

**NONWOVENS MANUFACTURING TECHNOLOGIES AND COTTON'S REALISTIC SCOPE IN
NONWOVENS****Paul Sawhney****Brian Condon****D.V. Parikh****Mike Reynolds****Jim Riddle****Southern Regional Research Center
Agricultural Research Service, USDA
New Orleans, LA****Introduction**

Cotton commodity continues to be under pressure from its low and depressed prices for decades, geo and political factors, competition with manufactured fibers, and, very importantly, its gradual decline in consumption by the U.S. domestic mills. In fact, the current domestic consumption of virgin cotton is less than five million bales a year, while the domestic production on average has been around 20 million bales (2003-2008). For one reason or another, if this trend of domestic cotton production and consumption continues, it indeed could be potentially harmful to the commodity and, hence, to the U.S. cotton producers and users. Beside the substantial cotton exports of recent years (which still are good and encouraging but may not be booming anymore), one window of opportunity that we possibly can also explore for benefit of the cotton producers and users is to thoroughly investigate profitable uses of cotton in nonwovens that are growing fairly well globally. To this end, the U.S. Department of Agriculture, through its Agricultural Research Service, has invested new money in a new research program directed toward utilization of cotton in the nonwovens. State-of-the-art equipment has been procured to conduct research for development of new and improved nonwoven structures and end-products containing cotton. This article briefly describes the existing, modern nonwovens (NW's) manufacturing technologies and the research and developments efforts that currently are being contemplated to establish a new ARS-CRIS (Current Research Information System) Project to determine and possibly develop the realistic scope of classical virgin cotton in the nonwovens of today and tomorrow.

Nonwovens Manufacturing Technologies

Although there have been quite a few technologies and their derivatives in the past few decades to manufacture the not-so-sophisticated nonwoven fabrics, the following paragraphs briefly describe the modern classic technologies and methods that are most commonly used today to produce functional, woven-like, nonwoven fabrics for numerous applications, such as personal care, medical, hygiene, household, industrial, automotive, filtration, and the like, predominantly using manufactured fibers, viz., polypropylene, polyethylene, polyester and rayon and sparsely using natural fibers, e.g., cotton, jute, pulp, wool, etc.:

1. Web Formation Methods:**A. Spunbonding**

This is the most commonly used method for producing a web from thermoplastic polymer chips that are melted, extruded and, on line, converted into a web of synthetic fibers, such as polyethylene, polypropylene and polyester. The extruded fibers together continuously form a wide web-like sheet that is allowed to cool off, thereby allowing inter-strand bonding. The web sheet may be rolled and shipped to converters or may be further processed on line to modify its aesthetics and/or functional performance for the intended end product for a specific application. Spunbonding offers an order of magnitude greater productivity, compared to traditional weaving and knitting. For example, a typical spunbonding process may efficiently produce a continuous fabric-like structure up to 200 yards a minute, compared to only a yard or so in a weaving process.

B. Meltblown

In this method, the extruded fibrous sheet from a molten polymer is first, i.e., before it is allowed to cool and bond, subjected to a continuous jet of hot air, which splits the extruded filaments into very fine fibers. This method of producing roll goods (webs) of synthetic fibers for subsequent nonwoven processes and end-products is also highly productive.

C. Carded Webs

This method, commonly referred to as “Dry-Laid,” is utilized for staples fibers, whether natural, synthetic or blends. Fibers are conventionally carded to form a web, which then can be cross-lapped to attain desired thickness and mass. It is a relatively slow and more expensive method to convert fibers into a continuous web of certain integrity. It is commonly used for cotton nonwovens.

D. Air- and Wet- Laid Systems

In the air-laid technique, staples fibers, possibly along with certain powders, resins, or thermally fusible, low-melting fibers, are pneumatically “gathered” and laid to form a web of required density. This method does not involve carding.

In the wet-laid technique, fibers of relatively short length, say, pulp, are passed through water or some other medium, which provides the required inter and intra fiber cohesiveness or adhesion to form a continuous web of desired structural integrity for down-stream processes. The method is not recommended for long fibers, as they may clog the system.

