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Cotton in nonwovens

Scope

This Technical Information Paper concerns the use of cotton in nonwoven products. The report will begin with a review of cotton growing, harvesting, ginning, and classing procedures, physical properties, fiber morphology, and a detailed discussion on cotton nonwovens and their production methods.

Safety precautions

There are no particular safety precautions associated with this TIP.

Growth of cotton

Cotton is a warm season, woody perennial shrub that is grown as an annual field crop throughout the sunbelt states of the United States and also in many other countries such as China, India, Russia, Pakistan, Brazil, etc. A wide variety of seeds are available to the cotton farmer, depending on environmental conditions in that area. The cotton plant blossoms when it is approximately one foot high and grows three to four feet tall at maturity. After the blossom falls off, a flattened green pod called the cotton boll is left. This boll matures in approximately 60 days, at which time it is a green, oval shaped pod about one inch. in diameter. During this period, there are three stages in the development of the cotton fiber within the boll. The first stage is the elongation period in which the thin primary wall is developed with a large vacuole. In the second stage the protoplast shrinks progressively while a mass of almost pure cellulose is deposited as a secondary wall on the inside of the primary wall. The third stage, called boll maturation, involves the filling of the major part of the cell volume by the secondary wall, which leaves the lumen, a central cavity containing the cytoplasm and the vacuole.

Each cotton boll has three to five compartments with seven to ten seeds in each. Each of these seeds sprouts about 10,000 cotton fibers. After the boll matures, it splits open and the cotton fibers burst out. Very quickly, after exposure to the air and sunlight, the tubular cotton cells collapse along their axis due to desiccation or drying out, and ribbon-like convoluted fibers are left (Fig. 1). Shown in Figure 1A is the fiber model indicating various structural components in the cotton fiber.

Harvesting and ginning

Before harvesting, cotton plants are defoliated to prevent the leaves from interfering with mechanical harvesting. Most of the U.S. cotton crop is machine picked with revolving spindles that remove the fiber from the boll, leaving any empty or unopened bolls on the plant. A small percentage of the crop is machine stripped, in which case the entire plant is stripped of opened and unopened bolls. In both cases, the seeds in the boll are removed with the cotton fiber, and this “seed cotton” is then sent to the gin for preparation for use in textile products.

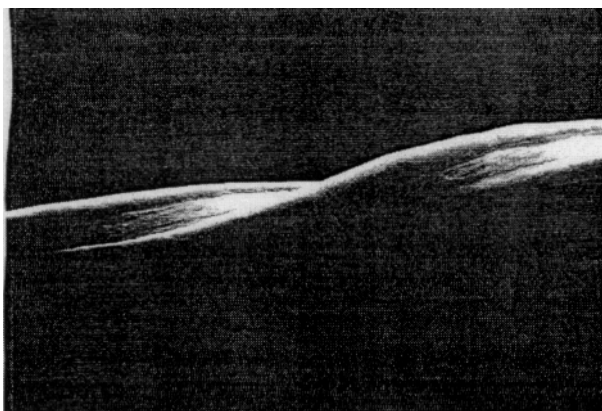


Fig. 1. Photomicrograph showing cotton fiber convolutions and internal structure.

