OVERVIEW OF NONWOVENS FROM FIBER PRODUCERS PERSPECTIVE

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Background

Nonwoven fabric technology is the most modern branch of the textile industry [1], and embodies both quite old and the very new processing techniques and materials [2]. From a fairly modest beginning with only a limited variety of raw materials, processes, and end uses, the nonwoven industry has reached a status of enormous diversity [3]. Today, nonwoven fabrics play key roles in hundreds of everyday products, from luxury automobiles to the familiar teabag [4]. In the past thirty years, the nonwoven industry has observed a phenomenal growth mainly because of a close alliance among nonwoven producers, fiber producers, binder producers, and machinery manufacturers. There are many nonwoven manufacturing processes and products that have been developed and commercialized in the past thirty years to address a variety of end-use markets.

The versatile and complex nature of the nonwovens industry is depicted in Figure 1 [5]. The term "nonwoven fabrics" has been defined in many ways. The American Standard for Testing Materials (ASTM) [6] has defined the term "nonwoven fabrics" as:

> A structure produced by bonding or the interlocking of fibers, or both, accomplished by mechanical, chemical, thermal, or solvent means and the combination thereof. The term does not include paper or fabrics that are woven, knitted, tufted, or those made by wool or other felting processes.

Nonwoven fabric is essentially an assemblage of fibers held together by mechanical or chemical means, resulting in a mechanically stable, self-supporting, and generally flexible, web-like structure. The most significant feature of nonwoven fabrics, and the one that contributes most to their economic appeal [4], is that the fabrics are usually made directly from raw materials in a continuous production line, thus partially or completely eliminating conventional textile operations, such as carding, roving, spinning, weaving or knitting. The simplicity of fabric formation, coupled with high productivity, allows nonwovens to compete favorably with wovens and knits on a performance per cost basis in many industrial applications (as in packaging materials, for example). However, in outerwear apparel fabric applications, where good drape properties, flexibility, and strength are required, nonwovens have yet to gain a significant technological advancement. Nevertheless, there has been a continuous effort through innovative manufacturing processes to develop newer nonwoven products that emulate the drape and flexibility of woven or knitted structures.

The purpose of this paper is to provide the reader with a broad overview of nonwoven technology complex with special emphasis on the use of different fibers in nonwovens.

Manufacturing of Nonwoven Fabric

The manufacturing of nonwoven fabric is very different from that of woven and knitted fabrics. Each nonwoven manufacturing system involve following generic steps:

- Fiber/raw material selection
- Web formation
- Web consolidation
- Web finishing and converting

Fiber/raw material selection

The fiber/raw selection is based on cost, ease of processibility, and the desired end use properties of the web.

- Fibers are the building block of all nonwovens. Most natural and man-made fibers are being utilized in the production of nonwovens.

- The raw material includes binders and finishing chemicals. Basically, binders are used for dry laid webs to adhere fibers to each other to provide strength and integrity to the web. However, some of the binders act more than just as adhesives [7]. In many cases, the binder system also acts as the finishing agent, e.g., as flame retardant, softener, water repellent, antistatic agent et cetra. A variety of binder types are available in the market. The main types are acrylics, styrene-butadiene, vinylacetate ethylene, vinylacetate acrylates, polyvinyl chloride, and homopolymer of vinylacetate.

Web formation

The laying down of the fibers to create a loosely held fibrous web structure is called as web formation. The formed web at this point is weak. The length of the fibers in the web is dependent on the web formation technique. The fibers can be discontinuous (staple) or continuous (filament) in length. There are many web formation techniques; the detailed description is given in the following section on classification of nonwoven fabrics.

There are many nonwoven web formation techniques, they can be divided into the following four generic categories [8, 9]: 1) Dry laid; 2) Wet laid; and, 3) Polymer laid, 4) Composite.

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Dry laid. Dry laid web structures are produced using principles and machinery associated with textile or pulp fiber handling [9]. In the dry laid process, first a natural and/or man-made staple fibrous web is prepared using carding machine or air laying machine:

> *Carded webs.* The carded webs are produced using conventional carding machines. A carding machine processes the fibers mechanically through a series of rollers covered with a saw tooth metallic wire or fillet card clothing. The web is created by condensing the fibers on a doffer roll [10]. A single layer of carded web is too light and diffuse to make into a fabric. Therefore, a number of layers must be laid on top of one another to get the necessary weight. The simplest way of doing this to put several carding machines in line and lay the carded web on top of one another. The fiber orientation in the web is manipulated by cross laying, and by laying parallel and cross laid webs on top of one another thus making a composite web.
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> *Air laid webs*. The air laid web is produced by air-laying or mechanical fiber randomizing processes. The fibers are first suspended in air and then deposited randomly on the conveyor belt or screen. The fiber size is relatively short, up to 75 mm in length. The orientation of fibers in the web is usually completely random and the properties of the web are somewhat isotropic. The best known random laid machine is the Rando-Webber manufactured by the Curlator Corporation of USA.

The carded or air laid web is then processed to achieve fiber-to-fiber bonding by chemical, mechanical, solvent, or thermal means to produce a nonwoven fabric with sufficient dimensional stability. The web weight range from 1 to 90 ounces per square yard. Typical end-uses for dry laid nonwoven fabrics are interlinings for garments; fabrics for carpet backing; diaper coverstock; apparel and upholstery backings; filter media; wipes; and personal hygiene fabrics.

