An overview of spunbonding and meltblowing technologies

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ABSTRACT: This paper presents an overview of the spunbonding and meltblowing technologies. It also addresses the differences between the two processes, product characteristics, process economics, and process equipment.

KEYWORDS: Bonding, characteristics, economics, equipment, joining, melt blowing, processes, properties, spun bonding, technology.

In the past 30 years, the nonwoven industry has observed a phenomenal growth, mainly because of a close alliance among nonwoven producers, fiber producers, binder producers, and machinery manufacturers. There are many nonwoven manufacturing processes and products that have been developed and commercialized during this period to address a variety of end-use markets. As an example, in the late 1950s, polymer laid systems were developed. Since then, many researchers have perfected polymer laid technologies in order to make an increasingly varied range of products. Although the research work on this technology was started in the late 1950s and an extensive number of processing and products patents were developed, there has been a dramatic resurgence of research and development work in the past few years.

In recent years, the increased acceptance of polymer laid fabrics in many end-use products has sparked an interest in this process from both a commercial and a scientific point of view. This paper describes two of the most important polymer laid systems: the spunbonding process and meltblowing process.

Spunbonding process

The concept of the spunbond process was developed simultaneously in Europe and the United States in the late 1950s, but it was later—in the mid-1960s to early 1970s—that the strength and potential of the spunbond technology were recognized for commercial applications. A large number of patents on the spunbond process design were filed during this period, and a few of them were used for commercial production processes.

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Process description

A primary factor in the production of spunbonded webs is the control of four simultaneous, integrated operations: filament extrusion, drawing, laydown, and bonding. The first three operations are directly adapted from conventional manmade fiber spinning and constitute the spun or web formation phase of the process. The last operation is the web consolidation or bond phase of the process—hence the generic term *spunbond (1).*

In its simplest form, a spunbond line consists of the following elements: an extruder for forming filaments; a metering pump; a die assembly; a filament spinning, drawing, and deposition system; a belt for collecting the filaments; a bonding zone; and a winding unit. A generic schematic of the spunbonding process is shown in **Fig. 1.**

The extruder and metering pump provide uniform polymer melt delivery to the die block assembly, one of the most important elements of the spunbond process. This assembly has two distinct components: the polymer feed distribution system and the spinneret block. The feed distribution system delivers uniform polymer melt to the spinneret block.

The filament spinning, drawing, and deposition are the three most critical steps in a spunbonding process. Basically, these steps are performed using a single integrated system. The main function of this system is to solidify, draw, and en-

tangle the extruded filaments from the spinneret and deposit them onto a conveyor belt *(2,3).*

Spinning. There are three generic types of spinning techniques used in a spunbonding process: melt, dry, and wet. The concept of these techniques is directly adapted from conventional filament fiber spinning techniques. Although any of these techniques can be used in the spunbond process, the melt spinning technique is most widely used because of its simplicity and economics.

Drawing. The drawing of the filaments follows spinning. In conventional fiber spinning, filament drawing is achieved using draw rollers. However, in a spunbonding process, drawing is achieved using a specially designed aerodynamic device.

Deposition. The filament deposition, which follows drawing, is also achieved using a specially designed aerodynamic device that is usually referred to as a fanning or entangler unit.

Over a period of the past 25 years, many filament spinning, drawing, and deposition systems have been patented and commercialized. Some of the basic principles involved have been proposed by Hartmann *(4).* A great number of spunbond processes can be fitted into one of the four routes proposed by Hartmann with appropriate modifications. Many filament spinning, drawing, and deposition systems have been commercialized based on these concepts.

The conveyor belt carries the unbonded web to the bonding zone. There are three basic bonding techniques used in a spunbond process: thermal, chemical/adhesive, and needling. The choice of a particular technique is dictated mainly by the ultimate fabric applications. Occasionally, a combination of two or more techniques is used to achieve bonding.

A spunbond web is usually wound on a cardboard core and processed further according to the end-use requirements. A combination of fiber entanglement and fiber-to-fiber bonding generally produces enough web strength so that the web can be readily used without further treatment.