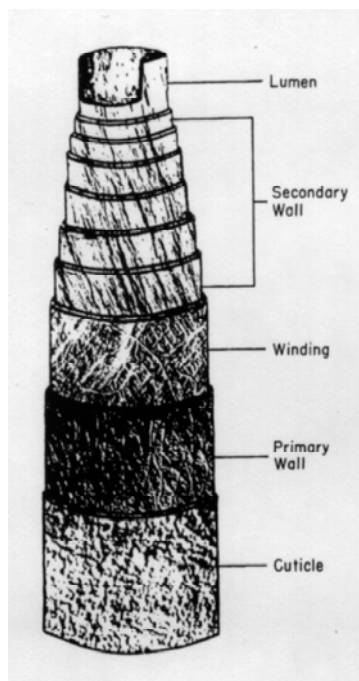


Fig. 1A. Mature cotton fiber showing cuticle through lumen

In its basic form, the cotton gin was invented in 1794 to separate cotton fibers from the seeds. However, state-of-the-art cotton gins today are also capable of drying the cotton and removing plant and field trash, and packaging the cotton in bales while maintaining the quality of the fiber. Most U.S. cotton is processed on a saw gin, which uses saw teeth on a large revolving cylinder to remove fiber from the cotton seed. Pima cotton, produced in some areas of the southwestern U.S., is processed on roller gins. The raw cotton, separated from the seed, is baled and samples are taken for classification testing by the USDA. The remaining cotton seeds are shipped to cotton oil mills, where linters (short fibers left on the seed) are removed from the seed in a “delinting” process. Usually this is a two step process, producing first cut and second cut linters. First cut linters are an inexpensive waste fiber used in various nonwovens, often in blends with other categories of cotton waste products. Second cut linters are very short fibers that are often used to produce very high grade bond paper.

Another by-product removed at the cotton gin is gin motes. These are small immature seeds with fiber attached. These gin motes are also used in various nonwoven products.

Cotton classing

The properties of cotton fibers vary from year to year for all different varieties, growth areas, and climatic conditions. To aid mills in the selection of cotton for each specific purpose and to determine pricing structures, a classification system was developed to describe the cotton in terms of fiber length, micronaire, strength, length uniformity, trash and color. All classification testing is now done by the U.S. Department of Agriculture on a testing machine known as the High Volume Instrument (HVI). The entire U.S. crop is HVI tested as required by law.

Physical properties

The three most important physical properties of cotton referred to when considering nonwovens are micronaire, length, and strength.

Micronaire

Micronaire is a measurement of the cotton fiber fineness, and is expressed in terms of weight per unit length, or more specifically, micrograms per inch. Micronaire is measured on the HVI tester by introducing a small sample of cotton into a porous chamber and measuring the resistance of air flow in proportion to the linear density of the fibers. Micronaire of cotton is governed by the variety of cotton planted, and varies within each variety due to fiber diameter and actual amount of cellulose present. In general, shorter staple length cottons tend to be coarser, and longer staple length cottons tend to be finer. The micronaire number may be compared to denier (grams per 9000 meters) by dividing the micronaire by 2.82, i.e., 4.8 mic cotton equals 1.7 denier.

Length

Cotton fiber length is determined genetically and is characterized by a fiber length array or length distribution pattern. Traditionally the cotton industry has placed great emphasis on small differences in fiber length, measuring the fibers to the nearest 1/32 of an inch. American upland cottons are classified as either short staple (up to 1 in.), medium staple (1-1/32 in. to 1-3/32 in.), or long staple (over 1-1/8 in.). The HVI equipment reports fiber length to the nearest hundredth of an inch. The length of most waste cotton, which is often used in nonwovens, will be less than that of raw, unprocessed fiber, and can be much shorter as linters, comber noils, strips, and motes.

Strength

Fiber strength is measured on HVI equipment and is reported in grams per tex. Depending again on the cotton variety, fiber strength of cotton currently being harvested in the U. S. may range from 20 to 32 g/tex. Other physical properties that may be important to the nonwovens producer are neps and trash content. Both of these can be very critical in certain lightweight roll goods. The Uster AFIS tester can be used to test for both of these properties.

An interesting feature of cotton is its high wet strength, which is in contrast to regenerated and derivative cellulose fibers whose strength decreases with increased moisture content. Properties of bleached cotton fiber are delineated in Table 1. Typical stress-strain curves of cotton and rayon are shown in Fig 2. The higher wet strength of cotton is due to the intermolecular hydrogen bonding between cellulose chains and the high degree of crystallinity.