2. Bonding Technologies (Bonding of raw webs into strong nonwoven structures/fabrics)

i) Needle-punching

A needle-punch is a machine that provides a mechanical bonding of a web’s constituent fibers. Many barbed needles of proper needle and barb specifications perform the mechanical bonding actions. Although this nonwovens manufacturing technology is not as efficient as other mechanical or chemical bonding technologies, it still is at least 20 times faster than the traditional weaving and at least 5 times more productive than knitting.

ii) Hydro-entangling (Hydro-entanglement)

This probably is the most common technology today for mechanical bonding of cohesive fibers and webs. This method further reinforces and strengthens structural integrity and improves functional performance of a nonwoven substrate. High-pressure water jets are used to provide the necessary energy to impart the required mechanical bonding of constituent fibers of the underlying substrate. Sometimes, spunlacing, which was first developed and named as such by DuPont several decades ago, is also the terminology used to imply Hydro-entangling technology. It is fast and productive and offers many online operations to attain different designs, finishing, and other attributes of the end-nonwoven product.

iii) Chemical, Resin, Thermal, Sonic Bonding (s) [Miscellaneous]

These bonding techniques are generally applied for producing certain nonwoven composites for numerous end-use applications, including industrial, awnings, building materials, furnishings, automotive components, roofing and the like.

iv) Stitch-through Technology

Although an old technology, it still is used for mass production of nonwovens for bedding, military, blankets, mattress components, etc... Warp knitting and sewing techniques are employed to reinforce a needle-punched or some other nonwoven substrate that by itself may not be strong enough for the intended application. This technology can be applied with or even without use of a stitching thread.

3. Finishing and Conversions of Nonwovens

Technologies for finishing of nonwovens vary depending on their end-use applications. However, unlike the traditional cotton woven and knitted fabrics, the nonwovens generally are not piece-good bleached, dyed, finished and tenterd). Dyes generally are added in the chip-melting/fiber-extrusion process. For producing certain bleached-cotton nonwovens, cotton mostly in fiber state is bleached, i.e., prior to any down-stream nonwovens processes. Bleaching of cotton in fiber state is rather costly and technically cumbersome in carding. However, nonwovens are chemically and

mechanically modified in many ways to obtain desired product-specific attributes. For example, nonwovens generally are more flammable than woven fabrics. Hence, flame resistance or suppression/retardancy (FR) of nonwovens is achieved with a heavier dose of certain FR-specific formulations. Similarly, nonwoven fabrics for certain medical, personal care, and wiping applications may require antiseptic and/or antimicrobial treatments. Similarly, abrasion resistance of cotton nonwovens may need to be beefed up for certain applications.

4. Testing of Nonwovens

As in case of any commercial product, testing of nonwoven products for uniformity, conformity and quality is essential to preserve the manufacturers' as well as the customers' interests. It is a human tendency to cut corners if there are no standard testing, monitoring and regulatory controls in place. Testing of nonwovens, like that of traditional textiles, is largely done according to the international standards framed by mutual involvement of various universities, nonwovens associations, and manufacturers of nonwoven roll-goods and end-products. Most of the required tests for nonwovens are similar (or slightly modified) to those that are in place for traditional textiles.

Well, since cotton is not a fusible fiber, we now can see that at present there are only limited options and technologies for preparing and bonding a cotton batt.. Cost effective formation of a continuous web/sheet/batt of required uniformity and specifications indeed is the main, underlying concept of today's almost all modern nonwoven products and their manufacturing technologies.. Obviously, because of these technological limitations, coupled with certain cost factors involved, considerable basic-applied research is needed to efficiently incorporate cotton in the future's nonwovens.

