PREPARING COTTON, WEB FORMING AND BONDING METHODS FOR COTTON NONWOVENS

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Abstract

To produce nonwoven fabrics from staple fibers a web of fibers must be formed. The web forming processes used for producing webs of cotton fibers will be discussed. To produce nonwoven fabrics, fiber webs are bonded together to impart strength. The bonding techniques that cotton lends itself to will be covered. Properties and uses of cotton nonwoven fabrics produced by the various bonding methods will be discussed.

Discussion

Ginning

Ginning, in its strictest sense, is the process of separating cotton fibers from the seeds which is what Eli Whitney's invention of the cotton gin accomplished in 1794. Today's modern cotton gin is required to do much more. To convert mechanically harvested cotton into a marketable product, gins have to dry and clean (remove plant parts and field trash) from the seed cotton, separate the fiber from the seed, further clean the fibers and place the fiber into an acceptable package, while preserving as nearly as possible the quality of the fiber. Table I shows the gin machinery arrangements for the two harvesting methods.(1) American Upland cotton is saw ginned, which is a process different from roller ginning used for American Pima cotton. Saw gin stands can operate at capacities as high as 12 (480 lb.) bales per hour. The saw gin removes the fiber from the cotton seeds using a cylinder that has saw teeth around its circumference. There are approximately 1350 gins located throughout the cotton belt. In the U.S., roller ginning is limited to the 10 counties in West Texas, New Mexico, California, and Arizona that produce Pima cotton.(1)

After the ginning process, the output fiber is compressed into bales. At this stage, the fiber is referred to as raw cotton. Samples are taken from both sides of every bale produced and sent to the USDA for classing. However, the cotton gin actually produces two products with cash value – raw cotton and the cottonseed. The cotton seeds removed during ginning are shipped to cottonseed oil mills. Short fibers (known as linters) that were not removed by ginning remain on these cotton seeds. At the oil mill, the linters are removed from the seeds by delinting machines, employing the same principles as saw gins. The seeds can be run through a delinting machine once, in which case the linters produced are known as "mill run" linters. Most mills run the seed through twice and produce "first-cut" and "second-cut" linters. First-cuts consist of longer, more resilient fibers and are used in a number of nonwoven products. Second-cuts are made up of short fibers and are used to produce high grade bond paper and a is a source of cellulose in the chemical industry. After removal of the linters, the remainder of the cottonseed is converted into food for people, feed for livestock, fertilizer and mulch for plants.

Another by-product of the gin is motes. Motes are small, immature seeds with attached fiber that are removed at a different stage of the gin stand than the mature seeds. The fiber can be removed from the motes using a delinting machine. This fiber is called "gin mote fiber" and is used in nonwoven products.

Physical Cotton Properties

The three cotton properties most often referred to in nowoven uses are micronaire, length, and strength.

Micronaire is an airflow measurement that is performed on a 3.24 grams (modern instruments are capable of using variable weight samples) test specimen which is compressed to a specific volume in a porous chamber. Air is forced through the specimen and the resistance to the airflow is proportional to the linear density of the fibers (expressed in micrograms per inch). The micronaire range for Upland cotton is 2.0 to 6.5, with 92% of the 1994 crop being in the 3.5 to 4.9 range. Since denier is approximately equal to micronaire divided by 2.82, Upland cottons ordinarily range from 0.7 to 2.3 denier.

Cotton fiber length varies genetically and has a fiber length array or length distribution. The HVI reports fiber length as the upper-half-mean length in hundredths of an inch. The lengths of linters and comber noils are less than 0.5 inches. The upper-half-mean length of U.S. Upland raw cotton is normally between 1.0 and 1.2 inches. Pima cotton can be as long as 1.6 inches.

Fiber strength is measured by HVI using 1/8 inch spacing between clamp jaws and reported in terms of gram-force per tex. A tex unit is equal to the weight in grams of 1000 meters of fiber. Therefore, the strength reported is the force in grams required to break a bundle of fibers one tex unit in size.

Another quality of cotton that is often referred to is nep content. A nep is a small tangled knot of fiber often caused by mechanical processing. Neps can now be measured by an AFIS nep tester and are reported as total neps per gram of cotton and average diameter in milimeters. Properly equipped and set machinery will minimize nep formation during processing.

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Raw Cotton

Raw cotton (gin output) contains cotton fiber as well as small plant parts and field trash that are not removed by the ginning process. The cotton fiber at this stage has a coating of oils and waxes that make it hydrophobic. Where absorbency and aesthetics are not important, fiber in this form is suitable for nonwovens to be used in industrial products.

Scouring and Bleaching

Cotton must be scoured and bleached for use in many nonwoven products where absorbency, whiteness, and chemical purity are desired.

