NATURAL FIBERS IN NONWOVEN PROCESSES

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Abstract

Although synthetic fibers have traditionally been the foundation of the nonwoven industry, natural fibers have been receiving increasing attention in the past few years. Woodpulp fiber forms the basis for an important segment of the industry; this includes virgin as well as secondary fiber. Cotton, in the bleached and unbleached state, is finding greater use in specialty segments.

Some bast fibers have also been used for years for their special end-product attributes in wetform processes. Flax and hemp are experiencing increased use in a growing variety of industrial applications. Some additional natural fibers are being investigated for nonwovens production as the search for special properties and low-cost in fibrous raw materials continues.

Introduction

An examination of the status and future of natural fibers in nonwovens processing is an appropriate topic for the Fourth International Nonwovens Symposium. For a conference sponsored by the National Cotton Council, however, to explore fibers other than cotton fiber may be a little suspect. However, consideration of applications, aspirations and successes of other competitive fibers and materials is often the stimulus that fosters cross-fertilization and synergy in unexpected ways. It is hoped that such will be true in the case of considering the use of natural fibers beyond cotton fiber and woodpulp fiber in nonwoven processes.

The concept of "beyond cotton fiber" instead of "other than cotton fiber" may be appropriate. Certainly the concept of combining cotton fiber with these other natural fibers in blends for nonwoven products may truly offer synergistic performance and economics.

Fibers in Nonwovens Processing

A quick, historical review of the fibers that have been used in nonwovens processing may be helpful in setting the stage for considering other fiber types.

Recognizing that early nonwovens technologies came primarily from three diverse industries helps to explain some of the historical and evolutionary trends in the industry.

In the late 1930's, the specialty paper industry made moves to introduce fiber types other than woodpulp, to obtain unique and diverse properties. With appropriate modification of processing equipment and also in raw materials, the wetform nonwovens technology emerged and offered new and specialized products.

In the 1940's and especially into the 1950's, the conventional textile industry contributed the beginnings of dryform nonwovens technology with the bonded carded web system, along with needlepunch and stitchbond variations.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:641-645 (2001)
National Cotton Council, Memphis TN

The period of the 1960's saw the development and refinement of extrusion-based spunbond technology, followed shortly thereafter by the meltblown technology. These contributions arose from the synthetic fiber-producing or plastics processing industry as a major contribution to nonwovens technology.

The dominant fiber in the wetform process contributed by the paper industry was cellulosic woodpulp fiber, of course. This fiber had been the key fiber for this industry for several decades. While it was not the most ideal fiber for wetform nonwovens processing, its performance was gradually augmented by the use of other fiber types, both synthetic and natural fibers, in the wetform process.

The dryform process contributed by the textile industry was based predominantly in its early phases on viscose rayon staple fiber. This fiber was close to ideal for the fledgling dryform nonwovens industry. It was clean, relatively pure, soft and absorbent; rayon staple fiber was uniform and processed very easily, along with being very suitable for latex adhesive bonding. A distinct advantage also was the fact that it provided a "finished fabric" off the production line, requiring no desizing, scouring or bleaching like its cotton cousin in woven textiles.

The spunbond processes arising from the synthetic fibers industry were based on the raw materials of the thermoplastic extrusion processes; hence, polyester, nylon and polypropylene were the dominant fiber types arising from extrusion nonwovens sources. The same was true of the emerging meltblown nonwoven industry segment, except that polypropylene rather quickly dominated this technology.

As has been true of the industry from its earliest beginnings, interprocess competition has been an important factor in the development and evolution of the industry. As a new and different twist to the technology comes along, it is a "trivial technology" at the outset and receives little attention. When this novel feature has real merits and advantages, it becomes a "disruptive technology", and can no longer be ignored. Although viscose rayon fiber was "The king" fiber of the dryform process industry for several years, the economics and performance of polyester fiber could not be denied, particularly in the industry's largest application, disposable diaper facing.

This new technology was trivial at first; three years were required for it to overtake and indisputably displace rayon fiber as "king". The industry was so firmly welded to rayon fiber as the fiber of choice that the introduction of polyester fiber had to be made in blend stages, but the change did come about.

However, polyester staple fiber did not retain its dominant position for long. Another "trivial" development was forming in the fringes of the industry --- polypropylene fiber and calender thermobonding technology to exploit it. This combination had a lot to offer the industry and its customers, and so could not be denied. As a result, this combination of fiber and technology became a "disruptive" factor that impacted the entire industry.

