III. Yarn and Textile Substrate Formation

14. Yarn Formation

YARN FORMATION

Yarn formation methods were originally developed for spinning of natural fibers including cotton, linen, wool and silk. Since the overall physical characteristics of the fibers and processing factors needed differed from fiber to fiber, separate processing systems were developed. As synthetic fibers were introduced, synthetic spinning systems for texturized and untexturized cut staple were developed as modifications of existing staple systems, whereas spinning systems for texturized and untexturized filament were developed separately. Staple yarn formation involves multiple steps and can include: (1) fiber cleaning and opening (as needed for natural fibers); (2) fiber blending (to assure uniform mixing in natural fibers or in fiber blends); (3) carding (to align fibers and to remove short fibers); (4) combing (if highly aligned fibers are desired); (5) drawing and spinning (to reduced the denier of the yarn, to provide twist and to give cohesion to the yarn); and (6) doubling or plying and twisting of the yarns (as needed to provide greater uniformity). In recent years a number of staple spinning processes other than ring spinning have been developed that reduce or shorten the number of steps necessary for formation of yarns suitable for textile substrate formation and are discussed separately following conventional ring spinning techniques. Yarn preparation from fiber filaments is much less complex and often no or only limited twist is imparted prior to use in the textile substrate. The steps involved in yarn formation are outlined in Figure 14-1.

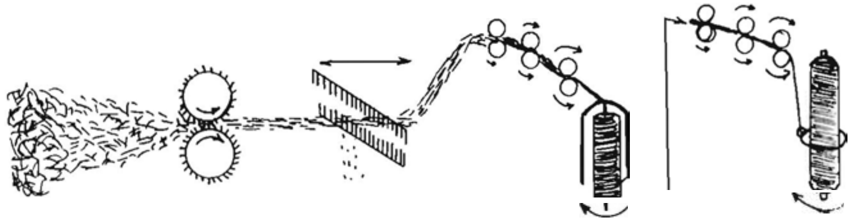

Figure 14-1. Spinning.

COTTON SYSTEM

When cotton bales arrive at the textile mill, they are highly compressed and have been ginned to remove seeds and some of the impurities present. On removing the cotton from the bales, the cotton is opened up, blended and mixed with cotton from other bales. During the opening and blending process, the fibers are separated and loosened from each other, trash is removed from the fibers, and the fibers are more randomly mixed to assure greater uniformity. Finally the fibers are formed into a thin partially oriented continuous web of intertwined fibers called a picker lap. The picker lap in turn undergoes carding to remove short fibers and remaining trash and to provide additional orientation to the fibers. Carding involves pulling, separating, and orienting the fibers by passing the lap between successive cylinders moving at different speeds and containing fine bent wire bristles that catch the fibers. The carded lap is removed by a doffer cylinder in the form of sliver (a rope-like fiber mass) and coiled into a rotating can. The sliver may undergo additional blending to improve its uniformity and density so that it may be more effectively drawn and spun into yarn. At this point, the sliver is suitable for drawing and spinning into medium and coarse yarns. Before drawing and spinning into fine yarns, the cotton sliver must first be combed to further straighten and orient the fibers and to remove additional short tangled fibers.

The drawing and spinning process involves passing the sliver between and through a series of rollers moving at progressively higher speeds to draw the sliver to a finer, more oriented, and uniform structure followed by twisting as the sliver is played onto a turning spindle. The drawing portion of the operation is referred to as the drafting process. The degree of twist will depend on the speed of the turning spindle with each complete turn of the spindle providing a single complete twist in the yarn. In the initial stages where little twist is present in the drawn sliver, the sliver is fed through a tube and onto the spindle. This process is called roving. Subsequent drawing and high speed twisting is carried out by ring spinning in which the drafted, lightly twisted sliver (roving) is fed from the drafting unit onto a high speed spindle via a traveller holding the spun yarn to a ring surrounding the reciprocating spindle. The traveller can move easily around the ring and provides a slight drag on the yarn as it is fed onto the spindle. Ring spinning proceeds at 5,000 to 10,000 revolutions per minute.

WOOLEN AND WORSTED SYSTEMS

Wool is spun into yarns by either the woolen or worsted system. The woolen spinning system is less complex than the worsted system and utilizes shorter wools of a wider range of lengths and diameters to give a low twist bulky yarn. The worsted system produces highly twisted fine yarns utilizing fine fibers of a narrow distribution of length and size. Fabrics made from woolen yarns tend to be bulky and contain more entrapped air; whereas fabrics from worsted yarns tend to be tightly woven and fine with a hard flat surface.

On arrival at the mill as bales, raw wool contains large amounts of grease, swint (salts from the body of the sheep), dirt, vegetable material and other impurities. The wool must be washed in successive baths of detergent solution to remove these impurities. The process is called scouring, and the weight of the raw wool can be reduced by as much as 50% by the scouring process. Wool grease (lanolin) is effectively recovered from the scouring liquor as a commercial product. Vegetable matter remaining in the wool can be removed by passing the wool through concentrated sulfuric acid to chemically destroy the cellulosic matter, a process called carborization. After washing and drying, the cleaned wool is blended and carded as described previously to form a sliver. At this point the sliver can be drawn and slightly twisted to form a roving which can then be spun into a woolen yarn. The sliver must undergo additional straightening, orientation, and removal of short fibers to be used in the worsted system. This process involves several successive steps including gilling (a form of pin orientation) and combing to give wool top. The wool top is drawn and slightly twisted in several stages to form a roving which is finally spun into a highly twisted worsted yarn.

OTHER STAPLE SYSTEMS

Other natural staple and synthetic fibers can be spun on cotton and wool systems if these systems are modified to take into account unique factors such as fiber length, crimp and linear density. Cut staple man-made fibers arrive in boxes at the mill and are ready for carding and processing into yarn. When two or more different staple fibers are mixed, it is critical to provide extensive blending before carding and repeated doubling of the sliver to assure intimate blending prior to roving and spinning. Other spinning methods that take fewer steps have been developed for staple spinning and are discussed under other yarn forming methods.

FILAMENT SYSTEMS

Filament spinning systems are much less complex because the fibers are continuous and do not need to be highly twisted to give a cohesive strong yarn. Filament yarn spinning usually involves man-made fibers and only the portion of the ring spinning system that involves twisting and winding onto spindles is used. Other methods are available to give cohesion to a filament yarn and are discussed under other yarn forming systems in the next section.