In regard to heat, the cotton fiber will decompose instead of melting like thermoplastic fibers. Long exposure to dry heat above 300°F will cause cotton to decompose gradually, and temperatures greater than 475°F will cause rapid deterioration. A common form of finishing cotton woven fabrics is wrinkle resistance (WR). WR finishes are usually applied to the cotton or cotton-synthetic blend fabric as a final processing step in the production of finished roll goods on a continuous range by immersing the fabric in an aqueous-based WR finish followed by squeezing out excess finish in a padding nip with subsequent drying and curing in an oven at 330°F for 3-5 minutes. If garments are treated to WR, the drying and curing time after application of the finish can be as much as 15 minutes at 310°F for the resin to react with the cotton. When blended with synthetics, cotton with synthetic fibers is successfully heat set at 360 to 385°F for up to one minute.

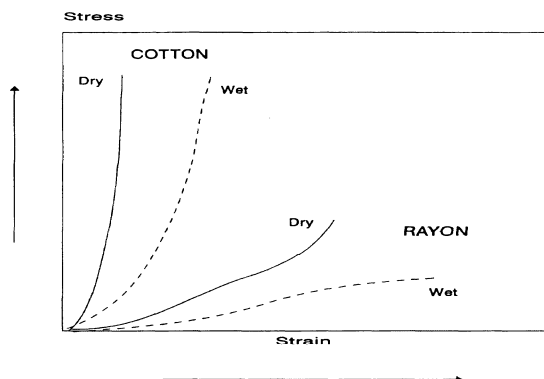


Fig. 2. Stress strain response of cotton fibers.

Table 1. Properties of bleached cotton fiber

1.	Length (in.):	
A.	Commodity Staple:	0.75 - 1.25
B.	Gin Motes:	0.5 - 0.75
C.	Comber:	<0.5
D.	First Cut Linters:	0.25 - 0.5
2.	Fiber diameter:	
A.	Micronaire ($\mu\text{g/in.}$):	2.0 - 6.5
B.	Denier (g/9000m)	0.7 - 2.3
3.	Elastic recovery:	
A.	At 2% Extension:	74%
B.	At 5% Extension:	45%
4.	Breaking elongation (dry):	3 - 9.5%
5.	Tensile strength:	
A.	Dry: 27 - 44 g/tex; 3.0 - 4.9 g/denier	
B.	Wet: 28 - 57 g/tex; 3.3 - 6.4 g/denier	
6.	Moisture regain at standard conditions:	7%
7.	Water absorbing capacity (USP method):	>24 g water/g fiber
8.	Specific gravity:	
A.	Cellulose polymer:	1.54 g/cm ³
B.	Cotton fiber:	1.27 g/cm ³
9.	Degree of polymerization (DP):	9,000 - 15,000 (Vs. 250-650 Viscose rayon regular, 500-600 High tenacity rayon, and 600-1500 Wood Pulp)
10.	Crystallinity by x-ray diffraction (average):	73% (Vs. 60% Viscose rayon regular, and 35% Wood pulp)
11.	Color (Hunter colorimeter):	
A.	Whiteness index:	90 - 100
B.	Blue reflectance:	75 - 85
12.	Thermal resistance:	
A.	Long exposure to dry heat above 300°F will cause gradual de-composition.	
B.	Temperatures greater than 475°F cause rapid deterioration.	
13.	Acid resistance:	
A.	Disintegrated by hot dilute acids or cold concentrated acids.	
B.	Unaffected by cold weak acids.	
14.	Alkali resistance:	
A.	Swelling in NaOH above 18% but no damage.	
15.	Organic solvent resistance:	resistant to most common industrial and household solvents.

Cotton fiber morphology

A mature cotton fiber structure consists of six parts (see Fig 1A).