Following in rapid succession were additional, competitive technologies which were able to carve out a position in the industry because of processing, performance, economics and related factors. Bicomponent binder fibers became more widespread, aided by the unique features of through-air bonding of this fiber. The use of high-pressure waterjets, along with specifically designed backing belts, provided fiber entanglement bonding that offered unique properties and combinations, particularly in web strength coupled with web softness, which was virtually unobtainable otherwise.

A trivial feature of waterjet entangling was the substantial mechanical energy transmitted to individual fibers in the web. This feature, when combined with fibers capable of splitting into fibril segments, opened up the possibility of producing unique micro-fiber fabrics via the nonwoven process.

More recently, combining the extrusion of splittable synthetic spunbond filaments, followed by web formation and then waterjet entanglement, has opened up exciting possibilities for unique microfiber nonwoven structures via integrated processes. And so the advances accrue.

Drivers for Change

With the shifting changes in business, societal, economic, environmental, technical, life style and almost every other aspect of the world's value system, it is not surprising that the climate faced by the nonwovens industry today presents numerous changes as well.

Fiber cost parameters have changed --- rayon fiber at 25 cents/pound for years shooting up to over a dollar per pound; crude oil in less than two decades --- going from \$18 to \$11 to \$30 per barrel. Environmental concerns have also intensified after having gone from hot to cool; now the emerging consensus respecting the environment seems to be --- Do little or no harm --- which can mean further changes.

The need for sustainability in raw materials has progress from a "trivial" level to an "interesting" level already.

Nmerous other drivers for change that could impact the nonwovens industry are on the horizon. Time will likely tell which of these factors are destined to become major, constructive or disruptive drivers and which are simply passing vagaries.

Exploitation of Nonwoven Process Technology

There are already some interesting and significant examples of the exploitation of nonwoven process technologies in responding to some of these drivers. Some of these situation provide a logical backdrop for the discussion of the role and utilization of secondary natural fibers, those natural fibers other than cotton and woodpulp fiber, in nonwovens processing technology.

The entire sector employing recycled fibers is one striking example that might provide some guidance in considering secondary natural fibers and nonwovens processing. While this activity may not involve natural fibers directly, it can often reveal areas and opportunities where such natural fibers can participate, with beneficial results.

One of our continuing projects has been directed toward helping a client expand the utility of woodpulp fiber obtained by recycling old newspapers.

The client had developed a profitable business involving the collection and fiberization of used newspapers. These secondary fibers were combined with flame retardant materials to provide an excellent residential building insulation. The typical Southwestern home with its low pitched roof is much more amenable to blown-in installation of insulation compared to the rolls of glass fiber batts.

The client wanted to expand the utility of their insulation from strictly horizontal applications to vertical applications, which could not be done conveniently by the blown-in method. What was needed was a relatively thick batt of lofty recycled newsprint fiber which had sufficient batt integrity and stability to allow horizontal installations. This was particularly desirable for the sidewalls of manufactured homes.

A very viable solution to the problem with an attendant opportunity for business expansion was achieved by blending in a modest amount of bicomponent binder fiber, followed by a hot air thermobonding process without compression. Such bats have the desirable low density required for excellent insulation properties as measured by R-values, along with very adequate mechanical stability for easy application in horizontal walls. The ease of cutting-to-shape and handling these batts were also distinct advantages.

This success led to consideration of other low-cost fibers for exploitation in the process. This effort has focused particularly on secondary fibers recovered from garneted apparel clippings. Additional fibers investigated have included short, cut fiber from cut pile carpeting, recycled mixed textile fiber waste, as well as others.

Fiber recovered from denim clippings has been a particularly interesting raw material, often providing distinct marketing advantages for the resulting nonwoven fabrics and batts because of the popularity and universality of the denim appearance.

This company has also been successful in displacing highloft batts from virgin polyester fiber with recycled lofty batts from cotton/polyester fiber blends, recovered from apparel and T-shirt clippings. Some of these applications have been especially noteworthy.

Trials of secondary natural fibers with this system in the same processing equipment have yielded interesting results, and further trials and exploitation of such natural fibers in the system are contemplated.

Extension to Secondary Natural Fibers

The primary natural fibers are those which are currently involved in a substantial commercial trade. They comprise wool, silk, cotton and woodpulp.