OTHER YARN-FORMING SYSTEMS

Since conventional ring spinning systems take several steps to reduce fibers to a spun yarn, several alternative techniques have been developed that reduce the number of these steps, Most of these processes have more limited usefulness with regard to the range of linear densities and type and distribution of fiber lengths that can be processed by these systems,

Open-End or Break Spinning

Open-end or break spinning systems have come into wide use for spinning of short and medium staple fibers directly from sliver to yarn in one step without carding or roving. Sliver is fed into a breaking or opening unit to separate the fibers from one another, and the fibers are then forced by air pressure into a hollow rotor rotating at high speeds (up to 50,000 rpm). The fibers are deposited by centrifugal force on the sides of the hollow rotor, and the resulting yarn is removed continuously by a stationary tube mounted within the rotor. The rotating rotor provides twist to the yarn and produces a yarn with somewhat greater higher pitch and bulk and somewhat lower strength than ring spun yarns. Open-end spinning operates at a rate up to five times that of ring spinning and can be effectively used for cotton, polyester-cotton blends, as well as other short and medium staple systems. Synthetic staple fibers such as polyester alone can not be effectively open end spun due to dusting of oligomer from the fibers that interferes with the spinning action of the rotor.

Friction Spinning

Friction spinning is a variation of the open-end spinning system and often referred to as the DREF system. In this system, one or more slivers are fed onto a rapidly rotating card drum which opens the sliver to form single fibers. The separated single fibers are blown from the card drum by a stream of air onto the junction of two parallel perforated drums turning in the same direction. The rotating perforated drums under suction cause the fibers to be compressed and twist around one another to form a uniform yarn which is continuously removed onto a spool. The resultant yarns are bulky and have properties similar to woolen yarns.

Air-Vortex Spinning

Air-vortex spinning is similar to open-end spinning but utilizes a stationary tube rather than a rotor. A high speed air vortex is created in the tube that deposits fibers within the tube and simultaneously provides twist due to the vortex. The yarn is continuously withdrawn as in the case of open end spinning.

Fasciated Spinning

In fasciated spinning long staple sliver without twist is introduced into a limited space and subjected to a torque jet operating at right angles to the flow of the sliver thereby imparting a false twist to the sliver. As the sliver exits the torque jet it rapidly untwists, and the outer fibers tend to break away from the sliver and wrap around the inner sliver to give a strong yarn consisting of mostly parallel fibers with some fibers tightly twisted around the outside.

Self-Twist Spinning

In self-twist spinning, two parallel slivers are fed between two reciprocating rollers which form identical left hand or right hand twists in each of the slivers alternating down the length of the sliver. The resulting false-twisted yarns are then brought together so that the right hand twist segment of one sliver is phased with the left hand twist of the other sliver. On relaxation, the slivers untwist over one another to form a stable yarn. The process was originally developed for spinning wool, but has been used extensively for acrylic yarns. In the related Selfil spinning method the self-twist yarn is wrapped by alternating phases of continuous filaments to form a highly stable wrapped yarn containing less than 10% filament.

Coverspun Spinning

Coverspun is both the name of a spinning system and a yarn. In this system staple rovings are drafted in a conventional manner, and then the roving is passed into a hollow vertical spindle. On the outside of the spindle a filament yarn, from a cylindrical spool rotating at 20,000 to 30,000 rpm, is fed into the top of the hollow vertical spindle with the roving. The rotating filament spindle causes the filament to wrap around the core of the staple to produce a wrapped yarn consisting of 80% to 95% staple. Polyester filaments are usually used to wrap pure yarns or blends of cotton, wool, nylon, and acrylic staple to form sewing threads or yarns for textile substrate production.

Integrated Composite Yarn Spinning

A composite yarn is formed by melt extruding fibers from a spinneret or by coating filaments with a molten polymer followed by coating the emerging fibers with short staple fibers. The resulting matrix is immediately twisted causing the staple fibers to imbed in the extruded fibers before cool ing. The resulting composite yarn is formed at a very rapid rate on the Bobtex spinning apparatus developed for this process.

Twist1ess Systems

In twist1ess systems liquid or powdered polymer adhesives are applied to sliver or filament tow and the adhesive activated by heating or steam to cause the individual fibers to adhere to one another. In some systems, after textile substrate formation from the twist1ess yarns the adhesive is removed to improve the aesthetics of the resulting textile. Adhesives used include polyvinyl acetate, polyvinyl alcohol. and starch.

15. Textile Substrate Formation

PREPARATION

Yarns often must undergo additional processing before they are ready for use in forming of a texti 1e substrate. The yarns may need to be rewound onto appropriate packages, reinforced by application of size, lubricated by appl ication of spinning oil, and/or drawn-in and tied into the machine used in fabric forming. The combined process used for size application and lubrication of warp yarns in weaving and warp-knitting is called slashing.

Winding

Winding processes involve movement of yarn from one package to another and often conversion of the overall size, shape and tightness of the packages. These processes also serve other important functions. Winding allows clearing of the yarn to eliminate thin spots, thick spots, knots, and other imperfections, and makes it possible to regulate tension within the package, combine or segment yarn packages, and prepare packages for dyeing prior to substrate formation. In shuttle weaving, it is necessary to prepare small packages referred to as quills or pirns that fit within the shuttle. The yarn is wound onto the pirn sequentially in such a way to assure steady and even release of yarn from the pirn during the weaving process.

Warping and Slashing

A specialized type of package formation is involved in preparing warp beams for weaving or warp knitting. A high degree of tension is placed on the warp during these processes, therefore the yarns must be lubricated to minimize friction between yarn and machine parts and adhesive must be applied to the yarn to strengthen and reduce the hairiness of the yarn. Warping involves winding yarns from several thousand packages placed on creels onto a flanged beam passing through a reed (a comb-like device). The reed maintains the yarns parallel to one another as they are wrapped onto the beam under as even a tension as possible. Warping of small sections of warp (tape warping) is also often carried out, and the tape warps are later placed parallel to one another to provide a full width warp for use in the loom or warp knitting machine.

Staple yarns and some filament yarns must undergo slashing. Slashing involves simultaneous application of sizing and lubricant to the warp from one bath called a size box, followed by drying to remove water or solvent, breaking the slashed warp yarns away from one another using least rods, and rewinding of the warp. Sizes and lubricants used on warps will vary with fiber type. Sizes used include starches and gums, cellulose derivatives such as carboxymethyl cellulose, proteins, polyvinyl alcohol, polyvinyl acetate. and acrylic copolymers, while the lubricants used are similar to spinning oils and include mineral and vegetable oils and waxes as well as derivatives of these materials.

Drawing-In and Tying-In

After warp beams are prepared, the warp yarns must be drawn through certain elements in the loom or warp knitting machine before fabric can be produced. This process in the past was carried out by hand using a special hooked wire to draw each yarn through the elements of the loom or wrap knitter followed by hand-knotting of the yarn to the corresponding yarn on the take-up warp beam. Machines are now primarily used to perform the function of drawing-in and tying-in at a high rate. Similar drawing-in of yarns for fill knitting and tufting is also necessary, but the process is not as complex as drawing-in a warp beam. In nonwoven formation, a sliver or a random or plied fiber web is used.