Process variables

The spunbonding process is quite complex and involves many operating variables. The processing variables can be divided into two categories: operational variables and material variables. By manipulating these variables, a variety of spunbond fabrics can be produced with the desired properties. Each of these variables plays a significant role in process economics and product reliability. Therefore, it is essential that each one is precisely defined and understood in order to optimize the spunbond process. The following are the major process variables that affect the filament and web properties *(2):*

- Polymer characteristics
- Melt viscosity and temperature
- Air temperature and flow rate
- Filament draw speed
- Polymer throughput rate
- Collection speed
- Bonding conditions.

Characteristics and properties of spunbonded webs

Spunbonded webs represent a new class of manmade product, with property combinations falling between paper and woven fabrics. Spunbonded webs offer product characteristics ranging from very light and flexible structures to heavy and stiff structures. The following are the main characteristics and properties of a spunbonded web *(2,3):*

- Random fibrous structure
- Generally white with high opacity per unit area
- High strength-to-weight ratios compared to other nonwoven, woven, and knitted structures
- High tear strength
- Planar isotropic properties due to random laydown of fibers
- Good fray and crease resistance
- High liquid retention capacity due to high void content
- High in-plane shear resistance
- Low drapeability
- Most are layered or shingled in structure; the number of layers increases with basis weight.
- Basis weight ranges from 5 to 800 g/m^2 but is typically 10–200 g/m^2.
- Web thickness ranges from 0.1 to 4.0 mm but is typically 0.2–1.5 mm.
- Fiber diameter ranges from 1 to 50 μm, but the preferred range is 15–35 μm.