Wet laid. Wet laid structures are produced using principles and machinery associated with papermaking [9]. In the wet laid process, natural or man-made fibers are first mixed with chemicals and water to obtain a uniform dispersion called a "slurry", at a very high dilutions of 0.01 to 0.5% weight of the fiber. The "slurry" is then deposited on a moving wire screen where the excess water is drained off, leaving the fibers randomly laid in a uniform web, which is then bonded and finished as required. The webs are usually formed at rates up to 300 m/min from textile fibers and up to 2500 m/min for tissue made from wood pulp fibers. The fiber length is very short, less than 10 millimeters, in most commercial processes. The web weight range from 0.3 to 16 ounces per square yard. Typical end-uses for wet laid nonwoven fabrics are tea bags, towels, wipes, surgical gowns and drapes, and others.

Polymer laid. Polymer laid structures are produced using principles and machinery associated with fiber extrusion [9]. In polymer laid process, first a molten polymer is extruded through a spinneret to form filaments or fibers. These filaments/fibers are then laid down on a moving conveyor belt to form a continuous web. The web is then bonded mechanically or thermally to make a polymer-laid nonwoven fabric. In most of the polymer laid webs, the fiber length is continuous. The filament/fiber diameter range from 0.5 to 50 μm. The web weight range from 0.5 to 20 ounces per square yard. Typical end-uses for polymer laid nonwoven fabrics are carpet underlay, packaging material, durable papers, geotextile fabrics, diaper and personal hygiene top sheeting, apparel and upholstery backing fabrics, and surgical drapes and gowns.

Composite. Composite nonwoven structures are produced using principles and machinery associated with fabric laminating or coating [9]. Usually, the composite structures are produced using pre-formed fabrics. A good example of composite structure is spunbond-meltblown-spunbond (SMS) fabric from Kimberley-Clark Corporation.

Web consolidation

Once the web is formed, the bonding of loosely held fibers in the web through some means is called as web consolidation. The web consolidation provides strength and integrity to the web. The web consolidation or bonding technique is divided into three generic categories: Mechanical, Chemical, and Thermal. Mainly the ultimate fabric applications and/or type of the web dictate the choice of a particular bonding technique. Occasionally, a combination of two or more techniques is employed to achieve bonding.

Mechanical. In mechanical bonding, the nonwoven web is bonded by entangling the fibers through mechanical means such as, needle punching, stitching, and spunlacing.

> *Needle punching*: In this process the fibers are entangled with each other by the use of barbed needles. The barbed needles, which are set into a board, penetrate into the web and then recede, leaving the fibers entangled. The degree of fibrous entanglement is manipulated by varying needle configuration, needle length, barb shape, and web advance rate. The form of a needle punch bond is more like a series of three-dimensional floating anchor points. The needle-punched web is quite extensible, bulky, and conformable [13]. It is easily adapted to most fiber web and requires less precise control than thermal bonding. In addition, it is the only bonding method suitable for the production of heavyweight nonwoven fabrics, as an example, 800 g/m^2. It is, however, only suitable for the production of uniform fabrics over 100 g/m^2, since needling tends to concentrate fibers in areas resulting in loss of visual uniformity at lower weight [11]. Usually, drylaid and polymer laid webs are needle punched. The

needle punching is used for geotextile fabrics, carpet-backing fabrics, automotive carpets, and blankets.

Stitch bonding. In stitch bonding, usually a fleece is made by cross-lapping the web from conventional flat cards. The fleece is then fed through the stitch area of the machine, where needles knit through the web warp threads of either man-made or staple spun yarns to consolidate the web into a nonwoven fabric. Stitch bonded fabrics are used for decorative fabrics, backing fabrics for artificial leather, shoe fabrics, and many others [14].

Spunlacing. This process is also as hydroentangling. In this process, high-pressure water jets entangle the fibers instead of needles. Usually, a staple fiber web from either a card or air-laying machine is layed on a perforated belt and is passed under high-pressure water jets. The high pressure jets of water cause the fibers to migrate and entangle according to the perforation in the belt. The web is then impregnated with binder in order to seal segments of the structure. Spunlaced fabrics are used for dust clothes, wipes, medical gowns, medical dressing, and disposable headrest covers in planes [14].

Chemical. In chemical/adhesive bonding process, polymer latex or a polymer solution is deposited in and around the fibrous structure and then cured thermally to achieve bonding. The bonding agent is usually sprayed onto the web, saturated in the web through various means, or printed on the web. In spray bonding, the bonding agent usually stays close to the surface of the material, resulting in a web with a little strength, high bulk, and a fair degree of openness. In saturated bonding, all the fibers are bonded to each other in a continuous matrix tending to give rigidity, stiffness, and thinness. Print bonding imparts varying degrees of openness, flexibility, breathability, and bulkiness in the unprinted areas.

Thermal. In this technique, the bonding is achieved by fusing of the thermoplastic fibers in the web at the crossover points. The fusion is achieved by the direct action of heat and pressure via a calender, an oven, a radiant heat source, or an ultrasonic vibration source. The degree of fusion determines many of the web qualities, most notably hand or softness. The web being bonded can be made by dry laid, wet laid, or polymer laid process. With the exception of mechanical bonding technique, chemical/adhesive and thermal techniques can be divided into two:

Point Bonding. The point bonding involves cohering of the filaments in small, discrete, and closely spaced area of the webs using temperature, pressure, and/or adhesives. Since point bonding can be accomplished with as little as 10% bonding area (90% unbonded area), such fabrics are considerably softer and more textile-like in handle [11].

