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Fabric Making Technologies

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19.1 Introduction

Fabric can be defined as the manufactured assembly of fibers and/or yarns. A wide variety of textile materials are used to produce fabrics including advanced materials. In the conversion of materials such as fibers and yarns to fabric, the fabric making technology that involves the processing machine, procedures, and parameters for fabric formation has significant influence on the properties and appearance of the resulting fabrics. There are many ways to make fabrics. The most commonly used techniques include weaving, knitting, nonwoven manufacturing, and braiding. Each fabric making method constructs a unique fabric structure that partially determines the fabric properties and appearance. Figure 19.1 shows the schematic of fabric structures formed by these methods.

Weaving is a traditional method used for fabric production wherein the resultant woven fabrics are manufactured by interlacing at least two sets of thread systems – warp and weft threads at right angles to each other. In a simple woven structure, the warp threads, which are called the warp ends in weaving terms, always run along the length of the fabric or up and down, while the weft threads, also known as picks or filling yarn in weaving terms, run in the horizontal direction or left to right and vice versa. The warp and weft threads are perpendicular to each other. More thread systems can be inserted into weaving machines to produce woven fabrics with different structures. In the past, they were mostly in one layer. With time, double-layer, triaxial, and three-dimensional (3D) woven fabrics have been developed for the textile market. They have various properties and applications for daily use.

Knitting is the second most popular technique of fabric making in the textile industry. In the knitting process, knitted fabrics are produced by interlooping yarns. There are two ways of knitting based on the direction of the yarn movement, which are known as weft and warp knitting. In weft knitting, the loops are constructed in the horizontal direction, while in warp knitting, the yarns are knitted along the vertical or diagonal direction. Compared with woven fabrics, knitted fabrics have better extensibility and formability due to their loop

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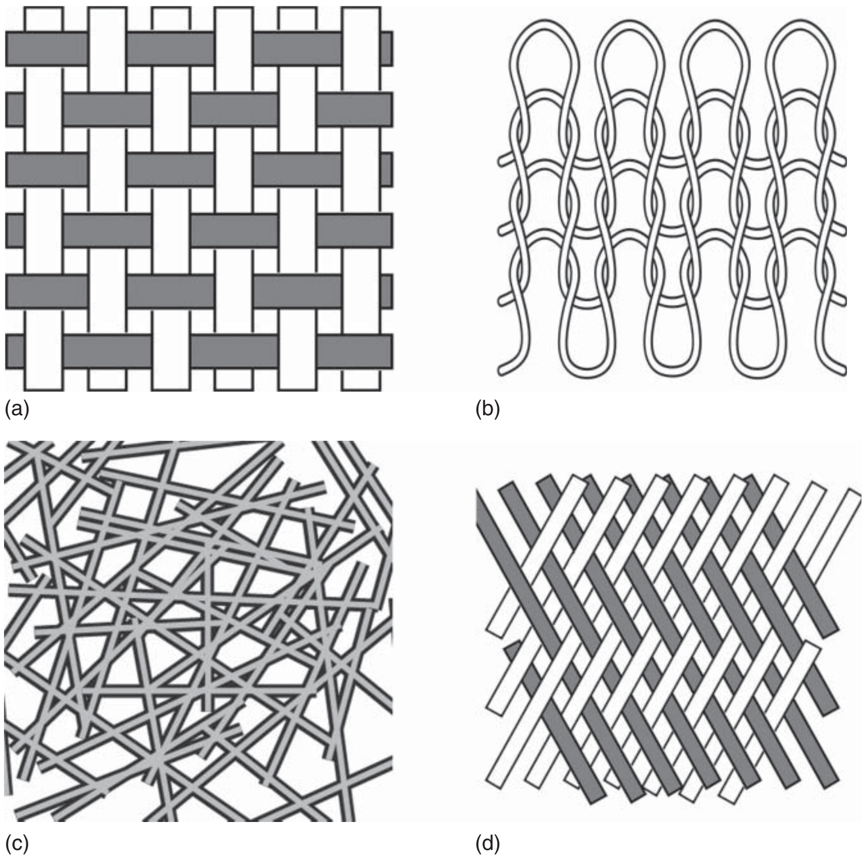

Figure 19.1 Schematic of structures of main fabric types. (a) Woven. (b) Knit. (c) Nonwoven. (d) Braided.

structure. Nowadays, knitted fabrics are widely used in apparel, home furnishings, and technical textiles.

Nonwoven fabric technology is one of the major technologies for the manufacture of fabric. Nonwoven fabrics are a manufactured sheet of web, sheet, or batt, which are produced with staple fibers or filaments through various bonding techniques that hold them together. In terms of processing by machinery, nonwovens do not need to be prepared through the yarn spinning process and can be directly made from fibers or even polymers. One of the greatest benefits of the production of nonwoven fabrics is that the production rate is much higher than that of fabrics produced by weaving or knitting technologies since there are fewer yarn procedures and the process can be more automated. A wide range of raw materials can be applied, regardless if they are natural or synthetic fibers. Nowadays, most synthetic or bicomponent fibers, or even special fibers such as nanofibers, glass fibers, and biodegradable materials, can be used to produce nonwoven fabrics since they have unique characteristics, uniformity, and consistency. These textiles can be applied toward different end uses, especially for hygiene, civil engineering, and building materials.

Braiding is a common process for constructing narrow fabrics or products, which are known as braided or plaited textiles. Braided fabrics are produced by interlacing three or more separate threads in such a way that they can cross one another in a diagonally overlapping direction. Based on the unique constructed structures through braiding, the resultant fabrics exhibit good strength in the primary loading direction and shear resistance as well as complex-shaped parts. Moreover, by varying the braided structures, different types of braided fabrics can be fabricated with different properties and shapes, including two-dimensional (2D) and 3D braids, biaxial and triaxial braids, and flat and circular braids. Traditionally, braiding was used to produce ropes and cords with a simple structure. Braids with complicated structures were normally thicker and stronger with high physical strength. Nowadays, braided fabrics are used for various industrial applications since they have good extension and are very pliable with nicely curved edges.

19.2 Weaving

19.2.1 Weaving Machines

Woven fabrics are manufactured by interlacing lengthwise warps and crosswise wefts into designed patterns on weaving machines. There are many different types of weaving machines that have been developed for the production of woven fabrics in the textile industry. Weaving machines are divided into shuttle and shuttleless based on how the weft yarns are inserted. Shuttle looms are the oldest and most simple type of weaving machines, where the weft yarn is inserted with a shuttle. Nowadays, shuttle looms are not commonly used for the production of woven fabric except for some of the specialty markets. They have been replaced by shuttleless looms, which started from the mid-twentieth century and include rapier, projectile, air-jet, and water-jet looms [1–6]. Compared with shuttle looms, shuttleless looms have a much higher production rate and are more flexible for manufacturing different types of woven fabrics.

