

CHAPTER X

NONWOVENS IN ABSORBENT MATERIALS

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1. INTRODUCTION

1.1. Nonwoven Definition

In a discussion of absorbency from either a theoretical or practical point of view, the topic of nonwoven materials enters early and frequently. Two characteristics of nonwovens make them particularly suitable for use in an absorbent structure: high bulk for imbibing and holding large amount of fluid per unit mass of material and low cost of converting raw material into final product. Several other properties that have significant impact on the use of nonwovens in an absorbent fabric are disposability, comfort, and ease of fabrication of the absorbent product. The latter is usually composed of a number of components, each supporting different but important functions. These are to receive fluid, imbibe it rapidly, hold it for a period of time, keep the clothing from soiling, keep the skin of the wearer dry, mask odor, be easily worn and removed, and be conveniently disposed off. Accordingly, the intimate and critical role that nonwoven materials have played in the development of commercial absorbent structures is such that it is often difficult to segregate the specific function of one component from that of another in the composite. Indeed, the challenge in the designing of an efficient absorbent product is to organize the structural elements into an integrated whole that benefits from the synergistic interaction between the parts. Where such cooperative functioning occurs, the maximum potential of the structure is realized.

The important role played by nonwoven materials in commercial absorbent structures has resulted in a somewhat parallel growth in the consumption of disposable nonwovens and absorbent products. This is illustrated by the data given in Table 1 [1], which gives the sales figures for disposable nonwovens and absorbent articles in the world. Accordingly, the growth in the sales and, therefore, in consumption, of absorbent products has been phenomenal during the past 20 years, and the trend can be expected to continue, especially as these products become affordable and adopted by the consumers in the developing countries. According to one forecast, the growth in the nonwoven sector, considering all materials, has been between 5–10 % during the past decade and this trend is expected to be continued during the next decade [2].

Table 1.

Approximate sales of disposable nonwoven fabrics and absorbent products in the world. The figures on absorbent products include those for diapers and training pants, feminine hygiene materials, adult incontinence pads and underpads.

	Sales in Billion \$					
	1975	1980	1985	1990	1995	2000
Disposable						
Nonwoven Fabrics	<0.4	2.2	3.7	4.3	6.0	7.9
Absorbent						
Products	<1.0	6.0	13.0	18.0	25.0	33.0
Diapers/Training						
Pants	<0.5	5.3	8.7	11.9	15.5	21.0
Adult Incontinence						
Pads	Small	0.2	0.4	1.5	2.6	3.8

Despite many attempts at defining the term, a satisfactory, universally accepted single definition of nonwovens is still to be developed [3-5]. A major effort, under the auspices of the International Standards Organization (ISO), has proposed the following [6]:

“A nonwoven is a manufactured sheet of directionally or randomly oriented 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 additionally needled or not. The fibers may be of natural or man-made origin. They may be staple or continuous filaments or be formed in situ.”

This definition suffers from a lack of succinctness and is burdened by additional footnotes, caveats and limitations. This was recognized by Batra et.al. [7] who proposed to classify nonwoven structures into three different groups, namely, the ‘fiber web structures’, the ‘net-like structures’, and the ‘multiplex structures.’ The definition given above closely coincides with that for the ‘fiber web structures.’ In order to account for the remaining structures, that are not knitted, woven or braided, or falling in the category of paper goods, they suggested the other two terms. However, in spite of the vagueness associated with the single term nonwovens, the latter continues to be used worldwide to represent a broad range of materials that are not knitted, woven or braided, or classified as paper, but are webs based on fibers or fibrils.

1.2. Common Usage of the Term

From a practical standpoint, the characteristic that is unique to nonwoven structures, in contrast to woven and knitted materials, is the absence of a yarn element in the fiber web [8,9]. Thus, nonwovens are an assemblage of fibers, which have not been put into an anisotropic yarn form required by the weaving, knitting or braiding processes.

Also, it should be recognized that nonwoven technology has had its genesis in three originating technologies/industries: textile, paper and polymer processing. Thus, there are segments of nonwoven technology (such as carding in the dry form process) that closely resemble a segment of the conventional textile industry. Other nonwoven structures bear an unmistakable resemblance to products of the paper industry (wet form process), while still other nonwoven materials rely heavily on polymer processing technology and synthetic fiber manufacture as a major sequence in their production (spunbond process).

Thus, there is a frequent tendency for more or less all of the structural elements in absorbent products to be classified as "nonwoven", which in one sense they are, being not of a "woven" nature. The somewhat generic term "disposable" has also heightened the tendency to broaden the scope of the definition. This ready acceptance of incorporating a wide variety of materials under a somewhat imprecise label is sufficiently widespread such that new structural materials initially associated with disposable absorbent products are almost inherently accepted as "nonwovens", even though they do not fit the above definition and may even have no fiber content whatsoever. Thus, perforated films, microporous films and high bulk tissues are frequently so classified.

Notwithstanding these problems of definition and classification, nonwoven materials proliferate, new absorbent products are developed and fundamental principles of absorbency are used and combined in producing unique and innovative articles. All of this has been to the advantage of the industry and the consumer.

In the current discussion, a broad view will be taken of the nonwoven materials, beyond that envisioned by the definition given earlier [6] or that proposed under the term 'fiber web structures' [7].

2. NONWOVEN STRUCTURES

In discussing nonwovens, consideration must be given to the interrelationships of the four major structural elements that influence absorbency:

- Constituent fiber.
- Assembly structure; the web properties resulting from the nature of the fiber assemblage.
- Type of bonding; the chemical or mechanical means of conveying integrity to the fibrous web.
- Finish; chemical and/or mechanical treatments conveyed to the formed and bonded web.

Each of these factors can have an effect on the absorbency of the resulting structure.

2.1. Fiber

Virtually every fiber, both natural and man-made, has been used in absorbent nonwoven structures. Naturally, the hydrophilic fibers have received major attention and utilization. Much of the nonwoven technology in use today was initially developed for the cellulosic fibers. Thus, cotton and rayon gave rise to nonwoven technology coming from the textile sector; wood pulp fiber, on the other hand, was the mainstay of nonwoven technology emerging from the paper industry.

In recent years, synthetic organic fibers have found increasing utilization in absorbent structures. Such synthetic fibers are sometimes utilized because of their inherent hydrophobic properties, whereas other structures utilize their generally superior mechanical properties, especially wet physical properties.

Being the structural element, fibers making up a nonwoven have a major influence on the absorbency characteristics. The major fiber properties exerting such an influence include the following: polymer type, linear density or denier, fiber cross-section shape, crimp, fiber finish, and fine structure.

The polymer type, particularly whether hydrophilic or hydrophobic, influences the inherent absorbency properties of the resulting structure. A hydrophilic, swellable fiber gives a structure that is able to absorb liquid via fiber imbibition, giving rise to fiber swelling; such a structure attracts and also holds liquid external to the fiber, in the capillaries and structure voids. A hydrophobic fiber, on the other hand, has only the latter mechanism available to it normally.

Fiber linear density or denier, related to the cross-section area, influences void volume, capillary dimensions and the total number of capillaries per unit mass. Fiber cross-section shape can affect many of the same characteristics but also the nature of the capillaries in a structure. Four deep grooved (4DG) polyester, trilobal rayon, L-shaped nylon are examples that are developed to enhance capillary flow [10,11].

Fiber crimp can influence packing efficiency of fibers and the resulting fabric bulk, both of which can influence the absorbency of a nonwoven structure. Also, the nature of the crimp, whether it is two-dimensional or three-dimensional, can have an influence. Fiber finish can also have an impact. The finish usually consists of a small amount (generally 0.1-0.5% by weight) of lubricant and other formulation components applied topically to a fiber. It is used in order to enhance a fiber's processing performance in the mechanical equipment used to open, blend and convert the fiber into a web. Because the finish is on the fiber surface, and the latter is often the only segment of fiber encountered by liquid, the finish can profoundly affect surface wetting, liquid wicking and other properties, directly influencing absorbency.

Further morphological features, such as surface rugosity, core uniformity, etc., can influence absorbency performance somewhat. This possibility has been exploited in a synthetic acrylic fiber produced with a micro-capillary core [12,13]. The micro-capillaries lead to surface holes along the length of the fiber. Although the fiber cannot swell, it can imbibe a significant quantity of liquid (30% by weight and more) by drawing it into the porous core through the surface perforations. A unique feature of such absorbency is the amount of water that can be held without the perception of surface wetness.

Consumption of major fibers by the North American nonwoven industry in total, that includes the absorbent segment of the industry, is provided in Table 2 [1]. The numbers related to the past decade indicate a surge in the use of polyolefins, a somewhat sustained use of polyester, a steady increase in the use of the natural cellulose fiber and a relatively low (as compared to the figure in 1975) but a steady use of the regenerated cellulose fiber. The changes noted in the numbers related to polypropylene and rayon in the table is to a significant extent due to the replacement of the latter by the former in the coverstock application of the absorbent products and the opening of new markets for meltblown

Table 2.

Shipments of synthetic fibers to North American nonwoven producers (in millions of pounds).

	Shipments (Million Pounds)					
	1975	1980	1985	1990	1995	2000
Polypropylene	13	35	139	231	273	458
Polyester	26	167	165	240	282	275
Cotton	*	*	47	50	68	73
Rayon	139	147	117	73	59	68

* Not available

polypropylene fabrics. Chapter VI contains detailed information on the inherent characteristics of fiber types employed in absorbent structures.

2.2. Web Assemblage

The manner in which the fibers are assembled into a web has profound effect on the web properties. The inherent versatility of the nonwoven process is exemplified by the fact that the web structure can range from the extremes of a highly oriented fiber configuration to one of completely random arrangement. As would be expected, the former has considerably different physical properties in different directions. A maximum in tensile strength would be anticipated along the axis of orientation, and minimum at right angles. Such a structure would be expected to have a minimum of tear strength. Such properties exist in the carded fiber webs of the dry form process. On the other hand, a fiber assemblage with a completely random orientation of individual fibers has isotropic properties, with essentially equal physical characteristics in all directions.

Nonwoven structures can also be assembled with fiber arrangement between these two limits, with the physical properties also lying intermediate to the ones given by the two characteristics. Because the fiber configuration in the nonwoven structure will have an effect on such things as packing, pore size, capillary dimensions, capillary orientation, etc., the absorbency properties of the nonwoven structure can also be expected to be sensitive to the nature of fiber arrangement in the web.

Web formation can also be supplemented by localized rearrangement of fibers giving rise to apertured fabrics [8,9]. This has allowed a manufacturer to engineer fabric with precisely controlled perforations and hence obtain modified liquid transfer properties. Further, the bundling of fibers possible by this process can enhance the fabric wicking capabilities, somewhat reminiscent of woven yarn structures.

2.3. Fiber Bonding

In a woven structure, the frictional forces existing at the yarn interlacings is responsible for the strength and integrity of the fabric. In a similar manner, the yarn frictional forces provide the inherent strength and integrity of the interlooped structure in a knitted fabric. In contrast, the nonwoven structure has less possibility for similar forces, as the structural element is a single fiber or group of fibers and the spaces between elements are

large and contacts between them few. Consequently, a bonding means is required in a nonwoven web to impart mechanical integrity. In general, the bonding can be characterized as derived from either a chemical basis or a mechanical or physical basis; in some cases, it is a combination of the two systems.

Many nonwovens are bonded by the addition of an external chemical binder. The nature of the latter and, in particular, the method of application of the chemical to the fibrous web has a profound effect on the absorbency of the resultant structure [14]. Because most binder materials are hydrophobic, the net effect usually is some reduction in absorbency [15]. In mechanical bonding, the inherent characteristics of the fibers are usually unaffected; consequently, the effect of mechanical bonding on absorbency of fibers is minimal. However, since mechanical bonding, e.g. needle felting, causes entanglement of fibers, two effects can take place: (1) the entanglement may restrict the inherent ability of structure to swell, and (2) the fabric may become more resilient and resist collapse when subjected to external pressure. These changes in the behavior of a web with mechanical bonding can have a significant impact on the capillary absorption of fluid, as has been shown in Chapter III.