TEXTILE SUBSTRATE FORMATION

Textile substrates are formed from yarns or fiber webs by several techniques including weaving, knitting, tufting, and nonwoven formation. In addition, composites of textile substrates are formed by methods such as adhesive bonding, formation of back coatings on fabric substrates, and flocking. Weaving involves interlacing two sets of yarns usually at right angles to one another using a 100m. The warp yarns are fed into the loom and filling (weft) yarns inserted into the warp using a shuttle or an alternative insertion technique. Knitting involves interconnecting yarns by looping them around one another. In warp knitting the yarns in a warp beam are looped over adjacent yarns in a zig zag repeating pattern to form a fabric, while in fill (weft) knitting a fill yarn is formed into a series of loops that are passed through the loops previously formed in the fill direction. In tufting, yarns threaded through needles are punched through a backing fabric and the loops thus formed are held in place as the needles are withdrawn from the backing followed by formation of the next tuft in the same manner. In nonwoven formation, a fiber web or yarns are entangled or bonded to adjacent fibers through use of mechanical or chemical bonding techniques to make a continuous interconnected web. Composites of textile substrates are formed by bonding two fabrics together by use of an adhesive to form a bonded substrate or backed substrate or by application of cut fibers to an adhesive-coated substrate to form a flocked substrate.

WEAVING

Weaving has been traditionally conducted on looms using a shuttle carrying a package (pirn) containing fill (weft) yarn which inserts the fill yarn into the warp which has been drawn-in and tied-in to the 100m. In recent years, many shuttle looms have been replaced with shutt1e1ess systems particularly for simple fabric constructions. The shuttle 100m continues to be the most versatile weaving machine capable of weaving the widest range of yarns into fabric. The basic components of a loom are presented in Figure 15-1 .

The 100m functions in the following manner. The warp beam is connected to a let-off mechanism that meters the warp yarns off the beam as fill insertion proceeds. Each yarn in the warp passes through metal warp stop mechanisms that can detect broken warp yarns, through the eyes of hedd1es that are contained in the various harnesses used to lift the warp yarns, through the reed used to beat-up the filling yarn, and finally onto the take-up beam. Each warp yarn passes only through the eyes of hedd1es within harnesses that will be used to raise that particular warp yarn. The more harnesses that are used in raising and lowering the yarns, the more complex the weave that is possible. The pattern of the warp is determined by which of the harnesses each of the warp yarns is passed. The actual raising and lowering of the harnesses within the 100m is referred to as shedding, and the space between the separated warp yarns is called the shed. The harnesses are raised and lowered by use of cams or a dobby attachment or can also be raised and lowered individually by use of a Jacquard mechanism.

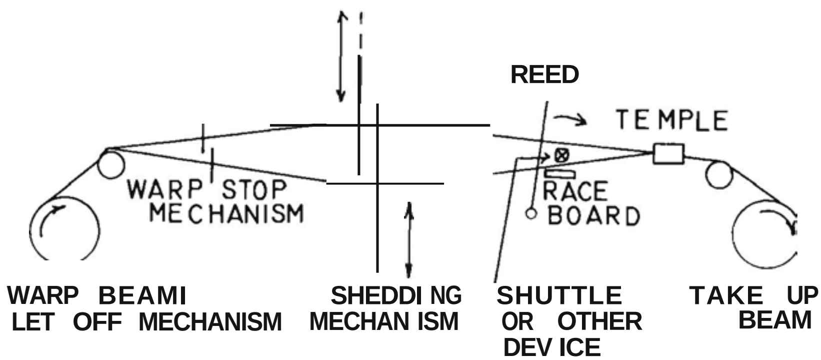

Figure 15-1. Basic components of a 100m.

The fill yarn is inserted at right angles to and through the shed by use of a shuttle or an alternative insertion mechanism by a process called picking. Below the insertion mechanism is the race board that helps provide support for the shed and the fill insertion area. The reed is placed between the open shed and the fill insertion area of the shed. After the fill yarn has been inserted, the reed is used to push the fill yarn tightly into place in the fabric by a process called beat-up. The temple provides uniform tension on the formed fabric to prevent loosening of the inserted fill yarns, and a take-up mechanism keeps proper tension on the fabric as it is formed and taken up. Therefore, the basic repeating sequence of actions in the loom is shedding to open the warp, picking to insert the fill yarn between the separated warp, and beat-up to push the fill tightly into place. The sequence must be carefully timed and synchronized to assure proper insertion. The ratio of fill insertion in shuttle loom varies from 75 to 300 picks per minute, while shuttleless insertion systems operate at 150 to 600 picks per minute. Fabrics woven from staple and filament yarns are found in Figures 15-2 and 15-3, respectively.

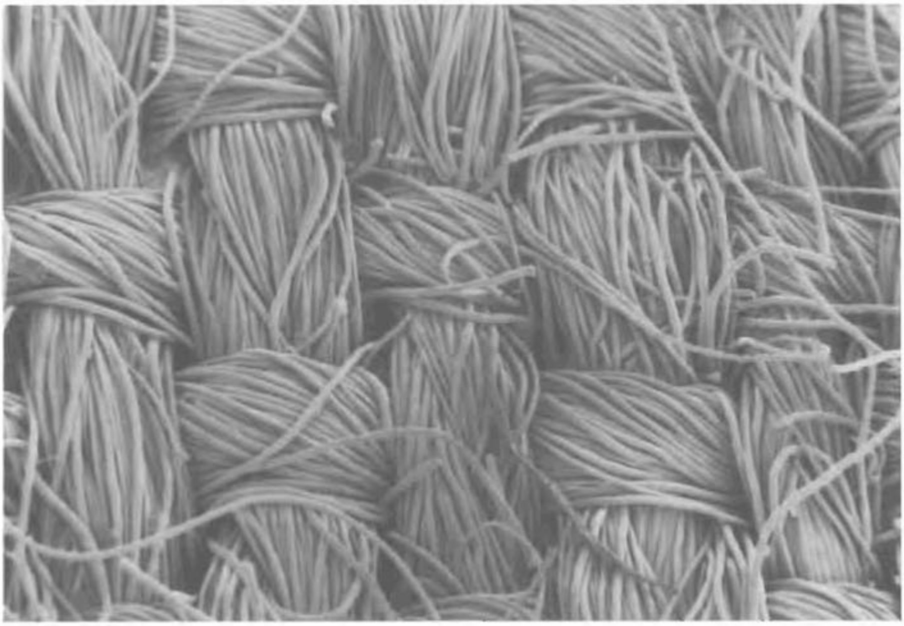

Figure 15-2. Woven staple fabric. x50.

