents. As mentioned above, since the energy required for steaming varies directly with wet pickup, low-wet-pickup processes are need for dyeing, printing and finishing. Further consideration of foam dyeing may be warranted due to the large potential for energy savings, as well as reduction in water usage. The use of digital printing systems developed for carpet printing is increasing. In addition to having the potential of reducing energy consumption due to low wet pickup, digital printing makes short, special-order production runs more feasible. Vacuum extraction of the dye liquor in the carpet following steaming and prior to washing offers the potential of recovering dyestuff, auxiliary chemicals and energy, thus requiring less water and/or energy needed for rinsing.

On-line moisture measurement and control of carpet dryers is not an economically viable option with the present state of the art. Development of measurement and control and devices will allow significant energy reduction in carpet wet processes, as well as improvements in process efficiency.

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