Area Bonding. The area bonding involves the use of all available bond sites in the web; however, every filament/fiber contact is not necessarily bonded, since not every contact necessarily is capable of forming a bond [12]. The bonding is achieved by passing the web through a source of heat, usually steam or hot air, and pressure. The area-bonded web is stiffer and more paper-like in appearance than point bonded web.

The following are the ways to achieve a thermal bond:

Thermal calendering. In this process, bonding is achieved by using an amorphous polymer binder fiber, a bicomponent binder fiber, a film, or the outer surface of a homogeneous carrier fiber as the bonding agent [13, 15].

Through-air oven. In this process, the binder fiber or powder melts entirely and forms a molten nucleus at the closest intersection of fibers in the web. Upon cooling, the binder solidifies and forms a weld spot [13].

Radiant heat source. In this process, a web is exposed to infrared radiant energy source. The heat energy is absorbed by the web, which results in melting of the binder fiber. Upon cooling, the binder solidifies and bonding takes place [13].

Ultrasonic vibrations. In this process, rapidly alternating compressive forces are applied to a localized area in the web. The stress build up due to compressive forces eventually gets converted into thermal energy, which makes the fibers soft and tacky. Upon cooling, the softened fibers make a bond with other fiber [13].

The nonwoven products manufactured using this method of bonding include most spunbond fabrics, diaper coverstocks (carded as well as spunbond), decorative fabrics, and many more.

Web finishing and converting

Web finishing is often performed after consolidation. Finishing treatments are applied to improve texture and feel of the web, and sometimes to alter properties such as, porosity, breathability, absorbency, and repellency. Finishing treatment methods are divided into two: mechanical finishing and chemical finishing. The mechanical finishing includes creping, embossing, calendering, and laminating. The chemical finishing include dyeing, printing, anti static and anti microbial treatments.

After the finishing step, nonwovens are often converted to end-use products on an integrated machine. As an example, folded towels or premoistened wipes for babies. The converting process usually includes one or more of the following steps: winding, rewinding, slitting, folding, cutting, sewing, sterilization, impregnation, and packaging.

Many a times, nonwoven fabrics require finishing treatment. However, the great majority of the nonwoven products are used as they are sold in the unfinished state. The principal finishing operations are divided into two: mechanical and chemical.

Mechanical. The mechanical finishing processes include calendering, brushing, embossing, laminating, creping and crushing.

Chemical. The chemical finishing processes include bleaching, dyeing, printing, surfacing, sizing, anti-microbial treatment, and flame-retardant finish.

Fibers Used in Nonwovens

The fiber requirements for nonwovens have become more demanding and challenging in recent years. This is simply because of the new technical and innovative uses of the nonwovens in a variety of applications. The fibers for nonwovens come in a variety of types and forms. The fibers provide the structural element to nonwovens. The following is a brief overview of fibers used in nonwovens.

Fiber selection is very critical in nonwovens and is dependent mainly on the end use performance and requirements. In this section we will explore the different types of fibers being used in nonwovens and their characteristics and properties. Before going any further first let's discuss the definition of a fiber.

Fiber is defined as, "a unit of matter characterized by flexibility, fineness, and a very high length-to-width ratio." The length-to-width ratio should be above 1000. Table 1 lists the length-to-width ratio of various fiber types.

A variety of fiber type, and forms are available and used in nonwovens, however, all nonwoven processes can not accommodate all available fiber types and forms. The fiber requirements are both product and process dependent. Therefore, each nonwoven process or product has a unique fiber requirement.

Classification of Fibers

The fibers used in nonwovens can be classified into three categories namely, Natural, Synthetic, and Bicomponent. A classification scheme is shown in Figure 2.

Natural Fibers. A natural fiber is "any fiber that exists as such in the natural state." These fibers can be readily converted into nonwovens. Many types of natural fibers are used in nonwovens for a variety of applications. The most commonly used natural fibers are Wood pulp and Cotton. Other natural fibers such as Wool, Kenaf Flax, Coconut or Coir, and Jute are used in special applications.

Woodpulp. A purified natural fiber extracted from hardwoods or softwoods in which the chief constituent is Cellulose. It is hydrophilic and mainly used as absorbent component of personal hygiene and sanitary products. The woodpulp or fibers are extracted from wood chips using one the following three methods: 1) Chemical Pulping Process; 2) Wet Grinding Process; and, 3) mechanical impaction process. Mostly the woodpulp fibers extracted using chemical pulping process are used in nonwovens.

Wood pulp fibers are natural, renewable, and abundant. A variety of woodpulp fibers are available, but for the absorbent applications, woodpulp fibers derived from soft wood chips such as from Southern Pine, hemlock, or other softwood trees are preferred [16].

Cotton. Cotton is often classified as vegetable fiber in which the prime constituent is cellulose, a carbohydrate that on account of its macromolecular structure is hydrophilic and very hygroscopic [17]. Cotton is the most important natural fiber used in nonwovens today. They are used in healthcare applications, filtration, personal care, and furnishings.

