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Fabric manufacturing

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Textile fabric may be defined as the flexible assembly of fibers or yarns, either natural or manmade. It may be produced by a number of techniques, the most common of which are weaving, knitting, bonding, felting or tufting. Conventional fabrics (woven, knitted) are produced in such a way that the fibers are first converted into yarn and subsequently this yarn is converted into fabric. The fabrics can also be produced directly from the fibers. Such fabrics are termed as nonwovens. Each of these methods is capable of producing a large number of fabric structures, depending upon the raw material, machinery and the process involved. These fabrics are used for a wide range of applications from clothing to the technical purposes.

1 Weaving

The history of weaving dates back to ancient times, when human beings used woven fabrics to cover themselves. There are evidences that Egyptians made woven fabrics some 6000 years ago and silk became economically important in China 4000 years ago [1]. It is the most commonly used technique of fabric manufacturing. The woven fabrics have a huge number of application areas like apparel, home textiles, filters, geo textiles, composites, medical, packing, seatbelts, industrial products, protection, etc.

The woven fabrics are produced by interlacement of two set of yarns perpendicular to each other [2], i. e. warp and weft as shown in Figure 1. The first set includes the threads running lengthwise in the fabric, while the second is represented by the threads placed in cross or width direction. The fabrics have varying structure, depending on the interlacement pattern of the yarns. This sequence of interlacements is termed as the weave design of the fabric. The properties of fabric are governed by its weave design as well as the fiber content used as the raw material.

Figure 1: Schematic of warp and weft in woven fabric.

2 Warp Preparation Steps

A summary of the process steps from yarn to the final product, i. e. loom-state fabric is shown in Figure 2. Here the warp yarn is subjected to a number of processes, termed as warp preparation before conversion into fabric, while weft yarn does not require any specific preparation. The warp preparatory process consists of the following operations: winding, warping, sizing and drawing-in.

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Figure 2: Flow of the weaving process.

Yarns produced in spinning are used as input of the warp preparation. Winding helps to prepare the yarn for a package which requires shape and size. Weft yarn is then provided to loom, while warp yarns are processed to give a sheet of yarns on warp beam by the process called warping. A coating of size material is applied to the yarn in the subsequent process to impart strength and make the yarn smooth. This warp sheet is then drawn in from the droppers, heald frames and the reed. The actual fabric forming process is carried out at the loom, where this warp sheet and weft are interlaced to give woven fabric.

2.1 Winding

Winding is a process in which yarn from bobbins, which is the end product of ring spinning, are converted into suitable form of package. This transfer of yarn from one type of package to another package, more suitable for the subsequent process is also called winding. Main objectives of winding process are to increase the package size, clear yarn defects and produce a package suitable for subsequent process (size and shape).

The yarn packages are either parallel or tapered, with respect to shape, as shown in Figure 3. The parallel packages may also have flanges, while tapered packages are without flange [1].

Figure 3: Package types; (a) tapered, (b) parallel without flange and (c) flanged parallel.

The winding process involved unwinding yarn from one package and rewinding it on to another package. The yarn may be unwound in two ways, i. e. over end and side withdrawal as shown in Figure 4. Winding rate is the speed at which the yarn is wound on package surface, while to and fro movement of yarn when it is laid on to package is called traverse. In case of near parallel package, traverse is very slow, but in case of cross wound package traverse is quick. There is no traverse in case of parallel wound packages.

Figure 4: Package unwinding; (a) side withdrawal, (b) over end withdrawal.

In the winding machine, yarn is taken from the bobbin / cop and is wound on the package after passing through the thread guides, balloon breaker, stop motion and yarn clearer. For cross winding, a grooved drum is also provided on the machine to traverse the yarn.

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2.2 Warping

In warping process, the yarns are transferred from a number of supply packages (cones) to the warp beam in the form of a parallel sheet. The main objective of warping is to get the required number of ends as per requirement. The three main types of warping are high speed / direct warping, sectional / indirect warping and ball warping. In direct warping, the yarns are withdrawn from the single-end yarn packages (cone) on the creel and directly wound on a beam. A number of beams are warped to get the required number of ends. For example, to produce a fabric with 6040 warp ends, 8 beams will be warped, each with 755 ends. These beams are then combined into a single beam in the sizing process. The process offers only limited pattern possibilities, and is preferred for simple patterns only.

The indirect / sectional warping process completes in two steps, i. e. warping and beaming. In first step, a portion of the required number of threads (called section) is wound onto a conical drum (Figure 5). All the sections are warped on the drum side by side, one after the other. In next step all the sections are unwinded from the drum and wound onto beam to complete the required number of threads. This beam may or may not be taken for the sizing process. The division of warp sheet into small sections provides unlimited patterning possibilities. Therefore this process is suitable for complex warp patterns. Ball warping is the process in which warping is performed in rope form on to wooden ball. The ball is wound on a special wooden core called "log". It is also a two stage process, suitable for denim fabric manufacturing, involving rope dyeing process. Re-beaming is done to convert the rope dyed warp yarn, stored in cans, into beam.

Figure 5: Direct and sectional warping machine schematic diagram (a) Direct warping machine, (b) Sectional warping machine

2.3 Sizing

Sizing, also termed as slashing is the coating of warp sheet with size solution. Weaving requires the warp yarn to be strong, smooth and elastic to a certain degree. There is always a friction between metallic parts and yarn during the weaving. So, the warp yarns need to be lubricated to reduce the abrasion. The application of size material helps to improve the mechanical properties of warp, reduce abrasion and the elasticity of yarn. The amount of sizing material relates to the tenacity, hairiness and linear density of yarn, and also to its behaviour during weaving. Another major objective of this process is to get the total ends on a weavers beam, combining the ends of all warp beams. The application of sizing material results in the following properties in yarn.

- High strength
- Low flexibility

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– Low abrasion

– Increased smoothness

– Less hairiness

The process of sizing can be classified on the basis of method of application into conventional wet sizing, solvent sizing, cold sizing and hot melt sizing [3]. The main parts of conventional sizing machine include (Figure 6) creel, sizing box, drying section, leasing section, head stock and size cooker.

Figure 6: Schematic diagram of conventional wet sizing machine.