2.4. Binders

Although the usual binder normally detracts from the inherent absorbency properties of a nonwoven structure, it is needed in order to generate strength and integrity in the fibrous web. Indeed, it was only with the introduction of efficient, effective binders, that the full growth of the nonwoven absorbent products has been achieved. The original bonding materials consisted of starch, mucilage and other natural animal and plant adhesives. These binders did convey some integrity, but were water-sensitive, stiff and quite inadequate [16].

The synthetic latex binders, originally based on poly(vinyl acetate), carried the nonwoven materials to a new performance level, permitting widespread use in absorbent, related and many other applications. With the advent of binders based on acrylic ester copolymers, a further enhancement in nonwoven performance was achieved that led to the opening of new and more critical applications for nonwovens [17].

A broad selection of chemical binders has been available to the nonwoven technologist, permitting rather precise engineering of the final product performance. Table 3 lists some of the major binder types, with selected characteristics of interest to absorbent applications [18].

Current commercial practice involves a rather extensive formulation of the binder chemical by the fabric manufacturer, in order to achieve optimum performance from the material. Since the application of chemical involves inevitable compromises between absorbency and mechanical integrity, the preparation used is such that it allows one to achieve best balance of properties. Formulation generally involves water dilution of the binder from the original approximately 50% solids, along with use of an acid or latent acid catalyst (to promote internal cross-linking), viscosity modifier, defoaming agent, and a surfactant. The resin add-on can vary from 5 to 50%. With most absorbent nonwoven structures, a resin content of 10-25% by weight is typical.

Table 3.
Chemical binders for U. S. nonwovens production.

Type (Solids %)	App. Share (%)
Acrylic (50%)	47
Polyvinyl acetate/ copolymers (50%)	22
Styrene butadiene (50%)	12
Polyvinyl chloride copolymers (55%)	4
Nitriles (50%)	1
Polyvinyl alcohol (100%)	1
Ethylene/vinyl acetate (100%)	12
Others	1

Because of the concern with the long term effects of chemicals used in the manufacture of the external binders, there has been a trend in recent years to emphasize "binder-free" products. This interest has also motivated the binder manufacturers to modify their polymerization methods and materials, and led to (1) the introduction of plastic dispersion-type binders, with no reactive capability [19] and (2) the development of "low formaldehyde" and "formaldehyde-free" chemicals [20,21]. Further, the concern with the chemical additives has stimulated the adoption and growth of the thermal techniques for the bonding of nonwovens, as these methods eliminate the need for external chemicals.

2.5. Web Finishing

In nonwoven processes, a web is generally "finished" as soon as the fibers are assembled into an appropriate structure and bonded by the selected chemical or physical means. However, it is possible to give additional chemical or mechanical treatment to the bonded web, which can have an important influence on absorbency and related characteristics. Thus, it is possible to put a chemical treatment on the fabric, which will provide a repellent characteristic [22]. At times, such a treatment can be advantageously employed when it is applied to only a portion of an absorbent structure; thus, a method has been described for the application of a liquid silicone chemical treatment to the sides of a sanitary napkin, to give it a "boat-type" containment capability.

Conversely, a chemical finish can be selected which may enhance the absorbency of the nonwoven structure, by modifying the wetting performance of a fiber surface and, therefore, affecting the wicking behavior.

Mechanical treatments can also be given to the substrate which will affect the absorbency characteristics. Mechanical softening treatments may involve fiber displacement, web buckling or other changes and affect the absorbency of the resulting structure. Embossing, calendering and surface glazing, and other mechanical treatments can be utilized to modify web properties and the related absorbency characteristics.

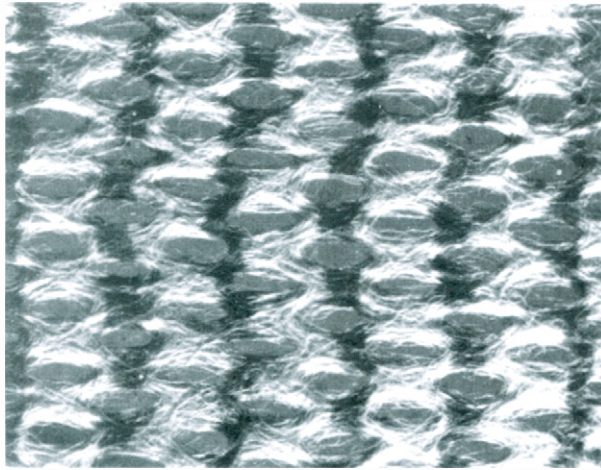


Figure 1. Print-bonded dry form nonwoven.

3. NONWOVEN FABRICATION

Nonwoven structures can be classified by a variety of means, the most common means being the process type or fabrication method. Such classification is usually based on the method of forming the fiber web.

3.1. Uni-Directional Dry Form Process

This process (also called card and bind process or carding process) involves forming a fiber web with fibers predominantly oriented along the longitudinal direction (machine direction). A conventional textile carding machine was originally used for this process; more recently, carding units specifically designed for nonwoven manufacture have been developed and used broadly within the industry [22]. The completeness of fiber parallelization or orientation in the long direction is dependent upon the effectiveness of the carding process, the tension applied to the web during its formation and prior to bonding, and other factors.

A dry form web is characterized by good tensile properties in the direction of the fiber orientation, but by poor properties in the transverse direction. Several methods have been developed to overcome or minimize this deficiency. In print bonding of such a web, careful design (Fig. 1) of the print pattern can help direct the strengthening contribution of the added binder to the weak cross direction [23].

Highly oriented webs can also be laid in plies in the cross direction, conveying fiber strength to that direction. These webs are discussed more thoroughly under the needlepunch process.

3.2. Bonding of Dry Form Web

The bonding method normally employed for the dry form web is chemical, involving a latex binder. The latter can be applied by a variety of methods, including saturation of

fabric, spraying a web, or printing binder with a roll. The saturation method is normally not considered for absorbent materials, as the binder covering virtually all fiber surfaces can greatly interfere with the absorbency process. Spray bonding involves applying spherical droplets of binder to the web via airless or air sprays. This leads to bonding where the fine droplets contact the fiber structure at cross-over points of two or more fibers. When a spray droplet fails to migrate or converge to a cross-over point, it serves no bonding purpose, rather adds weight and stiffness without strength. However, with a control on the amount of binder used by spraying, and appropriate binder rheology, most of the binder can be made to migrate to the cross-over points. The result is that a significant portion of the fiber web is left free of the adhesive, meaning that the fiber web retains its inherent absorbency properties, along with other desirable textile-like characteristics, particularly fabric hand.

The placement of the binder resin can be controlled to an even greater extent by means of print bonding. Innovative print pattern designs and technology associated with it have been developed to maximize the effectiveness of the added binder, with a minimum amount of deleterious effects [8,9]. In general, print bonding involves a compromise between fabric tensile properties, that are enhanced, and fabric properties such as absorbency, softness, and handle, that are degraded, by the process. In this method, the binder is positioned on the web in a discrete pattern. The process permits high control of the location of the chemical and its distribution. Processing conditions are selected such that the resin is distributed uniformly through the thickness of the web, without its migrating laterally outside of the pattern. Thus the binder location can be engineered precisely so that there is maximum benefit from the chemical used and minimum interference from it with the primary function of the structure. Consequently, the print bonding method is preferred for most dry form applications. Application of the binder in a specific pattern is normally achieved via a rotogravure process, utilizing engraved rolls [24]. A rotary screen printing unit can also be employed, with the binder resin used in the form of a paste [25]. More recently, the use of binder in the form of foam has been utilized [26]. This technique leads to reduction in the energy required to dry the printed web, as the latex binder is diluted with air rather than water, resulting in lower water load to be evaporated from the web.

A modification of the conventional dry form process has been used in nonwoven facings for absorbent products. This involves the use of thermal techniques for bonding [27,28]. A fabric contains fibers that are thermoplastic and capable of bonding with heat (Fig. 2). The fiber that has found particular utility in this method is polypropylene as its melting temperature range is suitably low and its melt flow viscosity is amenable to appropriate flow for effective bonding. With polypropylene fiber, either alone or in blends containing about 40% or more of the fiber, bonding can be done with hot, smooth, roll calenders. Since this process leads to a fabric with greater stiffness than desired, point embossing of only a portion of the total area is generally used to maintain the needed fabric softness.

Another version of this method involves the use of special binder fibers that have bicomponent structure. These fibers have a higher melting core with a lower melting sheath; the latter is activated by the temperature employed leading to bonding, while the former is unaffected and maintains its fibrous form and provides strength and stability to the web formed. In this case, thermobonding can be done with calender rolls (smooth or embossed)

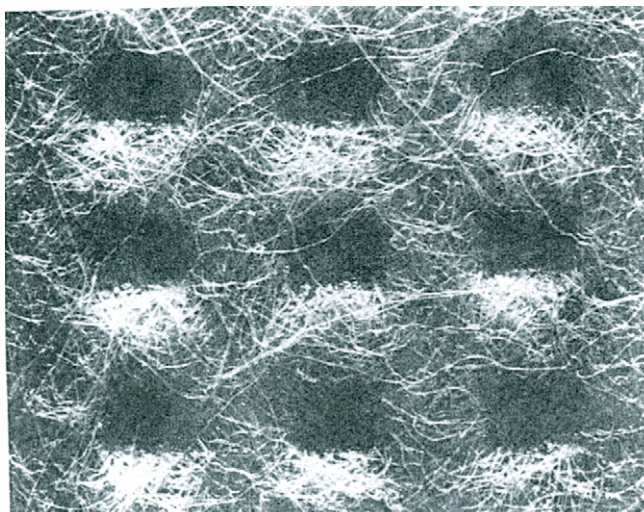


Figure 2. Point emboss thermobonded nonwoven.

or by hot air. Also, ultrasonics, infrared, and other selected sources of controlled heating can be used for the purpose.

3.3. Airlaid Process

A method that is often used to form fiber webs with random or isotropic orientation directly is the airlaid or the air form process. In this, individualized fibers are suspended into an air stream, and allowed to be deposited on a moving pervious belt or drum. By careful control on air flow pattern and receiver speed, the orientation of the fiber onto the forming element can be controlled [29,30]. This ensures that a fiber will have an equal probability of lying in any of the possible directions and lead to an isotropic web. A variety of continuous web formers have been developed that allow air forming of webs of different materials and of a broad range of specifications.

The random orientation of the fibers in the structure with some tendency of fibers to be lifted out of the X-Y plane and become partially oriented in the Z direction results in a web with higher bulk and larger void volume. This situation, of course, can have a significant positive effect on the absorbency properties of the resulting web. Bonding of web made by the air form process can be achieved by the same methods that are utilized for the bonding of the uni-directional dry form structure, i.e. saturation, spray, print or thermal bonding.