Wool. Wool fibers are derived from animal skin follicles. The term 'wool' refers to the fiber from the fleece of the sheep or lamb or hair of the Angora or Cashmere goat and may include the so-called specialty fibers from the hair of the camel, alpaca, llama, and vicuna. Sheep's wool is by far the more important type of wool fiber because it is the most plentiful [17]. The wool fibers are not used very much in nonwovens because of variations in quality and physical properties. However, in some instances the variation in physical properties such as thickness of the fibers is advantageous. Nonwovens from wool retain their shape fairly well and also provide high bulk, making them good insulators.

Kenaf. The Kenaf fiber is obtained from the bast layer of the plant Hibiscus cannabinus [17]. The properties of this fiber is similar to jute, Therefore, kenaf is used either as an alternative to, or in admixture with, jute. Due to its high temperature and humidity stability it is mainly used for industrial applications such as automotive interior.

Flax. The flax fiber is a natural, cellulosic, muticellular bast fiber. It is obtained from the inner bark of the stem of a plant grown in temperate and subtropical regions of the world [17]. The fabrics made from flax fibers are often referred as 'linen fabrics'. Flax fibers are mainly used in industrial nonwovens. In Europe flax fiber nonwovens are used as car interliner.

Coconut or Coir. It is obtained from the fibrous mass between the outer shell and the actual nut of a coconut.

After steeping in hot seawater, the fibers are removed from the shell by combing and crushing. It is classified as a seed fiber [17]. The coir fibers are stiff and have good resistance to abrasion, water, and weather. They are mainly used in matting or padding and filling for upholstery.

Jute. It is taken from the stem of the jute plant. Jute is also a bast fiber. Jut is shorter than most of the bast fibers which make it difficult to spin. Jute nonwoven webs are mainly used as carpet backing.

Synthetic Fibers. A synthetic fiber is "any fiber derived by a process of manufacture from any substance which, at any point in the manufacturing process, is not a fiber." Most of the synthetic fibers are based on the synthetic organic polymers. These synthetic organic polymers are derived from petroleum as well as from natural source such as cellulose.

Several synthetic fibers are being used in nonwovens. The most commonly used fibers are based on one component. In special applications, sometimes bicomponent fibers are used. There are two types of fibers available, namely, Organic and Inorganic. Organic fibers are hydrocarbon based while Inorganic fibers are a mineral or metallic based.

Organic Fibers. Organic fibers are divided into two categories, namely, Natural Polymer Base and Synthetic Polymer Base. The Natural Polymer Base fibers used in nonwovens is usually regenerated cellulosics. Usually cellulose or its derivative is dissolved in a suitable solvent and continuous fibers are extracted. The petroleum polymer base fibers are produced by reacting petroleum-based monomers with suitable catalyst.

Natural Polymer Base

Acetate. A manufactured fiber in which the fiber-forming substance is cellulose acetate where 92% of the hyrdoxyl groups is acetylated. These fibers are soft and suppple, and also have lower modulus than cotton. Due to their low softening point (180°F) they are mainly used as a binder fiber in nonwovens.

Rayon. A manufactured fiber composed of regenerated cellulose, as well as manufactured fibers composed of regenerated cellulose in which substituents have replaced not more than 15% of the hydrogen of the hydroxyl groups. It is hydrophilic and mainly used in absorbent and feminine hygiene products.

Rubber. Rubber is a natural polymer obtained by coagulation of the latex produced by certain species of plant, notably Hevea brasiliensis, the rubber tree that grows in tropical regions. The natural rubber is a polymer of isoprene in which the isoprene units are arranged in the cis configuration.

In 1930's extrusion techniques were developed to produce continuous rubber filaments from rubber latex. In production of rubber filaments, Rubber latex is mixed with vulcanizing agents, accelerators, antioxidents, pigments and other materials, and is extruded through glass spinnerets into a coagulating bath, commonly of acetic acid. The jets of latex coagulate, and the filaments are washed, dried and heated to bring about vulcanization of the rubber. The filaments are thus converted into fine highly elastic threads, which are dusted with talc to provide a smooth surface, which facilitates processing.

Rubber filaments are resistant to most inorganic acids, but is attacked by concentrated sulfuric acid and by oxidizing acids such as nitric and chronic acids. Rubber has good resistance to alkalis. Rubber filaments are used where elastic properties are needed, such as in baby diapers or in adult incontinence products.

Petroleum Base

Acrylic. A manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of acrylonitrile units. Usually the fibers are spun from acrylonitirle or co-acrylonitrile polymers therefore they are commonly referred as polyacrylonitrile (PAN) fibers. PAN polymer is dissolved in a solvent such as dimethyl formamide. The fibers are extruded in hot air or nitrogen steam moving in opposite direction to evaporate the solvent and carry the solvent to recovery system. The filaments are hot stretched to final diameter.

The earlier PAN fibers were exclusively spun from 100 percent acrylonitrile. But most of the present day PAN fibers are based on copolymers to improve dyeability and bulkiness. PAN fibers are used largely in staple fiber form for dry and wet laid nonwovens. The properties of the PAN fibers vary over a wide range. Typically they provide excellent chemical, mildew, and thermal resistance. PAN fibers are resistance to most organic solvents and the fiber strength is unaffected when exposed to organic solvents.