In conventional wet sizing, the fundamental constituents of size recipe are the size materials and a solvent usually water. The sizing materials are broadly classified into three groups namely adhesives, softeners and auxiliaries [4].

The adhesives perform two functions; bind the constituent fibers of the yarn together and form a film over the yarn surface, resulting in increased strength, low hairiness and more even yarn. The adhesives are classified on the basis of origin into natural, synthetic and modified adhesives, produced by treating natural adhesives with certain chemicals. The natural adhesives may be obtained from plants or animals, for example maize starch, potato starch, etc. The chemical modification of natural adhesives is performed to induce the desired properties. Some common examples of modified adhesives are modified starches and carboxy methyl cellulose (CMC). The chemically synthesized polymers like poly vinyl alcohol (PVA) and acrylics fall under the category of synthetic adhesives. Starch adhesives are used most commonly because of low cost and environment safety.

The softeners are added in the size recipe to lubricate the yarn and reduce abrasion / friction between adjacent yarns and between yarns and loom accessories. They also give a soft handle to the warp and size film, helping to decrease its brittleness. The softeners may be in solid form (wax group) or liquid form (oil group) and are obtained from animals, vegetables or synthesized chemically. The auxiliaries include antiseptic, antistatic, weighting, swelling agents and / or defoamers. The sized fabric must be subjected to a desizing process prior to the finishing stage. Desizing has a decisive effect on the waste water load in textile production.

2.4 Drawing In

The sized warp sheet is wound on to a beam called as the weaver's beam. It has the required number of ends and the yarns have adequate strength to bear the tensions of weaving process on loom. This beam is either used for drawing in or knotting / tying, depending on the requirement (Figure 7).

Figure 7: Drawing in / knotting procedure.

Style change involves the production of a new fabric style, while mass production means to continue the weaving of same fabric style just replacing the empty beam with a full beam of same type. Drawing in is the process of entering the individual yarn of warp sheet through dropper, heald eye and the reed dent (Figure 8). The yarns can be threaded wither manually or by using automatic machines.

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Figure 8: Drawing in schematic and yarn path.

The yarn is now fully prepared for conversion into the fabric, which takes place at the loom. The weaver's beam is gaited on the loom, while weft yarn is provided at right angle either from cone or bobbin depending on the picking media.

3 Weaving Mechanisms

The conversion of warp sheet into fabric by interlacing with weft yarn requires the basic operations to be carried out on loom in a specific order. It involves the primary motions, secondary motions and the stop motions [5].

3.1 Primary Motions

The primary loom motions include the following three operations:

Shedding: the separation of the warp sheet into two layers to form a tunnel known as the shed

Picking: insertion of weft yarn, across the warp sheet width, through the shed

Beat-up: pushing the newly inserted length of weft (pick) to the fell of cloth. These operations occur in a given sequence and their precise timing in relation to one another is of extreme importance.

3.2 Secondary Motions

The secondary motions facilitate the weaving of fabric in a continuous way [6]. These include:

Let off: this motion provides warp sheet to the weaving area at the required rate and under constant tension by unwinding it from weaver's beam

Take-up: this motion draws fabric from the weaving area at a uniform rate to produce the required pick spacing and wind it onto a roller.

3.3 Stop Motions

These motions are used in the interest of quality and productivity; stopping the loom immediately in case of some problem. The warp stop motion will stop the loom in case any warp yarn breaks, avoiding excessive damage to the warp threads. Similarly weft stop motion will come into action in the absence of weft yarn, and stop the loom.

4 Types of Shedding Mechanism

There are three most common types of shedding mechanisms, namely Tappet, Dobby and Jacquard shedding [7]. Tappet and dobby systems control heald frames while jacquard provides control of individual warp yarn.

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4.1 Tappet Shedding

This system is also termed as cam shedding. The cam is an eccentric disc mounted on the bottom shaft, rotating to lower or lift the heald frame. It is relatively simple and inexpensive system handling up to 14 heald frames [8]. But this system has very limited design possibilities and pick repeat, producing simple weaves.

4.2 Dobby Shedding

It is a relatively complex shedding system and can control up to 30 heald frames. The pick repeat to dobby system is provided by peg chain, punched papers, plastic pattern cards or computer programming, and is virtually unlimited. This system offers more design possibilities as compared to tappet shedding.

4.3 Jacquard Shedding

The jacquard shedding provides unlimited patterning possibilities. The working principle is relatively simple but involves more number of parts that make it a complex machine. Versatility of jacquard shedding is due to control over individual warp yarn. The jacquard shedding system can be either mechanical or electronic.

5 Types of Picking Mechanism

Picking involves the insertion of the weft yarn through shed across the width of warp sheet. The picking mechanism is mainly a function of the picking media, used for the insertion of weft (Figure 9). The picking media vary greatly on the basis weft velocity and the insertion rate; and are classified into shuttle and shuttle-less picking.

Figure 9: Mechanisms of weft insertion (a) Shuttle, (b) Projectile, (c) Rapier, (d) Air jet.

5.1 Shuttle Picking

It is the oldest technique of weft insertion on loom. The picking media is a wooden shuttle that traverses back and forth across the loom width. A pirn or quill having yarn wound on it is placed inside the shuttle. As the shuttle moves across, the yarn is unwound and placed in the shed. A picking stick on each side of loom helps to accelerate the shuttle by striking it. Shuttle travels on the race board, above lower portion of the warp sheet. The shuttle picking takes place from both the sides of loom.

5.2 Projectile Picking

Introduced first time by Sulzer in 1952, this machine uses a small metallic projectile along with gripper to throw the wet yarn across the loom width. The energy required for propulsion of projectile into the shed is provided

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by twist in the torsion rod. The projectile glides through guide teeth in the shed. It had low power consumption, versatility of yarns and a higher weft insertion rate as compared to the shuttle picking system.

5.3 Rapier Picking

This picking system uses a rigid or flexible element called rapier for the insertion of weft yarn across the shed. There are two major variations in the rapier picking; single rapier and double rapier. In case of single rapier picking system, the rapier head grips the weft and carries it across the shed to receiving end. The rapier has to return empty to insert the new weft. The double rapier picking makes use of two rapiers [9]. One rapier (giver) takes yarn to the centre of machine and transfers it to the other rapier (taker), which brings the weft to other side.