3.4. Airlaid Pulp Process

The special adaptation of the air form process has been used extensively in the production of highly absorbent nonwoven structures composed of wood pulp fiber [31,32]. This process, the so-called the air form or the airlaid pulp process, involves generation of an air stream filled with individualized pulp fibers and collecting them on a moving belt. The pulp suspension in air is usually generated by hammermill processing of dry pulp sheets,

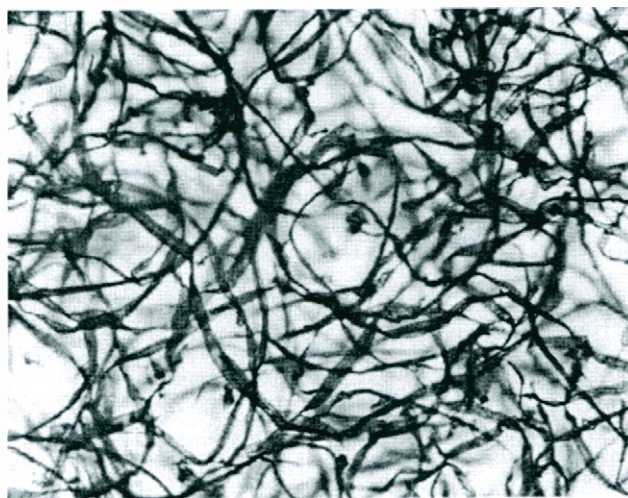


Figure 3. Airlaid pulp web.

followed by a technique that separates clumps. The air stream containing the suspended fibers is then passed through a moving porous belt that gives a random deposition of pulp fibers and leads to a bulky web. Bonding is normally accomplished by spraying of a latex that helps to preserve bulk. This is usually achieved by spraying binder resin first from one side of web, followed by drying and reversing and then spraying from the opposite side. After the second side is dried, the entire web is cured in a hot air oven [33,34]. Typically, the binder content in the final product ranges from 13-25% by weight. Also, thermal fusible fibers are used in some airlaid nonwovens in order to bind the pulp web. With proper processing, such structures can retain a large fraction of the original fabric bulk (Fig. 3), leading to a product that has high potential absorption properties. These materials are particularly suited for use in absorbent cores.

Although not normally recognized as a nonwoven material, the fluff pulp pad in many absorbent products is very similar in structure to that of the air formed pulp nonwoven, except that no bonding agent is employed. In this case, the pulp sheet is comminuted with a hammermill or similar device. In Europe, pin mills have normally been employed for the pulp sheet comminution process [35]. Because such pin mills do not generally have the "grinding" power of a hammermill, sheeted pulp used on such units is generally treated with an agent to facilitate comminution [36]. The pulp fibers are suspended in the air stream generated by the mill and the air-fiber stream is then conveyed to a pad forming station on the converting line [37]. For convenience and ease in manufacture of final products, the pulp pad is often formed onto a carrier tissue or other web substrate. Because the structure generally is not bonded, either by means of an external binder resin or by compressing the web to increase bonding, the fluff pad generally has relatively low integrity. This feature of fluff pad often requires special considerations in designing of the components for assembly in the final product.

There has been a significant effort devoted to improving the absorption performance of fluff pulp pads. The usual low density of the pulp mass generally leads to a significant

collapse in the thickness upon wetting. Accordingly, one of the procedures used has been the blending of short hydrophobic, synthetic fibers with pulp in the pad. By adding synthetic fibers to the pulp mass, a less water sensitive matrix is formed which assists in retaining void volume by preventing wet collapse. One of the most successful approaches along this line suggested is the admixture of melt blown micro-fibers with the pulp fiber prior to pad formation [38].

Another idea that has been proposed in the production of materials by the airlaying technology is the multi-bonded airlaid structure [39]. This applies to the preparation of multi-layer composites where multi-forming and multi-bonding stations are organized in one production line that also allows the incorporation of superabsorbent material in the structure. Such system provides a means to design and manufacture finished goods considerably more economically. An example of a product that could be produced on such a system is a diaper core where the complete multi-layer composite, each layer fulfilling a particular task, is produced in one step on an air-laid line.

3.5. Wetlaid Process

The wetlaid or wet form nonwoven process is derived from the paper industry, and bears a considerable resemblance to the normal Fordrinier paper manufacturing process. In this system, short fibers (generally one-quarter inch or less) are suspended in an aqueous slurry along with minor amounts of other constituents. The slurry is subjected to strong agitation in order to cause the fibers to be uniformly distributed. The formation of the web is then achieved by conveying the slurry to a moving wire belt, where the liquid drains through and the fibers are left in the form of a mat in largely random configuration. The web is then removed from the conveyor, taken through a bonding process, and then dried and wound up onto a roll.

Although the method appears largely similar to the papermaking process, there are critical differences [40,41]. Paper-making normally involves a furnish of 100% wood pulp, whereas wet form nonwovens can have compositions that range from a sizeable wood pulp content to a completely synthetic fiber furnish [42]. Wood pulp is frequently used in absorbent, wet form, nonwoven materials because it has an inherent high absorbency, is a low cost fiber, and provides a capability for self bonding through hydrogen linkages. Such bonding between the flat pulp fibers, so critical to paper manufacture, however, results in a product having paper-like properties, such as stiffness, high density, low tear strength, etc. In nonwovens, on the other hand, usually the fibers used are longer and crimped or convoluted, and the frequency of bonding used is lower. These lead to a fabric that is relatively bulkier and softer. To achieve more textile-like properties, in contrast to paper-like, the amount of wood pulp used and, therefore, the degree of hydrogen bonding developed are reduced. An external binder is generally employed to increase strength while maintaining bulk. Such a resin can be applied by spray, print or saturation methods. In addition, there is some use of the technique of adding binder directly to the original fiber slurry. The wet web is then dried and the chemical cured, as necessary. To retain maximum bulk, the web is subjected to minimum pressure during the wet form process. This is achieved by the use of flow through hot air during the drying operation [43,44].

Although not normally considered to be a nonwoven process, the technology for manufacturing high bulk sanitary tissue has a definite relationship to wet form nonwoven

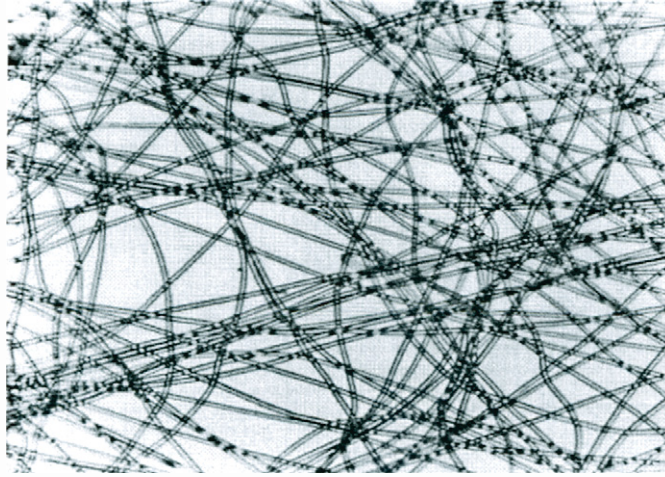


Figure 4. Spunbond nonwoven web.

technology in many respects. Thus, conditions and agents are employed to minimize hydrogen bonding [45]. The formed web is generally dried by a through hot air system to minimize web pressing and resulting web compaction. Also, there is often the use of an external chemical binder that enhances web strength and integrity [46]. In one process, a print bond technique is utilized for producing a bulky tissue. In this, the print bonded tissue is creped on a Yankee dryer; the presence of the bonded regions forces the unprinted regions to crepe, and develop bulk [47]. The resulting structure has the needed physical strength and high bulk, along with excellent softness and absorbency.

3.6. Spunbond Process

The spunbond technology combines the process of extrusion and orientation of thermoplastic synthetic fiber with that of the formation of web and bonding of the nonwoven technology. The result is an integrated process capable of producing a bonded synthetic fiber web of continuous filaments derived from a synthetic polymer in a one-step operation, i.e. it is possible to go from the resin pellet to the finished fabric in one stage [48]. Accordingly, there is significant economic advantage associated with the process. Since the web is derived from continuous filaments and that comparatively strong autogenic bonds are normally formed, the spunbond fabric in general has excellent tensile strength and tear resistance. Also, the web forming step is such that the resulting web is essentially isotropic in structure and properties (Fig. 4).

Inasmuch as this system is based on polymer processing, spunbond structures are normally derived only from man-made filamentous materials, and most usually from thermoplastic resins. Consequently, the spunbond materials are hydrophobic in character. Despite this fact, these materials find extensive use in facings in absorbent structures, especially as the web weight can be reduced to a low level because of the inherent strength of the structure [49].

Spunbond fabrics of particular commercial significance are derived from polyester, polyamide and polypropylene resins. The most frequent method of bonding employed is autogenic bonding, i.e., constituent filaments are made sufficiently fluid so that the filament surfaces touching each other will bond together upon re-solidification of the polymer. However, this often results in excessive bonding points and inadequate filament orientation, with a resulting fabric that is stiff and made up of low strength filaments. Consequently, the more common method used for bonding spunbond webs is to form an isotropic web from the oriented filaments and then pass the web through a thermobonding calender to accomplish bonding. If maximum strength is required, the bonding will be "areal" or over-all of the web. This again will lead to a stiff fabric. To achieve a softer fabric, "point bonding" is used, generally obtained by employing a hot calender roll of elevated points and a smooth back-up roll. Sufficient temperature and pressure are applied to deform and melt weld the filaments within the bond site, but not enough to completely destroy the fiber properties and convert the polymer in the site to an unoriented film.

Principles developed in the design of bond patterns for print bonding dryform nonwovens are also utilized in the design of thermobond print patterns [50]. The amount of bonding area for a typical spunbond fabric ranges from about 10% to 35% or more. Again, by judicious control on the design of the bond site, relative placements, percent bonded area, and other factors, desired balance between strength, softness and other fabric properties can be achieved.

3.7. Needlepunch Process

The needlepunch technology is the most widely used method for mechanical bonding. For this process, the base web employed is normally derived from either the air forming or the carding-cum-cross-lapping process. The cross-laying is done in a continuous manner, often onto another carded uni-directional web. The result, in this case, is a fiber web with one layer having a uni-directional orientation in the machine direction and the other succeeding layers having a uni-directional web oriented at 90° to the machine direction, or more correctly, at an angle of less than 90° to the machine direction because of the continuous nature of the process. By proper selection and juxtapositioning of webs, it is possible to more or less completely control the fiber orientation in the resulting cross-lapped web [51].

Bonding is achieved by the mechanical action resulting from penetration of a barbed needle into the fiber web. The barbs on the needle are arranged such that as the needle penetrates, fibers from the top layer of the web are engaged in the barbs and are driven transversely through the thickness of the web. As the needle retracts, the fibers are released from the one-way barbs. This results in mechanical entrapment and orientation of the portions of fibers in the Z-direction (thickness) of the web. By control of the needle penetration and the repetition of the needling action from the opposite side of the web, a three-dimensional, mechanically entangled network can be achieved [52]. In the resulting structure, often called a needlefelt, the mechanical entanglement is of groups or tufts of fibers rather than of individual fibers. As the extent of needling is increased, a more dense structure results that possesses increased strength, tear resistance and fiber tie-down.

There is a minimum amount of fiber that can be employed in the mechanical entanglement of a needlefelt web. Consequently, most needlefelt structures have a weight of

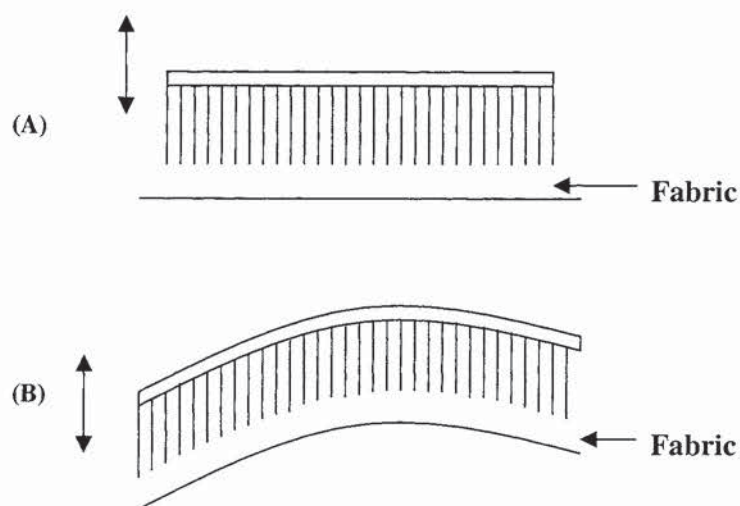


Figure 5. Needle zones. (A) conventional loom, (B) contoured needle zone of H1 needle loom [55].