Rapier weaving machines are a primary type of shuttleless weaving machine used for making woven fabric with a versatile insertion system and excellent control of the filling yarn in the process. In rapier looms, flexible or rigid rapiers are used to insert the weft yarn across the shed. There are two types of rapier weaving machines: single or double rapier looms. In the former, only one long and rigid rapier, which is made of metal or a composite material, is used to feed the filling yarn and then retracted, while there are two rapiers in the latter: a giver, which picks up and carries the filling yarn to the shed center, and a taker, which takes the yarn from the giver and transports the yarn to the end of the shed. The advantage of a two-rapier system is increased efficiency as opposed to the use of a single rapier loom. In addition, there are rigid and flexible double rapier machines. Nowadays, flexible double rapier looms are preferred over single or rigid rapier looms due to their advantages, such as space saving and a higher machine speed.

Projectile weaving machines involve a small bullet-like gripper that holds and then brings the weft yarn through the shed without the use of a heavy shuttle. During the insertion of the weft yarn, a picking lever beats the gripper with the yarn to slide through a channel composed of the thin prongs of a rake. When the gripper arrives the other side of the machine, it is braked in the receiving unit. Several grippers are usually used in projectile looms. After one gripper reaches the other side of the loom with the weft yarn and then returns to the starting position by the conveyor system, the other grippers are ready for the next picking. Compared with the shuttle loom, the grippers of the projectile loom can move faster and farther because of the reduced dimensions and the mass of the carrier. Therefore, projectile weaving machines are more suitable for producing wider woven fabrics and thus commonly used for the production of technical fabrics.

Jet looms take the weft yarn across the loom by using the force of air or water at high pressure. Thus, jet looms can be operated at higher speeds as opposed to projectile or rapier looms. However, they cannot accommodate heavy or bulky yarns, nor can they produce fabric with wider dimensions as they have less yarn-carrying power. In air-jet weaving machines, the filling yarn is propelled by compressed air that come from several nozzles to weave fabric. The main and tandem nozzles provide weft yarns with an initial propulsion force, while the relay nozzles found in the entire shed offer additional high-velocity air to assist with conveying the yarn through the warp shed. Another main feature of air-jet looms is that a specially designed profiled reed is used for the weft yarn insertion wherein the profiled reed builds a channel to guide the air, which prevents the abrasion of the inserted wefts with the warps. They are one of the most popular types of weaving machines since the weft insertion rate is very high with low production requirements and thus offers high productivity for mass production, relative to other shuttleless machines. Many standard types of fabrics or fabrics with a variety of styles can be produced through air-jet weaving, such as denim, glass, or terry fabric.

The operation principle of water-jet looms is similar to that of air-jet looms. During the weaving process, the nozzle provides highly pressurized water to insert the weft yarn. A small amount of water is required for the fabric production, and the weaving process is carried out at extremely high speed. Therefore, water-jet looms are very efficient. However, efficient drying units need to be equipped on the water-jet looms to dry the wet fabric. The main disadvantage of the water-jet weaving machine is that it is more suitable for weaving hydrophobic filament yarns such as polyester and nylon [1, 4–9].

In addition to these different weaving machines with weft yarn insertion systems, there are three types of shedding systems, namely, the cam, dobby, and jacquard machines. Their function is to separate the warp sheet into at least two layers for weft yarn insertion. For producing common types of fabrics, weaving machines are normally equipped with a dobby shedding system, which include negative, positive, and rotary dobbies. The latest manufactured weaving machines use rotary dobbies as they are suitable for the high speed of these machines and offer flexibility for changing patterns. Weaving machines equipped with a dobby shedding system control the movement of the warp yarn by using the harnesses, which means warps on the same harness have the same movement. In order to vary the movement of the warp yarn for weaving a pattern, more harnesses are used, but the number of harnesses that can be accommodated in a dobby system is limited. Therefore, when the patterning capacity of dobbies fails to meet the requirements of the weaving design, a jacquard shedding system must be used. The main feature of jacquard shedding is that this mechanism can control the movement of the warp yarn individually. In recent years, jacquard shedding machines are becoming more and more ubiquitous for manufacturing woven fabric since they can produce extraordinary and intricate patterns or figures, such as brocades, tapestry, and damask. There are mechanical and electronic jacquard looms with single or double lift mechanisms [10, 11].

There are also special types of weaving machines that have been developed for high productivity or creating special woven fabrics, including multiphase, circular, and triaxial weaving machines. The multiphase weaving machine can insert several weft yarns simultaneously so that more than one shed can be formed at a time. Thus, this machine offers high productivity. In circular weaving machines, the shuttles run continuously and circularly around the periphery in a ripple or wave shed. The produced fabrics are in a tubular form and mainly used for sacks and tubes. In triaxial weaving machines, two sets of warp threads and one set of weft threads are interlaced to form a multitude of equilateral triangles. The constructed fabric structures are unique and endow the resultant fabrics with good tear, burst, and abrasion resistance. Triaxial fabrics are largely used for industrial purposes, such as conveyor belts, reinforcements for plastics, and aerospace accessories.

19.2.2 Woven Structures

A woven fabric is formed by the interlacement of the warp and weft threads. This interlacing pattern is called the weave of a woven fabric. The final fabric properties and appearance depend on the weave and other structural parameters such as the fabric density and yarn count. Weaves are planned on point paper wherein each vertical column and horizontal row means a warp end and a weft pick, respectively. In a weave diagram, each square represents an intersection point between a warp and a weft yarn, and if the warp yarn crosses over the weft yarn at this point, the square is filled or shaded with a mark. On the other hand, if the weft yarn is above the warp yarn in the point of intersection, the square will be left blank. An unlimited variety of weaves can be designed for woven fabrics. The most commonly used weaves in the production of woven fabric include fundamental weaves and their derivatives, combined weaves as well as compound weaves. Each has their own characteristics.