5.4 Water Jet Picking

The water jet picking involves the insertion of weft yarn by highly pressurized water. This pressurized water takes the form of a coherent jet due to the surface tension viscosity of water. The flow of water has three phases: acceleration inside pump, jet outlet from nozzle and flow into the shed. The amount of water used for the insertion of one pick is less than 2 cm^3. This system is mostly preferred for the synthetic yarns.

5.5 Air Jet Picking

In air jet picking system, the weft is inserted into the shed by the use of compressed air. The yarn is taken from the supply package / cone and wound on to the feeder before insertion to avoid tension variations. The weft is then passed through the main nozzle which provides initial acceleration to the yarn. The auxiliary nozzles are present at specific distance along the width to assist in weft insertion. A special type of reed, called profiled reed is used for air jet picking. The channel in the reed guides the yarn across the shed and avoids entanglement with warp. It has an extremely high weft insertion rate.

6 Weave Design

The woven fabric is produced by interlacement of warp and weft, and this interlacement pattern is called weave design of the fabric [10]. The three basic weave designs are plain, twill and satin.

6.1 Plain

The simplest interlacing pattern for warp and weft threads is over one and under one as shown in Figure 10. The weave design resulting from this interlacement pattern is termed as plain or 1 / 1 weave. The 1 / 1 interlacement of yarns develops more crimp and fabric produced has a tighter structure. The plain weave is produced using only two heald frames. The variations of plain weave include warp rib, weft rib and matt or basket weave.

Figure 10: Basic weaves and their cross sectional view.

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6.2 Twill

This weave is characterized by diagonal ribs (twill line) across the fabric. It is produced in a stepwise progression of the warp yarn interlacing pattern. The interlacement pattern of each warp starts on the next filling yarn progressively. The two sub categories based on the orientation of twill line are Z- and S-twill or right hand and left hand twill, respectively. Some of the variations of twill weave include pointed, skip, and herringbone twill [11].

6.3 Satin / Sateen

The satin / sateen weave is characterized by longer floats of one yarn over several others. The satin weave is warp faced while sateen is a weft faced weave. A move number is used to determine the layout in a weave repeat of satin, and number of interlacements is kept to a minimum as shown in Figure 10. The fabrics produced in satin weave are more lustrous as compared to corresponding weaves.

7 Specialty Weaving

There are certain specialty weaving techniques used for the production of a specific fabric type, for example circular loom, terry towel loom, denim fabric, narrow loom, multi-phase loom, 3D weaving loom, carpet / rug weaving, etc. The weaving is also used for the production of certain industrial fabrics and technical textiles [2] like conveyor belt fabrics, air bag fabrics, cord fabrics, geotextiles, ballistic protection, tarpaulins, etc. The denim fabrics are woven with a coarse count, high thread density and 3 / 1 twill weave. Dyeing is an additional process involved in the warp preparation for these fabrics [12]. The warp yarn of these fabrics is dyed with indigo dyes in such a way that only surface is dyed and core remains white. The narrow loom usually involves a needle for the weft insertion. It usually draws the warp sheet directly from the creel through tensioning rollers, thus helping to increase efficiency and productivity.

The towels are piled fabrics produced from two different set of warp; one serving as the ground and the other as pile. More length of pile warp is consumed as compared to ground warp. Therefore, two beams are required to produce such fabrics and need additional attachments on loom. In multiphase loom, several weft yarns are inserted simultaneously across the series of sheds. These shed are arranged sequentially in the warp direction. The 3D loom produces a 3 dimensional fabric on the required shape [13]. The carpet weaving involves a loom with two beam arrangement as in case on terry towel fabrics. The ground warp let-off, pile warp let-off and cloth take-up is controlled by servomotors [14]. It allows easy change of pile height and pick density. The tension in the pile warp sheet is controlled by a pneumatic beam brake.

8 Knitting

Knitting is the second largest and most growing technique of fabric manufacturing in which yarns are interloped to make thick yet flexible and elastic fabric [15]. Knitting is derived from the Dutch word “Knutten” which means to knot. There are many theories about the history of knitting. According to one theory knitting is linked with knotting fishing nets. This also affirms the historical views that knitting was started by the Arabian seafarers who were sailing and trading in the Middle East back in 200 AD. The earliest example of knitwear we could find is the sock from Victoria and Albert Museum which is knitted in stocking with single needle called Nalbindning. In 600 AD, knitting is believed to have been transferred to Europe with the wool trade. In the13th and 14th centuries some products in circular shape are found which are named as Madonna Knitting. Followed by this was an era of fashionable knits as in 1420s which are also known as knitting guilds. These were the articles which attracted wealthier and more influential clientele and this was Elizabeth I’s period from where history of knitting can be traced. Introduction of fashion items in knitting attracted attention of many from the adjoining areas of Europe and it was 17th century where knitting socks got popularity. After Industrial Revolution in 18th century knitting was found primarily performed with knitting machines and the first knitting machine was thought to be invented by William Lee in 1589 and his wife was a hand knitter. Elizabeth I was reluctant to patent the machine because of its likelihood of unemployment among the masses but it thrived in France. This art remained in the hands of the underdeveloped and poor section of the society till the first half of the 20th century [16].

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Knitting is fabric formation technique in which the yarn is bent into loops and those loops are interconnected to form fabric [17]. Knitting can be defined in simple words as the interloping of yarn as shown in Figure 11. The bending of yarn provides better stretchability, extensibility, comfort and shape retention properties. However they tend to be less durable than the woven fabric.

Figure 11: Interloping pattern of knitted fabric

9 Comparison of Woven and Knitted Fabrics

The woven fabrics produced by interlacement of two sets of yarn and knitted fabrics formed by the interloping of yarn, have unique characteristics and have their own end-user applications [15]. In most of the cases, both fabrics can be a substitute for each other and selection of the right fabric can possibly meet the requirement of the wearer in a better way. Table 1 presents a comparison between woven and knitted fabrics.

Table 1 Comparison between woven and knitted fabrics, machine and process.