60 g/m² (~ 2 oz/yd²) or more; a weight of 50 g/m² is about the minimum that can be effectively needle bonded.

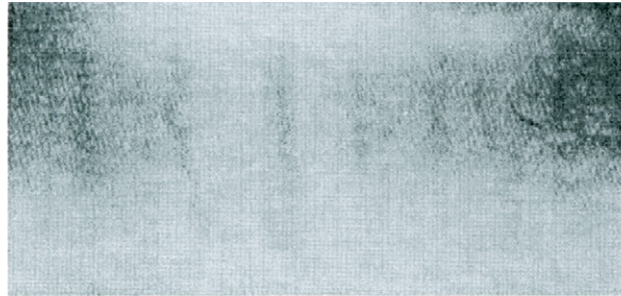
The absence of added chemical binder gives the needlefelt fabric a structure that possess the inherent absorbency of the structural fibers. The needlepunching process itself results in consolidation of the fibrous web by creating an interconnected network of capillaries in three dimensions. As a result, needlefelt webs are highly resilient and have high capability for absorbing rapidly and holding large amount of fluid.

Advances have taken place in the needlefelt technology in recent years. The feed system has undergone some changes that enhance the precision and the uniformity of the feed and the control of the feed material to the needle loom. One example of these is the micro control feed monitoring system for the needlefelt machine [53]. The greatest advance is in the needle loom design itself [54]. A new loom introduced recently is equipped with a distinctly contoured needle zone (Figure 5) that allows needles to penetrate a web at different angles, both less than and greater than 90° to the X-Y plane (Figure 6) [55]. The result is a better integrated structure, claimed to be obtained at higher production rate [56].

3.8. Spunlace Process

This process utilizes staple fiber web with a specialized type of mechanical bonding [57,58]. The fiber webs can be either oriented or isometric, but in common with other processes, more uniform properties and better overall performance is obtained with the latter. For bonding, the system uses high energy, closely spaced, water jets that emerge from an injector and impinge on a web substrate and entangle loose arrays of fibers (Fig. 7). The process is claimed to have the capability of producing a variety of surface and fabric patterns from many different precursor webs made from essentially any fiber that is not too stiff or

(A)



(B)

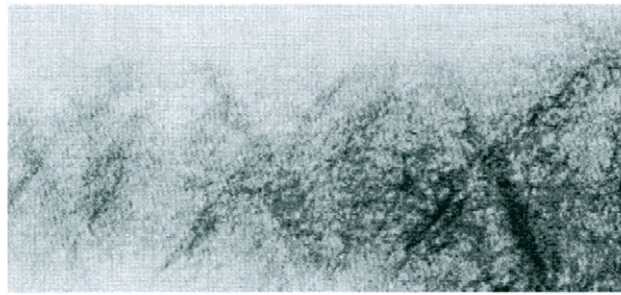


Figure 6. Micrographs of needled fabrics. (A) Conventional needle loom web, (B) H1 needle loom web.

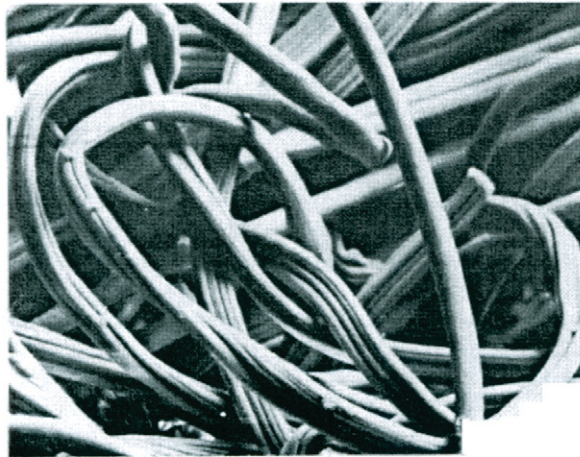


Figure 7. Spunlace web from rayon and polyester.

brittle to bend or move. The injectors are positioned above the moving backing belt or rotating cylinders, which are perforated and carry the unbonded web through the unit.

Two different bonding configurations have been employed widely in the process [59,60]. One is the horizontal system, wherein the fiber web is carried horizontally on a perforated backing belt through the water jet bonding zone; the water jets are also arranged in a horizontal manner, generally with two or more jet manifolds providing the streams. This action accomplishes bonding from one side of the web; if it is desired to entangle from the other side as well, the partially bonded web is led over rolls so that it could be turned and then bonded from the opposite side.

The alternative system utilizes perforated rotating drums for support of the unbonded material. In this case, the water jet manifolds are mounted around the periphery of the drum, and placed close to the drum surface to minimize the distance from the jet orifice to the web. A drum of one-meter can normally accommodate 3 to 8 jet manifolds. Again, when it is desired to entangle the web from both sides, the partially entangled web is removed from one drum, turned or reversed in direction and entangled from the other side.

A system will normally consist of two aprons, one at the feed end and the other at the receiving end, and two cylinders, all four serving to support the web and receiving water streams. The two cylinder system facilitates bonding from both sides of a fabric.

The precursor web can be formed practically by any of the drylaid (airlaid or carded), wetlaid, direct-laid (spunbonded or meltblown) methods for spunlacing with varying degrees of success [60]. For the drylaid precursor, a carded, carded/cross-lapped, or airlaid web of staple fibers is used. For the wetlaid precursor, uniform (isotropic) sheets are made by dispersing fibers in water at very high dilution and depositing on a screen to separate water from fibers.

Wood pulp/polyester fiber blended spunlace fabrics were originally the largest volume of products produced by the process; this resulted from the fact that medical fabrics (for disposable gowns, drapes and packs) were the primary spunlace fabrics used during the early commercialization of the process [61]. In the past few years, however, other spunlace fabric types have become significant commercial successes. Fabrics produced from 100% bleached cotton fibers are included in this category which have been used in a variety of absorbent product applications.

Two processes have been employed for producing the wood pulp/polyester fiber blended spunlace materials. One process involves a special, lightly bonded, low density wood pulp sheet. The latter is formed by conventional papermaking process using a special grade of long fiber wood pulp, usually based on a furnish of western red cedar. This paper sheet is unwound onto the top of a partially bonded isotropic polyester web and then subjected to water jet entangling. The finished sheet has a wood pulp-rich top layer and a polyester-rich bottom layer after entangling from both sides.

The alternative process involves an airlaid web formed by a special air forming equipment [62] fed with a blend of long fiber wood pulp and polyester fiber. This web forming system has the capability of controlling placement of the wood pulp and polyester fibers in the initial web, so that again the final fabric has a wood pulp-rich top layer and polyester-rich bottom layer after entangling.

Most commercial wet-laid machines will generally be limited to fiber lengths less than 1/2 inch, meaning that the fabrics produced from these webs will usually have lower

strengths than those produced from dry-laid precursor webs. However, a resin bonding step can be added if higher strength is required but this is usually done at the expense of flexibility.

In addition to drylaid and wetlaid precursors, a direct-laid precursor can also be used. These are the ones made directly from molten polymer continuously spun into fibers and deposited on a moving apron in a fashion similar to spunbonding and meltblowing processes. These webs do not by themselves entangle well as the continuous filaments lack mobility. However, composite fabrics with excellent three-dimensional stability can be produced by hydroentangling a composite containing a drylaid or wetlaid staple fiber web superimposed on a direct-laid fabric that serves as a reinforcing scrim for the structure [60]. This variant of the spunlace process is especially useful in producing a composite web of a lightweight spunbound fabric around whose filaments a wood pulp layer has been entangled. This can provide a strong yet absorbent fabric from relatively low-cost raw materials.

The water jet employed in the spunlace operation is a means of conveying enough energy to the loose fiber web to cause vigorous movement of individual fibers, sufficient to result in entanglements. The more the entanglements, the greater the strength. To maximize the energy transfer from the jets to the web, the pressure of the water must be relatively high (800 to 2,000 psi or more), the jets must be compact (columnar streams) and not spread out (fan streams). The columnar jets must be parallel and not collide, as this would destroy the entangling capability. These requirements dictate a precision in the design, manufacture and assembly of the manifold components.

The forming belts or supports (patterning belts, backing belts) which support the fiber web as it passes into and through the entangling zone are important elements in the process [63]. In essence, the impaction of water jets forces fibers onto and into the backing belt, giving the fiber web surface the mirror image of the surface of the belt. If the backing belt has larger holes or apertures, an apertured web results; using this system one can actually produce a design or pattern if the latter can be incorporated into the belt. By using a backing belt with very fine apertures, a spunlace fabric approaching a non-apertured appearance and structure can be obtained. This versatility associated with the configuration of the supporting belt provides the capability to produce a wide range of surface and structural features in a spunlace fabric.

The hydroentangling line incorporates a unit for extraction of water by vacuum slots beneath each needling support to remove water penetrating the web. Inefficient water removal can lead to flooding and loss in entangling intensity. Additional water may be removed by high vacuum extraction process to reduce the drying load. The next step in the process is drying, which is often achieved with a through hot air system. A final step in most spunlacing lines is finishing, which is used to impart special characteristics to a product. It may involve a chemical treatment such as a wetting agent or an antimicrobial agent, or a physical treatment such as creping, calendering or heat setting.

Microscopic examination reveals that entanglements are frequent but the fibers are not tightly entangled. The combination of jet orifice spacings and screen patterns produce densely packed loosely entangled areas (see Fig. 11, Chapter III). Unless special care is taken, 100% cellulosic fiber composition is likely to lead to a papery structure; however, a blend containing short cellulose and synthetic fibers can produce a fabric that has excellent drape and bulk, as well as required strength.

The mechanical entanglement of the spunlace process is in contrast to the entanglement of the needlepunch process, which is entanglement of tufts of fibers [64]. A vast majority of spunlace fabrics are produced in basis weights ranging from about 20 g/m² to about 100 g/m². A web of weight less than 20 g/m² does not develop enough integrity unless an auxiliary means of bonding or very low denier fibers providing high number of fibers are used. Webs weighing more than about 100 g/m² are usually too heavy to be penetrated by water jets, unless very high energy levels are used.

As normally practiced in commercial operations, the entanglement, especially on fabric surface, is high enough to lead to a strong fabric with good fiber "tie-down." Because chemical binder is not normally used in this system, the spunlace fabric is also characterized by excellent softness and hand. As expected, the absorbency of the structure is excellent, being unhampered by external binder. There can be some restriction to total absorbency, however, by the fact that extensive linkages in densely packed regions can limit the swelling potential of individual fibers, which may result in reduced absorbency compared to that expected in an equivalent non-entangled fiber web. Nevertheless, this nonwoven system constitutes an important process for a number of absorbent products, most specially those used in the health care field.

A modification of the hydroentangling system has also been described and used [65]. This involves fiber entanglement at a relatively low level, which is still sufficient to convey some strength and integrity; this reduced level of cohesion is then supplemented by a limited amount of external latex binder, which conveys additional strength and integrity to the structure. The resulting web has the desired strength and integrity with only a small compromise in absorbency because of the low level of resin used. Also, the modest amount of resin employed (1-5% by weight) does not add much stiffness to the fabric. Consequently, the combination process, involving hydroentangling and latex resin bonding, can provide a fibrous web with a superior balance of absorbency and other physical properties.