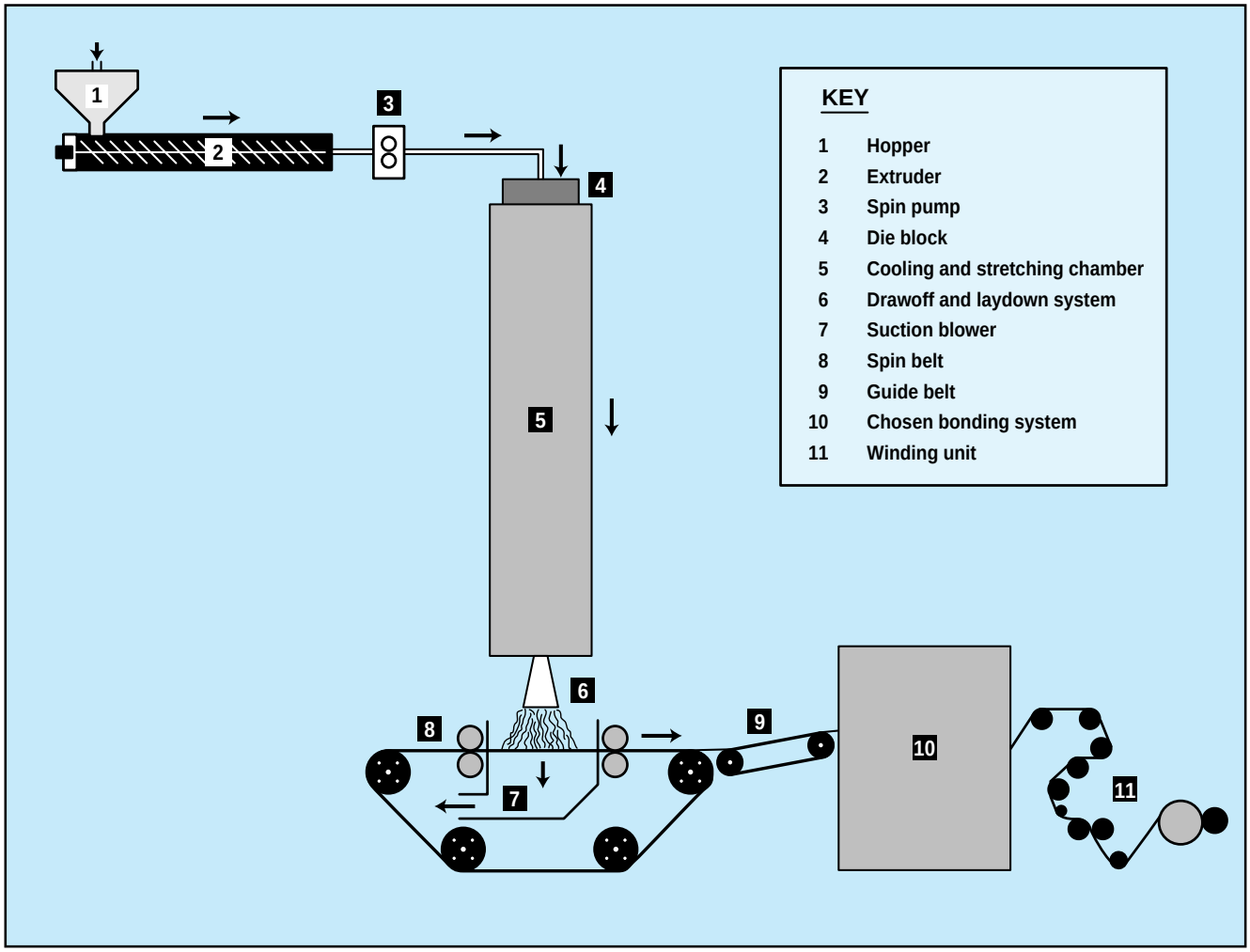
Application of spunbonded webs

Spunbonded webs are finding applications in a variety of end uses. In the early 1970s, spunbonded webs were predominantly used for durable applications such as carpet backing, furniture, bedding, and geotextiles. By the 1980s and 1990s, however, disposable applications accounted for an increasingly large percentage, primarily because of the acceptance of lighter spunbonded polypropylene webs as a coverstock for diapers and incontinence devices *(5).* Spunbonded webs are classified as follows: automotive, civil engineering, sanitary and medical, or packaging *(2,3).*

Meltblowing process

In the early 1950s, meltblown nonwoven fabric technology was developed to make microfiber filters that were used to collect radioactive particles form the upper atmosphere. The microfibers (also referred to as superfine or meltblown fibers) are fibrous materials generally less than

1. Schematic of a typical spunbonding process



10 μm in diameter. Such fibers are found in nature in the form of spider silk and pineapple leaf fibers *(6).* Manmade microfibers are made using a variety of materials and production techniques. The submicron glass fibers in "glass wool" are a prime example.

In the late 1960s, the Esso Research and Engineering Co. (now Exxon Chemical Co.) recognized the strength and potential of microfiber technology for commercial applications. Exxon started developing a low-cost method of producing blown microfibers from polypropylene. After extensive research and development, which was based on Went's original work on microfiber technology *(7,8),* Exxon researchers patented the blown microfiber process (usually known as the meltblown process). Later, the company licensed the meltblown technology to others and concentrated on producing resins to supply this novel process *(9).*

Other companies also have proprietary blown microfiber production processes. However, as a result of Exxon's dominant technology position, coupled with tailored resin and competent authorized equipment suppliers, most of today's meltblown production lines in the nonwoven industry are licensed through Exxon. A comprehensive list of companies involved in meltblown fiber production is given by Cain *(10).*

Process description

A schematic of the meltblowing process is shown in **Fig. 2.** A typical process consists of the following elements: an extruder, a metering pump, a die assembly, and web formation and winding equipment.

The extruder and metering pump provide uniform polymer melt delivery to the die assembly, which is the most important element of the meltblown process. This die assembly has three distinct components: a polymer feed distribution system, a die nosepiece, and air manifolds. The polymer feed distribution system delivers uniform polymer melt to the die nosepiece.

The air manifolds supply the high-velocity hot air (also called primary air) through the slots to the top and bottom sides of the die nosepiece. A high-velocity hot air is generated with an air compressor. As soon as

the molten polymer is extruded from the die holes, high-velocity hot air streams attenuate the polymer streams to form microfibers. As the hot-air stream containing the microfibers progresses toward the collector screen, it draws in a large amount of surrounding air (also called secondary air) that cools and solidifies the fibers. The solidified fibers subsequently get laid randomly onto the collecting screen, forming a self-bonded nonwoven web. Fibers in the meltblown web are held together by a combination of entanglement and cohesive bonding. The fibers are generally laid randomly (and are highly entangled) because of the turbulence in the air stream, but there is a small bias in the machine direction due to directionality imparted by the moving collector. The collector speed and the collector's distance from the die nosepiece can be varied to produce a variety of meltblown webs. A vacuum is usually applied to the inside of the collector screen to draw in the hot air and to enhance the fiber-laying process *(11).*

The meltblown web is usually wound on a cardboard core and processed further according to the end-use requirements. The combination of fiber entanglement and fiber-to-fiber bonding generally produces enough web cohesion so that the web can be readily used without further bonding *(9).* However, the webs subsequently may be thermally calendered with a smooth or patterned finish, or webs may be thermally laminated with other substrates.