Two techniques of commercial scouring and bleaching are kier and continuous. The use of new opening and cleaning equipment allows kier bleached cotton to be produced with quality equal to continuously bleached cotton. Comparing the merits of the two bleaching methods is not our purpose. Both processes accomplish scouring and bleaching by the same chemical interactions but with different mechanical handling (Table II). All U.S. production is from the kier system. U.S. production is reported to be about 80 million pounds annually.

The first stage of scouring and bleaching includes opening and mechanical cleaning. It is important to remove as much of the non-lint material as possible. This allows for through bleaching of the remaining non-lint particles. Several cleaners are available. However, there is one called the Lintmaster™ opener/cleaner, developed by Cotton Incorporated and J.D. Hollingsworth, that is superior. It has a high production rate (660 lbs. per hour) and accomplishes high cleaning efficiency (75-80%) without causing fiber damage (i.e. no increase short fiber or nep content).

Scouring is accomplished by saturating the cotton fiber with a caustic soda (sodium hydroxide) solution. The alkali solution is allowed to remain on the fiber at elevated temperatures to speed chemical reactions. During this time, the natural oils and waxes are saponified (converted into soaps), the plant matter is softened, pectins and other non-celllulosic materials are suspended so they can be washed away. After a predetermined amount of time to allow for complete scouring, the alkali, saponified waxes, and suspended materials are rinsed away with water.

At this point, a bleaching solution is applied to the fiber. A stabilized oxidizing agent, hydrogen peroxide or sodium hypochlorite, is used in the bleaching liquor to whiten the fiber by the destruction of natural coloring matter. In the U.S., hydrogen peroxide is the most widely used agent in the bleaching of raw cotton in fiber form. This bleaching solution remains on the fiber at elevated temperatures for a fixed amount of time to allow for proper removal of the color bodies, then, the bleaching solution is rinsed away. Cotton bleached with hydrogen peroxide contains no dioxins because lignin and chlorine are both absent.

After scouring and bleaching, all the impurities have been removed and the cotton fiber is in the form of 99.9% cellulose. If properly done, this fiber will meet the demands for U.S. Pharmacopoeia purified cotton. The requirements for the United States Pharmacopoeia[2] are shown below:

TEST	SPECIFICATIONS
Absorbency – sinking time, sec.	10 sec. max
Water Retention – from sinking test	24 times orig. wt.
Ash Residue	0.2% max.
Water Extract	0.35% max.
Ether Extract	0.70% max.

Fiber Finish

After scouring and bleaching, all the impurities have been removed from the cotton fibers, including the efficient fiber finish of oils and waxes provided by Mother Nature. Therefore, fiber finish is essential when considering bleached cotton . To be processed through the high production web-forming equipment used for making nonwovens, a lubricant and antistatic agent must be added as a fiber finish. Finishes are available to allow for efficient mechanical processing without interfering with absorbency, as well as finishes that can reduce or eliminate absorbency.

Cotton Incorporated has performed extensive fiber finish evaluations and the most useful test, with the exception of actual carding, was found to be a sled test from ICI and the procedure is listed below:

1. The fiber sample is prepared for testing by carding 450 grams of fiber through a Shirley Card and collecting the web by layering on a turning cylinder. To insure sample uniformity, the web is removed from the cylinder and carded a second time.

2. The card web is pulled apart and removed from the cylinder. Test specimens are cut four inches square from the layered web thickness. Individual web specimens are then placed on the apparatus for testing.

3. The sled is placed on top of the fiber sample and a 2 kg weight is placed on top of the sled. The sled is connected to a load cell of an Instron, or other tensile testing instrument, with a wire.

4. The rate of pull by the tensile testing instrument is 25 mm/min and the force recorded on a chart. The friction force value is taken when the chart reaches a steady level and is recorded in grams.

A trial was conducted where bleached cotton was finished with three different finishes and the fiber was tested using the sled test. Raw cotton was also tested as the control. The results presented in Table III show that raw cotton has lower fiber-to-fiber friction than any of the bleached samples, and that the finished samples have lower grams-force values than the bleached unfinished fiber.

These results are shown as a bar graph in Figure 1. This test method is sensitive enough to distinguish effects of fiber finishes, and from other investigations, these differences were realized in actual carding trials. Sodium acetate is included in each of the finish formulations because of its static electricity dissipating benefit, but studies have shown that it alone has no influence on fiber-to-fiber friction test values.

Cellulose Chemistry

After scouring and bleaching, cotton is 99.9% pure cellulose. Cellulose is a macromolecule made up of anhydroglucose units united by 1,4, oxygen bridges (Figure 2). The anydroglucose units are linked together as beta-cellobiose; and so anydro-beta-cellobiose is the repeating unit of the polymer chain. The number of these repeat units that are linked together to form the cellulose polymer is referred to as the degree of polymerization (dp).