Aramid. A manufactured fiber in which the fiber-forming material is long chain synthetic polyamide having at least 85% of its amide linkages attached directly to two aromatic rings. Aramid fibers are based on aromatic polyamid polymers. These fibers are extremely strong and stiff resulting from their crystal structure and orientation. The presence of aromatic groups also makes them flame resistance and thermally stable. The Aramid fibers are mainly used in industrial applications, such as heat shield fabrics, heat resistance gloves, and needlepunched bulletproof fabrics.

Novoloid. A manufactured fiber containing at least 85% by weight of a cross-linked novolac. Novoloid fibers are cross-linked phenolic-aldehyde fibers typically prepared by acid-catalyzed cross-linking of a melt-spun novolac resin with formaldehyde. Such fibers are generally infusible and insoluble, and possess physical and chemical properties that clearly distinguish them from other synthetic and natural fibers.

These fibers are generally elliptical in cross-section, with a ratio of diameters of approximately 5:4. They are light gold in color and darken gradually to deeper shades with age and exposure to heat or light, although there is no significant concomitant change in other fiber properties. The fibers have a very soft touch or hand, and are generally without appreciable crimp. They are used in wet and dry laid nonwovens, frictions sealing applications, filtration and surface veils.

Polyamide. A manufactured fiber in which the fiber-forming substance is any long chain synthetic polyamide having recurring amide groups (—NH—CO—) as an integral part of the polymer chain.

There are two types of polyamide fibers available for nonwovens, namely Nylon 66, which is polyhexamethylene diamine adiapmide, and Nylon 6, which is polycaprolactum. Nylons have good chemical and dimensional stability therefore they used in filter fabrics specially for oils. Nylons also have good strength properties, which make it one of the toughest fibers in common use. It has excellent abrasion resistance and can withstand rigorous rubbing and scraping. Nylon is not commonly used fiber in nonwovens. It is used in resin bonded and needlepunched nonwovens.

Polybenzimidazole (PBI). A manufactured fiber in which the fiber-forming substance is a long chain aromatic polymer having recurrent imidazole groups as an integral part of the polymer chain. The base polymer is made from tetraaminobiphenyl and diphenyl isophthalate and the fibers are dry spun from a dope with dimethylacetamide as the solvent.

PBI fibers are considered to be high performance fibers with high chemical resistance that does not burn in air. The fiber retains flexibility, dimensional stability, and significant strength even after a prolonged exposure to flame or extreme heat. It has high moisture regain and low modulus with comfort properties similar to cotton. The natural color of the fiber is Khaki but can be dyed to any medium or dark shade.

Due to their excellent thermal and chemical resistance combined with good comfort properties, the PBI fibers are used for high temperature protective apparel, insulation, and filtration applications. Usually PBI fibers are carded and needled punched for many of the applications.

Polyester. A manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of an ester of dihydric alcohol and terephthalic acid. The polyester resins are produced using one of the following methods: (1) The glycol and a terephthalate ester react to form a polymer chain, releasing methanol; or (2) the glycol and trephthalic acid react directly to form the polymer with water as the by-product. The fibers are melt spun from the polymer. Polyester fibers can be modified in many different ways to meet a variety of end use requirements. The main uses of polyester fibers are in interlining and filter applications.

Polyolefin. A manufactured fiber in which the fiber-forming substance is any long-chain synthetic polymer composed of at least 85% by weight of ethylene, propylene, or other olefin units except amorphous (non-crystalline) polyolefins qualifying as defined in the Textile Fiber Products Identification Act.

The polyolefin polymers are manufactured using saturated hydrocarbons (compounds with a double bond between two carbon atoms). Although there are many potentials saturated hyrdrocarbons that can be used to synthesis, only two can be successfully synthesized to form fibrous polymers, namely, ethylene and propylene. The polymerization of propylene and ethylene yields polypropylene and polyethylene.

Polypropylene. Polypropylene (PP) is classified as the olefin fiber. Under suitable polymerization condition, the propylene monomer produces fiber forming polypropylene resin.

PP is the most widely used resin in nonwovens especially in polymer-laid nonwovens. PP exists in three forms: isotactic, syndiotactic, and atactic. Only isotactic PP is the principal type used commercially because it allows polymer chains to pack closely enough for crystallization.

> *Isotactic PP.* It is a stereo specific polymer because the propylene units are added the head to tail so that their methyl groups are all on the same side of the plane of the polymeric backbone. It crystallizes in helical form and exhibits good mechanical properties, such as stiffness and tensile strength. Isotactic PP is sold commercially in three basic types of product: homopolymer, random copolymer, and block copolymer. Homopolymer has the highest stiffness and melting point of the three types and is marketed in a wide range of melt flow rates (MFR).

Syndiotactic PP. It is made by inserting the monomer units in an alternating configuration. It lacks the stiffness of the isotactic form, but has better impact resistance and clarity.

Atactic PP. It is made via a random insertion of the monomer. This form lacks the crystallinity of the other two. It is mainly used in roofing tars and adhesives applications.

Fiber grade PP resins are mainly isotactic homopolymer. PP homopolymer when drawn or oriented, gives a material with improved tensile, stiffness, tear strength, and clarity resulting from the alignment of the polymers during orientation step. Several important fiber technologies take the advantage of the drawability of PP resins and are major consumers of PP resins. Low-melt flow resins are used for monofilaments and slit film applications. Medium to high melt flow rates polypropylene is used to produce continuous fine denier filaments, extruded through spinnerets in a process called melt spinning. Spunbonding process usually requires narrow molecular weight distribution with high melt flow rate resin, typically 30 to 80 MFR. Melt blowing process can have a wide range of narrow molecular weight melt flow rate resin, typically 30 to 1500 MFR.