Plain, twill, and satin/sateen weaves are three types of fundamental weaves, as shown in Figure 19.2. They have a simple structure but form the basis of even the most complex weaves where every warp and weft thread within a repeat is interlaced by only one thread of the opposite system. Plain weaves are the simplest and most commonly used weave of all woven fabrics. In this structure, weft filling yarn is alternately passed through the warp yarn, which follows the order of one up and one down. If the plain weave is extended in the warpwise or weftwise or

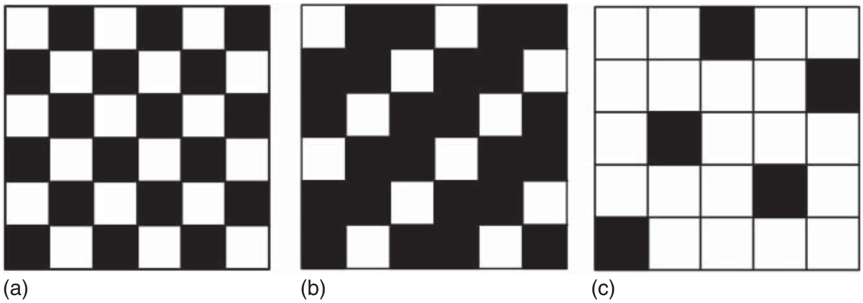

Figure 19.2 Fundamental weaves. (a) Plain. (b) Twill. (c) Sateen.

both directions, new structures with rib or basket effects are further created, such as warp rib, weft rib, and basket weaves in a regular or an irregular form.

Twill weaves also have a simple structure but can generate pronounced diagonal lines along the fabric width. Twill lines are created by the stepwise progression of yarn interlacing patterns that appear on both sides of the fabric, and the fabric constructed with a twill weave is usually strong and durable. In terms of the direction of the twill lines, there are two types: right-hand and left-hand twill. In the former, the twill lines run from lower left to upper right, while the twill lines run from lower right to upper left in the latter. There are several factors that affect the prominence of twill weaves, including the nature of the yarn, yarn floats, fabric density, and relative direction of the twill and yarn twist. By extending the floats and changing the move number and direction of the diagonal lines on the twill weaves, various twill weave derivatives can be created in woven fabrics. Commonly used twill derivatives are pointed, herringbone, curved, broken, and elongated twills as well as diamond and diaper weaves.

Sateen/satin weaves have a higher luster on one side of the fabric since there are many long floats on the fabric surface that reflect light. Sateen is a weft-faced weave wherein the long weft float is on the top surface of the fabric while the satin weave consists of long warp float on the fabric surface, thus a warp-faced weave. During the weave design, both repeat and move numbers are important parameters. The satin/sateen weaves may be modified by subtracting or adding marks or changing move number or both [12–14]. Consequently, a series of satin/sateen weave derivatives can be produced such as reinforced and rearranged sateen/satin.

Combined weaves are constructed on the basis of two or more fundamental weaves and their derivatives, which results in irregular or uneven fabric surface or small woven figures on the fabric. Commonly used combined weaves include crepe, honeycomb, and mock leno weaves, Bedford cords, simple spot figure designs, and stripe and check weave combinations. Crepe weaves give fabric the appearance of being covered by minute spots or seeds through several construction methods. Honeycomb weaves are a very special type of weave that can create a 3D cell-like structure for the fabric with excellent moisture and water absorbent properties. Mock leno weaves endow fabrics with an open structure and small holes or gaps similar to leno weave fabrics. By floating the ordinary weft or warp threads on the surface of the fabric in an order, spots or small figure designs can be created for decorative purposes. By combining two, three, or more weaves or weave variations in the warpwise or both the warp and weft directions, stripe and check effects form on the fabric surface.

Compound weaves are often referred to as a group of weaves that feature more than one layered structure to make multilayered, 3D, and other specialized types of woven fabrics. These fabrics are constructed with more than one system of warp and weft threads that are often arranged in different planes by forming two or more layers. Common types of woven fabrics fabricated with compound weaves are warp and weft backed, double, treble, gauze and leno, warp pile and weft pile fabrics, carpets, and other types of 3D fabrics. Figure 19.3 illustrates several compound weaves and structures for woven fabrics. Backing fabric is based on backed weaves, in which a second series of either weft or warp threads back single layer fabric in order to increase fabric weight and enhance warmth while maintaining a smooth surface. When double weaves are constructed, two layers of threads in which one is woven above the other and stitched together form double fabrics. There are three common types of double fabrics based on the stitching methods: self-stitched, center-stitched, and interchanging double fabrics. By using conventional or specialized weaving machines, different types of 3D woven fabrics can be manufactured. In general, 3D fabrics are produced in several layers. Solid, hollow, and shell structures have been developed in 3D woven fabrics. 3D solid woven fabrics are classified as having multilayer, orthogonal, and angle interlock architectures. They feature compound construction with different fabric thicknesses so as to provide better mechanical properties, such as fabric strength. A 3D hollow structure can be created with multiple layers of woven fabrics with even and uneven surfaces. The hollows can be triangular, rectangular, or cell shaped, which can improve the air permeability and thermal conductivity of fabrics. 3D shell woven fabrics are manufactured with a curved shell structure, which can maintain fiber continuity. Moreover, they can also feature spherical or cubic shells [15, 16].

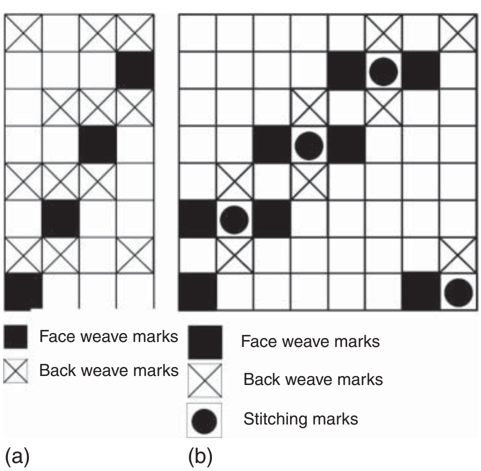

Figure 19.3 Compound weaves and structures. (a) Weft-backed weave. (b) Self-stitched double weave.

In addition to the fabric weave, there are other important structural parameters that have great impacts on the properties and appearance of woven fabrics. The main parameters are yarn linear density (count), fabric sett (density), cover factor, yarn crimp, and fabric weight (area density). The term "sett" is normally expressed as the number of threads per unit length (inches or cm) including the warp and weft densities, which are used to indicate the spacing of threads in a fabric. The cover factor is the fraction of the fabric area that is covered by the component warp or weft yarns. It shows the relative closeness of the yarns within the fabric by considering both the yarn count and fabric density. In a woven fabric, yarns are not straight, but in a wavy shape due to the interlacing of the warps with the wefts. This waviness of the yarn is called yarn crimp. The yarn crimp is an important parameter because it affects the property and appearance of fabric as well as the yarn length required for an intended fabric. Fabric weight is expressed in mass per square area, e.g. g/m^2 or oz/yd^2, which can be calculated based on the yarn linear density, fabric density, and yarn crimp.