Current Consumption of Cotton in Nonwovens

Although cotton fiber certainly has quite a few very good attributes (such as high absorbency; an excellent substrate for chemical/functional modifications; wear-comfort; soft and supple hand; static-freedom; natural; renewability/sustainability; environmental biodegradability, etc.), it so far has had only a minimal participation in the rapidly growing nonwovens sector of textile industry. Today's nonwovens overwhelmingly (>98%) utilize manufactured fibers, such as polypropylene, polyethylene, polyester, nylon, rayon, pulp, etc., that can be efficiently used for producing disposable (generally non-reusable) products for many end-use applications and markets, such as sanitary products; hygienic and cosmetic products; industrial and household wipes; surgical gowns and masks; medical end-use products; sheeting; air and fluid filters; building and roofing materials; automotive interior components; military camouflage, tents, combat gear and other work outfits; geo and landscaping; reinforced composites and laminates; and even some semi-durable or durable (reusable) apparel/garments. The use of especially good spinning quality, virgin cotton is almost negligible (less than 1%, if at all) in today's huge and yet growing nonwovens industry. This is partly due to economics and partly because of certain technical and technological reasons. Fiber orientation and/or "entanglements" in cotton nonwoven fabrics are not well understood.

Nonwoven structures, compared to the traditional woven or knitted fabrics, somewhat lack the strength, stability, down-stream processability, and certain special characteristics that may be essential for the intended end-use applications. Cotton nonwoven fabrics compared to woven or knitted fabrics may somewhat also lack the integrity, durability, uniformity, and drape in the end-uses, such as apparel, where cotton historically has been enormously popular as the King fiber. Further, for certain cotton nonwoven products and for certain medical, cosmetic and hygienic end-uses, the U.S. (machine-picked and ginned) raw cotton must be thoroughly cleared of its foreign matter content and then scoured and bleached in the fiber state. Although an hydro-entangled nonwoven cotton fabric structure may be sufficiently strong and stable to be bleached in fabric form, it may be difficult and perhaps costly to efficiently hydro-entangle greige cotton, whose foreign matter content is known to cause filtration problems in the water recycling and conservation. Furthermore, the natural waxes and other fine foreign particles in greige cotton may get firmly trapped/embedded in an hydro-entangled nonwoven fabric, which, in turn, could cause certain difficulties in the downstream dyeing and other finishing processes as well as in the end-use applications. All of the above stated technical factors, coupled with the current cost factor for bleached fiber, ultimately make the cotton fiber somewhat uncompetitive in today's nonwovens markets. The following items briefly summarize why cotton thus far has not appreciably participated in the nonwovens boom and, now, what really makes cotton so compelling for certain nonwovens products and applications:

Probable Reasons for Lack of Cotton Use in Today's Nonwovens?

1. A vast majority of current markets for nonwovens fall under “disposable or non-reusable” Category. Obviously, because of the cost factor, these markets historically have not used the (required) relatively expensive (bleached) cotton and, therefore, cotton’s unique properties have not been adequately investigated, appreciated and utilized.
2. Nonwovens, mainly due to their fiber orientation and bonding, inherently are relatively weaker, non-uniform, more combustible, and less stable compared to equivalent, traditional textiles. Hence, certain in-process cotton nonwoven structures may be somewhat difficult to handle in wet finishing, such as scouring, bleaching, dyeing, and/or any special chemical treatment. This, in certain cases, may necessitate use of a raw stock of bleached cotton, which, as stated previously, is costly as well as cumbersome in the down-stream processes. Certain modern nonwovens technologies, such as hydro-entangling, demand a raw stock largely free of foreign matter and contaminants that easily can disrupt and clog the system and/or increase the cost of water supply and/or its filtration. Thus, the use of costly bleached cotton in this scenario also becomes an economic issue.
3. Cotton generally needs substantial preparatory processing for its cleaning and homogenization that are essential for attaining the desired uniformity and consistency of the nonwoven end-product. From crop to crop, the quality, price and supply of cotton may be somewhat unpredictable for an efficient manufacturing operation.
4. Generally, the nonwovens inherently are relatively stiffer than the traditional, classical textiles and, hence, may not drape as well, particularly in case of the apparel and household textiles where cotton essentially is the best-suited fiber.
5. Classical cotton textiles efficiently utilize stress-strain relationship of constituent fibers and yarns, whereas the nonwovens inherently lack that relationship because their constituent fibers are mechanically or chemically bonded and randomly bundled together, resulting in a plastic-like rigidity. The constituent fibers in a nonwoven structure exhibit little flexibility, slippage and yield, which for apparel are essential.
6. Huge capital investments and extremely high productivities of modern, ultra-high-speed nonwovens manufacturing technologies obviously necessitate continuous, uninterrupted mass-scale productions day in and day out of pretty much the same (i.e., standard) nonwoven roll goods or substrates, in order to achieve a reasonable return (profit) on the investments. However, the existing system of small-lot and diverse-style production of traditional cotton textile fabrics/apparel to satisfy a hugely-diverse human population currently may not permit economic justification, especially for nonwoven clothing applications. However, this viable argument against nonwovens” could change with proper research and development of cotton nonwovens for certain large-volume, mass markets, such as the disposable, reusable, semi-durable, or even durable wipes, cosmetic pads, antistatic medical gowns and other products, sheeting, hospitality linens, drills, denims, towels and toweling, upholstery, automotive components, furnishing fabrics, undergarments, special-purpose bras, and the like!!