A further modification of the spunlace process utilizing no external resin has been described [66]. In this case, the low level of fiber entanglement, achieved as above by using low water jet pressure, is supplemented by adding a small amount (~ 15%) of thermoplastic binder fiber. After drying the fabric, additional heat is applied to melt and thus activate the latter. A polyolefin bicomponent fiber is used for this process, although other binder fibers can also be employed. This same technique, involving addition of a low melt fiber, is now used at times to enhance the physical properties of needle punched fabrics as well [67].

An additional modification described recently is the use of nylon/polyester multi-component splittable fiber. The treatment with water jets splits the material into micro denier nylon and polyester filaments and entangles them to produce a soft, drapable, and strong nonwoven [68].

3.9. Meltblown Process

Meltblowing is one of the more recent technologies that has established itself as an important nonwoven process for producing structures that find applications in a number of products, including absorbent. It is a unique, one-step process that dates back to the work of Manning in 1946 [69], for making filter cartridges, and of Wentz in 1954 [70], at the Naval

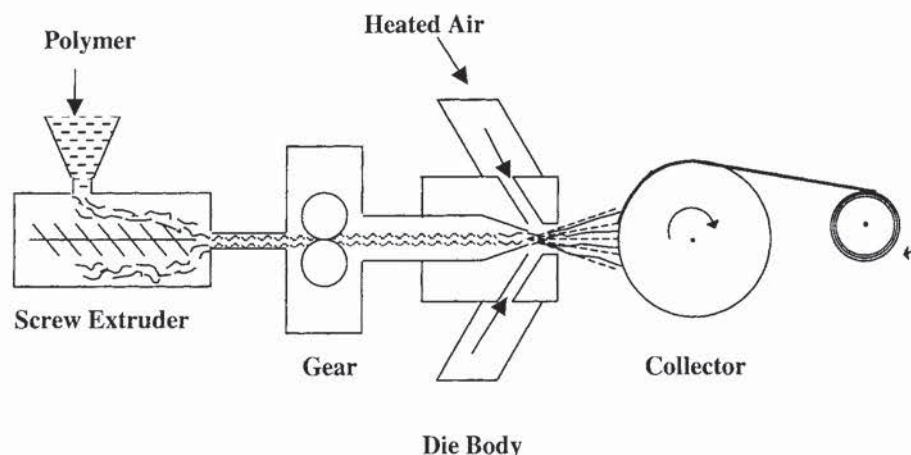


Figure 8. Schematic of a meltblowing process.

Research Laboratory, that showed that the melt of a polymer emerging from orifices could be blown into super fine fibers by hot, high velocity, air.

In this process, a molten polymer is converted into ultra fine fibers and collected on a rotary drum or a forming belt with a vacuum underneath the surface to form a nonwoven web. Two hot air streams at near sonic velocity at the die exit attenuate the extruded stream of polymer. The meltblown process is similar to spunbond in basic concept except it utilizes a die instead of a spinneret and uses air to convert a polymer thread-line into superfine filaments by extreme drawing of the molten polymer (Figure 8). A typical meltblown web contains fibers of a range of sizes (Figure 9), the latter may vary from as low as 0.01 to as high as 20 denier [71]. The fibers are tacky and tend to stick to each other and take the shape

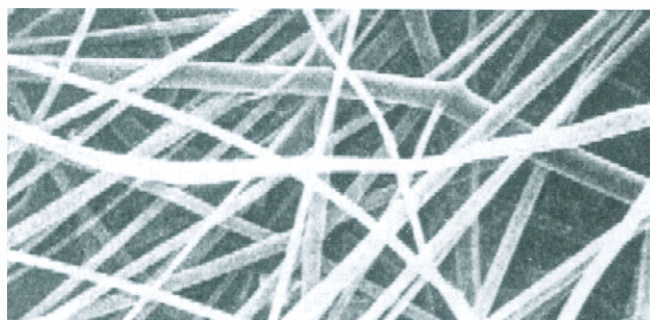


Figure 9. Micrograph of a meltblown fabric showing variable fiber size [72].

of the apron or object on which they are collected. It is recognized that the fibers are weak and lack abrasion resistance. Also, some critical defects such as the presence of micro shots, roping of fibers, and non-uniformity in structure are found to characterize a web [72]. Studies are currently devoted to understanding the causes of such defects and to finding means of alleviating them. Some of the factors that have been suggested to play a role are the air pressure employed at the die exit, the die-collector distance at which fibers are collected, the manner in which the material is quenched, and the nature and the extent of cross flow of air existing at the die [72,73].

Accordingly, the application of meltblown fabrics is currently restricted to those products in which strength and uniformity are not major requirements. Studies have shown that fibers tend to be largely non-crystalline and un-oriented, especially as compared to the fibers obtained from spunbonding of the same polymer. However, the microdenier feature of the fibers in a meltblown fabric make the latter highly suitable for filtration and absorbent applications. The material most widely used currently in the formation of meltblown fabrics is polypropylene, which accounts for 90% or greater of the total production.

Although polypropylene, polyethylene, polyester, and nylon are the major polymers that have been traditionally tried with this technology, studies have shown that successful meltblown materials can also be developed with other materials, such as the biodegradable polyvinyl alcohol [74] and nearly every other thermoplastic material. A great deal of progress has also been made in developing composite structures by combining webs produced by other processes with ones produced by meltblowing. Such products contain fibers of different types and, especially, different deniers, which can lead to unique structures with properties not possible from a single material or process [75].

3.10. Laminate Process

Another important technology for the formation of nonwoven materials is the lamination process. This method involves combining bonded webs into multi-layered structures in order to obtain combination of properties. The individual webs are normally bonded together with latex adhesive, hot melt resin, thermobonding, or by other means. The resulting sheet structure possesses the attributes of the individual webs going into the laminate, modified somewhat by the properties arising from the integrated structure itself. Thus, strength is often enhanced in a laminate structure, generally at the expense of softness. The laminar nature of the composite can affect the total absorbency and particularly the wicking performance. Also, such structures sometimes involve an impervious film as one component of the composite. In this case, it can act as a barrier to absorbency.

3.11. Polymer Web Process

There is another group of miscellaneous web structures that are often classified as nonwoven materials and are used for a variety of functions in absorbent products. These are the sheet materials such as thin foams [76], plastic nets [77-79], perforated films [80,81], and similar materials. Although not truly nonwoven materials, inasmuch as they are not composed of fibers, they often possess a manufacturing or functional relationship to nonwovens. The method of manufacturing these miscellaneous materials are as diverse as their natures. They frequently arise from modified plastic processing techniques and often represent the combination of technologies. In general, they are not hydrophilic, and hence,

not inherently absorbent. Because of their structure and characteristics, however, these materials can often substitute for a component of an absorbent product.

3.12. Advanced Composites from Combination of Technologies

During the past several years, advances in equipment, especially those representing meltblowing, spunbonding, hydroentangling, airlaying and carding, have no doubt driven the growth. As an example, turnkey production lines are now available that are capable of producing spunbond polyolefin webs with sizes down to 1.0 denier per filament and finer. Changes in needle loom design and availability of composite lines that combine webs from different processes in one operation are other examples. It appears clear, however, that in the future, product innovations, particularly in areas of composites wherein different materials processed with different technologies are combined, will be the accelerators [75]. Many possibilities exist and have been tried, and some of these have already become commercial realities.

Attractive composites can be made with airlaid/spunlace combination. In the production of many types of products, e.g. wipes, a manufacturer can obtain not only a superior product but also the latter at a fraction of the total cost. For example, infusion of pulp by airlaying into web during spunlacing enables a fabric to be produced that has comparable absorbency to one obtained using staple rayon but at a lower cost. A typical blend for pulp and fiber is 50/50. A good example of an application where airlaid pulp is fused with spunlace on a spunlace line is baby wipe or cleaning cloth.

The greatest emphasis in the development of composite fabrics, however, has been placed on the use of the meltblown and spunbond systems. Examples of structures being widely used include spunbond (SB)/meltblown (MB), known as SM, and SB/MB/SB, or SMS, composites. The production and properties of these are particularly enhanced by the use of bicomponent polypropylene/polyethylene materials in the preparation of MB webs. The spunbond fabric, or spunbond combined with ultra-light weight meltblown fabric, is suited for cover stock for diapers and sanitary products. Other lines are now available that are capable of S, SS, SSS, SMS and SMMS, etc., structures of polypropylene and other synthetic polymers, in speeds exceeding 500 m/min and filament denier lying in the 0.7-10 range.

There has been a continuing interest in the development of polypropylene and polyethylene bicomponent meltblown nonwovens with polypropylene core providing high strength and mechanical stability and polyethylene sheath contributing softness and greater ease of thermal bonding. Recently, core/sheath [82] and side-by-side [83] bicomponent fiber based meltblown fabrics have been developed. Commercial spunbond lines are also providing polypropylene/polyethylene bicomponent material for diaper top sheet and it is noted that the trend to fine denier polypropylene spunbond is continuing with denier lying in the 1.0-1.2 range for diaper use [84].

Most interesting of the composite structures being examined and that relate more directly to absorbent applications are the cotton-surfaced and the cotton-centered nonwovens that are capable of being produced on an integrated line. To make cotton-surfaced products, a cotton/polypropylene web is placed on one or both sides of a polypropylene spunbond web

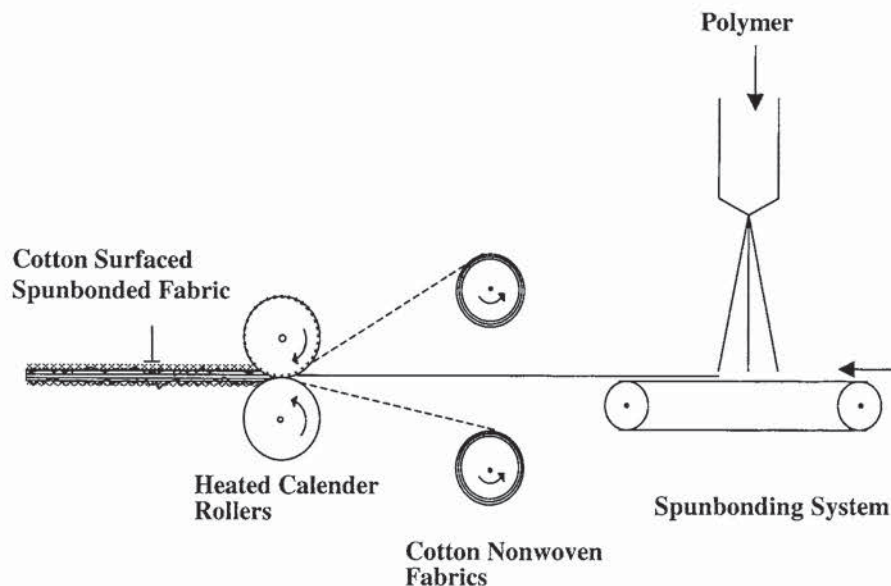


Figure 10. Schematic showing preparation of cotton-surfaced composite on spunbond line.

prior to calender bonding (Figure 10). Recently, publications describing the development of cotton-surfaced materials for personal hygiene applications have appeared in the literature [85,86]. The cotton-centered nonwovens are laminates having cotton sandwiched as a core between two layers of meltblown and/or spunbond webs, with the size and the characteristics of each of the three adjusted to suit the application. For developing such products, the cotton used could be of regular length, fed from a pre-formed roll, or of small or linter size, deposited directly from an airlaying system on the site in coordination with the formation of the spunbond/meltblown webs (Figure 11).