Traditional wool fiber has found only very limited use in nonwoven processing. However, there are some recent interesting and successful developments being achieved with commodity wool fibers in the needlepunch process. It is interesting in this regard that the needlepunch process was originally developed to mimic the natural felting capability of wool fibers and to extend felt-like structures to waste fibers and coarse fibers originally, and then eventually to form felts from synthetic fibers. Wool fibers have some interesting characteristics that could be exploited to advantage in selected nonwoven technologies.

While silk fiber has not been considered a raw material for nonwoven processing, it is very interesting to realize that a silk spunlace nonwoven fabric (Toyobo Co., Ltd., Osaka, Japan) was exhibited and promoted at the recent ANIC 2000 show in Osaka.

Certainly there has been much said and written about the use of the two major natural fibers --- cotton and woodpulp ---- in nonwoven processing technologies. These two primary natural fibers that are being used to such a considerable extent in the nonwoven industry comprise one lignocellulosic fiber (woodpulp fiber), and one non-lignocellulosic fiber (cotton).

The use of cotton has certainly stimulated considerable research and development in the dry form and spunlace processes. Similarly, woodpulp fiber has been the mainstay in the sizeable and growing airlaid pulp nonwovens business segment.

The secondary natural fibers that are of potential interest are all lignocellulosic fibers. They can be classified in the following manner according to the part of the plant where the fiber is located, as shown in Table 1.

Table 1. Classification of Natural Cellulosic Fibers.

Bast or Stem Fibers	Leaf Fibers	Seed Hair Fibers
Flax	Abaca	Cotton
Hemp	Sisal	Kapok
Kenaf	Piña	Coir
Ramie		
Jute		

The cell walls of the plants involved consist of cellulose and lignin; the latter is a complex polyphenolic crosslinked polymer which serves as the binder material for the cellulosic fibers in the cell walls of higher plants. The physical properties of these fibers, such as tensile strength, modulus and elongation depend on their cellulose content, microfibrillar angle, cell dimension, cell shape and cell arrangement (Shishoo, 1997).

The physical properties of various natural fibers of interest are summarized in Table 2. For comparison purposes, typical properties of the important synthetic fibers are also give in the table.

Of these secondary natural fibers, flax, hemp, jute and kenaf are probably the most interesting and the most important for consideration at this point (Ozsanlav, 1997).

Flax is a bast fiber derived from the dry stem or straw of an annual plant of the Linaceae family of the Linum genus. The flax plant is aggressively cultivated in several areas of the world (Russia, Canada, Belgium, Netherlands, Ireland, New Zealand, and others), as it is the source of four useful components: the stem gives rise to the flax fiber, which is the basis for linen textiles, the seed is the source for linseed oil and linseed cake, an animal feed; the remaining leaves and core of the stem are generally referred to as bract, which is also a product of commerce (deJong, 1998).

It is interesting to note that flax was the major source of cloth fiber for centuries, until the rapid growth of the cotton industry, which occurred after 1800. Prior to that time, flax was king of the fibers. This was true for apparel as well as household, industrial and other uses.

Flax has a more highly oriented molecular structure than cotton, and is, therefore, more crystalline, has a higher Degree of Polymerization and is stronger than cotton.

The degree of recent interest in flax as a major commercial fiber has resulted in the organization of an official ASTM Committee to deal with standards and methods involving the fiber (Buckley, 1999).

Hemp is another important lignocellulosic, secondary natural fiber, one that is struggling to overcome its current illegitimate status. Because of its relationship with marijuana, the cultivation of hemp is illegal in the U.S.A. at the present time; it is cultivated widely around the world, however.

This fiber is also a bast fiber derived from the bark of the stem. The core remaining after removal of the fiber is used for a variety of uses.

It is interesting to note that there was at least 60-tons of hemp fiber on the historic naval ship USS Constitution ("Old Ironsides"). This fiber was used in the sails, the rigging and ropes, the pennants, ensigns and flags, as well as in the clothing and uniforms; a further amount of hemp fiber was utilized in the oakum sealant, as well as in the paper used to produce the maps, logs and bibles that were on board (Herer, 1998).

There is a rather substantial, ongoing effort in the USA to legalize the cultivation of hemp for industrial fiber applications. This effort is centered on a variety of the hemp plant that is very low in the production of THC (delta 9-tetrahydrocannabinol), the active narcotic ingredient in marijuana.