Sr. #	Parameter	Woven Fabric	Knitted Fabric
1	Process requirement	Fabric requires two sets of yarn for interlacement, one is warp and other is weft yarn.	Fabric can be produced from a single end or a cone of a yarn in case of weft knitting.
2	Dimensional stability	More stable	Less stable. Careful handling is required for knitted fabric during wet processing and stitching.
3	Comfort	Less comfort due to tight structure	More open spaces that give better air permeability and moisture management
4	Shape retention properties	Woven garments retain their own shape	Knitted garments get the shape of the wearer's body, hence, best for undergarments
5	Crease resistant	Poor crease resistance	High crease resistance
6	Development route	Yarn preparation requires like warping, sizing drawing, etc.	Fabric can be produced from yarn package. So process route is very short
7	Conversion cost	Conversion from yarn to fabric involves various processes. The conversion cost is higher.	Conversion requires no preparation, so conversion cost is low
8	Environmental effect	Preparation includes a sizing of warp yarn that has to remove before color application, that may cause environmental pollution	The yarn is just waxed. No need to size the yarn, so development cause less environmental hazards

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10 Types of Knitting

The knitted fabric can be categorized into two major classes i. e. warp and weft knitting on the basis of yarn feeding and direction of movement of yarn in fabric with respect to the fabric formation direction.

The weft knitting technique is more common as the fabric can be produced from single end and there is no need of yarn preparation like warping. In weft knitting, the direction of movement of yarn is in the weft direction of the fabric [15]. The loops are formed horizontally with the same yarn, as shown in Figure 12.

Figure 12: Yarn direction: (a) Weft knitting, (b) Warp knitting.

The warp knitting technique is a more advanced technique and the fabric is much closer to the woven fabric in terms of dimensional stability. The loops that are formed are connected in the warp direction and movement of yarn is also in the warp direction as shown in Figure 12.

10.1 Weft Knitting

Weft-knit fabric is familiar for their comfort and shape retention properties. The fabric can be produced from a single end. The movement of yarn in the weft direction provides the stretch ability in both directions that could be engineered to achieve the required properties. The apparels, either inner or outerwear, are the most demanding area of weft-knit fabric. This technique is further classified into different machine type and structure that is given in Figure 13. Circular knitting machines are particularly used to produce tubular fabric. Circular machines are classified into three major categories on the basis of cylinder and Dial. The first category in which machine has only one cylinder, needles are placed inside the cylinder trick that moves up and down for loop formation. Popular structures are single jersey and their derivatives. The second type of machine has both dial and cylinder. The needles are placed in both dial and cylinder. The cylinder needles move up and down while dial needle moves in to and fro manner. The major machine types are Rib and Interlock. The difference in their construction is the placement of tricks or grooves. The grooves on Rib machine of both dial and cylinder are alternative to each other whereas on interlock the grooves are exactly opposite to each other. The third class is Purl, in which the machine has two cylinders. These cylinders are superimposed. The purl fabric is also known as link-link fabric. The needle is hocked on both sides. The same needle is placed in opposite tricks of these cylinders [19]. The flat machines can produce both single and doubleknit fabrics.

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Figure 13: Classification of weft knitting machines and their structures.

10.2 Weft Knitting Machine Elements

The needle is the most important and essential part of loop formation. The needles are placed in tricks or cut of bed (flat or circular) at regular intervals so that they can move freely during the loop formation cycle. Generally, machine manufacturers prefer to use the latch needle for their machines. The latch needle is self-actuating and no auxiliary part is required. Different needle types and their parts are shown in Figure 14.

Figure 14: Needle types and their parts: (a) Latch needle, (b) Compound, (c) Bearded needle.

There are three main types of needle

1. Latch needle
2. Spring Bearded needle
3. Compound needle

Another important part of the machine is sinker. The sinker is a thin metal plate placed on the horizontal surface at perpendicular to the needle. They move to and fro in between the needle. The sinkers get their movement from the sinker cams. The purpose of the sinker is to hold the old loop when it is cleared from the needle. The sinker is used both in weft and warp knitting [19]. Different types of sinkers are used in different machines to produce the required variety of results. The machine that has double bed construction does not need to use sinker as either bed needle hold the old loop while other bed needle is in working position. The sinker and their parts are given in Figure 15. The sinker performs one or more of these functions:

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1. Loop formation
2. Holding down
3. Knocking over

Figure 15: Sinker and its parts.

11 Loop Formation Cycle with Latch Needle

The loop formation cycle of the latch needle explains the working of needle during loop formation process in weft knitting. The loop formation cycle is explained in Figure 16.

Figure 16: Loop formation cycle of latch needle.

1. The needle starts moving upward as the direction given by cam. The latch opens and old loop slips on the latch.
2. Now the needle clears the old loop. In this step the needle goes to its maximum height.
3. From this step the descending of needle starts, the needle engages the new yarn in the hook. This is a feeding of new yarn.
4. The needle moves down. The latch is now closed. This is a knock over position, the old loop is totally disengaged from the needle.
5. The final step is the loop pulling process. The needle goes to lower-most position and pulls the new loop from the previously formed old loop.

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12 Principle Stitches in Weft Knitting

There are mainly four basic types of stitches in weft knitting, namely knit, tuck, purl and miss or float. Most of the weft-knitted fabrics and their derivatives are based on the combination of these stitches.

Knit Stitch

Knit stitch is formed when the needle is raised enough to engage the new yarn in the hook by the camming action and old loop is cleared. The technical back side of the knit stitch is called a purl stitch [18]. The clearing position of knit stitch is illustrated in Figure 17.

Figure 17: Stitch types:(a) Knit, (b) Tuck, (c) float or miss stitch.

Tuck Stitch

Tuck stitch is formed when the needle is raised to get the new yarn but not enough to clear the previous formed old loop. The needle then holds two loops when it descends as shown in Figure 17. The needle can hold up to four loops only, and so it has to clear the previous held old loops quickly. The fabric gets thicker with tuck stitch as compared to knit stitche due to the accumulation of yarn when needle clears all the old loops. The structure becomes more open and permeable to air than knit stitches. It can also be used to get different color effect in the fabric [19].