Polypropylene is mainly used in diaper coverstock, disposable garments, air filter fabric, and as a binder fiber in cotton based nonwovens.

Polyethylene. Polyethylene (PE) resin is a newcomer in polymer-laid nonwovens. The availability of fiber grade PE resin was first announced in 1986. Polymerizing ethylene monomer makes polyethylene. It can also be copolymerized with other materials to modify or enhance properties. For example, the density of polyethylene can be manipulated by the type and amount of comonomer reacted with ethylene to make the polymer. This commoner, in combination with the manufacturing process, affects the type, frequency, and length of branching occurring in molecule. There are three basic types of polyethylene, namely:

HDPE Resin. The term HDPE is an acronym for high-density polyethylene. The typical density of this resin is 0.950 g/cc and higher.

LDPE Resin. The term LDPE is an acronym for low-density polyethylene. The typical density of this resin range from 0.910 to 0.925 g/cc.

LLDPE Resin. The term LLDPE is an acronym for linear low-density polyethylene. The typical of this resin range from 0.915 to 0.930.

Fiber grade PE resins are mainly HDPE and LLDPE. Low melt flow rate HDPE resins are used for filament applications. Medium to high melt flow rate LLDPE resins are used to produce continuous fine denier filaments. Both spunbonding and meltblowing require a medium melt flow rate PE resins. Typical range is 0.5 to 300 melt flow rate.

Polyphenylene Sulfide (PPS). A manufactured fiber in which the fiber-forming substance is any long-chain polymer composed of at least 9=85% of the sulfide linkages attached directly to two aromatic rings. This is a high melting point, high heat resistance, excellent chemical resistance, and high strength fiber. This fiber is available only in staple form and used in high temperature filtration applications and protective clothing. Usually used in needlepunched or wetlaid nonwovens.

Polytetrafluoroethylene (PTFE). Fluorine containing manufactured fibers characterized by high chemical stability, relative inertness, and high melting point. PTFE fibers are made by emulsion spinning, a process that essentially results in fusion of fibrils by passing an emulsion through a capillary, then drawing the resulting fiber. The resulting fibers consist of chains of carbon atoms, linear, and no cross-linking, with each carbon atom carrying fluorine atoms. The fiber has a modest tensile strength and is particularly resistant to the effect of high temperatures and corrosive chemicals. It has a very low frictional coefficient and therefore provides slippery hand and non-stick properties. They are also non-flammable and have excellent ultra-violet and extreme weather stability. These fibers are mainly used in high temperature filtration applications. Usually carded PTFE web is needled onto a woven fabric substrate. The PTFE layer provides the thermal and chemical resistance. Moreover, the non-stick nature of the PTFE is beneficial in easy removal of filter cake providing a longer serviceable life.

Spandex. A manufactured fiber in which the fiber-forming substance is a long chain synthetic polymer composed of at least 85% of segmented polyurethane. The term spandex is thus based on the chemical structure of the fiber. The Spandex fibers are elastomeric in nature. In fact they are referred as synthetic rubber and have been used in place of natural rubber filaments.

The technique used in Spandex fiber spinning depends on the chemical structure of the fiber. One of the three generic synthetic fiber-spinning methods can be used; namely, melt, solution, and wet or reaction spinning. Of the three spinning methods, dry or solution spinning is most widely used in the production Spandex filaments. In dry or solution spinning method, first polyurethane pre-polymer is dissolved in a suitable solvent and additives. The dissolved polymer solution is dry spun at a rate of more than 200m/min into a long chamber heated to 340 °C to evaporate the solvent. The filaments are then wound on core for subsequent processing.

Spandex is lighter in weight, more durable, and suppler than conventional rubber filament. Spandex can be extruded into very fine filaments and can be repeatedly stretched over 500% without breaking and 100% recovery. Spandex has good chemical resistant and does not deteriorate from oxidation. It also has resistance to body oils, perspiration, and detergents.

Superabsorbent Fibers or Powder. These fibers are derived from superabsorbent polymers. They are commonly referred as SAP fibers. They are mainly used to absorb large quantity of water or other bodily fluids. The SAP fibers are designed in such as way that they well on absorbing liquid and become hyrdogels that can retain most of the liquid, even under pressure [16]. These fibers exhibit: high rates of absorbency, high water retention, insolubility in water and most organic solvents, and stability to heat and light. They are usually blended with woodpulp and used as absorbent core material in baby diapers and sanitary pad.

Vinyon. A manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of vinyl chloride. These fibers have low moisture regain, low flammability, low strength, and high static electricity. They are mainly used in industrial nonwovens such as in filtration.

Inorganic Fibers. These fibers are derived from minerals. Inorganic fibers are manufactured from different minerals except asbestos, which is found in fibrous state.

Glass A manufactured fiber in which the fiber forming substance is glass. The key properties are moisture resistance, high stiffness, good dimensional stability, high temperature stability, and high electrical resistance. The glass fibers are predominantly used in air and liquid filtration.

Metallic A manufactured fiber composed of metal, plastic-coated metal, metal-coated plastic or a core completely covered by metal. These are specialty fibers and mainly used in high temperature industrial applications such as gas, liquid, and membrane filtration.