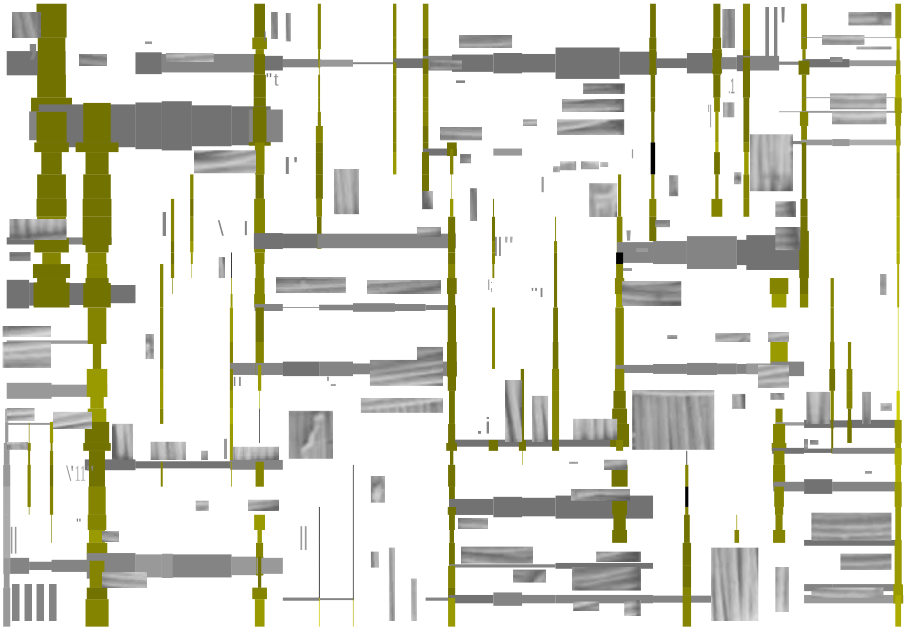

Figure 15-3. Woven filament fabric. x45.

Shedding Mechanisms

The cam system is most limiting in the complexity of weaves possible since only 8 to 10 harnesses can be effectively raised and lowered by this method. The cams are generally positioned below the harnesses and raise and lower the harnesses by use of mechanical tappets. For more complex weaves the dobby mechanism or the Jacquard system must be used.

The dobby mechanism is actually mounted on the side of the loom and is capable of raising as many as 20 to 28 harnesses. The dobby mechanism uses a slotted drum and continuous pattern chain containing patterns of pegs on each bar of the pattern chain to lift selected harnesses during shedding.

As a bar of the pattern chain is presented to the slotted drum, the pegs present on that bar enter and block the corresponding slots in the drum. In turn, this prevents hooks attached to the harnesses from entering the slots, engaging, and raising that harness. Where the slots are not occupied by pegs, the hooks attached to individual harnesses enter the slots, engage, and that harness is raised. When the next bar on the pattern chain is presented to the slotted drum, a new series of harnesses are raised depending on the pattern of pegs on that bar.

In the Jacquard system, each warp yarn is attached by an individual heddle to a draw string mounted above the loom and may be raised and lowered independently. The draw strings from the warp yarns pass parallel to each other through separate holes in a perforated board. A series of horizontal needles mounted above the perforated board are pressed against a continuous series of cards having a pattern of perforations. Each cord is in turn attached to a rod that passes through the eye of one of these needles. The upper ends of these rods are hooked and rest over a series of bars called griffes. Where the card has a perforation the needle passes through the perforation, the hook for that warp remains on the bar, and as the bar is raised the warp yarn is lifted. Where no perforation is present, the hook is disengaged and the warp yarn is not lifted. By this method extremely complex and intricate patterns can be developed. Due to the complexity of the mechanism, the weaving rate is much slower with Jacquard than with dobby or cam mechanisms.

Fill Insertion

Until recent years fill (weft) insertion was carried out by traverse of a shuttle containing a package of fill (pirn) within the shed back and forth across the width of the warp. As a result, fabrics produced by shuttle weaving have a selvedge (edge) in which the fill turns in a U at the edge of the fabric to return as the next row of fill in the fabric. Different filling yarns can be inserted by use of multiple shuttles in a magazine arrangement. Because movement of the shuttle back and forth across the fabric is necessary in a shuttle 100m, a mechanism for projection (picking) and checking of the shuttle at both sides of the loom is required. The picking stick strikes the shuttle to provide the force necessary to accelerate the shuttle to sufficient velocity to rapidly travel across the width of the loom (picking). As the shuttle nears the other side of the loom, damping mechanisms slow or decelerate and ultimately stop the shuttle (checking), so that it is ready for rapid return across the loom width. The picking and checking action of a conventional loom requires large amounts of energy, and a high degree of vibration is inherent in shuttle systems. In order to minimize energy consumption and machine vibration and to increase the rate of fill insertion, a number of shuttleless systems of fill insertion have been developed. Although these systems are not as versatile as shuttle fill insertion, the improved efficiency and reduced noise levels of these insertion methods make them quite suitable for weaving of less complex weaves. Ultimately, shuttleless systems are expected to be used in production of 80% of all woven fabric.

The shuttleless systems can be divided into two major categories, mechanical systems and fluid systems. Mechanical systems include the use of grippers or rapiers (single and double), while fluid systems use an air jet or water jet. The major fill insert methods are presented in Figure 15-4. The shuttleless systems all insert individual premeasured lengths of fill yarn. Therefore a fill package does not have to be carried across the shed thereby greatly reducing the energy required for fill insertion. The premeasured fill is generally only introduced from one side of the 100m, and a traditional stable selvedge with the fill yarn turning back on itself is not produced. The edge of the fabric produced by the shuttleless systems is normally fringed. However, the fringed selvedge can be reinforced by use of a higher density of warp yarns at the selvedge or by attachments producing tucking-in of the selvedge or a leno selvedge. In shuttleless looms, the fill yarn is usually premeasured and cut and held in place by a vacuum tube or on a storage drum prior to insertion.

The gripper system is most closely related to the shuttle system. The gripper is fired as a projectile across the width of the 100m carrying a single length of fill. The gripper is much smaller and 1ighter than a shuttle, since it does not need to carry a fill package. Multiple grippers are used, and a gripper after insertion of fill yarn is returned by a conveyor system back across the 100m. A multiphase gripper system is also used in which a series of grippers each carrying fill yarns are conveyed across that loom in sequence by use of a magnetic or mechanical drive mechanism. This method must use phased shedding and beat-up motions to permit simultaneous movement of several grippers across the face of the 100m. Although the velocity of the multiple grippers across the loom is much slower than use of a single gripper, the composite rate of fill insertion is much faster than more conventional looms.

In the rapier systems, the fill yarn is carried across the warp by a single or two mechanical arms. The rapiers must be removed from the shed prior to beat-up. In the single rapier system the end of the arm contains a clip to hold the fill yarn that releases the yarn after the fill yarn is completely inserted. In the double rapier system, one arm equipped with a clip (giver) conveys the yarn to the middle of the shed, and the taker on the other arm simultaneously is inserted from the other side and takes the yarn across the rest of the shed. Since rigid rapiers effectively double the width of the loom, flexible rapiers that uncoil on fill insertion have been developed that reduce the loom width.

SHUTTLE

Figure 15-4. Fill insertion methods in weaving.