Miss or Float Stitch

When the needle does not move upward to clear the old loop and also does not take the new yarn that presented to it then the miss or float stitch is formed. Needle is not activated in miss stitch. Moreover, it holds the old loop as shown in Figure 17. Float stitch on the successive needles produce longer float of yarn that may cause the problem of snagging. The float is preferably used where we need to hide some color from the technical face of the fabric. The hide yarn floats at the back of the fabric. The yarn gets straighter in float stitch construction so the extensibility decreases as compared to tuck and knit stitches [19].

13 Knitting Terms and Definition

13.1 Loop Parts

The needle loop has different parts. The loop parts are important to understand the technical face and back side of the loop. The loop parts are given in Figure 18.

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Figure 18: Parts of a knitting loop.

13.2 Technical Face and Back

If the feet of the new loop cross under the legs of the old loop and legs cross over the head of the old loop, then this side is technical face or it may be defined as the side having all the face of the knit loop. Figure 19 illustrates the interloping of the old and new loops, forming technical face side. If the feet of the new loop cross over the legs of the old loop and new loop legs pass under the head of old loop then it is said to be a technical back side. The interloping pattern of technical back is given in Figure 19.

Figure 19: Fabric sides: (a) Technical face, (b) Technical back.

13.3 Wales and Courses

The series of loops that are immersed vertically are known as wales. The consecutive loops that are connected horizontally are called courses. The rows and columns of loops connected are shown in Figure 20.

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Figure 20: Schematic pattern of a knitted fabric.

13.4 Stitch Density

The number of loops or stitch per unit area is called stitch density. This can be calculated by the product of course and wales density. In one inch square area of fabric, there are 6 loops or stitches as displayed in Figure 20.

Stitch density of a knitted fabric is expressed as wales density and courses density. The number of wales per unit length is called the wales density, normally measured in wale / inch or wale / cm. In Figure 20, there are three wales in one inch of fabric.

The number of courses per unit length is called the course density, normally measured in wale / inch or wale / cm. There are two complete courses in one inch of the fabric as shown in Figure 20.

13.5 Stitch Length

The stitch length is the most important part of knitting. It is basically the length of yarn consumed to make one complete loop [16]. The knitted fabric dimensional, physical and mechanical properties are truly based on the stitch length that can be engineered to meet the requirement of the fabric. The individual loop is shown in Figure 18.

14 Warp Knitting

Warp knitting may be defined as the loop formation process along the warp direction of the fabric [18]. The simultaneous sheet of the yarn is provided to the machine along the warp direction for the loop formation process. The sheets of yarn are supplied from warp beam as in weaving. Each warp end is provided to each individual needle. The same yarn runs along the warp direction and the needle draws the new loop yarn through the old loop that was formed by another yarn in the previous knitting cycle. Each yarn also passes through the guide mounted on guide bar that provides the movement of the same yarn between the needles.

The warp knitting machines are flat and fabric formation technique is more complex as compared to weft knitting. The flow process is given in Figure 21. The comparison of warp and weft knitting is given in Table 2.

Figure 21: Flow process of warp knitting.

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Table 2 Comparison of warp and weft knitting [19].

Sr. #	Weft Knitting	Warp Knitting
1	Individual yarn is provided to feeder. If a machine has 90 feeders and all are active, then 90 courses are inserted in a complete revolution.	Simultaneous sheets of yarns are fed to the machine. Number of ends required will be equal to the number of needles on the machine.
2	Loop formation along the weft or course direction of the fabric.	Loop formation along the wale or warp direction of fabric.
3	The yarn is supplied in the form of cones or cheese. The number of cones required will be equal to the number of feeder available on machine.	Yarn supplied to machine from warp beam, so additional warping process is required to prepare warp beam.
4	The spun yarns are mostly the raw materials for weft knitting so only waxing may require to avoid abrasion between the yarn and the machine parts.	The filament yarn is used in warp-knitted fabric according the end application. Antistatic oiling is required to avoid static charge.
5	The weft-knitted fabric has less dimensional stability so careful handling is required.	The warp-knitted fabric is dimensionally very stable due to overlapping and underlapping of yarn.
6	The weft-knitted fabric is more stretchable in both directions (warp and weft)	The warp-knitted fabric are less stretchable and mostly they stretch in the weft direction.
7	Latch needle is preferably used in weft-knitting machine.	Latch as well as bearded and compound needles are used in warp-knitting machine.
8	The application of weft-knitted fabric is mostly apparel including both outer and inner garments.	The application area of warp-knitted fabric is not only apparel but also have huge demand for domestic, industrial and technical applications.

14.1 Classification of Warp Knitting Machine

Warp knitting machines are categorized on the basis of construction of different machine parts and their operations. Tricot and Raschel are two main categories of machine. Further classification of warp knitting is given in Figure 22, while comparison of Tricot and Raschel warp knitting is given in Table 3.

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Figure 22: Classification of warp-knitting machines and their structures.

Table 3 Comparison of Tricot and Raschel machines [18].

Sr. #	Machine Parts and their Operations	Tricot	Racshel
1	Needle Type	Bearded and compound needle is mostly used	Latch needle is preferably used
2	Sinkers	Sinkers work through out the knitting cycle	Sinkers active only when the needle rises
3	Machine Speed	Machine can run at a speed of 3500 courses / min	Raschel machine works at a bit lower speed of up to 2000 courses / min
4	Gauge	Tricot machine gauge is expressed by the number of needles per unit inch	Gauge defined by the number of needles per two inch
5	Warp Beams / Guide bars	Option to use less number of guide bars that can be up to 8	Minimum 2 and maximum 78 guide bars can be used
6	Structure type	Comparatively less complex or simple structure can be developed	Advance and complex structure can be produced on raschel
7	Take down angle	The take down angle is 90º	The angle is 160º
8	Fabric Width	More wider fabric can be achieved up to 170 inches	Width of fabric is limited to 100 inches

15 Applications of Knitted Fabrics

The application area of knitted fabric is mainly classified into three major categories such as clothing which includes weft-knitted vests, sweaters, pullovers, stockings, sportswear, underwears, etc. The home and furnishing textile is the second major class comprises of warp-knitted curtains, terry towel and weft-knitted blankets, upholstery, etc. The knitted fabrics also have a huge applications range in technical textile. Both warp- and weft-knitted fabrics are used in medical textiles such as compression bandages. The automobile industry also has the consumption of warp-knitted fabric in the form of seat covers, roofing and filtration. Packaging materials and mosquitoe nets are also made with knitted fabric [20].