19.2.3 Properties

The properties and appearance of woven fabrics depend on the fiber and yarn and their structure, which are commonly evaluated in terms of tensile strength and elongation, tearing strength, abrasion resistance, air permeability, fabric bow and skew, and fabric dimensional changes in accordance with ASTM, AATCC, or other testing method standards. Fabric tensile strength and tearing strength are crucial for the durability of garments, especially for finished woven fabrics such as denim fabric. Fabrics with a plain weave and its derivatives normally have maximum binding points with short yarn floats, which result in their high tensile strength but low tearing strength. Fabrics with a twill weave and its derivatives can be fabricated with more warps and wefts per unit area than those with a plain weave, so they have a higher thickness and density. There are many prominent diagonal wale lines on twill fabrics. Twill fabrics are usually durable with adequate tensile and tearing strength. Fabrics fabricated with a satin or sateen weave structure have fewer binding points and longer floating lengths, which can provide a smooth and luster surface. However, such a structure causes the yarns to more easily ravel and fray. In addition, satin/sateen fabrics have good ability to resist tearing but have low tensile strength [1, 7, 12, 16, 17].

19.2.4 Applications

As a primary type of fabric, wovens are widely used in daily life. Their applications include the three main areas of apparel, home furnishing, and technical products. Compared with knitted fabrics, woven fabrics have high stability and a tighter structure due to yarn interlacing that makes woven fabrics suitable for more formal garments. Plain weave fabrics can be made thick or thin and are widely used for shirts, blankets, canvases, and organza and chiffon fabric. Twill weave fabrics are mainly for the production of suits and jeans. Sateen or satin fabrics are usually found in evening and wedding dresses and for decorations. Besides, in order to meet the growing demand of customers for comfort and function in terms of fabric for home furnishing, more and more woven fabrics are applied in this area. Woven products include bedspreads, floor coverings, cushion covers, curtains, towels, sheets, pillowcases, etc. More complex structures are commonly employed in these types of textiles for the required thickness, color, and pattern.

Woven technical textiles are becoming universal today, which include those for medical use, sportswear, filtration, industrial use, protection, civil engineering applications, transport, and packaging and in geotextiles [1, 2, 12, 17]. Woven fabrics can be used as medical and biological textiles for hygienic and clinical purposes. The construction of such fabrics needs to be extremely stable and durable. For hygiene purposes, woven fabrics are commonly used in nappies, incontinence pads, or tampons. Besides, woven fabrics can be applied for protective and healthcare textiles, such as operation dresses and staff uniforms for doctors and nurses. Moreover, woven fabrics can be used as implantable materials, which are utilized as vascular grafts, sutures, and artificial limbs. In the latest developments, they are applied in extracorporeal devices that include artificial livers, kidneys, and lungs. Woven fabrics are the primary textile product used for automobiles since they have a highly stable structure and high mechanical resistance. They are usually applied in seat covers, headrests, door panels, and reinforcements. Woven fabrics are also commonly found in airbags with or without a coating. The purpose of airbags is to reduce the forward motion of passengers when an accident takes place in a split second. Therefore, the fabric used for airbags should be able to resist the force of the movement and have substantial strength. Woven technical textiles are usually used in sports applications. Waterproof and breathable fabrics are some of the popular fabrics in sportswear, which are mainly applied in outdoor apparel, especially for winter coats because not only can this prevent liquid penetration but also allow water vapor transfer to the outside environment and provide a comfortable temperature for the human body. This type of fabric is manufactured with a high fabric density or application of coating and laminating. Another important application of woven fabrics is as 3D fabrics, which are widely used as reinforcements and preforms for advanced textile composites due to their properties and shapes.

19.3 Knitting

19.3.1 Knitting Machines

Weft and warp knitting machines are two types of knitting machines used in the textile industry. The former is the most commonly used knitting machine due to the advantages of versatility, ability to quickly change patterns, requirement of little floor space, and low investment. The key components of weft knitting machines include knitting needles, needle bed, cam box, sinker, and yarn feeder. The needles are the main knitting element that is responsible for loop formation and subsequent interlooping with the help of the sinker. The sinker that is positioned in between the needles performs functions such as loop formation, holding down, and knocking over. The needle bed is a metal plate with a slot for needle insertion and movement. Cams provide the needles and other elements with a suitable reciprocating action for the knitting action. Weft knitting machines can be generally grouped into flat bed or circular bed machines in accordance with the needle bed arrangement. There are typically two types of flat needle beds that are organized in an inverted V formation. Latch needles are commonly used and placed in the grooves on the machine, which are also known as needle tricks. The machine gauge is normally 3–18 needles per inch. The yarn can change direction with each course on a flat bed machine, while the yarn runs continuously and horizontally in the same direction on a circular machine. In the circular machine, two sets of needles are arranged in a circular form at right angles to each other wherein one set is in the vertical and the other is in the horizontal. Latch, bearded, and occasionally compound needles can be used. By using the multiple yarn feeds, hundreds of yarns can be knitted in one rotation, so weft knitted fabric can be quickly produced. Single jersey, rib, interlock, and purl fabrics can be manufactured by using circular machines [18–23].

In terms of warp knitting, the yarns from the warp beam in the form of a parallel sheet are used to form fabric through loop formation. Each yarn is fed to an individual needle. During the same knitting cycle, every needle in the needle bar conducts the action of yarn feeding and loop forming simultaneously. A typical warp knitting machine consists of several functional elements, including needles and needle bar, presser bar, sinkers and sinker bar, guides and guide bars and warp beams. With regard to the production of warp knitted fabrics, there are two popular classes of warp knitting machines with one or two needle bars employed, which are called tricot and Raschel machines. In the tricot machine, bearded or compound needles and sinkers are normally used. Warp beams are positioned at the back of machine, and also, the guide bars are moved from the back to the front of machine in fabric knitting. Moreover, the machine gauge used in a tricot machine is high, which ranges from 28 to 40 needles per inch, and the machine speed can be up to 3500 courses per minute or even higher. Continuous filament yarns are commonly used in fabric production. Latch needles are generally used in Raschel machines, and sometimes, compound needles are now common for the production of warp knitted fabric. The warp beams are placed on the top of the machine, and the guide bars run from the front side toward the back side to knit warp knitted fabrics in overlapping and underlapping arrangements. Furthermore, the machine gauge is coarser from 12 to 32 needles per inch. The machine speed is lower compared with that of the tricot. More yarn guide bars need to be mounted on the machine. Besides, a wide range of yarns can be used, and various products can be manufactured [18–22].