Fluid fill insertion systems do not use a device to carry the fill yarn across the loom. They operate by impinging sonic velocity water or air jets onto the end of the yarn which accelerates and carries the yarn across the loom. Since liquid water is more cohesive than air and the energy conferred to the water is not as readily dissipated as the energy conferred to air, the water jet is capable of conveying the fill yarn greater distances than an air jet. The major disadvantage of water jet fill insertion methods is related to the hydrophilic character of the water and its ability to dissolve many sizes and to wet out hydrophilic fibers. Therefore, water jets can only be effectively used on hydrophobic fibers such as polyester that are unsized filaments or that contain sizings unaffected by water. To enhance the projection distance of air jet systems, guides are mounted across the loom that are inserted through the warp during fill insertion to provide a turbulence-free path across the loom. Also booster jets are often mounted periodically across the loom and fired sequentially as the fill yarn is inserted to assist in carrying the yarn across the width of the loom.

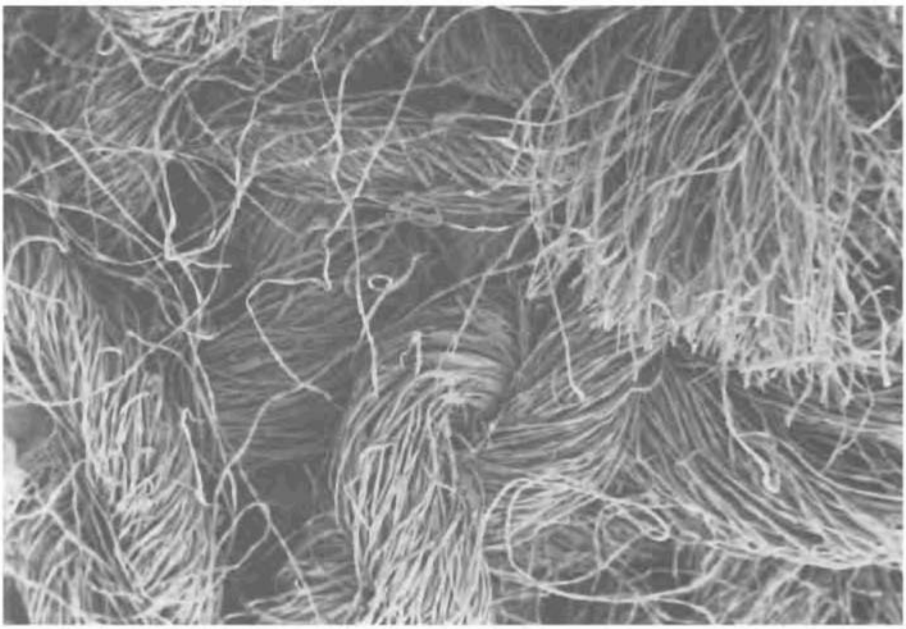

Figure 15-5. Loop pile woven staple fabric. x30.

Special Weaving Methods

When pile type fabrics are produced on a loom an additional warp is necessary. The tension on one of the warps is released before beat-up permitting warp loops to be formed. Also, two warps can be used to weave a double fabric with yarns connecting the two fabric sections. When these yarns are cut, two cut pile fabric pieces are then formed. A looped pile and sheared pile-woven fabric are found in Figures 15-5 and 15-6. Carpets can be woven on looms using more than one warp and a complex fill insertion system. The loops formed in the warp direction are held in place by wires inserted through them from the sides of the loom until the loop is firmly locked in place by the weaving of the backing and then removed. Carpet looms are very complex and carpet formation is very slow. Therefore, most carpeting is produced by tufting.

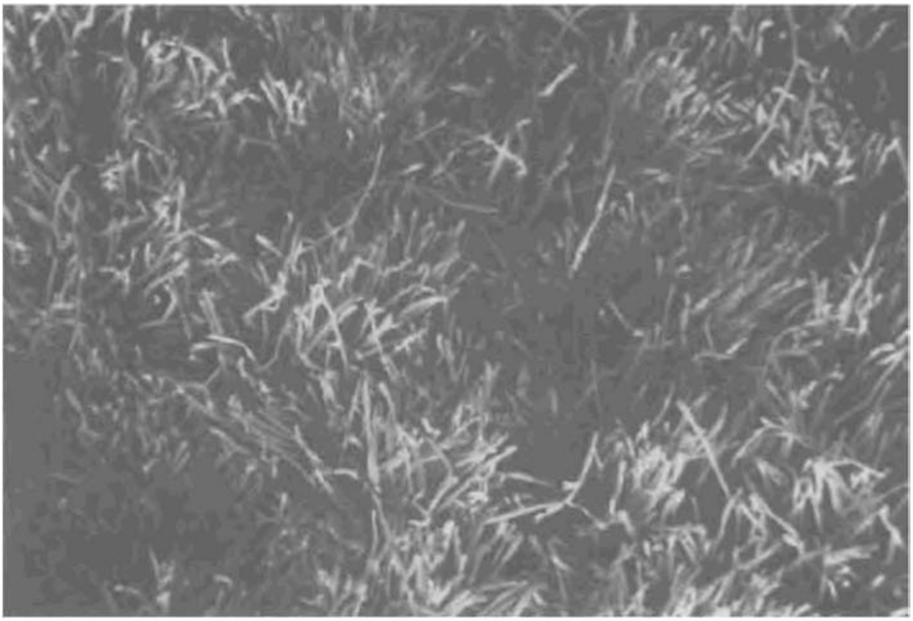

Figure 15-6. Sheared pile woven staple fabric. x40.

Very stable fabric structures can be produced by bringing two warp yarns into the loom at 60° angles to one another and inserting fill in the normal fashion to form a triaxial fabric.

KNITTING

Knitted fabrics are formed by use of hooked needles to interconnect loops of yarn to form a pattern. The needles used are one of three types, bearded, latch, or compound. The hooked needles pull the yarn through a previously formed loop and must close as they pass through the loop and use different closing mechanisms depending on needle type. The bearded needle uses a presser bar to close the needle, while the latch on a latch needle is closed by the loop of yarn it passes through. Compound needles are opened and closed by a programmed mechanism such as a cam mounted near the base (butt) of the needle. These types of needles are used for both warp and fill knitting. In warp and fill knitted structures the row of loops running horizontally across the fabric are referred to as courses, whereas the rows of loops running vertically up the fabric are called wales. Examples of a warp and fill knit are found in Figures 15-7 and 15-8.

Figure 15-7. Warp knit. x30.

Figure 15-8. Fill knit. x30.