16 Nonwoven

During the nonwoven fabric production, the yarn manufacturing as well as yarn preparation processes (required in woven fabric) are eliminated. Due to this reason nonwoven fabrics are cheaper as compared to the conventional fabrics. The great advantage of nonwoven fabrics is the speed with which the final fabric is produced. All yarn preparation steps are eliminated, and the fabric production itself is faster than conventional methods. Not only the production rate is higher for nonwovens as shown in Table 4 [21], but the process is more automated, requiring less labor than even most modern knitting or weaving systems. The nonwoven process is also efficient in its use of energy.

Table 4 Production comparison of woven, knitted and nonwoven fabrics (INDA).

Method	System	Production (m^2 / hour)
Weaving	Shuttle	15
Overall average 0.583 m^2 / min	Rapier	30
	Water jet	35
	Projectile	40
	Air jet	55
Knitting	Double knit	125

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Overall average 8.5m^2 / min	Rib	175
	Single jersey	250
	Raschel	800
	Tricot	1200
Nonwoven	Stitch bonded	450
Overall average 335.5 m^2 / min	Needle punched	7200
	Card bond	15000
	Wet laid	30000
	Spun laid	48000

In the 19th century, realizing that a large amount of fiber is wasted as trim, a textile engineer named Garnett developed a special carding device to shred this waste material back to fibrous form. This fiber was used as filling material for pillows. The Garnett machine, though greatly modified, today still retains his name and is a major component in the nonwoven industry. Later on, manufacturers in Northern England began binding these fibers mechanically (using needles) and chemically (using glue) into batts. These were the precursors of today's nonwovens [22].

The term 'nonwoven' rises from more than sixty years ago when nonwovens were considered as cheaper alternative of conventional textiles and were generally made from carded webs using textile processing machinery [22]. The nonwovens industry is very sophisticated and profitable, with healthy annual growth rates. It is perhaps one of the most intensive industries in terms of its investment in new technology, and also in research and development. Therefore, the nonwoven industry as we know it today has grown from developments in the textile, paper and polymer processing industries. Today, there are also inputs from other industries including most branches of engineering as well as the natural sciences.

16.1 Definitions

Different definitions of nonwovens are available by different organizations. According to the ASTM D 1117–01, nonwovens can be defined as:

> "A textile structure produced by the bonding or interlocking of fibers, or both, accomplished by mechanical, chemical, thermal or solvent means and combinations thereof"

According to the standard ISO-9092:1988, the nonwovens are:

> "Manufactured sheet, web or batt of directionally or randomly orientated fibers, bonded by friction, and / or cohesion and / or adhesion, excluding paper and products which are woven, knitted, tufted, stitch-bonded incorporating binding yarns or filaments, or felted by wet-milling, whether or not additionally needled. The fibers may be of natural or man-made origin".

The Association of Nonwoven Fabrics Industry, USA (INDA) defines nonwovens as:

> "A sheet, web or batt of natural and / or man-made fibers or filaments, excluding paper, that have not been converted into yarn, and that are bonded to each other by any of several means.
>
> To distinguish wet-laid nonwovens from wet-laid paper materials the following differentiation is made. (a) More than 50 % by mass of its fibrous content is made-up of fibers with a length to diameter ratio greater than 300. Other types of fabrics can be classified as nonwoven if, (b) More that 30 % by mass of its fibrous content is made up of fibers with a length to diameter ratio greater than 600 and/or the density of the fabric is less than 0.4 g / cm^3.

The European Disposables and Nonwovens Association (EDANA) describes the nonwovens as:

> "A manufactured sheet, web or batt of directionally or randomly oriented fibers, bonded by friction, and / or cohesion and / or adhesion, excluding paper and products, which are woven, knitted, tufted or stitch-bonded, or felted by wet-milling, whether or not additionally needled. The fibers may be of material or man-made origin. They may be staple or continuous filaments or be formed in situ". To distinguish wet-laid nonwovens from wet-laid papers, a material shall be regarded as a nonwoven if, (a) More than 50 % by mass of its fibrous content is made-up of fibers with a length to diameter ratio greater than 300; or (b) More than 30 % by mass of its fibrous content is made up of fibers with a length to diameter ratio greater than 300 and its density is less than 0.40 g / cm^3."

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16.2 Nonwoven Products

Nonwoven fabrics have wide area of applications depending upon the properties required in the end product. EDANA has given the nonwoven fabric applications according to the end use as shown in Figure 23.

Figure 23: Application areas of nonwovens [23].

Nonwoven fabrics have wide range of products like disposable gowns, face masks, gloves, shoe covers, dressings, sponges, wipes, diapers, sanitary napkins, lens tissues, vacuum cleaner bags, tea and coffee bags, hand warmers, interlinings, incontinence products, floor covers, air filters, paddings, blankets, pillows, pillow cases, aprons, table cloths, hand bags, book covers, posters, banners, disk liner, sleeping bags, tarpaulins, tents, crop covers, green house shadings, weed control fabrics, golf and tennis courts, road beds, drainage, sedimentation and erosion control, soil stabilization, dam embankments, etc. [24, 25].

16.3 Raw Materials for Nonwovens

Different types of man-made and natural fibers are used in the nonwoven fabric production. Man-made fibers have 90 % share of the total fiber consumption [22].

Polymers, fibers and binders are the basic raw materials for nonwovens. Most of the fibers and binders are made of polymers. A polymer is a large molecule built up by the repetition of small single chemical units. Large molecules are called macromolecules consisting of hundreds to millions of atoms linked together by chemical bonds (typically covalent bonds) which are called primary bonds. The special properties of polymers result particularly from secondary bonds acting between the macromolecules which are known as van der Waals forces. Virtually all types of fibrous material can be used to make nonwoven fabrics depending on:

- The required profile of fabric
- The cost effectiveness
- The demands of further processing

Most common fiber types used in nonwoven fabric production are: polypropylene, polyester, viscose rayon, polyamide 6 and 6.6, bicomponent fibers, surface modified fibers, superabsorbent fibers, Novoloid fibers, wool is used in felts production, cotton in hygienic goods and another quantitatively important group of fiber raw material for nonwovens is waste fiber materials.