Process variables

The meltblowing process is also quite complex and involves many operating variables. The processing variables can also be divided into two categories as explained in the spunbonding section. The following are the major process variables that affect the filament and web properties *(12,13):*

- Polymer characteristics
- Melt viscosity and temperature
- Air temperature and flow rate
- Die nosepiece, air angle, and air gap
- Polymer throughput rate
- Collection speed and distance.

Characteristics and properties of meltblown webs

Meltblown webs offer a wide range of product characteristics. The main characteristics and properties of a meltblown web are as follows *(12,13):*

- Random fiber orientation
- Low to moderate web strength
- Generally highly opaque (having a high cover factor)
- Derives strength from mechanical entanglement and frictional forces
- Most meltblown webs are layered or shingled in structure; the number of layers increases with basis weight.
- Fiber diameter ranges from 0.5 to 30 μm, but the typical range is 2–7 μm.
- Basis weight ranges from 8 to 350 g/m^2 but is typically 20–200 g/m^2.
- Microfibers provide a high surface area for good insulation and filter characteristics.
- Fibers have a smooth surface texture and are circular in cross section.
- Fibers vary in diameter along a single fiber.
- A close examination of approximately 800 photomicrographs showed no "fiber ends" (except a few near the "shot" area); therefore, the fibers are believed to be continuous in length.
- Fibers show thermal branching.

The exact cause of thermal branching is not known, but according to Malkan *(11),* fiber branching occurs when propagating fibers collide with other propagating fibers, which in turn strip off portions of polymer streams as fine branches (filaments). Richardson *(14)* pointed out that when the velocity of the liquid jet relative to that of the air jet increases, portions of the liquid are stripped off as filaments. It is believed that fiber splitting (branching) occurs when extrudate is stressed in complex ways in-flight toward the collector.

Applications of meltblown webs

Meltblown webs, due to their inherent properties such as large fiber surface area, are suitable in filtration, insulation, and liquid absorption applications. The fine fiber network (large surface area) results in enhanced filtration efficiency, good barrier properties, and good wicking action *(15–18).*

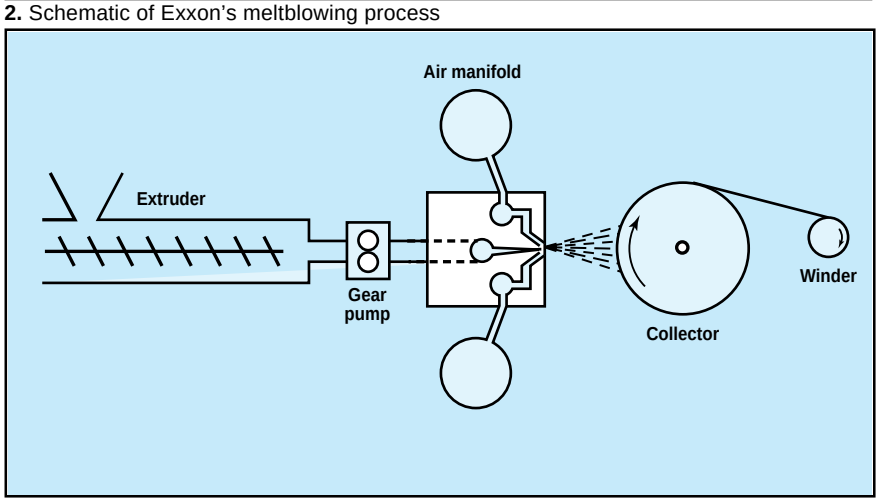
Process equipment and layout

As discussed in the process description section, even though the two processes are conceptually simple, the production of high-quality webs at a commercial scale requires precisely designed and fabricated equipment. Although several nonwoven companies have the in-house capabilities to design and fabricate their own equipment, many others look to competent equipment vendors to build and supply key components or a complete turnkey line.

Spunbonding

Many spunbond web manufacturing companies, such as DuPont, Freudenberg, Amoco, and Kimberly-Clark, have developed proprietary technologies. These companies use their technology for in-house applications and do not license the technology or equipment to others. There are many nonwoven equipment manufacturing companies that have developed spunbond technology for licensing and purchase. Several major systems are as follows:

2. Schematic of Exxon's meltblowing process



- Docan system by Lugri
- Reicofil system by Reifenhäuser
- Impianti system by S.T.P. Impianti
- Meccaniche Moderne system by Meccaniche Moderne.