4. ABSORBENT STRUCTURES

In the current context, the major absorbent structures considered are disposable infant diaper, feminine sanitary napkin, underpad, adult incontinence pad, wound dressing (primary and secondary), absorbent wipe and oil absorbent. This list could be lengthened considerably by including derived structures and products, and by considering ancillary potential and applications in a broad range of other materials; however, the examples chosen will serve to illustrate important principles involved.

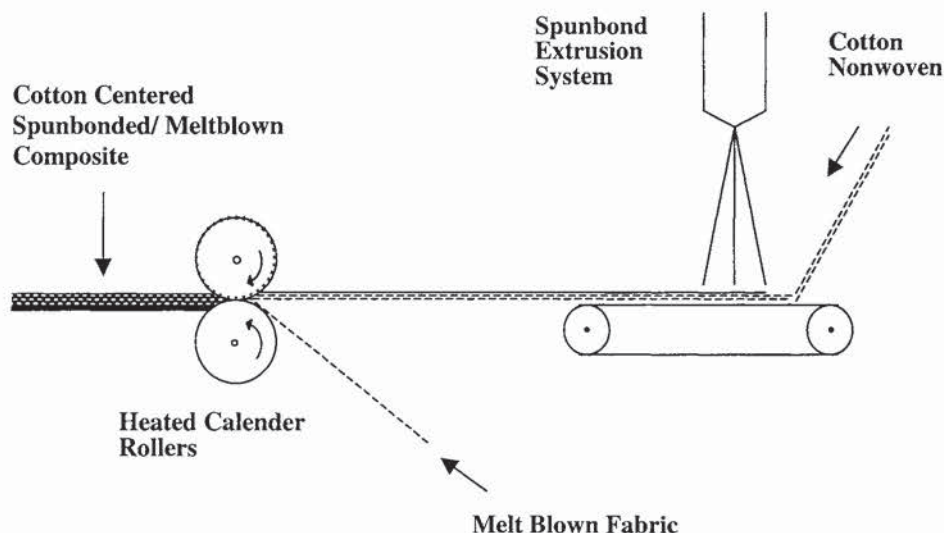


Figure 11. Schematic showing preparation of cotton-centered composite with spunbond and meltblown webs forming the outer surfaces.

4.1. Historical Development of Absorbent Products

Over the past four decades, there has been a rapid shift in the structure of absorbent products, particularly diaper, from the use of traditional woven cotton cloth and cotton wadding to carefully engineered disposable structures employing an increasing amount of specifically designed nonwoven components. During this same period, there has been a pronounced trend toward the use of fluffed wood pulp as the absorbent reservoir in such structures. The universal use of fluff pulp pads, accelerated by the desire to use lower cost materials, has no doubt fostered the increase in the use of nonwoven facings and other components in absorbent products.

Through the years, there has been an evolution in the design of such products to those known today. A variety of materials and configurations have been devised and used; however, in general, the current absorbent structures, such as diaper and incontinence pads, are composed of three or four elements, namely nonwoven facing, absorbent core, with acquisition/distribution layer and superabsorbent polymer, and fluid barrier backing. As an example, the structure of a current "premium" diaper, featuring these and other components, is illustrated in Fig. 12.

4.2. Prototype Structure

In this configuration, an absorbent structure is ready to receive fluid on the upper surface, the nonwoven facing. This surface must be sufficiently wetted by the incoming fluid in order for the former to allow the latter to penetrate into the underlying layer. Ideally, the

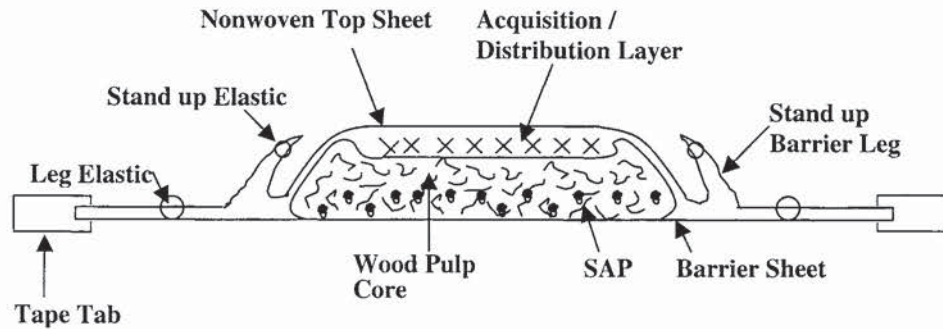


Figure 12. Schematic of a highly engineered diaper product.

wetting (strike-through) is rapid and accompanied by some spreading, to enlarge the area of fluid transfer. These characteristics are usually facilitated by the use of an appropriate surfactant or wetting agent.

The function of the facing in this and similar absorbent products is to present a surface with the following characteristics:

- Softness; pleasing tactile aesthetics, especially in contact with sensitive skin.
- Drapeability; ability to deform and conform to curved surfaces.
- Fluid Permeability; to allow easy passage of fluid into absorbent reservoir.
- Aesthetics; smooth, clean, uniform surface.
- Safety; inert or non-toxic surface for contact with skin.
- Separation; non-adhering material that allows easy removal of product.
- Dryness; to maintain essentially a dry surface in contact with skin.

In some structures, the fluid, after passing through the facing or topsheet, immediately contacts the fluff pulp pad which acts as the absorbent reservoir. In others, an intermediate layer (transition layer) is encountered behind the facing. This tissue is utilized to enhance [87,88] flow of fluid away from the backside of the facing, transport fluid along its plane [89], and increase the volume of the pulp pad involved in absorbing fluid. An additional tissue layer is sometimes used to add superabsorbent polymer to the system. The polymer is frequently inserted at the bottom of the absorbent pad, to minimize gel blockage of the structure by the swollen material.

The backing or back layer of the normal absorbent structure is usually an impervious film, most frequently made of low density polyethylene. It may be a thin multi-layer film that is embossed to provide improved softness and hand and tear resistance [90]. The obvious function of this component is to restrain the fluid within the pad, present a dry surface to the exterior of the product, and provide the user freedom of movement and feeling of comfort. The film may be breathable to add another dimension to the comfort.

While the four-component system is a useful prototype for a variety of absorbent products, many variations and special features have evolved and have been developed for specific articles. The adaptation of the general architecture to specific applications is best illustrated by considering each major absorbent product separately.

4.3. Disposable Infant Diaper

4.3.1. Introduction

A pad of sanitary tissue or paper wadding comprised the first disposable infant diaper product. This hand-shaped pad was combined with a separate square of plastic film by the Swedish mother under the harsh conditions of shortage experienced during World War II [91]. Where the wet strength of the tissue was inadequate, pieces of tissue were frequently left on the moist skin, requiring an unpleasant cleaning up step. Consequently, a cover characterized by sufficient wet integrity was sought. The light weight rayon nonwoven facing was developed for such use, that provided a significant improvement in performance. The product was improved following the war and widely adopted.

In the interests of economy, fluff pulp was introduced as a superior, low cost replacement for tissue as the absorbent reservoir [92]. In Europe, this led to a rectangular shaped, fluff pulp pad, sometimes wrapped with tissue and then over-wrapped with an envelope of nonwoven. This pad could then be used with the separate square of plastic film. For convenience, the plastic film was eventually replaced by a close-fitting plastic panty, with the absorbent pad as an insert. This gave rise to the traditional 2-piece disposable diaper of Europe.

On the U.S. scene, the adoption of the concept centered on an integral, 1-piece structure, the so-called unitized concept. The latter, building on the structure of the flat hospital underpad, resulted in a rectangular pad, which was folded into an appropriate shape, much like a cloth diaper. Closure and fit was accomplished with safety pins, in much the same way as with durable woven cloth diapers. In the mid-60's, a major manufacturer improved upon the idea by folding and glueing, so that a pre-formed product with better fit, easier application, and superior performance resulted. The addition of the self-contained tab closure provided considerable convenience. With many variations, this style led to the current infant diaper of the shaped, one-piece construction [93]. In many parts of the world, this is known as the "American-style" diaper.

This diaper still has four elements. The functions and the structures of the absorbent core and the barrier sheet are well understood and those of the former, in particular, are adequately covered in discussions of the airlaid, wetlaid, spunlace and other technologies in Sec. 3. The functions and the structures of the remaining two elements, namely the topsheet and the acquisition/distribution layer, are not covered. These components of the diaper need detailed discussion, especially the topsheet, since it performs complex and multiple functions. A concern with side leakage has also led to the introduction of leg elastics and cuffs in modern products. These and other aspects of a diaper are attended to in the sections that follow.

4.3.2. *Diaper coversheet*

The nonwoven fabric that is positioned next to the skin of the wearer of an absorbent sanitary product has been given various names, including: a) cover, b) coversheet, c) coverstock, d) facing, e) topsheet, and others. Despite this variety in descriptive terms, there is no uncertainty about the item involved; it is the soft, nonwoven fabric on the diaper surface that contacts the skin or body of the wearer.

The primary product requirements of the diaper facing have been outlined above. From the standpoint of the diaper technologist, a continual balance, involving inevitable compromises, must be sought among the requirements, along with the minimizing of the cost of this component which is used in such large volume. As might be expected, the nature of the nonwoven facing itself has undergone changes and considerable improvements during this evolution.

Two decades ago, most of the diaper facing was produced from rayon fiber by the dry form and print bond processes, with a small portion derived from the laminate process. At that particular stage of commercial development, there was strong acceptance of the concept that the coverstock used on an infant diaper had to be absorbent. Fiber selection, processing conditions and binder considerations all focused on the requirement for maximum absorbency of the diaper facing.

Within the past two decades, however, there has been a complete turnaround in this concept, to the point that today's basic requirement is for a nonwoven facing to be essentially hydrophobic. This resulted primarily from the desire to provide a dry surface in contact with the skin, which was thought to be more comfortable and less irritating and toxic for the wearer. Such a dry surface is viewed as essential to the maintenance of skin health.

As a consequence, the fiber of choice in sanitary protection facing products has shifted from the hydrophilic rayon to the wholly synthetic hydrophobic fibers. The change that occurred was originally to polyester fiber material, which took over the bulk of the facing market by 1979. This was primarily because a major absorbent product manufacturer in the United States adopted a latex bonded polyester nonwoven fabric as the cover stock of choice [94]. Within a few years, however, another shift took place, this time to thermal bonded polypropylene fiber facing [95].

A major driving force for the change to polypropylene was not only the desire for dry surface properties, but also a recognition of the desirability for having a facing that was binder free. The elimination of formaldehyde and other concomitant chemicals, present in the latex bonded facings, had been viewed as a desirable direction for the future. Consequently, there has been a growing interest in the use of thermal bonded nonwoven technology in order to produce hydrophobic facings without chemical additives. This process involves a fiber web of wholly or partially thermoplastic fiber (generally polypropylene) bonded by means of a hot embossing roll. At the emboss site, partial melting of the binder fiber occurs, resulting in a bond capturing several adjacent fibers (Fig. 2).

The changeover to thermal bonded materials for topsheet was also accelerated by national legislation in Japan that virtually forced the removal of formaldehyde-containing products from applications involving contact with skin. Also, around the same period, substantial interest was shown in the use of thermal bonded facing made with polyolefin bicomponent material as the binder fiber. The most prominent fiber employed consisted of a 3 denier material with a core of polypropylene and eccentric sheath of high density

polyethylene [96]. This fiber has been used in 100% form as well as in blend with rayon or conventional polyolefin. When facings are derived from 100% bicomponent material, the bonding has been of the overall type, leading to fabric with strength high enough to allow for the use of very lightweight stock, e.g. 10 g/m².

Polypropylene-based fabrics have now become the preferred diaper coverstock material around the world. The use of this fiber provides the desired hydrophobic nature to the facing at a reasonable cost as this resin is one of the lowest cost, high volume, commercial polymers.