Production of nonwovens is carried out after considering the following points:

- Process ability in a particular technology
- Impact on the product properties

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– Price

Thus, it is very essential to study different fiber properties for the development and production of nonwoven fabrics. According to a study carried out by Tecnon Ltd. the world consumptions of different types of fibers are as: polypropylene 63 %, polyester 23 %, viscose rayon 8 %, Acrylic 2 %, polyamide 1.5 %, others 3 %. Polypropylene fibers consumption is highest in nonwoven fabric production due to certain properties like: low density, hydrophobicity, low melting and glass transition temperature, biological degradation resistance, chemical stability, good mechanical strength [22].

17 Manufacturing of Nonwoven

Production of nonwoven fabric is comparatively easier as compared to the conventional fabric production method like weaving. First of all, fiber type is selected from natural or manmade origin and then selected fibers are converted in the form of a regular sheet or web. In the third step fibrous sheet or web is bonded together for consolidation and strength of sheet and in last step finishes are applied over the consolidated web according to the end use. The production sequence of nonwoven fabric is shown in Figure 24.

Figure 24: Nonwoven production steps.

Nonwoven fabrics can be classified on the basis of fibers orientation during web formation and bonding of the web. Structure based classification of nonwoven fabric is shown in Figure 25.

Figure 25: Structure based classification of nonwoven fabrics.

17.1 Web Formation

After the fiber selection web formation is the major step of nonwoven fabric formation. During web formation fibrous sheet, web or batt is formed having two dimensional or three dimensional assemblies. Orientation, dimension and structural arrangement of fibers in the web greatly influence the final product properties. Fibrous sheet or web formation is classified in three areas: dry laid, wet laid and polymer laid (Spun bonded). Dry

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laid technique is directly related to the conventional spinning process while wet laid technique is related to the paper making industry and polymer laid technique is directly related to the polymer extrusion through spinneret.

17.2 Dry Laid Web

Dry laid web formation is concerned with carding process of spinning. Carding produces one or more webs, in which fibers are preferentially oriented in the machine direction (MD). A multilayer web is produced by using more than one card machines in a single line. The major objective of carding is to disentangle and mix the fibers to form a homogeneous web of uniform mass per unit area. This purpose is achieved by the interaction of fibers with toothed rollers situated throughout the carding machine. The first and the most basic principle of carding is "working" and the second is "stripping". The whole carding process is essentially a succession of "working" and "stripping" actions linked by incidental actions. Every card has a central cylinder or swift that is normally the largest roller and small rollers (called worker and strippers). Generally small rollers operate in pairs and situated around cylinder and carry out the basic function of working and stripping. Many cards have more than one cylinder with their own small rollers. Arrangement of rollers in a basic carding machine is shown in Figure 26.

Figure 26: Working and stripping actions.

Worker and stripper pairs around the cylinder perform both opening and mixing functions. Doffer cylinders condense and remove the fibers from the cylinder surface in the form of a continuous web. The points of teeth on a worker roller directly oppose the points of cylinder teeth in a point-to-point relationship. The worker revolves in the opposite direction to that of the cylinder. The teeth on worker and cylinder travel in the same lateral direction at their point of interaction, causing a "working" action between the worker and cylinder. Then a stripping action between the stripper and the worker, followed by a further stripping action between the cylinder and the stripper. After removal of the web from the first card machine, it is allowed to pass under the second card machine through a conveyor, to achieve the required thickness of web. Batt drafting is done to increase the fibers orientation in the machine direction.

17.3 Wet Laid Web

The technology of wet-laid nonwovens is closely related to that of paper and papermaking which itself goes back some 2000 years, developed in China. But wet-laid nonwovens are differentiated from paper manufacturing and regarded as nonwoven: if more than 50 % by mass of its fibrous content is made up of fibers (excluding chemically digested vegetable fibers) with a length to diameter ratio of greater than 300; or more than 30 % by mass of its fibrous content is made up of fibers (excluding chemically digested vegetable fibers) with a length to diameter ratio greater than 300 and its density is less than 0.40 g / cm^3.

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A dilute slurry of water and fibers is deposited on a moving wire screen and drained to form a web as shown in Figure 27. The web is further dewatered, consolidated, by pressing between rollers, and dried. Impregnation with binders is often included in a later stage of the process. Wet laid web-forming allows a wide range of fiber orientations ranging from near random to near parallel. The strength of the random oriented web is rather similar in all directions in the plane of the fabric. A wide range of natural, mineral, synthetic and man-made fibers of varying lengths can be used.

Figure 27: Schematic of wet laid web formation.

17.4 Polymer Laid Web

Polymer-laid, spun laid or "Spun melt" nonwoven fabrics are produced by extrusion spinning processes, in which filaments are directly collected to form a web instead of being formed into tows or yarns as in conventional spinning. As these processes eliminate intermediate steps, they provide opportunities for increasing production and cost reductions. In fact, melt spinning is one of the most cost efficient methods of producing fabrics. Commercially, the two main polymer-laid processes are spun bonding (spun bond) and melt blowing (melt blown). A primary factor in the production of spun bonded fabrics is the control of four simultaneous, integrated operations: filament extrusion, drawing, lay down, and bonding. The basic stages of spun bonded nonwoven fabric include [22]:

Polymer melting → Filtering and extrusion → Drawing → Laydown on forming screen → Bonding → Roll up

The first three operations are directly adapted from conventional man-made filament extrusion and constitute the spun or web formation phase of the process, while the last operation is the web consolidation or bond phase of the process, hence the generic term spun bond. All spun bond manufacturing processes have two aspects in common:

- They all begin with a polymer resin and end with a finished fabric.
- All spun bond fabrics are made on an integrated and continuous production line.