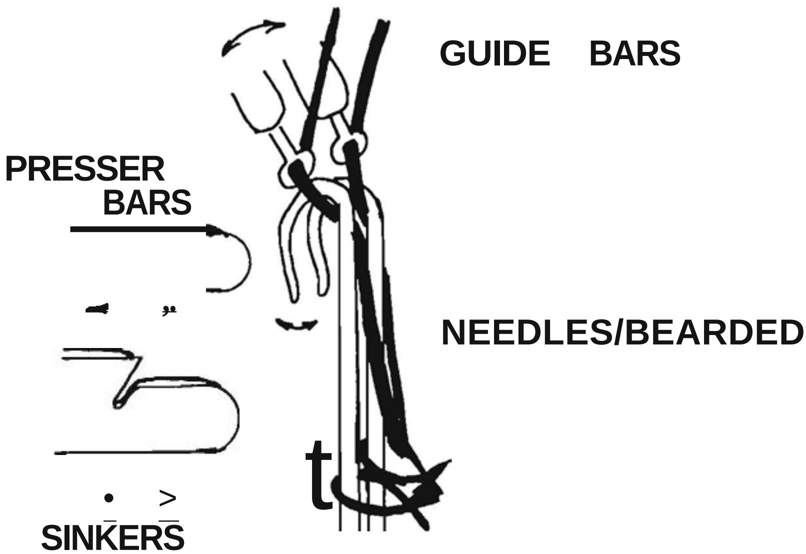

Figure 15-9. Basic elements of a warp knitting machine.

Warp Knitting

Warp knitting is the knitting method most related to weaving. Warp knitting uses a warp beam prepared in the same way as for weaving. The warp is fed into the warp knitting machine, and finished warp fabric is taken up in much the same fashion found on a loom. The actual mechanism of fabric formation is quite different, however. The basic elements and motions of one element of a warp knitting machine are found in Figure 15-9. In a warp knitting machine, there are one or more warp yarns per needle in the machine and each warp yarn is attached to and passes through the eye of an individual guide bar that is used to position the yarn for knitting and to move the yarn from needle to needle to give the characteristic zig-zag pattern of loops running vertically up the warp knitted fabric. The needles are either bearded, latched or compound and individually mounted vertically in a horizontal row attached to a straight bar. The guide bars are mounted in front of the horizontal row of needles and move back and forth in concert in predetermined patterns to present the yarns to the appropriate needles for knitting. The more warp yarns per available needle, the more complex a knitted structure that is possible. In forming fabric the guide bars wrap the warp yarns across the faces of the individual needles. The needles then close by the mechanism appropriate to that type needle and the yarns are drawn down through the loops formed in the previous cycle. The needles then move back up into their original position and open to receive the next yarn or yarns. Sinkers are used to hold the loops taut and in place, while the guide bars introduce the yarns to the needles. In general, the simplest warp knitting machines use bearded needles and limited guide bars per needle to form tricot fabrics. In these machines a presser bar is mounted parallel to the needle bar to close the needles as the warp yarns are drawn through the set of loops formed in the previous cycle. The more complex Raschel, Milanese and Simplex machines are capable of more extensive patterning and use latched or compound needles. The production speed and efficiency of warp knitting machines is very high and represents the fastest means of converting filament yarn into fabric. Warp knitted fabrics can be stabilized by introduction of warp and/or fill yarns into the warp knit structure during knitting. Pile or terry fabrics are produced by introduction of tow into the knitted structure followed by cutting to form a pile or by use of multiple warp yarns to introduce terry loops, respectively.

Fill (Weft) Knitting

Fill (weft) knitting involves insertion of a filling yarn into the knitted structure by drawing the fill yarn as a successive row of loops through the previously knitted loop structure to form a new course of loops running across the knitted structure. The yarn may be fed back and forth across the knitted fabric to form a flat fabric or successive yarns may be laid in the same direction spaced behind each other to form a tubular fabric. The basic elements of a segment of a fill knitting machine are presented in Figure 15-10. In fill knitting the needles operate in a sequenced sine-shaped wave. After the needle takes the yarn, it starts down through the previously made loop and the needle closes by the process appropriate to the needle type. After the needle with yarn passes completely through the previous loop, the needle opens, releases the newly made loop and moves upward through the loop to begin the process again. It is possible to program individual needles within the fill knitter to go through the full knitting cycle, or go through a partial knitting cycle in which the knitting needle does not fully clear the previous loop (a tuck stitch), or does not go through the knitting cycle at all (float or miss stitch). Such programming is carried out by use of cams or pattern wheels that interact with patterns of tabs or indentations on the butt of the knitting needle. More complex programming of patterns is possible when multiple needle systems are used in conjuction with slot, pin and blade, multiple disk, or punched card and tape mechanisms referred to as Jacquard mechanisms. Multiple needle systems are mounted in parallel rows 60 to goo out of plane to one another. Such multiple systems also can be used without complex Jacquard programming to simultaneously form double sets of loops in knitting to form ribbed and interlock knitted fabrics depending on the gauging of the needles in relation to each other. Fashioning or shaping of the knitted tube formed is al so possible by programming of the number and which individual needles are used within each row of courses formed or through movement of loops from one needle to another before the next row of knitted loops are formed. As in the case of warp knitting, fill knitting can be used to form tufted or pile fabrics or additional warp or fill yarns can be laid into the structure to provide additional stabil ity.

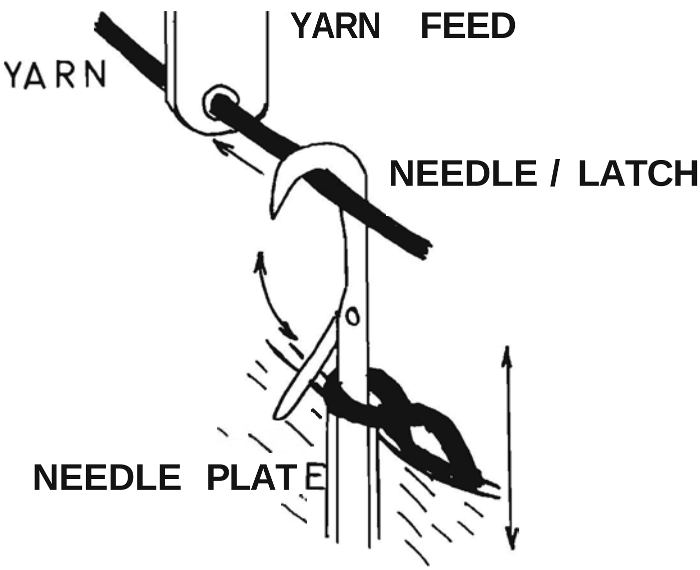

Figure 15-10. Basic elements of a fill knitting machine.

TUFTING AND PILE FORMATION

Tufting is a rapid process for formation of continuous rows of yarn loops across the face of a textile backing substrate. The yarn loops on the tufted substrate then can be cut or sheared to form a cut pile if desired. As mentioned earlier, woven and knitted pile substrates can be formed by introduction of additional yarns into woven and knitted structures. Pile substrates can also be formed by nonwoven and composite forming processes and are discussed below. Because of its high efficiency, today 95% of carpets are formed by the tufting process.

In tufting, a woven or film primary backing material is passed under a row of tufting needles each carrying a yarn. The needles penetrate the backing to form a loop which is held in place as the needle is withdrawn through the backing. Subsequent loops are made in the same manner to form continuous rows of tufted loops on the substrate. After the loops are formed all or some of the tufted loops may be cut by special cutting devices. After the tufted yarn has been inserted into the backing, a layer of adhesive must be applied to the back side of the tufted structure to mechanically fix the tufted yarns in place. Often a secondary backing in the form of a textile substrate is placed and fixed by adhesive over the back side of the yarns or a rubber coating or a rubber or polyurethane foam backing is applied to the back of the tufted substrate. The basic elements of the tufting process are found in Figure 15-11.