19.3.2 Knitted Fabric Structures

By controlling the motion of the needle on a knitting machine, different types of knitted fabrics can be produced with different fabric structures. There are three fundamental knitting stitches for the production of weft knitted fabric: knit, tuck, and miss stitches. The majority of knitted fabrics are produced with the knit stitch. Knit stitches are a normal loop formed when a needle knocks over the old loop and receives a new yarn. Then, the loop formation is carried out by the old loop. The function of the needles is to rise to the clearing position, carry the yarn down, and then form the loop. In the formation of a tuck stitch, a needle receives the new loop but still grips the old loop, so there are two stitches on the needle. To form a tuck loop, a needle is only raised to the tuck position where the old loop is still on the latch of the needle. A miss stitch is also known as a float stitch, which is created when a needle that is holding the old loop fails to receive the new yarn and then feeds the yarn into the two nearest needle loops. The purpose of miss stitches is to reduce space widthwise and increase fabric stability [18].

Depending on whether a single knit stitch or a combination with other stitches is used, weft knitted structures can be created with different effects. Weft knitted structures can be mainly categorized as single or double jersey structures. Single jerseys are produced by using one set of needles of the machine, while double jerseys are made by using two sets of needles. Single plain jersey knitting is the simplest knitting construction in that all the loops can be knitted by using V-bed, circular, or fully fashion machines. Each loop has the same shape, which is formed on the face side of the fabric because only one set of needles is applied. The "technical face" of the fabric has a V-shape appearance while the Ω-shape appearance forms on the "technical back" of the fabric.

In the case where two set of needles are used for double jersey production, each set can produce their own loops on one side of fabric. Therefore, complicated structures with special effects can be easily constructed on double jersey machines. There are three basic structures and their derivatives, including rib, interlock, and purl. Rib structures are one of the common knitted structures in which loops are constructed in the opposite directions by using two sets of needles. The 1×1 rib is the simplest rib fabric wherein one wale of face loops is alternated with two wales of back loops. In the same way, more rib structures such as 2×2, 3×3, and 3×2 can be constructed. No curling problem may occur on the edge of fabric and fabric with a rib structure can acquire good elastic recovery. Furthermore, there are a variety of rib derivatives, such as tubular, cable, half Milano, and full Milano. Interlocking is fabricated by using both long and short needles. The row of interlocks comprises joining the two half gauge 1×1 ribs by interloping sinker loops. It has a perfectly balanced structure and the same appearance on both sides of the fabric, like the face of a single jersey. Moreover, it can be elongated to 30–40% in the crosswise direction. The interlock of 2×2, 3×3, and 4×4 can also be fabricated according to its basis.

In weft knitted jacquard fabrics, a diversity of colors and designs can be found on the fabric surface by selecting needles and colored yarns to knit for desired colors and figures. Jacquard fabric can be classified into two types: single jersey jacquard and double jacquard. In single jersey jacquard, a tie-in technique called "accordion" is used wherein specific needles are cleared to tuck the height. Consequently, the length of the floats can be minimized at the fabric back. By using one more set of needles to knit the back loop, the double jacquard can overcome the floats in a single jacquard. Moreover, it is commonly used to produce different types of backings, such as birdseye and twill backings [18, 22, 25].

Basic warp knitted structures are constructed by using warp knitting machines with only one yarn guide bar and one set of needle bar, including pillar stitches, half-tricot and variation, atlas, and double loop stitches. Pillar stitches are produced by feeding the same yarn on the same needle. They are usually used with other types of structures to produce fabric with particular effects. Half-tricot is the structure formed by alternatively feeding the same yarn on two adjacent needles. The basic half-tricot is in 1×1 lapping movement, and the loops are easily inclined because of the production with the single guide bar. The structures in the 2×1 and 3×1 lapping movement are common structures in half-tricot variation, which have a longer underlap space. The atlas structure is constructed where the yarn guide bar laps increasingly in the same direction for a minimum of two consecutive courses. In addition, double loop stitches are constructed by overlapping two needles for the mixing of the weft and warp loops [18, 25, 26].

Nowadays, warp knitting machines with two yarns guide bars are universal. Through the use of two guide bars, advanced fabric structures can be developed by combining two or more basic structures. The simplest structure of the advanced fabrics is the full tricot, which can be constructed with two half-tricots in symmetrical lapping movements. Besides, locknit and reverse locknit are the most commonly used structures for warp knitted fabrics, which are developed based on the half-tricot in 1×1 and 2×1 lapping movements, but the movement of the guide bars is reversed. Satin is the reverse structure with sharkskin that can be constructed by half-tricot and its variation in a 3×1 or 4×1 lapping movement. For queenscord, it is also composed of pillar stitches and half-tricot variation in a 3×1 or 4×1 lapping movement.

19.3.3 Properties

Modern knitted fabrics can be produced in a wide range of structures that endow the resultant fabrics with different properties. In general, knitted fabrics have high resilience and wrinkle resistance and are light in weight, better form fitting, soft, and comfortable. However, they may shrink easily after washing and pill after rubbing. Compared with weft knitted fabric, warp knitted fabric has less stretchability but better dimensional stability.

Usually, knitted fabrics have the distinct property of high stretchability and recovery. The 1×1 rib and 2×2 rib structures can provide substantial stretch. However, the stretch can be reduced by introducing horizontal linear yarns into the fabric structure. The recovery property means that when the fabric is stretched to a considerable length and then released, it will gradually return to its original form, which allows the fabric to extend in different directions – diagonal, vertical, and horizontal at the same time – and then the fabric recovers. Rib fabrics normally exhibit a much better recovery property than plain fabrics. In order to further enhance the fabric stretchability and recover property, elastomeric yarn elements under tension can be incorporated into the structure for elastic knitted fabrics.

Similar to the property of elastic recovery, wrinkle resistance is one of the characteristics of knitted fabrics. Generally, knitted fabrics are thicker, the yarns are more mobile in the fabric structure, and the yarn twist is lower compared to woven fabrics, which results in better wrinkle resistance of the knitted fabrics. It is also beneficial for garment production since it leads to ease-of-care garments.

In general, knitted fabrics offer good wear comfort that result from their high stretch properties for better conformability, good insulation property, and sweat transportation property.

The dimensional stability of fabric is its ability to resist permanent changes in its dimensions. Common knitted fabrics do not have a good performance in dimensional stability if they do not have any aftertreatment. Mostly, the dimensional changes of fabrics occur after the first laundering and drying cycle wherein the fabrics shrink or grow at different percentages lengthwise or widthwise. After several washing cycles, the knitted fabrics finally become steady. The dimensional stability of knitted fabric depends on the materials as well as the knitting structures. Interlock, double knit, and other fabrics with weft or warp inserted yarns are unusually more stable and exhibit less shrinkage. The dimensional stability of knitted fabric can be evaluated in accordance with ASTM and AATCC standards.