1. *Cuticle*: An outer waxy layer, which consists of pectins and proteinaceous materials. It serves as a smooth, water resistant coating which protects the rest of the fibers. This layer is removed by scouring.
2. *Primary wall*: This is the original cell wall and is made up of small strands of cellulose called fibrils. These fibrils make up a well organized system of continuous, very fine capillaries. These fine capillaries tend to “rob” liquids from coarser capillaries, and this accounts for cotton's excellent “wipe-dry” performance.
3. *Winding layer*: This is the first layer of secondary thickening. It differs from either the primary wall or remainder of the secondary wall. Fibrils are arranged in an open netting type pattern aligned at 40 to 70 degree angles to the fiber axis.
4. *Secondary wall*: This wall consists of concentric layers of cellulose that make up the main portion of the cotton fiber. After the fiber has reached its maximum size during the growth period, a new layer of cellulose is added to the secondary wall. Fibrils are deposited at angles of 70 to 80 degrees with points where the angles are reversed along the length of the fiber.
5. *Lumen wall*: The lumen wall separates the secondary wall from the lumen and appears to be more resistant to certain reagents than the secondary wall.
6. *Lumen*: This is the hollow canal that runs the length of the fiber. It is filled with living protoplast during the growth period. After the fiber matures and boll opens, the protoplast dries up and the lumen will naturally collapse.

Throughout the fiber structure there are variously sized pores or capillary spaces between variously sized fibrils in each of the six fiber parts. Thus the cotton fiber can be seen as a microscopic sponge with a complex porous structure. This internal structure makes cotton accessible to liquids and vapors, thus giving cotton its characteristic wickability and absorptive capacity.

The cotton fiber itself is a flat, twisted ribbon with 50 to 100 convolutions per inch. The fiber is fibrillated on the end where it was joined to the cotton seed and tapered on the other end. This gives cotton a soft touch or feel since there are no sharply cut ends as there are with synthetic fibers.

Discounted cotton fiber

Many bleached cotton nonwoven products for consumer and medical markets can be made satisfactorily from by-products such as gin motes, comber noils, and other mill waste. In these cases, finished products are made from card sliver or carded batts where fiber-to-fiber cohesion is not critical; thus shorter, waste cotton fibers are used. However, nonwoven roll goods production on high speed carding or air lay equipment usually requires a #1 grade bleached cotton. For these applications, a micronaire of 4.8 or greater and a staple length of 0.95 in. or greater is recommended. Fiber strength of at least 23.0 grams per tex and a length uniformity of 81.0% or more is also suggested. For certain lightweight roll goods, the removal of plant trash in bleached cotton is very critical. Criteria for these products should be a low percentage of visible foreign matter level of 0.10 or less, as measured on the Uster AFIS tester.

Cotton nonwovens

Nonwovens are the fastest growing sectors of textile materials, and they continue to grow all over the world. Many of these nonwoven-based consumer products are used in health and hygiene applications. In such situations, cotton becomes the fiber of choice. Advantages of cotton include superior wet strength as well as a quick dry surface. Bleached cotton fibers have high levels of absorbency, are soft to the touch, breathable and biodegradable. However, other issues such as quality, processability and cost, have limited the share of cotton to relatively low levels among other fibers. With recent advances in science and technology, it is possible to obtain cleaner cotton at a cheaper

price. Also, with increasing cost of petroleum products, and change in polymer and fiber supply market, synthetic fibers are becoming expensive, and the future looks brighter for cotton in nonwovens with increasing opportunities for growth. The methods of producing nonwovens, especially those applicable to cotton fibers, their application potential, the nonwoven market, and recent research in different areas for cotton nonwovens are discussed in the following sections

Nonwoven fabrics are flat, porous sheets or web structures that are made directly from separate fibers or from molten plastics or from plastic films by entangling fibers or filaments mechanically, thermally or chemically. According to International Nonwovens and Disposables Association (INDA) (1), "Nonwovens are a sheet, web, or batt of natural and/or man-made fibers or filaments, excluding paper, that have not been converted into yarns, and that are bonded to each other by any of several means." Nonwovens can be produced from both natural and synthetic fibers or directly from polymers by a variety of techniques that involve web formation and bonding.