The property of hydrophobicity in a diaper facing is necessary but not sufficient for optimum performance. The fabric must also quickly pass liquid through to the interior of the diaper. The perfect facing must function as a “one-way valve”, quickly passing liquid through (rapid strike-through), restricting passage of the liquid back through in the reverse direction (wet-back), and presenting a dry and soft fibrous surface to the skin. Consequently, a technology for conveying wetting properties to the surface of the facing to insure rapid strike-through of the voided liquid was necessary. This is most easily achieved by uniformly adding onto the surface of the facing a small amount (0.2 to 0.6 weight %) of an effective rewetting agent. This is generally applied by spraying.

A shortcoming of the topical application of the rewetting agent is that it can be rather quickly removed by multiple discharges, which is not uncommon with infants. Removal of this agent by passing urine through the facing, of course, reverts the fabric surface to its original hydrophobic condition; this can lead to product failure by run-off of the subsequent insults. This situation has led to the development and use of “durable” finishes, which can survive several insults. Such a durable rewetting agent is most easily used by adding the latter to the polymer prior to extrusion of filament in the spunbond process. A similar approach can be taken with polypropylene staple fiber, but with increased production problems.

4.3.3. *Standing leg cuff*

A recent innovation in diaper design has been the introduction of a fold in the facing along the two longitudinal edges of the diaper. This fold is inserted to provide side barriers in the target zone of the diaper. The concept of the design is to provide additional protection against side leakage. This is achieved effectively when the fold is made to stand up from the surface of the diaper, see Figure 12.

This design feature has been given various names, including standing leg cuffs, stand-up cuffs, and others. In order to accommodate this element on the top surface of the diaper, about 30% more facing is required. Further, the facing involved in the fold is more effective in preventing leakage if it is impervious to liquids. Desirably, the cuff should still “breathe” or transmit moisture vapor for wearer comfort [97]. The combination of liquid imperviousness and air permeability in a lightweight nonwoven fabric is effectively achieved by a composite of a spunbond web combined with a meltblown web of micro fibers discussed in the next section. The polypropylene and spunbond filament web provides excellent strength and other physical properties, while the meltblown web of extremely fine denier polypropylene fibers functions as a barrier to liquid, still affording reasonable breathability.

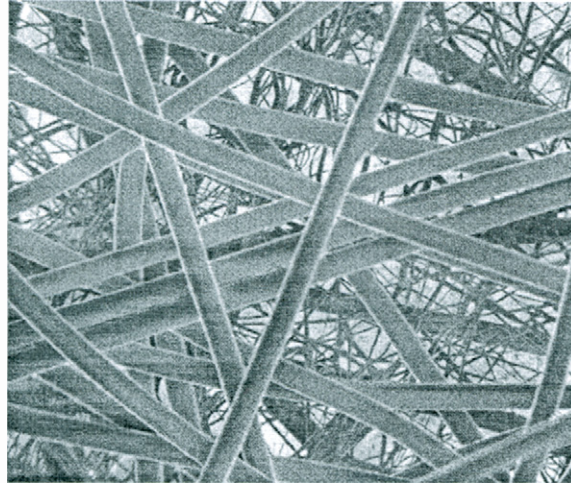


Figure 13. Micrograph of a polypropylene SMMS fabric [99].

4.3.4. Spunbond/meltblown components in coversheet

As pointed out earlier, the meltblown process, licensed by Exxon Chemical, produces a random web derived from micro-denier thermoplastic fiber, usually polypropylene, or a bicomponent fiber based on it [75,98]. This fabric has some self-bonding capability because of modest mechanical entanglement of the fibers as they are formed into a web: the adhesion is often supplemented by thermal bonding in a pattern. Because of lack of strength in meltblown fabrics, a facing consisting of meltblown fibers is usually a composite with the meltblown material sandwiched between layers of spunbonded fabrics and bonding together by calendering.

Such a composite leads to a unique structure, claimed to provide desirable performance at lower basis weight and cost [99]. The most popular combination structure is SMS (or SMMS, SSMMS) in weight ranges from 10-25 g/m² comprising 1-5 g/m² meltblown microfibers. The spunbond layers provide high tensile strength in both the machine and the cross-directions, whereas the meltblown microfibers greatly improve visual uniformity and liquid barrier properties. The topsheet given proper hydrophilic treatment combines high strike through with effective retention of superabsorbent particles (SAP) smaller than 100 microns. Figure 13 illustrates a low weight (15 g/m²) SMMS fabric comprised of meltblown fibers accounting for less than 15% of the material by weight.

Table 4 shows the results of one analysis in which the performances of several multilayer spunbond/meltblown fabrics were compared. All structures shown gave acceptable strike-through, against repeated insults, and rewet results. The differences are seen in the values of tensile properties, air permeability and pore size. From the data in the table, it is seen that a 13 g/m² SMMS fabric has only slightly lower mechanical properties than found in the 15 g/m² SS fabric, but superior particle retention and barrier characteristics. The former is particularly suited for application as a barrier against release of superabsorbent

Table 4.

Comparison of the properties obtained with different spunbond/meltblown configurations [99].

Composite Fabric Structure	SB (dtex)	MB Fiber Diameter (μm)	Basis Weight (g/m^2)	Weight Dist (g/m^2)	Tensile Strength (N/50mm)	Air Perm ($\text{l}/\text{m}^2/\text{s}$)	Pore Size (μm)
SMMS	1.7-1.9	2-6	13	5.5/1/1/5.5	32/13	2200	80-90
SMMS	1.7-1.9	4-8	13	4/2.5/2.5/4	24/10	2000	70-80
SMMS	1.2-1.4	2-6	8	3/1/1/3	28/11	2400	80-90
SS	1.7-1.9	-	15	7.5/7.5	34/16	6000	1000+

through the acquisition layer and the topsheet. Such a composite can also be configured for use as a breathable back sheet having the required liquid barrier properties. Apparently, by adjusting the fraction and nature of the spunbond and meltblown materials in the composite, the nonwoven technologist should be able to engineer a fabric for facing or barrier sheet for numerous applications that presents the best combination of economy and performance.

4.3.5. Secondary facing

With a hydrophobic fabric, the desire for rapid strike-through often requires an absorbent material immediately beneath the nonwoven facing, which not only absorbs rapidly but also has a high rate of wicking away from the wetting site. This situation is generally facilitated by insuring an intimate contact between the topsheet and the pulp pad, such as achieved by inclusion of an absorbent tissue between the back of the sheet and the pad. In some products, this tissue is adhesively bonded to the back side of the facing in order to obtain the desired contact. This may be especially necessary for shaped elastic leg diapers, where the shaping feature may cause the cover material to tend to pull away from the absorbent pad.

During the past few years, there has also been an interest in a "secondary facing" concept, to augment rapid passage of liquid from the back of the cover into the adjacent pulp pad or ply. This has taken the form of a very light weight fiber web with little or no bonding between the primary facing and the absorbent core. In another form, the single facing is fabricated with a rough top (outer surface) and a smooth bottom (inner surface). In this system, liquid tends to move from the rough side to the smooth side, enhancing wicking toward the center.

4.3.6. Acquisition/distribution layer

This mechanism of enhancement of liquid movement has been further advanced by the use of an acquisition/distribution layer (ADL) between the topsheet and the absorbent core. The ADL generally takes the form of a composite fabric with a density gradient through the thickness. The top one-third of the fabric has low density (often higher denier fiber) with relatively large voids and higher void volume; it is especially effective in the acquisition of the presented liquid, even at high discharge rates. The middle one-third of the fabric is at a somewhat higher density with smaller voids, while the lower one-third is of

higher density yet, with even finer voids and often smaller denier fibers. The higher density portions of the composite have more and finer capillaries and hence develop greater capillary pressures. As a result, the higher capillary pressures effectively move greater volumes of liquid to the outer regions of the structure, providing greater absorbent capacity through more effective use of the entire absorbent core [100,101].

The ADL layer provides for more rapid liquid acquisition (minimizing flooding in the target zone), and more rapid transport and thorough distribution of the fluid into the remainder of the absorbent region [102].

4.3.7. Diaper Performance Properties

Special fabric characteristics relating to diaper performance have been developed over the years, with assistance from the industry trade associations, such as INDA (USA) [103], TAPPI (USA) [104], EDANA (Europe) [105], ANNA (Japan) [106] and other Standards organizations such as ASTM (USA) [107], as well as from specific industries and commercial organizations [108-112]. These properties include such special tests as 'strike-through' (time in seconds for liquid to penetrate topsheet), 'run-off' (volume of liquid not absorbed when poured onto a fabric maintained at specified angle), and 'wet-back' (volume of liquid squeezed out of an absorbent and back through the facing under standard conditions). Other properties of interest that relate to the performance of the diaper, include 'total Absorption' (saturation to the drip-free point), and 'absorption under load' (total amount absorbed and held under a standard load). For details about testing of absorbent products, see Chapter XI.

4.4. Feminine Sanitary Napkin

A similar evolution to that involved in disposable diaper has occurred with the feminine sanitary napkin. The original manufactured product consisted of paper wadding encased in a woven cotton gauze cover folded into a tubular shape. In some cases and geographical regions, the woven cloth was substituted with a knitted cotton tube. In both instances, excess fabric was employed to provide a tail or tab on each end of the product; the tabs were used to position and retain the napkin in the perineum area by fastening them to a belt worn around the waist. Fluff pulp eventually replaced the wadding as the absorbent core, and a dry form nonwoven facing replaced the woven or knitted cover. Lately, the trend has been towards smaller pads (thin, mini) and elimination of the tab in favor of a pressure sensitive adhesive on the film backing for positioning and affixing the pad to the undergarment.

In common with infant diapers, the nonwoven coverstock formerly used on feminine napkins was required to be as absorbent as possible. Consequently, the typical cover of the second generation product was a printed, dry form nonwoven produced from rayon fiber. This essentially gave in to a more hydrophobic napkin facing. This was first achieved by the use of blends of polyester and rayon and later by the use of wholly synthetic material. Polypropylene spunbond nonwoven has been one of the main structures employed.

Other types of nonwoven facings have been used in limited ways on a variety of feminine absorbent products. These have included a plastic net and a plastic net emboss bonded with a light weight web of polypropylene fiber [113,114]. Another type of facing introduced by a leading manufacturer is a perforated film structure, produced by a thermal

forming/perforating process. This gave the film a controlled size apertures and a three-dimensional structure [115]. Although the facing was non-fibrous, the 3-dimensional thermal forming of the film surface and the presence of the perforations conveyed a somewhat cloth-like hand. The facing gave excellent resistance to wet back because of the "apparent" thickness of the structure. Also the strike-through performance was good, provided that the absorbent tissue was in intimate contact with the back side of the cover; this performance leads to a very desirable 'clean and dry' sanitary napkin.

In the fluffed pad itself, steps can be taken to facilitate liquid movement [116]. The so-called "Burgeni Skin" fosters lateral movement along the surface of the pad, hence involving a greater volume of the latter as an absorbent reservoir. This paper-like structure or skin can be formed by spraying a limited amount of water on the pad and then moderately compacting the outermost layer of fibers into a densified "skin" [117]. In essence, this skin provides a somewhat densified layer that facilitates liquid migration by the increased capillary pressure of the compacted fibers. This technique also conveys some structural integrity to the material, facilitating high speed processability.

Because of the requirement for product compactness and the demanding dynamic activities of many consumers of napkin, there has always existed a desire to achieve an anatomical shape for the product. This can be achieved by forming the absorbent pad or core into a 3-dimensional shape rather than into a simple rectangular box configuration. This has been achieved by the use of "pocket formers," or "drum formers," for separate preparation of the core structure [118,119].