Kenaf is a soft bast fiber obtained from the kenaf plant. This plant consists of a single, straight, unbranched stem with an outer fibrous bark bound with lignin, and an inner wood core. The kenaf stem grows to a height of 15 to 18 feet, with a stem diameter of 1 to 1.5 inches (Ramaswamy 1994, 1999).

This fiber source has generated considerable interest, as the plant is capable of a yield of 6-10 tons of dry fiber per acre---nine times the usual yield of wood (Young, 1987). The fiber is long in length and quite strong. It is used for twine, cordage and similar applications. It has been investigated extensively as a source of paper fiber (Tao, 1997).

Other secondary natural fibers that have generated some interest and have potential use in nonwovens technology include ramie and jute (bast fibers), kapok and coir (seed fibers), abaca, sisal, piña (leaf fibers) and others. Abaca (commonly called Manila hemp, although it is not a true hemp) has been used for many years as a reinforcing cellulosic fiber for wetform applications.

Nonwoven Applications

An outstanding example of the union of secondary natural fibers and nonwoven technology is the activities of the company FlaXlin Oy in Aminnefors, Finland. This company has a new Valmet "IFB"system (Integrated Forming and Bonding System) integrated into a new production line. This line consists of two Temafa Mixer-Openers, one for each of the fiber feeds (flax fiber and polyester bicomponent binder fiber). The opener is equipped with a continuous weigh control, which is tied into the central control computer system. The two fiber streams are merged onto a horizontal conveyor, which then transfers the blended fiber to an air conveyor system fitted with a metal detector and rejection unit.

The blended mix is then passed through two Fine Openers for additional opening-mixing-cleaning. The fiber is then moved by an airveyor into a spray unit where nozzles spray on a solution of flame retardant (guanadine sulfate solution). The sprayed fiber is then fed through a large cylinder into a large Timafa Mixmaster, where it has a residence time of about one hour. The fiber then goes through a Trützschler Fine Opener and then onto the full width of a special 2.5-meter card.

The card is fitted with eight baffles for uniform distribution and control over the full face width. The card has four rollers, one feed roller and three high speed turbo-rollers, providing three stages to accelerate and separate the fiber. The card has an air doffing system with fibers sent through a short nozzle section onto a forming belt running over a vacuum drum. Then the fiber web is placed onto a carrier belt and transported through a short oven.

The oven is actually a back-up for their thermal bonding system, as the IFB concept uses hot air at the bonding temperature of the binder fiber to preheat the fiber during the fiber forming and doffing stages. As a result, the fiber normally comes off the web former at the appropriate bonding temperature. The stripping air for doffing the fiber is about 10° C. below the bonding temperature. The full IFB concept is to have no oven beyond the web former, but to use simple cooling to complete the web bonding. The web is fully set by the use of a cooled air stream used in controlled amounts.

After edge trimming and slitting, the sheets are cut to length and packaged. The product consists of an intimate blend of flax (85%) and bicomponent PET/co-PET binder fiber (4.5 dpf, 15%). The completed batt is about eight-inches thick. The flax is obtained from Holland, Belgium, Lithuania and Estonia. The product has an insulation R-value of about 40, and is being used in industrial and residential insulation in the Nordic countries.

This same plant runs several other flax products for agricultural applications. An interesting one is used in aqua-culture. This involves the growing of vegetables and other plants in nutrient solutions without soil. The traditional support used in this method is a fibrous basalt mineral wool batt, used extensively throughout Europe. The basalt batt cannot be used for more than five planting cycles, because of accumulation of plant materials within the batt that inhibit further plant growth. The disposal of these thick basalt batts is a major problem, which is easily ameliorated by the use of the competitive flax batts.

An American investment group is currently installing a flax fiber processing plant in Canada which will be capable of producing multi-million pounds of flax fiber per year. The output of the mill, of course, will be linseed oil, linseed oil meal for cattle food, flax fiber and flax core. The flax core is very useful, as it contains very little lignin. It is primarily used for production of hardboard with thermoset resins, but some of this material produced in fine fiber form is used as a non-nutritive filler for MacDonald's hamburgers.

A substantial amount of hemp fiber is currently being raised and processed in Canada. Kenex Ltd. of Pain Court Ontario, Canada is one of the main suppliers of the fiber. This company processes the hemp material, producing a fiber with various degrees of purification; the greater amount of processing and purification leads to higher quality of fiber. After removal of the fiber, the core material, which is the inside of the hemp stem remains. This material is used in volume for horse bedding and work is being done to combine it with thermoset resins to produce a hard, dense material, such as Masonite (TM) panels.