19.3.4 Applications

Knitted fabrics are widely applied for apparel and domestic products, such as T-shirts, sweaters, socks, stockings, panty hose, lingerie, sportswear, swimwear, sheets, and towels. In garment manufacturing, knitted fabrics are the second largest fabric type used for garments. In addition to traditional knitted fabrics, more specialized knitted fabrics are also developed for garments, including fleecy, raised, highly elastic, and plated fabrics. Nowadays, there is the rapid development of knitted fabrics applied in the technical textiles and composites. Based on the certain properties of knitted fabrics such as extensibility, moldability, openwork, and lightness, not only warp knitted fabrics but also weft knitted fabrics find more applications in these areas. With these two fabrics in different structures, many technical products can be manufactured by advanced knitting machines and techniques [18–21, 24–27].

Spacer fabrics have been developed for technical applications by using both warp and weft knitting technologies. Concerning the structure of space fabrics, two surface layers are interconnected by relatively thick monofilaments, which makes the fabric 3D, elastic, and compressible in the thickness direction. The main features of space knitted fabric include excellent compression elasticity and cushioning, high air permeability and thermal insulation, and good flexibility in surface design. The properties of the space fabric can be adjusted by varying three components: yarn material, fabric construction, and finishing. The space fabric can replace foam in shoes, bras, beds, and seats. The spacer fabrics also can be used for the manufacturing of mattresses for beds and tables.

Knitted fabric structures have the role of reinforcement in polymer composites. That is, warp and weft knitted fabrics with inlay yarns enhance the stiffness and strength of these composites. When inserted and warp stitch yarns are used to reinforce in-plane and through-thickness, this multiaxial warp knit increases the ability of fabric to conform to complex shapes and increases its tolerance to damage. Applications of these kinds of knitted fabric composites include bumper bars and door members for automobiles, rudder-tip fairings for passenger aircrafts, and aircraft radomes, helmets, and body armors.

With regard to medical applications, knitting technology is very flexible and versatile so that medical textile products and tubular fabrics for medical devices can be easily developed and produced through warp knitting. Also, the apparel worn by doctors and nurses in hospitals and clinics are normally produced by using knitting technology, such as their undershirts and socks. Most medical appliances such as artificial blood vessels, surgical meshes, and coverings of artificial heart valves are also made with weft and warp knitted fabrics in recent years. Moreover, the various types of bandages, surgical stockings, and certain parts of orthopedic equipment are produced with knitted fabrics as they have high extensibility. In addition, knitted fabrics can serve as important components of functional clothes. For example, spacer fabric is constructed as two layers – a top and a bottom layer that are kept apart by a pile layer, which has pile threads that allow elasticity. Thus the flexible structure of spacer fabrics means that they can be used as electric switches or pressure sensors when electrically conductive yarns are used to form the layers. These sensors can also be applied onto undershirts, trousers, and socks to fabricate functional clothing.

19.4 Nonwovens

19.4.1 Manufacture of Nonwovens

The basic steps for making a nonwoven fabric are first to form fibers into a web, which are then bonded and finally undergo the processes of drying, curing, and finishing, as shown in Figure 19.4. There are a variety of techniques that can be applied in the formation and bonding of a fiber web, which thus result in different fabric structures and properties. Web formation is the creation of a loosely joined sheet structure by laying down fibers through four basic techniques: drylaying, wetlaying, polymer laying, and other specialized techniques. Drylaying involves carding or airlaying of staple fibers. Carding blends and combs fibers into a web or batt, which can be parallel laid, that is, formed by feeding carded fiber layers parallel into a conveyor belt through carding machines, or random/cross laid, in which each fiber layer after carding is mounted at right angles to the main conveyor. The former results in a web with high strength and orientation in the machine direction but not in the cross direction. The latter results in a web with high strength in the cross direction but not oriented to the machine.

Airlaying allows isotropic web properties and is the aerodynamic formation of a fiber web, which involves feeding fibers into an airstream and then transported to a conveyor belt where the fibers are randomly deposited in the form of a web; thus the web is randomly oriented.

Wetlaying involves the use of a slurry of water and fibers or an aqueous suspension of fibers that are deposited into a perforated drum or a screen belt and then

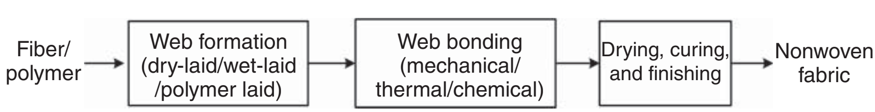

Figure 19.4 Basic steps for making a nonwoven fabric.

dewatered, dried, and cured with heat, much like the papermaking process. The fibers in the web are also randomly oriented. Wetlaying is appropriate for mass production at high speeds [28–34].

Direct or polymer laying means that nonwoven webs are produced from thermoplastic polymers in which they are spunlaid, meltblown, and electrospun. These are also known as direct laid webs, which are produced directly from filaments or short fibers during an extrusion spinning process. This method is one of the most cost-efficient ways of producing fabrics. In spunbonding, molten polymer is extruded through a spinneret, and the filament extruded is drawn into a specially designed aerodynamic device. The filaments formed are deposited onto a moving conveyor or screen drum, and then the web structure is formed. Following that is the web bonding and winding for making the fabrics. Polymers with high and broad molecular weight distribution are commonly applied for producing uniform spunbond webs, such as polypropylene, polyester, and polyamide. During the meltblowing process, molten polymer is extruded through a linear die, and then the extruded polymer streams are rapidly attenuated into extremely fine diameter fibers by using a high-velocity hot airstream. The attenuated fibers are subsequently transported toward a collector conveyor by high-velocity air blowing, thus creating a self-bonded meltblown web that consists of fine fibers. In electrospinning, the molten polymer or polymer solution is drawn from the tip of a capillary to a collector by using an electric field wherein the jet emerges from the charged surface and then electrical forces increases the polymer liquid to stretch the jet. This method is mainly used to produce nanofibers with diameters in the range of 40–2000 nm and their webs with appropriate polymer and solvent systems [30–32].