The spunbond equipment layout is predominantly vertical. The equipment is laid out in sections as follows:

- The top section consists of the extruder, gear pump, and die block assembly.
- The middle section consists of the fiber formation and air supply assembly.
- The bottom section consists of the fiber laydown, spin belt, and bonding assembly.

The vertical space requirement depends on the type of fiber formation assembly; 50 ft is normally the minimum requirement. The horizontal space requirement depends on the total width of the die and the type of bonding unit. Usually, three times the vertical space is the minimum requirement for the horizontal space.

Meltblowing

Meltblowing is similar to spunbonding technology, and many meltblown web manufacturing companies, such as 3M and Freudenberg, have developed proprietary technologies. Unlike the spunbond process where there are many key players and a variety of processes, most of the meltblowing processes in the market are based on the Exxon process.

Exxon has developed agreements with several competent equipment builders to supply complete lines or turnkey lines to Exxon licensees. The complete turnkey line systems are as follows:

- Accuweb system by Accurate Products
- Meltblown system by Reifenhäuser
- J & M system by J & M Laboratories.

These systems can be licensed and purchased from the respective companies. Exxon has also assigned many vendors through which key components for the meltblowing systems may be purchased.

The meltblowing process equipment layout, which can be vertical or horizontal, is simpler and more compact than that for the spunbonding process. A vertical layout is preferred when multiple dies are used, but a horizontal layout is preferred when a single die is used. The vertical space requirement, usually a minimum of 20 ft, depends on the die-to-collector distance. The horizontal space requirement depends on the total width of the die and end product requirements. Usually, three times the vertical space is the minimum requirement for the horizontal space.

The main advantages of purchasing a turnkey line (for spunbonding or meltblowing) are as follows:

- Less expensive than developing the technology
- Success rate is high
- System can be tailored to the customer's requirements
- Modifications at a later date are more easily made.

Process economics

In nonwovens manufacturing, the process economics can be influenced by many factors, such as energy requirement, capital investment, production speed, and ease of raw material conversion. This discussion focuses on energy, capital investment, and production speed.

Energy

Spunbonding processes use less energy than meltblowing processes. The former consumes about 2–3 kW·h per kg of polymer processed, while the latter consumes about 6–8 kW·h per kg of polymer processed. The meltblowing process is more energy intensive because compressed hot air is used for fiber attenuation. About 70% of the total energy is used for hot air. This higher energy consumption results in a higher product cost. Typically, a 2.0-oz. polypropylene spunbond web costs US$ 0.22–0.24/yd^2, while its meltblown equivalent is US$ 0.32–0.37/yd^2.

Capital investment

The initial investment for the spunbonding process is three to four times higher than that for the meltblowing process.

Production speed

The spunbonding process is inherently faster than the meltblowing process. This is mainly due to the number of holes in the spinneret or die block, and process complexities. For example, the spunbonding spinneret block usually has 100 holes/linear inch, while meltblown nose tip has 25–30 holes/linear inch.

Process mechanics

Spunbonding and meltblowing processes incorporate many engineering concepts. Some of the key concepts are as follows:

- Dynamics of the melt spinning process, which include mass balance, force balance, and energy balance
- Deposition ratio
- Polymer residence time in an extruder
- Residence time in nip during calendering.

A complete description of these concepts is given by Malkan and Wadsworth *(19)*.

Process literature

Despite the extensive research and development activities in the spunbonding and meltblowing areas, there is a paucity of published research studies, mainly due to the secretive and competitive nature of the developmental work. However, there is considerable patented literature available that is based on process enhancement and product development studies. An in-depth review of meltblowing process patents is given by Moore *(20)*. There are about 50 published research studies on the spunbonding and meltblowing processes that are based on processing science and theoretical concepts. A complete review of this literature is given by Malkan *et al. (2,3,12,13)*.

Markets

Spunbond and meltblown manufacturing constitutes one-third of the total nonwovens production in North America *(1)*. The polypropylene resin is by far the most widely used resin in both of these processes. Polypropylene makes up 60–70% of the total spunbond production in North America. In meltblowing, polypropylene constitutes 70–85% of the total North American production.

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