A considerable amount of the hemp fiber is being processed in the U.S.A. for two-dimensional and three-dimensional hard surface panels for the automotive industry (Parikh, et. al., 2000). In this process, the hemp fiber is blended with polypropylene fiber or other thermoplastic fibers and powders and then is formed into a web of 2 - 3 inches in height.

This web is then passed through a needlepunch loom, where it undergoes considerable compaction. The resulting needled web is supplied in roll form or in sheet form to custom molders. The sheet is placed in a mold where it is subjected to heat and pressure. The final product is a 2-dimensional or 3-dimensional structure which is quite rigid. This type of structure is being used increasingly in various automobiles applications; usage includes headliners, door panels, package trays and other components (Parikh, et.al., 2000). Auto components of this type are finding considerable use in Europe, even in top line, expensive automobiles. The recyclability of these parts is a particularly attractive feature in Europe, where statutory requirements for recycling components are becoming very stringent.

A variety of natural fibers can be used in this type of system, although hemp is used in largest volume. Various thermoplastic resin fibers and resin materials are used, depending upon the needs of the customer. Some bicomponent binder fiber has also been employed for some specific applications.

A major producer of this type of needled web is Indiana Bio-Composite (Elkhart, Indiana). This company obtains their hemp from Canada and Europe and uses some kenaf as well.

Several natural fibers are used in a similar process except that the fiber material is hammermilled to a fine powder or "flour" state. This powder is blended with various thermoplastic resins to provide a molding compound used by thermoplastic molders or plastic extrusion processors. North Wood Plastics (Baraboo, Wisconsin) is a major compounder and supplier of this type of product. They use a considerable amount of wood flour (pine and maple wood), but also use flax powder, comminuted rice hulls and various other natural fiber raw materials.

This company has also processed extremely short fibers produced from the clipping of the pile of tufted carpets to make a cut pile or sculptured carpet. They have also supplied a reprocessed denim waste material compounded with a thermoplastic resin which is molded into plastic clothes hangers, which are then employed in displaying denim garments in retail shops.

Because economics is a major part of the process equation involved in using natural fibers, the comparative cost of these fibers is important. As would be expected, the greater the amount of processing to obtain higher quality fiber adds to its cost, resulting in a range for prices for these various fiber qualities. At the present time, these natural fibers fall into the following price ranges.

	Cost Per Pound
Flax fiber	18 - 35 cents
Hemp fiber	25 - 40 cents
Kenaf fiber	15 - 30 cents

It is interesting to note that waste and secondary cotton fiber processed from apparel clippings for use by the nonwovens industry provides a raw material in the 10 - 18 cents per pound price range.

Conclusions

It is apparent there are some distinct opportunities for the use of secondary natural fibers in selected nonwoven processes. These fibers can bring to nonwoven process technology important benefits such as improved performance, enhanced economic value, disposability improvements as well as the emerging feature of sustainability. With the unique flexibility and versatility of nonwovens processing technology, it is not difficult to imagine many and varied opportunities for a synergistic combining of these natural fibers with this technology.

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Table 2. Typical Properties of Natural Cellulosic and Synthetic Fibers.

Property	**Cotton**	**Rayon**	**Flax**	**Hemp**	**Kenaf**	**Polyester**	**Polypropylene**	**Nylon 66**
Strength, g/d	3.0 - 4.9	2.3 - 3.0	3 - 5	3 - 5	3 - 5	2.0 - 4.5	3.0 - 4.3	3.0 - 5.0
Elongation, %	3.7	18 - 24	1.5 - 4.1	1.5 - 4.2	1.5 - 3.5	18 - 40	30 - 80	20 - 75
Density, g/cc	1.54	1.52	1.5	1.5	1.5	1.38	0.91	1.14
Modulus	Med-High	Low	Med-High	Med-High	Med-High	High	High	Med-High
M.P., E F.	Dec. 300	Dec. 300	Dec.	Dec.	Dec.	470 - 490	330	480 - 500
Ave. Diameter microns	12.5	-	17 - 20	15 - 30	15 - 40	-	-	-
Moisture Content, %	8 - 10	11	6.5 - 12.3	7.4 - 11	7.0 - 12	0.4	0.1	4.0 - 4.5