After the fiber web is formed, the bonding between fibers must be strengthened and stabilized by applying different bonding techniques [27]. These include chemical, mechanical, and thermal bonding, which are commonly used web bonding techniques with adhesives or application of heat and pressure. Mechanical bonding interlocks or entangles fibers in the web through needle punching or water jets, that is, through needle punching or hydroentangling, which are the most commonly used methods. During the needle punching process, the fiber web is fed into a space between a bottom bed plate and a top stripper plate. The barbed needles on a needle board punch the fed fiber web through the plates. Consequently, the fibers in the web are mechanically interlocked or bonded. The geometry and density of the needles are important because they greatly affect the properties of the final nonwoven fabric. In hydroentangling, the needles in needle punching are replaced with high-velocity water jets that entangle the fibers. In the production process, the fibrous web is fed onto a moving conveyor in the form of a flat bed or cylindrical surface. Then high-velocity water jets entangle the fiber web with turbulent water and fully bond the fibers. The de-energized water is then drawn through the permeable conveyor sleeve into the vacuum box for recycling and reuse [30, 33–35].

In chemical bonding, also known as adhesive bonding, adhesive binders are applied onto the fiber webs to hold and bond the fibers together through various techniques such as saturating, spraying, printing, and foaming. Following that, the water in the web is evaporated through drying, and the binders thus bond the fibers. There are a variety of binders available that not only bond the fibers but also affect the properties of the resultant nonwoven fabrics. For example, spray bonding adhesives can provide some strength but high bulk, while saturation bonding provides high rigidity and stiffness. Latex polymers have now become the most commonly used binder for the chemical bonding of nonwoven fabrics due to the widely available different varieties, their good versatility, ease of application, and cost effectiveness.

The thermal bonding process fuses thermoplastic components in the form of homofil fibers, powder, film, web, etc. by using a heat supply on fiber to fiber crossover points with calender rollers and oven and ultrasonic bonding machines. The function of heat is to cause the thermoplastic component to become viscous or to melt. Consequently, the polymer flows to the fiber-to-fiber crossover points to form bonding regions followed by cooling. Hot calender bonding applies heat energy to the fiber web by passing the web through the nip of a pair of heated rollers. During this process, area bonding or point bonding can be formed by varying the surface pattern of the rollers. The ultrasonic bonding process generates thermal energy and transfers this to well-defined, restricted areas in the web through a mechanical hammering action onto the web surface by using an ultrasonic horn.

19.4.2 Properties

Nonwoven fabrics can have a wide diversity of properties, which depend on the composition and fabric structure. The latter is determined by the methods used to produce the nonwoven fabrics, including web formation, bonding, and finishing. Moreover, these properties can instill and realize specific functions, such as absorbency, liquid repellence, resilience, stretchability, softness, or flame retardancy. These properties are usually combined for specific applications.

Needle punching that uses barbed needles to entangle fibers can produce very thick textiles for various applications. Thin fabrics that are lint-free and have an excellent soft hand feel and high in quality can be produced for medical textiles with hydroentanglement. Products made by thermal bonding can be relatively soft and textile-like, while chemical-bonded nonwoven fabrics can be used for low-cost carpets, scraps, and highly stiff products [30, 31, 35].

Spunbond fabrics are very popular nonwoven fabrics because they can provide particular properties that act somewhere like between paper and woven fabric. The diameter ranges between 15 and 35 μm, whereas the weight ranges typically between 10 and 200 g/m^2, which means such fabrics range from very light with a flexible structure to heavy with a stiff structure. They have planar isotropic properties due to a random web structure. These fabrics offer excellent chemical and physical stability, such as good tearing strength, shear resistance, fray and crease resistance, and high liquid retention capacity. Furthermore, they have a high strength-to-weight and strength-to-cost ratios. Meltblown fabrics have a random fibrous structure and are constructed by using microfibers with a fiber diameter that ranges between 2 and 7 μm. Their structure and constituted fibers endow meltblown fabrics with a high surface area and smooth surface texture that result in good insulation and filtering characteristics [30, 33].

19.4.3 Applications

Nonwoven fabrics can be endowed with a variety of chemical and physical properties and thus can be used to produce a spectrum of products that fit a wide range of applications. They can be used alone or as components of apparel, home furnishings, and healthcare and engineering products as disposable or durable products, depending on the application. Disposable nonwovens can only be used once or reused a few times, whereas durable nonwovens are made to be used for a longer period of time. General applications of disposable nonwovens include personal hygiene products, such as diapers and feminine hygiene products, or medical products, such as surgical gowns and drapes. The main applications of durable nonwovens cover a wide range of areas including hygiene products, wipes, medical and surgical products, protective clothing, interlinings and garments, upholstery, furniture and bedding, floor coverings, buildings and roofings, civil engineering products and geosynthetics, filters (gas and liquids), and automotive items. According to a report from the European Disposables and Nonwovens Association (EDANA), nonwovens are mostly used for hygiene products, followed by civil engineering products and building materials and then wipes [30, 35–37].

Around 33% of nonwoven textiles are used for hygiene products including diapers and feminine hygiene and adult incontinence products. There are two major characteristics of nonwovens that make them exceptional as absorbent hygiene material, which are their high bulk for absorbing and retaining a large amount of fluid at a low product cost and their lightness in weight prior to use. Spunbonded and thermal-bonded nonwovens are also widely used for hygiene products due to their favorable structural characteristics and comfort. They are also low in cost as well as environmentally friendly. Chemically bonded nonwovens are still used for sanitary napkins but have the disadvantages of causing discomfort and environmental problems.

In the nonwoven industry, nearly 15% of nonwovens are found in the wipes market due to their absorbency, versatility, uniformity, and durability that traditional wiping materials cannot compete. Some of the nonwoven wipes are developed for consumers, including those for personal care, babies, and household cleaning. They are convenient to use and dispose, provide exceptional performance, and are low in price, which are the key demands of customers. Then there are wipes for industry applications, such as food services and medical applications. Their disposability and low cost are key for their popularity. They are therefore found in different industry segments, including food services, factories and shops, automotive industry, and hospitals.

19.5 Braiding

19.5.1 Braiding Processes and Machines

Different kinds of braiding machines have been developed to produce different kinds of braids including 2D and 3D structurally braided fabrics. Maypole braiding machines are popular 2D braiding machines that consist of a carrier motion system, track plate, take-off, and other additional components. In carrier motion systems, the most important part is the carriers with bobbins that move following the track driven by horn gears. Bobbins are installed in the carrier, and the yarn length is adjusted by the carrier during the production process. The track that determines the path of the carriers can define the type and structure of the braid. A classical braiding machine has a base and a track plate wherein one, two, or more tracks can be used for producing flat, tubular, or other types of braids. The take-off mechanism is also important in a braiding machine because this determines the braided angle of the product, one of the most important parameters of braided structures, and thus significantly influence the properties of braids. In the Maypole braiding machines, there are two sets of yarn carriers that interlace and rotate yarn on a circular track at different preset angles. One set travels in the clockwise direction and the other set rotates in the anticlockwise direction. Consequently, two sets of yarns on the carriers are interlaced together at a biased angle to the machine axis to form braided fabrics. Then the produced braid is continuously moved forward by a take-up mechanism [38–40].