The pocket former consists of a shaped mold, fabricated from stainless steel screen, so that a vacuum can be drawn on it. The top of the device is open. Several such units are located on the periphery of a rotary drum. The individualized woodpulp fibers are brought via an airstream and blown into the pervious shaped mold, with the vacuum on the back side to assist in the uniform filling of the latter. Superabsorbent polymer powder can also be positioned in the woodpulp core at the desired position. By providing a short puff of air from the backside of the mold, the shaped core can be released and carried on the manufacturing line for the rest of the processing.

In general, napkin top sheet fabric lighter than the coverstock used on an infant diaper. This results from the fact that the absorbent product is subjected to less severe mechanical action and the recent trend has been toward designing smaller size sanitary napkins. Another consideration that dictates the difference in structures and sizes of the sanitary napkin and the diaper or the incontinence pad is the quantity of fluid discharged at one time and its constitution.

In a dynamic field of product development such as the absorbent sanitary materials, new technical innovations can result in a paradigm shift, giving rise to the use of a different, advanced technology [120,121]. Such is again occurring in the fabrication of the absorbent core for sanitary napkins. In this case, there is a growing use of preformed airlaid pulp fabric to replace the current wood pulp fiber core. The airlaid pulp fabric can be supplied and used on the converting line directly, eliminating the large, noisy, and dusty pulp sheet grinding operation. The fabric can be provided in a range of weights and configurations specifically designed for this use. For example, the web can be provided with the incorporated superabsorbent polymer at the desired position in the structure. Although the raw material in this form may have a higher price, simplified, integrated converting operations make the

change attractive.

This same concept is being considered for an integrated absorbent core structure for other absorbent products, such as diapers and adult incontinence pads [122], but the larger core size and greater absorption capacity requirements of some of these can create some economic problems in the use of airlaid pulp fabrics.

A significant use of superabsorbent polymer also occurs in some brands of sanitary napkins. In many cases, the solid polymer in powder form is lightly affixed to a tissue. This composite layer is then inserted between the backing film and the absorbent pulp pad, or in a lower layer of the pad. This location, away from the source of the liquid, is important, as the wetted, swollen, superabsorbent material is a gelled mass that would tend to block the capillaries and retard the progress of fluid into the structure. Hence, the placement of the polymer must be carefully selected to insure that it attracts and holds fluid but does not retard the flow-in of the subsequent additional liquid.

4.5. Underpad

In general, the nonwoven absorbent structures utilized for underpads have been similar in design and configuration to those used for early disposable diapers, the latter being derived from the former. Because the underpad is stationary in use and has less critical performance expectations, lighter weight and lower quality facings have often been used on this product. Lightweight rayon dry form topsheet was the industry standard for many years. Lightweight fabrics produced via the wet form process have also been used. In such cases, the nonwoven fabric has generally been produced from a blend of wood pulp and short cut polyester fiber or short cut rayon fiber in varying proportions. Latex print bonding has normally been employed for these structures.

A successful underpad has been produced by simply combining an impervious polyethylene film with a heavier weight all pulp fabric (85 g/m²), produced by a modified tissue process. There has been some use of superabsorbent powder in underpads.

An underpad product has also utilized a facing of a plastic net produced by the attenuated extrusion process [123].

4.6. Adult Incontinence Product

A wide variety of absorbent products for adult incontinence have been offered commercially. In most cases, these structures have used conventional absorbent materials and construction details, similar to those of the disposable baby diaper, modified for different body dimensions. There has been a greater use of simple insert nonwoven covered pads utilized with tight-fitting elastic briefs; this product type is reminiscent of the two-piece infant diaper.

Adult incontinence pads similar to the one-piece wing-fold infant diaper design have also been offered commercially. Similarly, elastic leg shaped products have been commercialized in several designs. In a similar fashion, a pull-up or pant style adult pad with extensive elasticsation of the top, i.e. the waist, has generated considerable interest and commercial success.

In general, nonwoven facings and absorbents similar to those used in infant diapers have been employed. Among these also is a perforated film, similar to the one used in some sanitary napkins [124]. However, the weight of the fabric is sometimes increased to provide

for the large volume of fluid involved and the greater mechanical action encountered. Because of the desire to maintain a compact design and to insure user dignity, there has been an increased interest in the use of superabsorbent polymer materials in adult products as well.

Accordingly, the adult pads now also tends to be highly engineered body shaped structures that use components similar to those employed in the modern day diapers and the other personal hygiene items [125].

4.7. Wound Dressing

Nonwoven materials have been used rather extensively as the facing, as well as the entire absorbent pad of a wide variety of wound dressings and surgical pads. Initially, latex bonded uni-directional nonwoven fabrics were utilized as the facing of a limited range of surgical dressings; these fabrics generally replaced the traditional bleached, woven gauze.

The nonwoven topsheet was often combined with an absorbent structure of folded tissue, rayon fiber sliver or similar material. There has been some use of a hydrophobic plastic netting thermally adhered to the surface of pads, or a polyethylene coating applied to the latter, in order to convey easy wound release properties [126,127]. Although such a plastic netting could be visualized as a structure interfering somewhat with absorbency, the netting was porous enough for the fluid to enter into the nonwoven fabric and, subsequently, into the absorbent pad beneath the latter.

During the past many years, there has been a growing interest in the use of a spunlace nonwoven material in a broad range of dressings, surgical sponges, surgical pads and similar important health care products. A widely used fabric for this application has been a spunlace web derived from 70% rayon and 30% polyester in approximately 70 g/m² weight. This fabric, folded into a 4-ply sponge, has been able to replace the earlier 16-ply woven gauze sponge with equivalent absorbency, less linting, and softer hand [128].

An absorbent thermally bonded nonwoven web has also been offered as a surgical sponge. This fabric has had the unique point embossed bond pattern, characteristic of the use of twin spirally grooved heated rollers [129]. Although this process could use a variety of fiber compositions, the blend of 50% polypropylene and 50% rayon was given the greatest commercial emphasis.

Needlepunch fabrics from hydrophilic, hydrophobic and blends of fibers have been used for absorbent applications in dressing products. Sufficient structural integrity is often obtained with a modest amount of needling, which provides a fairly bulky structure with good absorbency rate and capacity.

4.8. Absorbent Wipe

One of the most obvious requirements for a wiping product is rapid absorbency. This is true of wipes employed in industrial applications as well as of ones used in institutional and household uses. Disposable and semi-durable nonwoven materials have been extensively employed in these markets.

Wiping performance in the industrial sector is generally concerned either with aqueous or oil-based material pickup. Although some wipes are capable of functioning in both situations, optimum performance is usually obtained when a wipe is designed for either the aqueous or the oil pickup. Superior performance in the oil pickup is generally provided

by hydrophobic materials, such as polyester, polyolefin or nylon, whereas the aqueous pickup is enhanced by the use of hydrophilic materials, such as cotton, rayon or wood pulp.

Although substantial use has been made of the waste fabrics, usually woven or knitted, in the industrial wiping sector, there has been growing acceptance and use of clean, specifically engineered, nonwoven structures in this application [130]. A major portion of this market has been served by latex bonded dry form nonwovens with particular use of rayon fiber [131]. Such fabrics have offered acceptable performance in removing oil and superior performance in picking aqueous fluids. In some instances, special latex binder compositions have been required in order to meet the low organic solvent emission specifications of the application. Wet form nonwoven webs have also been offered into this market which have provided performance superior to that given by the disposable paper material that controls a major share of the industrial wipe market. This technology has been especially useful in the development of very low linting products required for clean room application [132].

Spunlace nonwoven fabrics have found ready acceptance in many of the more critical industrial wipe applications. A popular wipe has been spunlace fabric produced from a blend of 40% polyester and 60% wood pulp. The fabric is binder-free and has most of the pulp on one surface. It features good absorbency along with acceptable softness, strength and abrasion resistance.

A major commercial application of meltblown nonwoven materials has been in the industrial wiping sector. These webs are generally composed of 100% polypropylene micro-fibers. They are bonded by emboss calendering and treated with a surfactant to provide easy wetting characteristic for use on aqueous systems [133,134]. Also, these materials are particularly effective in wiping oil-based fluids. For increased durability, the meltblown micro-fiber web is often combined with one or more layers of polypropylene spunbond fabric. This provides an absorbent material with considerably greater strength and surface abrasion resistance.

A range of absorbent wipes produced by the composite process has been used in the institutional wiping sector. The most common structure made by this process has a core of two-ply high bulk tissue and a facing on both sides derived from an apertured rayon, latex bonded dry form nonwoven fabric. The entire composite is adhesively bonded in a distinctive pattern [135].

There has been some use of stitchbonded nonwoven webs derived from various fibers, often secondary or low cost waste fiber. This technology has been particularly utilized in Europe. In a similar manner, several European companies have offered an absorbent nonwoven material for industrial and household markets produced by the needlepunch process. These absorbent materials have usually been made from a blend of 85% rayon and 15% polypropylene fiber. The web is normally given a modest amount of needling on a pre-needle loom, followed by a hot air thermal bonding step in which the polypropylene fiber is melted and converted into binder [136]. Thus, integrity conveyed by the modest needling is further augmented by the thermal bonding action of the polypropylene component.

4.9. Oil Absorbent

There has been a growing interest in recent years in absorbents specifically designed for oil and grease pickup. These are meant to protect the environment by absorbing oil from spills, and avert accidents by absorbing grease and similar fluids from around walkways,

plant entrances, machines, kitchen floors, etc. Several commercial absorbent nonwoven materials have been utilized in this application, with very satisfactory results [137].

The polypropylene meltblown micro-fiber webs have been especially useful for the pick-up of these fluids. Such webs float on water, and have a considerable affinity for oil on the surface. The polyolefin materials are particularly effective in this application, as oil and grease will actually displace any water originally present in the pores of the absorbents [138,139].

Airlaid pulp has also been utilized in this application. In this case, the hydrophilic nature of the wood pulp fiber is masked by the use of a small amount of paraffin wax finish, applied as a post treatment to the fabric. With this finish, the pulp fabric can be used to pick up oil and grease, with the latter again displacing any water (including sea water) originally picked up by the material. Fabrics made by other nonwoven processes, including spunlace, spunbond, and those made by combination of technologies, have also been proposed for use as sorbents of such fluids.

5. POTENTIAL FUTURE DEVELOPMENTS

Because of the advances made in absorbent nonwoven materials and their success in a broad range of commercial products, it is natural to expect that the use of nonwovens in absorbent structures will grow. As the detailed mechanism of absorbency is uncovered and as the critical performance parameters required are delineated, it is obvious that better products and new applications will emerge.

The introduction of specialty fibers in absorbent applications will undoubtedly grow, particularly in the synthetic fiber sector. This will involve the exploitation of the unique capillary structure and potential wicking performance of certain synthetic fibers. Further, the use of micro denier materials and hollow fibers, along with those possessing a porous core, multi-lobal shape and grooved surface, will undoubtedly receive increased attention.

With increasing skill on the part of the fiber technologists to create fibrous precursor webs, including composites with specific orientation and configuration of fibers, the possibility grows for engineering fibrous structures specifically designed to enhance and control absorbency characteristics. As the growth of binder-free systems increase, these structures can utilize the maximum potential offered by the constituent fiber without the interference from a foreign agent. Also, as more bulky, lofty, open structures are devised, the full use of void space can be achieved. Stable structures with as little as 3% fiber volume are currently possible. With appropriate technology, it should be possible to utilize with full advantage this enormous void volume in absorbent structures of the future.

6. ACKNOWLEDGEMENT

The authors gratefully acknowledge the help of Mr. Ian Butler of INDA, the Association of the Nonwoven Fabric Industry, for reviewing the manuscript and making several helpful suggestions. In addition, the authors thank many other individuals from the nonwovens and the absorbent products industry with whom they conferred during the writing of this chapter.

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