It may be noted that wood pulp, rayon, and cellophane (all three derived from wood cellulose) are also constructed of cellulose polymers. Cotton cellulose differs from the above primarily by having a higher degree of polymerization and a higher degree of crystallinity. Crystallinity indicates that the fiber molecules are closely packed and parallel to one another (Figure 3). Table IV and V show the degrees of polymerization and crystallinity of some cellulosic fibers. Higher crystallinity and degree of polymerization in polymers are associated with higher strengths.

The cellulose chains within the cotton fibers tend to be held in place by hydrogen bonding. These hydrogen bonds occur between the hydroxyl groups of adjacent molecules and are more prevalent between the parallel, close packed molecules in the crystalline areas of the fiber.

The three hydroxyl groups, 1 primary and 2 secondary, in each repeating cellobiose unit of cellulose are chemically reactive groups. These groups can undergo substitution reactions in procedures designed to modify the cellulose fibers or in the application of dyestuffs, finishes, and for crosslinking.

The hydroxyl groups also serve as principal sorption sites for water molecules. Directly sorbed water is firmly chemisorbed on the cellulosic hydroxyl groups by hydrogen bonding.[3]

Of particular interest in the case of cellulosic fibers is the response of their strength to variations in moisture content. Generally, in the case of regenerated and derivative cellulosic fibers, strength decreases with increasing moisture content. In contrast, the strength of cotton increases with increased moisture. Typical stress-strain curves of cotton and rayon (measured at 65% RH) in the dry and wet stages are shown in Figure 4. The contrast seen between the fibers in their response to moisture is explained in terms of intermolecular hydrogen bonding between cellulose chains and their degrees of crystallinity.[3]

Thermoplastic fibers melt at elevated temperatures and have a glass transition temperature (Tg) below the polymers' melting point. At the glass transition temperature, a thermoplastic fiber becomes brittle and loses its elasticity. Cotton is not a thermoplastic fiber; therefore, it has no glass transition temperature and remains flexible even at very low temperatures. At elevated temperatures, cotton will decompose instead of melting. Long exposure to dry heat above 300°F will cause cotton fibers to decompose gradually, and temperatures greater than 475°F will cause rapid deterioration.[4]

Absorbency

Recent absorbency studies conducted at North Carolina State University compared water holding capacity and wicking rates of bleached cotton and a trilobal rayon, used for absorbent products. The specifications of the fibers are given in Table VI. To eliminate any influence of fiber finish, both samples were scoured with a mild sodium hydroxide solution. The scoured fibers were then carded to form 100 g/m^2 webs. Two web structures, one needlepunched and the other un-needled were tested for absorbency rate and water holding capacity using the Gravimetric Absorbency Tests System (GATS) equipped with a specially designed cell.[5] The test specimens were subjected to environmental pressure of 12 gf/cm^2 using applied weight.

The absorbency rate for both the un-needled and needled cotton webs were higher than the trilobal rayon (Figure 5). At a probability level of 95%, the absorbency rate was only significantly different for the needled cotton web.

The water holding capacity for both the un-needled cotton and the needled webs were also higher than for the trilobal rayon (Figure 6). At a probability level of 95%, the capacity is significantly higher for cotton in both the un-needled and needled webs. The explanation lies in the fact that cotton cellulose has higher molecular weight and crystallinity than rayon. This causes the cotton to have greater modulus than rayon in the dry and wet state (Table VII) which means cotton fiber is stiffer and resists collapsing under pressure, thereby retaining the thickness of the web. Since "the main factor affecting capacity is thickness per unit weight of the web; the greater the thickness per unit weight, the greater the pore volume, and therefore, the greater the capacity",[5] As the data indicates, needling increases absorbency capacity of both fibers. The needling process imparts structural rigidity to the web which allows the web to resist collapsing; therefore, retaining its thickness and capacity.

Effect of Micronaire on Nep Formation

Cotton with a micronaire value of 4.5 or greater is more desirable for use in nonwoven roll goods manufacturing since high micronaire cotton contains fewer neps or small bundles of entangled fibers which result in unsightly appearing fabrics. It is well documented that finer fibers (lower micronaire) are more prone to nep formation.

A study was conducted where two bales of cotton with identical properties, except for micronaire, were selected. Table VIII shows the comparison was strictly between 3.0 and 4.5 micronaire cottons. In Table IX, the influences of mechanical processing and bleaching on nep content are shown. Differences in the original bale are typical, but the difference shown in the card webs is dramatic.

Web Forming

Fibers must be placed in a loose sheet structure called web forming. There are three web forming processes: dry laid, wet laid, and melt spun.

Dry Laid

The dry laid processes are carding and air laying and are used to process staple fibers.