Potential Uses of Cotton in Nonwovens?

The following are some very good arguments in favor of using of cotton in nonwovens:

1. Cotton is a naturally sustainable substance. It is also biodegradable, easily disposable, and, hence, eco-friendly. Thus, extra efforts should be made to replace petroleum-based fibers with cotton, where affordability and functional performance of new products are reasonably justified. In this regard, Wal-Mart – the largest retailer in the world - is playing a very significant role in the effort for more use of cotton in consumer and other goods by endorsing the “Vision on Sustainability and Environment” – Textiles Network [<http://www.walmartfacts.com>].
2. Cotton nonwoven products, if functionally and commercially acceptable, can be produced at speeds that may be an order of magnitude greater than those of the traditional weaving process, which could considerably offset the high manufacturing costs that the U.S. cotton textile industry is partly suffering from. As mentioned previously, the processes of making nonwovens are relatively much less labor-intensive and environment-sensitive compared to the traditional spinning and weaving.

3. Because of its unique characteristics of high absorbency, static-freedom, ease of blending with other fibers, and excellent substrate for functional chemical derivitization, cotton obviously should be the fiber of choice for many existing nonwoven applications, such as institutional sheets; upholstery; household furnishings; wipes; towels or toweling; medical, personal-care, cosmetic and sanitary products; and composites for certain industrial and technical applications. Cotton may also be ideally suitable for many potential new applications, even including nonwoven apparel.

4. Because of varying soil and environmental conditions, cotton quality varies considerably from crop to crop. Almost every year, a certain portion of cotton production worldwide suffers damage of one kind or another that renders the cotton production unsuitable for its efficient utilization in the traditional textile processing, viz., yarn spinning and weaving. This cotton of inferior quality is significantly discounted in price. Sometimes, it is even unsellable in the classical cotton markets. It is quite possible that the substantially discounted cottons may be efficiently used in the nonwovens arena to produce certain useful products of significant economic significance. Furthermore, it is quite imaginable that certain cotton cultivars of double- or even triple- than-normal yield (per unit area) may process and perform as good as (or, even better than) the classical cottons in certain nonwovens technologies and for certain end-use products and applications. So, we in the USDA intend to explore it all to promote the value-added, mass utilization of this naturally sustainable fiber in the nonwovens!

5. Long-term, potentially escalating costs of fuel/energy and, consequently, transportation/shipping will curb imports and exports of especially heavy goods and commodities. This should encourage and brighten once again the indigenous production and utilization of cotton in the U.S.

Research Efforts Towards Development of Cotton-Based Nonwovens at USDA-ARS-SRRC

Research/Project Goal:

Understand the fundamentals of (cotton) nonwovens (NW) processes and products. Conduct basic and applied research to discover and develop innovative cotton-containing nonwoven materials and end-use products by developing new and improved pre- and post- product processes, treatments and conditions as well as by replacing manufactured fibers with cotton in existing nonwoven products.

Proposed Objectives:

1. Establishment of a fully functional Cotton Nonwovens Research Laboratory with capabilities of the following processes and equipment:

- a) Fiber opening, cleaning and blending
- b) Tandem carding
- c) Cross-lapping
- d) Pre-needling, slitting and winding
- e) High-pressure hydro-entangling (mechanical bonding) of fibrous material, hot-air drying, and fabric winding.
- f) A modern chemical-treatment and fabric-finishing laboratory that is equipped with almost every textile wet finishing process that will be needed for many chemistry-based applied research investigations to modify functional characteristics and attributes of any specific application or end-use product of cotton content.