Over the past three decades, consumption of nonwoven products has grown at the rate of almost 10% per year. This tremendous growth has been due to their ease of manufacture, higher processing speeds, lower cost of production, and ability to produce fabrics with a range of properties. Typical production rates are listed in Table 2. Compared to only a few meters per minute possible with the woven or knitted fabrics, nonwovens can be produced at the rate of a few hundred to thousand meters per minute. This high production rate combined with the fact that the intermediate yarn formation is eliminated helps in keeping the cost of nonwovens very low. This low cost of roll goods production has helped in the tremendous growth of nonwoven products.

Table 2. Typical production rates of different fabric formation processes

<i>Fabric formation process</i>	<i>Production rate, m/min</i>
Weaving	1-6
Knitting	3-16
Nonwovens - web forming	
Carding	120-400
Spunbond	200-2000
Wet-laid	2000
Nonwovens - bonding	
Stitchbonding	40
-Needling	30-500
Calendaring	2000
Hot air bonding	5000

Nonwoven fabrics possess specific characteristics such as strength, stretch, resilience, absorbency, liquid repellency, softness, flame-retardancy, cushioning, washability, filtering, bacterial barrier and sterility. Nonwoven fabrics can be used in a wide variety of applications, which may be limited life (short life) or single-use fabrics as disposable materials or as durable fabrics (2, 3). Nonwovens are used almost everywhere--in agriculture, construction, military, apparel, home furnishing, travel and leisure, healthcare, personal care, and house hold applications. Whereas in some areas nonwovens are replacing traditional fabrics, because of their unique properties, and they are finding many new applications as well. Cotton nonwovens are used as swabs, puffs, wipes, filters, waddings, personal care products like in diapers & feminine hygiene products, semi-durable segments like bedding, household furnishing, pillow fillers, etc. Some of the major uses are listed in Table 3.

Both natural and synthetic fibers, organic and inorganic, can be used to produce nonwoven fabrics. The fibers in these structures may be staple or continuous, or may be formed in situ. Advantages of cotton and other natural fibers include superior wet strength as well as a quick dry surface, notably in wipes. Bleached cotton fibers have high levels of absorbency and are soft to the touch, breathable and biodegradable. One quickly-growing area, especially

throughout Europe and Japan, is spunlaced cotton used for cosmetic wipes and other disposable products; these trends are likely to spread to other markets as well.

Table 3. Products from cotton nonwovens

Personal Care Products

Swabs
Cosmetic pads
Tissues
Medical/Dental – wipes, sponges, plugs
Diaper Components – Coverstock, acquisition layer, cores, back sheet
Feminine Hygiene – pads, tampons
Adult continence
Baby and consumer wipes

Durable/Semi durable products

Apparel – clothing, performance wear, outerwear, medical gown and drape, interlinings
Home furnishings – bedding, mattress pads, wall coverings, decorative felts

Industrial Products

Filter media
Geotextiles
Protective apparel
Absorbent media – Oil and chemical
Insulation – Thermal and acoustical
Packaging

Production of nonwovens

In most cases, the formation of nonwovens consists of two basic steps, web formation and bonding. The web formation in nonwoven production is a critical contributor of the end-use product performance. Three basic methods are used to form a web: dry laid; wet laid; and polymer laid, the latter of which consists of spun laid, melt blown and electrospun web formations. Webs have little strength when they are formed and must therefore be consolidated or bonded in some way. The three basic types of bonding are chemical, thermal, and mechanical. Whereas cotton webs can be successfully bonded by mechanical processes, additional binder polymer or fiber is required to use chemical or thermal bonding. The nonwoven formation methods used in the industry are summarized in Figure 3.

Web formation

Dry laid

In the dry laid process, conventional staple fibers are used, which are usually 10 to 100 mm or longer. The fibrous web is prepared using the classical textile carding machine or air laying machine to separate and orient the fibers mechanically. Carding is the most common process to produce nonwoven fabrics from staple fibers (Figure 4). The card separates the fiber stock into individual fibers with minimum fiber breakage. The carding process achieves opening and thorough blending of different species of fibers. Carding is performed by the mechanical action in which the fibers are held by one surface while the other surface combs the fibers, causing the separation of