Bicomponent Fibers. These fibers consist of two components divided, along the length of the fiber, into two or more distinct regions. The bicomponent fibers can be classified into several types according to the manufacturing and also component distribution within the fiber cross sectional area. The main types of bicomponent fibers are Sheath-core, side-by-side, islands-in-the-sea, and citrus. Of these four types, Sheath-core type is most popular in nonwovens. Sheath-core fibers are manly used in thermal bonding and spunbonding web production, where the core component provides the strength to the web and the sheath component provides good coherent bonding among fibers. The use of bicomponent fibers in nonwovens is still in its infancy. The advancement in bicomponent spinning technologies and new applications requirements will dictate more use of these fibers in future.

Fiber Manufacturing

Natural fibers are naturally available in staple fiber form except silk fiber, which is continuous. Therefore, they do not undergo a manufacturing process. Once the natural fibers are collected from various sources, such as vegetables and animals, they go through extensive processing to make fiber suitable for further processing, such as carding.

The synthetic fibers are manufactured through a process called spinning. The word spinning has been adapted from the textile manufacturing process. In textile manufacturing operations, spinning is a process where staple fibers are formed into continuous textile yarns by several consecutive steps, such as opening, carding, roving, attenuating and twisting. In synthetic fiber manufacturing, spinning refers to general process of polymer extrusion, fiber formation and attenuation.

The are three generic types of spinning techniques employed in the manufacturing of the synthetic fibers. The concept of these three generic spinning techniques is directly adapted from the conventional filament fiber spinning techniques. The three generic spinning techniques are Melt, Dry, and Wet. The following is a brief discussion on these techniques [13]:

Melt Spinning. It is a process in which the fiber-forming polymer is melted and extruded into air or other gas, where it is cooled and solidified, as in the manufacture of olefins, polyester, and nylon.

Dry Spinning. It is a process in which a solution of the fiber-forming polymer is extruded in a continuous stream into a heated chamber to remove the solvent, leaving the solid filament, as in the manufacture of acetate.

Wet Spinning. It is a process in which a solution of the fiber-forming polymer is extruded into a liquid coagulating medium where the polymer is regenerated, as in the manufacture of viscose or cupra-amonium rayon.

Properties of Fibers

Since the fiber is the basic structural element in nonwovens, the fiber properties directly contribute to the final performance of nonwovens and also conversion into nonwovens. A minor variation in fiber properties sometimes can have a strong effect on their processibility and end use performance. Therefore, it is extremely important to understand the various properties of fibers. Knowledge of fiber properties will also help in selecting the right fiber for a nonwoven. Usually the fiber properties are classified into three categories: Physical, Mechanical, and Chemical.

Physical Properties. The physical properties of fibers mean different surface and morphological characteristics. Some of the important physical properties of fibers for nonwovens applications are as follows: Fiber length, fiber denier or size, cross-section, surface contour, crimp, moisture absorption and regain, covering power, thermal shrinkage, melting point, molecular weight distribution, and abrasion resistance

Mechanical Properties. The mechanical properties of fibers mean the study of structural responses to applied forces and deformations. These properties contribute both to the behavior of fibers in processing and to the properties of the final nonwoven webs. The mechanical properties of a fiber cover a large number of effects, all of which combine to determine the particular character of the fiber. Because of their shape, the most studied and, in many applications, the most important mechanical properties of fibers are their tensile properties—their behavior under forces and deformations applied along the fiber axis [*]. The tensile properties include strength, elongation, initial modulus, and elasticity.

Chemical Properties. The chemical properties of fibers mean the ability of fibers to withstand the effects of external chemicals or agents during processing and during the use without suffering harmful effects. Some of the important chemical properties are resistance to acids, alkalis, and organic solvents, resistance to insects and microorganisms, and effects of sunlight and infrared radiation.

Characteristics and Properties of Nonwoven Fabrics

Nonwoven fabrics are quite distinct and versatile in their characteristics and properties compared to the conventional woven and knitted fabrics.

The key characteristics of nonwoven fabrics are as follow [18]:

Physical properties—adjustable to a certain extent;

Handle—adjustable between extremely soft and extremely hard, but this adjustment causes marked changes in other properties;

Drape—falls between conventional textiles and paper;

Surface area—always greater than conventional textile fabric;

Bulk—adjustable, usually greater than conventional textile fabric;
Appearance—with some exceptions, less attractive than that of conventional textile fabric;

Price—usually cost effective than conventional textile fabric.

The woven and knitted fabrics manifest their properties from the arrangement of fibers in the yarn and the arrangement of yarns in the fabrics [19]. Likewise, the properties of nonwoven fabrics are largely dependent on fiber properties, fabric structural geometry, and particularly the type of fiber-to-fiber bonding. Moreover, nonwoven fabric properties can be "tailor-made" through the use of the various web manufacturing and bonding processes, the selective use of fibers/raw materials, and various finishing processes.

Uses of Nonwoven Fabrics

Nonwoven fabrics are entering a continuously broadening field of applications with new products appearing almost daily. Although, disposable surgical and sanitary nonwovens were among the first to gain recognition, the diversity of applications and growth possibilities for new products lies principally in the area of apparel applications and durable industrial fabrics. The uses of nonwovens can be classified as follows:

Automotive. Today nonwoven webs are used throughout the automobile in many different applications. One of the major uses of nonwoven webs in automobile is as a backing for tufted automobile floor carpets. The nonwoven webs are also used for trim parts, trunkliners, interior door panel, and seat covers.