In the fabrication of 3D braids, the production principle is similar to that of 2D braiding, but the standing end yarns, also known as the core end, are an addition to the movable braiding threads. With the use of static yarns, they can be interlaced to the braids. There are four types of machines for producing 3D braids: circular, four-step, two-step, and 3D rotary braiding machines.

In the braiding process on circular braiding machine, the carriers with yarn bobbins move in two concentric orbits in the opposite directions. The braided yarns are intersected at a certain angle, and then the carriers change at the crossing point after one cycle of interlacing. Concerned on the machine in two-step process, the threads can move on the base plate only in two movement directions that move through the cross section formed by stationary standing ends. The productivity is high and efficient. Besides, 3D rotary braiding machines are universal and user friendly. There are mobile carriers on the base plate with horn gears in a square form. In the operation, each horn gear and carrier with bobbins can be shifted in different directions or stopped individually. Therefore, carriers with bobbins are free to move to any braiding point in the braiding area and also easy to move in a diagonal path. Thus, variable cross sections and scale over the length of the braid can be achieved [38–42].

19.5.2 Braided Structures and Properties

Braided structures can be classified as 2D or 3D. The former include two types of yarn intertwining configurations: biaxial and triaxial constructions. Biaxial constructions are the most commonly used braided structure wherein only two sets of yarns are interlaced together in a diagonal formation. In order to enhance the tensile and compression strength as well as modulus of the braid for its applications in fiber-reinforced composites, a third set of longitudinal yarns can be introduced to form the braid in a triaxial configuration, together with the biaxial interlaced yarns. The latter have multilayered interconnected structures and have been mainly developed through composite structures. Three dimensional braided structures can be produced by using the newly developed braiding machines that are computer controlled. Since they have thicker and 3D architectures, they can be fabricated with different cross sections. Commonly, 3D braids can be categorized as tubular or rectangular-shaped structures. In 3D tubular braids, the yarns not only move in helical clockwise and anticlockwise directions but also pass under and over each other in the tube wall thickness direction. Braided fabrics with rectangular-shaped structures are produced by using a rectangular loom [39, 40, 42, 43]. Compared with 2D braids, 3D braiding can produce complex near-net-shape preforms, and the resultant composites have better impact damage tolerance and delamination resistance.

The properties of braided fabrics depend on the interlacing patterns of the braided yarns. Commonly used patterns include diamond, regular, and Hercules stitches, which are similar to the 1/1 plain, 2/2 twill, and 3/3 twill weaves of woven fabrics, respectively. Depending on how the carriers and horn gear are arranged, various patterns can be created. Besides, the geometry of the braided structure is also important for the resultant braid properties, including the line, stitch, and braiding angle. When interlacing the yarns in the diagonal direction, there is a braiding angle, which is usually in the range of 30–80°. The braiding angle is the most critical geometrical parameter for the production of braided architectures.

The characteristics of braided fabrics rely on the type of braiding yarns and architecture of the braid. Normally, braids have good dimensional flexibility since they can be controlled shapewise. In addition, braids have good porosity, ability to resist shear, and strength. Braided composites exhibit good impact resistance, efficient reinforcement for parts where torsional loads are applied, improved interlaminar shear properties, and reduced manufacturing cost of composite structures.

19.5.3 Applications

Braided fabrics have mainly been applied in the fields of engineering, medicine, and automotive in the previous century. Braided fabrics feature greater burst strength and flex fatigue and appropriate for use as hydraulic and fuel hoses in cars, trucks, earth-moving equipment, marine engines, and aeroplanes. In recent years, they are widely employed for technical purposes, such as fiber-reinforced composites, medical implants, and sports applications [42, 43].

Compared with other composites, braided structure composites have a more stable structure with isotropic properties, outstanding strength, and crack resistance. Therefore, braids can be applied to reinforce composites. In aerospace applications, braided composites have been used as rocket nozzles, rotor blades for helicopters, helicopter drive shafts, missile casing, stator vanes, and composite ducting, Braided structures are also applied in the transportation and civil engineering field, including as ropes, cables, drive shafts, belts, hoses, and concrete and wall reinforcements. In recreation, braided composites are used in hockey sticks, baseball bats, tennis racquets, and sports bicycle frames.

Medical applications of braids include sutures, stents, scaffolds, braided pillar implants, artificial limbs, and cartilage. Since braided textile has excellent agility, pliability, and surgical ease of use, high tensile strength, and a silky smooth feel, it is very suitable for polyethylene sutures. The braiding technique can also be used for the fabrication of stents because this technique provides a versatile design for different applications. Moreover, braided fibrous scaffolds can serve as a base for tissue regeneration, so it is appropriately used as ligament scaffolds. In addition, the fracture resistance and longevity of braided structures mean that they can be used in dental posts for tooth restoration and repair [44].

In terms of sports, braided products can be used for lines in fishing since their structure can provide adequate toughness and abrasion resistance. Besides, polyester or polyethylene braided cords can be applied as archery strings for reinforcement. Furthermore, braided ropes can be manufactured for sail masts, which can maintain its stiffness and retain a constant diameter.

19.6 Future Trends

In the conversion of different materials to fabrics, various fabric making technologies including weaving, knitting, nonwoven manufacturing, and braiding are widely used in the production of fabrics for applications in apparel, furnishing, and technical textiles. With the advancement of materials, high-performance and functional fibers are now being realized and used to make fabrics that meet the demands for comfort, health, and safety as well as create aesthetics in fashion and domestic textiles and endow particular properties and functionalities in technical products. Fabric making technologies are continuously progressing, targeting to enhance fabric quality, advance production flexibility, increase productivity and automation, and enable environment-friendly processing as well as improving responses to consumer demands through innovations in machinery and optimization of the manufacturing process. It is clear that complex and functional fabrics will need to be further explored for technical applications since technical textiles are the fastest-growing sector in the textile and clothing industries. In order to accommodate this rapidly growing demand, advanced fabric making technologies and their produced fabrics will be further developed with advanced materials, machinery, and processes, such as manufacturing technologies for 3D woven, knitted, nonwoven, and braided fabrics, technologies for integrating different functions into fabrics, multiaxial warp knitting machines, and large braiding machines.

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