The primary and secondary backings used for carpets until recently were woven jute; however, polyolefin and polyester films and coarse woven polyolefin slit film filaments have been increasingly used as backing materials. Nylon yarns account for over 70% of the yarns used to form the tufted face of the substrate, with polyester, polypropylene, acrylic, modacrylic, and wool yarns being used to lesser extents. Nylon dominates the tufted carpet market due to its overall toughness and resiliency. Tufting leads to a wide range of looped pile and cut pile carpet substrates with the number of tufts per unit area, the length of loops or pile, and the fiber type affecting the nature and performance of the carpet.

The tufting process utilizes a large quantity of yarn that is not seen in the finished product, namely the segments of yarn on the backside of the primary backing. Several alternative processes have been developed to minimize this problem, although tufting remains the primary method used. In the alternative processes either premeasured lengths of yarn are forced through a tightly woven fabric backing and then fixed with adhesive or adhesive is applied to the face of the backing substrate and pile is fixed into the adhesive layer on the face of the substrate. Such techniques are limited to the production of cut pile substrates. Flocking is a related method for forming a pile or fuzzy surface on a fabric substrate. In flocking, adhesive is applied to a fabric substrate and then cut fibers or yarns are fixed to the adhesive using mechanical or electrostatic methods to orient the pile vertical to the fabric substrate.

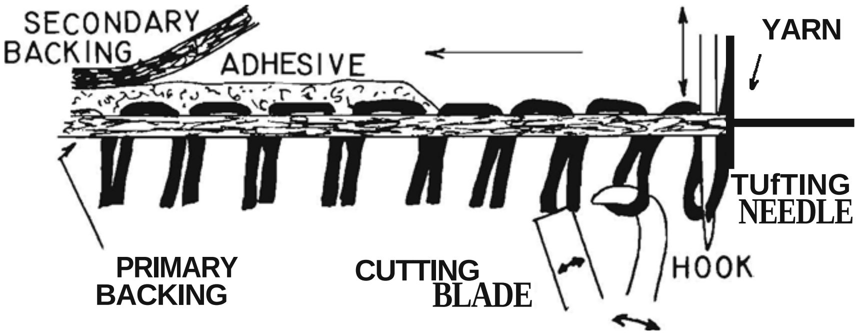

Figure 15-11. Basic elements of a tufting machine.

NONWOVEN FORMATION

Nonwoven textile substrates can be formed through entanglement and/or bonding of fibers in the form of webs or yarns by various chemical and mechanical means. Such methods used to form nonwovens minimize greatly the number of steps required to go from the fiber to the finished substrate and greatly reduce the cost of production of the substrate. The strength, flexibility, and utility of the resulting nonwoven substrate is generally less than that of a similar woven or knitted substrate. Therefore, nonwoven fabrics have been used little in apparel other than in interfacing or as felts. but have found extensive use in medical, industrial, and home furnishing applications. Examples of a nonwoven felt and an adhesive-bonded nonwoven are found in Figures 15-12 and 15-13.

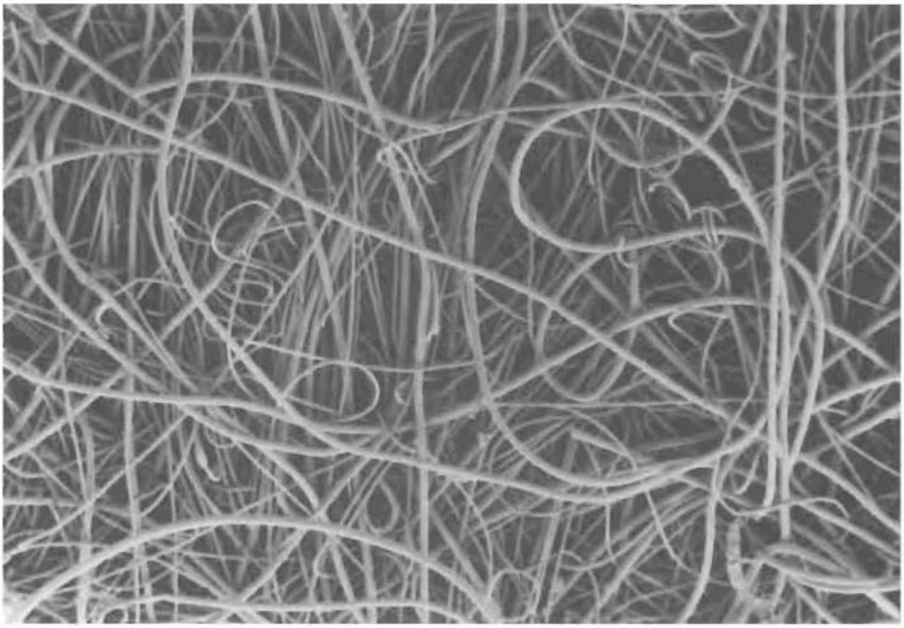

Figure 15-12. Nonwoven felt. x35.

The fiber web or in some cases films or yarns used in nonwoven formation are prepared by conventional processes. Web formation is carried out by carding, garnetting, air laying, or wet laying of staple fibers. The web can also be formed by direct laying of extruded filaments onto a moving belt or through extrusion of a film followed by slitting or embossing and stretching. The webs are laid in a random or oriented fashion with oriented webs being parallel, plated, or crosslaid, in one or more plies. The webs or in selected cases yarns are entangled or are bonded together by four basic processes: mechanical entanglement, stitching, self-bonding, and adhesive bonding.

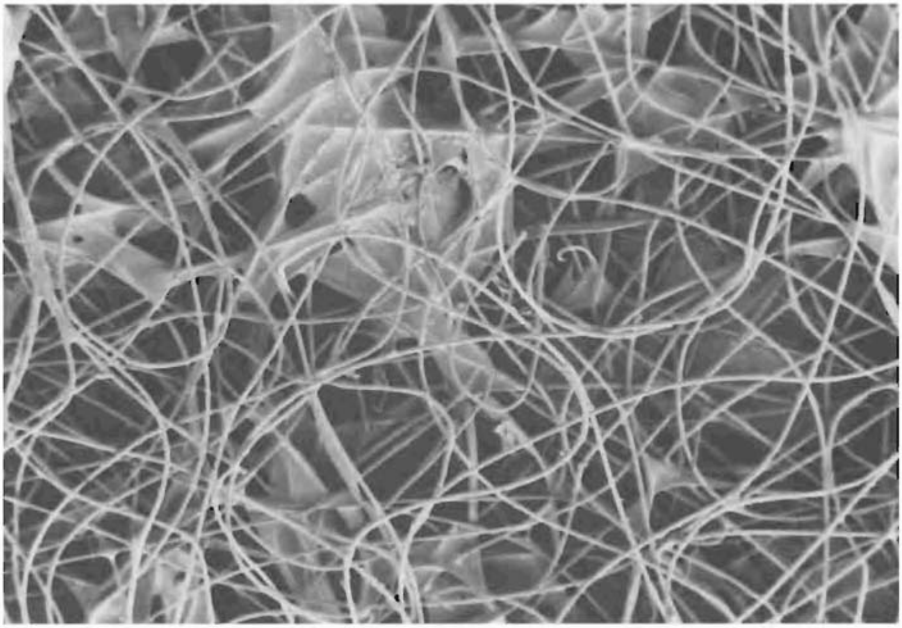

Figure 15-13. Nonwoven adhesive bonded material. x35.