Melt blowing is a process in which, usually, a thermoplastic fiber forming polymer is extruded through a linear die containing several hundred small orifices. Convergent streams of hot air (exiting from the top and bottom sides of the die nosepiece) rapidly attenuate the extruded polymer streams to form extremely fine diameter fibers (1–5 μm). The attenuated fibers are subsequently blown by high-velocity air onto a collector conveyor, thus forming a fine fibered self-bonded nonwoven melt blown web as shown in Figure 28.

Figure 28: Schematic of melt blown web formation [22].

In general, high molecular weight and broad molecular weight distribution polymers such as polypropylene, polyester and polyamide can be processed by spun bonding to produce uniform webs. Medium melt viscosity polymers, commonly used for production of fibers by melt spinning, are also used. In contrast, low molecular weight and relatively narrow molecular weight distribution polymers are preferred for melt blowing. In the past decade, the use of polyolefin, especially polypropylene, has dominated the production of melt blown and spun bonded nonwovens. One of the main reasons for the growing use of polyolefin in polymer-laid nonwovens is that the raw materials are relatively inexpensive and available throughout the world.

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18 Web Bonding

After the web preparation, next major step in the nonwoven production is web bonding. Different web bonding techniques are available depending upon the end product properties and cost. Nonwoven web bonding mainly has three categories:

- Thermal bonding
- Chemical bonding
- Mechanical bonding

18.1 Thermal Bonding

Thermal bonding requires a thermoplastic component to be present in the form of a fiber, powder or as a sheath as part of a bicomponent fiber. The heat is applied until the thermoplastic component becomes viscous or melts. The polymer flows by surface tension and capillary action to fiber-to-fiber crossover points where bonding regions are formed. These bonding regions are fixed by subsequent cooling. No chemical reaction takes place between the binder and the base fiber at the bonding sites. Binder melt and flow into and around fiber crossover points, and into the surface crevices of fibers in the vicinity, and adhesive or mechanical bond is formed by subsequent cooling. Thermal bonded products are relatively soft and bulky depending upon the fibers composition. Thermal bonding process is economical, environment friendly and 100 % recycling of fibers components can be achieved. In thermal bonding technique generally hot calendar rollers are used to bind the fibrous sheet. Thermal bonding has further sub categories: point, area, infra-red, ultra-sonic and through air bonding.

18.2 Chemical Bonding

In chemical bonding, different types of chemicals or binders – rubber (latex), synthetic rubber, copolymers, acrylics, vinyl esters, styrene and different natural resins are sprayed on the nonwoven web for bonding purpose. Latex binder is most commonly used for nonwoven web bonding. During chemical bonding process chemicals are sprayed on the nonwoven web or web is allowed to pass through the chemical box. In chemical bonding different techniques are used for the web bonding. Most frequently used chemical bonding processes are spray adhesives, print bonding, saturation adhesives, discontinuous bonding and application of powders.

18.3 Mechanical Bonding

In mechanical bonding process, fibrous sheet or web is bonded together through the application of liquid or air jets, punching needles and by stitching. Depending upon the selection of any type of mechanical media, nonwovens are classified as hydro entanglement, needle punching and stitch-bonded fabrics. In hydro entanglement techniques, fibrous sheet is allowed to pass under the liquid jets provided by multiple nozzles. Through the jet pressure web is fused, consolidated and provide strength to the sheet as shown in Figure 29. The major disadvantage of this technique is the drying of sheet after consolidation. Hydro entangled nonwoven fabrics are used in wipes and medical nonwoven industry because of their additive free, lint free, soft, strong, and cost effective characteristics.

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Figure 29: Hydro-entanglement bonding assembly [22].

In needle punching method, fibrous web is allowed to pass under a bar containing multiple needles. These needles pass in through the thickness direction of web and entangle the fibers to give strength to the fibrous sheet. Schematic representation of a needle punching is shown if Figure 30. Needle punched nonwovens are used in automotive, construction, home furnishing industries, geotextiles, shoe felts, blankets, filters and insulators.

Figure 30: Schematic representation of needle punching technique [22].

Stitch bonded nonwoven fabrics are produced by stitching the fibrous web or sheet with other fibers or yarns. The performance properties of stitch bonded nonwoven fabric depends upon the stitching yarn type, stitch density, stitch length, stitching yarn tension and machine gauge. Stitched bonded fabrics may be of one side stitched, two sides stitched or one side stitched with the projection of pile on the other side of the fabric. In order to get flexibility in the fabric Lycra yarn is used and for higher strength fabric, high performance yarns are used for stitching purpose. Commercially, two stitch bonding systems: Maliwatt and Malivlies are available. Stitch bonded fabrics are used to produce vacuum bags, geotextiles, filters, and interlining, the biggest market is shaped by home furnishing industry.

19 Finishing

Keeping in view the end use of nonwoven fabric, different types of finishes are applied over the fabric. The variety of both chemical and mechanical finishes provided new horizon for the application of nonwoven fabric. Different types of wet finishes, dyeing, coating as well as calendaring, embossing, emerising and micro creping were used. These days, many types of chemical finishes like the antistatic finish, antimicrobial finish, water repellent finish, UV absorbers, flame retardant finish, soil release agent, optical brightener and super absorbent finishes are applied on the end product keeping in view the performance application of the product. Plasma treatment, microencapsulation, laser etching, biomimetic and electrochemical finishes are under developing stages for nonwoven finishing.

20 Characterization of Nonwoven

Nonwoven fabric is different from other textile structures, because it is produced from fibers or fibrous sheet rather than yarn. In addition to the fiber and binder type, structural properties of nonwoven fabric are influ-

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enced by the web formation process, bonding technique and finishing process. The structure and dimensions of nonwoven fabrics are frequently characterized in terms of fabric weight / mass per unit area, thickness, density, fabric uniformity, fabric porosity, pore size and pore size distribution, fiber dimensions, fiber orientation distribution, bonding segment structure. Majority of nonwoven fabrics have porosities >50 % and usually above 80 %. The fabric weight uniformity in a nonwoven is normally anisotropic, i. e. the uniformity is different in different directions (machine and cross direction) in the fabric structure. Certain mechanical properties like tensile strength, tear strength, compression recovery, bending and shear rigidity, abrasion and crease resistance frictional properties are tested according to the end use.

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