2. Process Development and Optimization (of various critical processing parameters and conditions involved in producing cotton nonwovens)

- a) Determine optimum levels of fiber opening, cleaning and carding that would enable satisfactory processing of virgin/greige cotton (not bleached cotton) in subsequent (NW) processes of needle punching and hydro-entanglement (CRITICAL).
- b) Determine the critical effects of cotton fiber's classical properties, viz., length, strength, fineness/maturity, non-uniformity/variability, short fiber content, etc., on the NW process performance/efficiency and product quality. Possibly determine the best NW-specific cotton variety/cultivar!
- c) Determine the critical effects of NW process parameters and conditions on the performance and quality of the process and product, respectively

- d) Develop techniques and standards of handling, packaging, storing and transporting cotton nonwoven roll goods and related in-process materials.
- e) Develop and optimize (standardize) certain testing methods for evaluating new cotton nonwovens.

3. Product Developments and Optimizations (Long-Term):

- a) Determine or develop certain “standards and grades”(classification) of cotton for NW’s, in order to predict and produce certain broad types of nonwoven products and end-use applications, such as specific wipes, medical accessories, bed sheet, hygiene and cosmetic products, mattress materials, diapers/incontinence, undergarments, and the like.
- b) Develop technologies to produce a few commercially viable and, very importantly, globally competitive functional wipes for certain specific end-use applications, say, wipes for food/meat industry, automotive industry, household cleaning, strong and durable napkins, flushable tissue, shop towels, etc..
- c) Develop nonwoven fire-barrier fabrics of low, medium and high densities for both non-durable-FR applications for mattress, furniture, etc., as well as durable-FR applications for uniforms, tents, computer/server covers, and the like.
- d) Develop cotton nonwoven blends and composites for specific applications, such as building materials, concrete reinforcement, tire cord, PVC-coated nonwoven cotton strands for insect screens, non-spun ply/cable/ropes, soil stabilization to prevent its erosion (especially in Louisiana’s coastal regions), filtration, etc.
- e) In-situ and/or post-process/fabrication modifications of required or desired aesthetic and functional attributes of certain cotton nonwovens materials and end-products, using new chemistry and other relevant sciences and technologies. An hospital bed sheet may be one of initial developmental targets.
- f) Examine the cost and environmental impacts of any successful research and developments.

4. Technology Transfer and Marketing of Cotton Nonwovens:

- a) Drivers: Sustainability/renewability of cotton fiber; biodegradability/life cycle; high productivity; low labor cost; “Natural” appeal; unbeatable absorbency and, hence, superb reactivity of cotton fiber;
- b) Challenges: Unusual variability of cotton supply; identification and difficult follow-up of (secretive) target industries that currently use non-cotton fibers in their successful products; nonwovens industry is in bits and pieces, while cotton utilization generally requires high-volume, mass productions; exhaustive and costly R&D and testing, including compliance with rigid regulations of several regulatory agencies, such as EPA, Consumer Safety Commission, etc., are required for assessing commercial potential of any new development.

ANTICIPATED OUTCOMES OF THE RESEARCH:

Cost reduction; reduction of environmental impact; improved quality of cotton-containing products; increased use of cotton in nonwovens; creation of new U.S. jobs; national security.

Related Projects:

- a) Application of nanotechnology to modify certain surface, mechanical and functional properties of cotton nonwoven materials and the products made thereof. Emphasis will be on developing soft hand; good drape; improved abrasion resistance and hence increased durability; flame protection; wrinkle resistance; dimensional stability; safeguards from terrorists’ activities and cruelties; controlled dispensing of antimicrobial chemicals, or filtration of objectionable substances through media of “nano-treated” cotton nonwovens.
- b) Possible CRADA’s with CI, Eco Lab, P& G; PGI; Texas Tech Univ; Clemson Univ; University of TN; Freudenberg, e-Spin, and Texas A & M Univ..
- c) Discovery of fundamental chemistry to significantly enhance cotton’s appeal and attributes.
- d) Fibrillation of cotton fiber to investigate its nano-scale potential.

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