Mechanical Bonding or Entanglement of Nonwovens

A number of processes exist for mechanically entangling or bonding a web to form a nonwoven substrate. One method that is mechanical in nature does not involve a web but rather splitting of a polyolefin film. In this process a film is extruded followed by either a discontinuous pattern cut by knife slitting or by embossing the film followed by biaxial orientation to form a network structure.

Methods that involve mechanical bonding or entangling of fiber web include wet laying, felting, needling, and air or water jet techniques. Wet laying essentially uses the process used for making paper. A slurry of short staple fibers in water or solvent is continuously laid onto a moving wire screen. The water or solvent remaining in the fiber mass that does not fall through the screen is removed by squeeze rolls and subsequent drying to form a randomly oriented nonwoven substrate. The strength of the wet laid nonwoven can be increased by adding chemicals or binders to the slurry during the process. Felting of a fiber web involves the entanglement of fibers in such a way that the fibers "ratchet" on one another and make the web more dense. This can be accomplished by use of the natural felting action of scaled keratin fibers such as wool in the presence of moisture and mechanical action or by heat-induced shrinkage of fibers like polyester accompanied by mechanical action. Needle punching of a web involves passing the web between bands of needles which continuously punch through and withdraw from the web. The needles have reverse barbs and cause reorientation of some fibers in the web and complex entanglement of the web in the vertical as well as horizontal direction. Needle punching from both sides of the web will provide a stronger substrate. Water jets or air jets can also be used to entangle a web. The fiber web is passed under a series of high velocity water jets or air jets that are programmed to deliver short bursts of water or air at intervals. The jets disrupt the web and form bonds through mechanical entanglement of fibers in the web. In general, mechanical bonding and entanglement methods give soft drapable fabrics of low to moderate mechanical strength.

Stitching or Stitch Bonding

Yarns or fiber webs are bonded together by stitching the webs together by a series of needles that operate very similarly to conventional warp knitting machines. Therefore guide bars must be used as part of the mechanism to interconnect the threads being sewed into the yarns or web being fed into the machine. Stitch-bonded fabric substrates are usually made using filament thread to form a reasonably strong but quite flexible structure. Yarns and webs can also be crosslaid in these stitch-bonded processes. The processes operate at very high operating speeds using inexpensive yarns or webs with fabric substrate being formed at 50 to 200 meters/hr.

Stitch bonding of yarns is usually carried out on Malimo machines, whereas web stitching is carried out on Maliwatt or Arachne machines. Pile stitching machines such as Malipol, Araloop, and Locstitch have also been developed for formation of pile fabrics.

Self Bonding

Techniques have been developed to bond thermoplastic fibers to each other by use of heat and/or solvent. In some cases, low levels of binder are added to the substrate prior to bond formation to assure a higher level of bonding. Spunbonding is the most widely used of these techniques. In spunbonding, a web of continuous filament thermoplastic fibers, such as polyester and polyolefin are extruded and randomly laid onto a moving conveyor belt and then subjected to heat and pressure between embossed rolls to form periodic bonds between fibers in the web. The flexibility of the web formed by spunbonding is determined by both the density of the web and the number of bonding points per unit area. Melding involves use of specially prepared web of sheath/core filaments that can be subsequently bonded by use of heat. The sheath/core fibers have a lower melting polymer substrate making up the sheath than contained in the core. Passing the web between embossed rolls under pressure held at a temperature above the softening point of the sheath polymer, causes the fibers in the web to be bonded at crossover points in the structure. Since the cores of the fibers are unaffected by the treatment, the resulting bonded web is quite strong. A third method, called gel bonding, involves use of a solvent applied to the fiber web. Solvent is metered onto the fiber web causing softening and gelation of the fiber web, and the web is then passed through embossed pressure rollers. The gelled surfaces of the fibers merge at crossover points and on solvent removal by heating form a bond between fibers. The above processes form fabric substrates of moderate stiffness.

Adhesive Bonding

Application of adhesive to the fiber web followed by pressure and heating to cure the binder and bond the fibers in the web to one another is another extensively used method of nonwoven formation particularly for non-thermoplastic fibers such as cellulosics. The adhesive is applied as a solution, suspension, or emulsion to the fiber web by padding, spraying, or printing or by appl ication as a foam. The adhesives used are usually thermosetting or thermoplastic (hot melt) adhesives. After application the web is subjected to heat to drive off solvent (usually water) and to melt and soften a thermoplastic adhesive or to cause reaction or curing of a thermoset adhesive. The adhesive, on curing, tends to concentrate at the fiber crossover points due to capillary action. Nonwoven formation by adhesive bonding tends to form moderate to stiff substrates with the degree of stiffness being dependent on the nature and density of the fiber web, the type and concentration of adhesive used, and the number of bonds per unit area.

COMPOSITE FORMATION

Flexible composite textile substrates are formed by either coating textile substrates with a continuous polymer layer or lamination of two or more textile substrates together by use of an adhesive polymer layer. The polymer coating can be applied neat, from solution, as an emulsion, or in the form of a film or thin foam. Inflexible fiber-polymer composite substrates are formed by imbedding fibers, fiber webs, fiber tows, or fabrics in a stiff polymer matrix. Inflexible composites have found extensive use in engineering and aerospace applications particularly where high performance properties are important. Owing to their inflexibility, they lose any properties characteristic of textile substrates.

In order to get a good bond between the fabric substrate and the polymer coating in laminated and coated fabrics it is essential to get a good adhesive bond between the textile substrate and the coating or adhesive. This is particularly important since the substrate and polymer may have very different stretch and recovery properties. Adhesive failure under stress is the most probable cause of failure in these materials. In coated fabrics, elastomeric properties are necessary to achieve a serviceable coated substrate.

In coated substrates, the polymer coating is metered and spread evenly onto the fabric surface as a controlled viscosity solution, aqueous emulsion, or hot melt polymer followed by drying and curing if needed. A urethane foam can be bonded to a textile substrate, by carefully melting the foam surface with a flame and joining the melted foam surface to the textile substrate under pressure followed by cooling. Laminated fabrics are bonded under similar conditions except that two fabric faces are brought together and bonded by the polymer layer used.