Civil Engineering. The nonwoven fabrics used for civil engineering are often called as geotextiles. Nonwoven geotextiles are expanded into a multiple of related uses, e.g. erosion control, revestment protection, railroad beds stabilization, canal and reservoir lining protection, highway and airfield black top cracking prevention, roofing, etc [15]. The particular properties of nonwoven webs, which are responsible for this revolution, are chemical and physical stability, high strength/cost ratio, and their unique and highly controllable structure, which can be engineered to provide desired properties [15].

Clothing. In clothing applications, the nonwovens are used principally as interlinings and interfacing fabrics, because of their special quality of crush resistance, shape retention, and resiliency [10]. Presently nonwovens, such as melt blown, are also used as thermal insulator in fashion garments.

Household. The nonwoven webs are extensively used in household products. The principal use include, bed spreads, napkins, closet accessories, table cloth, wash cloth, wipes, window shades, drapery headers, dust cloth, sheet and pillow cases and many more.

Sanitary and Medical. The use of nonwoven web as a coverstock for diapers and incontinence devices has grown dramatically in the past decade. This is mainly because of the unique structure of nonwoven, which helps the skin of the user dry and comfortable [11]. And also, the nonwoven webs are cost effective over the conventional textile fabrics.

In medical applications high performance nonwoven webs have replaced many traditional materials. The particular properties of nonwoven webs, which are responsible for medical use, are breathability; resistance to fluid penetration; lint free structure; sterilizability; and, impermeability to bacteria. The medical applications include: disposable operating room gowns; shoe covers; and, sterilizable packaging [11].

Packaging. Nonwoven fabrics are widely used as packaging material where paper products and plastic films are not satisfactory. The examples include: metal-core wrap, medical sterile packaging, floppy disk liner, high performance envelopes, and stationery products.

Closing Remarks

Nonwoven fabric technology is the most exciting segment of the textile industry and will be one of the most important in the years ahead as nonwoven fabrics penetrate many more areas now occupied predominantly by conventional textiles [3]. Despite the maturity of some of the nonwoven technologies, their growth is expected to continue at a steady rate. The technologies expected to gain importance are spunbonding, melt blowing, and spunlacing. The use of natural fibers will increase due to their renewable nature and they may find many of the niche and innovative industrial applications.

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Table 1. Length-to-width ratio of various fibers.

Fiber	Width (µm)	Length (mm)	L/W Ratio
Silk	11	Continuous	α
Cotton (Short Staple)	18	25	1400
(Long Staple)	18	50	2800
Wool (Apparel)	20	50	2600
(Carpet)	40	150	3800
Nylon (Hosiery)	20	Continuous	α
(Apparel)	16	50 / Cont.	3200 / α
(Carpet)	43	50 / Cont.	1200 / α
Polyester (Apparel)	21	50 / Cont.	2400 / α
Acrylic (Apparel)	19	50	2700
(Carpet)	43	50	1200
Polypropylene (Carpet)	48	50 / Cont.	1100 / α

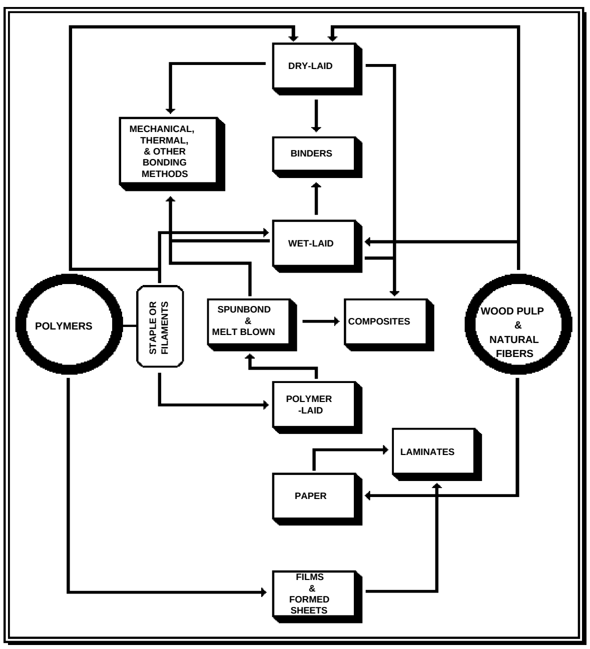

Figure 1. Flow diagram of nonwovens industry complex.

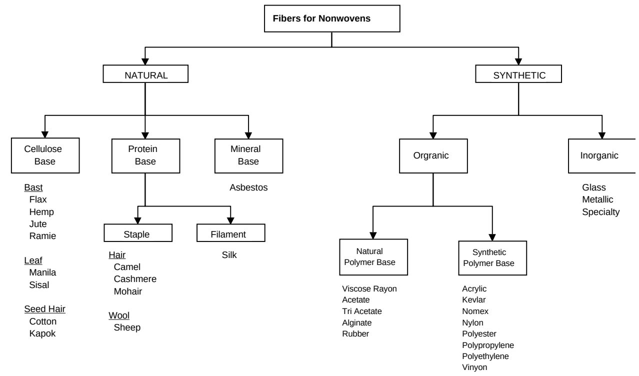

Figure 2. Classification of Fibers for Nonwovens.