Carding

This process uses a rotating main cylinder covered with wire teeth that carry the fibers past stationary flats, revolving flats, or rolls that are also covered with wire. The fast moving cylinder moves the fiber past the slower moving stationary flats or rolls (Figure 7). This combs and parallels the fibers and places them in a web structure. The fibers are primarily in the machine direction, which produces a web with high machine direction (MD) strength, and low cross machine direction (CD) strength. A randomizing roll can be used to disorient the fibers in the web, but even under the best conditions, you can still expect the MD strength to be twice that of the CD (2 to 1 strength ratio).

Carding with stationary or revolving flats is the preferred method for cotton and will produce the best quality webs. Roller top cards can be used, but tend to create neps. Setting the rolls closer to the main cylinder will minimize nep formation. The web weights produced by a card are 0.2 oz/yd^2 to 1.5 oz/yd^2.

Air Laid

An air laying system opens the fibers using a wire covered roll similar to a card. The oriented fibers are suspended in an air stream and collected on a screen to form a web (Figure 8). The fiber orientation is random and these webs have a one to one strength ratio. Air laying systems form neps in cotton while processing. The web weights produced by air laid equipment are 1 oz/yd^2 to 20 oz/yd^2 and higher.

Wet Laid

In this process, fibers are suspended in water. The fiber/water slurry is pumped to a forming box where the water flows through a moving belt and the fibers are filtered out on top of the belt, forming a wet web. The excess water is removed by vacuum or squeeze rolls (Figure 10). The fibers are randomized so the web has isotropic properties. Only short fibers are used in this process, normally in the 2-6 millimeter range. Cotton linters are the only cotton fibers used in the wet lay process. Longer cotton fibers tend to wrap around each other and form non-uniform slurries and therefore non-uniform webs.

Melt Spun

Spunbonded and melt blown fabrics make webs directly from continuous filaments as they are being extruded from molten plastic. Spunbonded fabrics are very strong and contain filaments above 1 denier (Figure 11). Melt blown fabrics are fairly weak and contain filaments less than 1 denier (Figure 12). Cotton cannot be processed using this system, but can be joined to these types of fabrics to form composites.

Crosslapping

A crosslapper is used with dry laid webs to layer them on top of each other and increase the web weight. In the case of oriented card webs, the crosslapper moves the fiber orientation from the MD to CD direction (Figure 9).

Web Bonding

Most webs have insufficient strength in the unbonded form and may be bonded together by mechanical entanglement or by chemical or thermal bonding. There are some cotton nonwoven products produced without bonding such as Q-tips™ , cotton balls, and pill bottle stuffing.

Needlepunching

In needlepunching, barbed needles are punched through a web (Figure 13). The barbs grab the fibers on the way through the web forcing them through in the Z direction. When the needles are removed, the fibers remain located in the Z direction of the web. This fiber entanglement adds strength to the web. The fabrics are sometimes referred to as needle felts. Fabrics can be produced from 1 oz/yd^2 to 20 oz/yd^2 and above. The largest markets for cotton needlepunched fabrics are in filtration, home crafts, mattress pads, and apparel shoulder pads.

Hydroentangle

Spunlace is a term that is synonymous with hydroentangle. This process uses high velocity jets of water to impact a web and cause the fibers to entangle with each other (Figure 14). The fabrics created take on the mirror image of the belt pattern that supports the web through the water jets. This allows for production of fabrics that have wide varieties of patterns and are completely binder free. Hydroentangled fabrics are very strong and the most textile like of all nonwovens. The largest markets for hydroentangled cotton fabrics are medical sponges, industrial and consumer wipes.

Chemical Bonding

A fiber web supported by a belt has a chemical binder, usually latex, is applied to it by dipping, spraying, foaming, or printing (Figure 15). The web and binder are dried and cured. The fibers adhere to each other at points where they intersect. These fabrics are normally in the 0.5 to 2.0 oz/yd^2 weight range. The largest markets for chemical bonded cotton fabrics are surgical gown interlinings and polishing fabrics.

Thermal Bonding

n this method, thermal plastic fibers are joined together at cross over points by raising the temperature high enough to soften or melt the fibers. To use cotton with this method, a thermoplastic fiber or powder is blended with bleached cotton fibers. Bleached cotton produces a superior fabric because the natural oils and waxes interfere with bonding. The two methods used in nonwoven manufacturing to melt thermal plastic fibers are called **through-air bonding** and **calendering** (Figure 16). The through-air method uses a vacuum to pull hot air through the web and melt the fiber. This produces a high loft fabric. A wide range of fabric weights can be produced. Because of the low fabric densities, these are used in insulation, apparel and home furnishings. In calendering, the web is passed through heated rolls to melt the fiber. Normally, the bottom roll is smooth and the top roll has a pattern. Only the fibers under the raised portion of the pattern are bonded. Instead of heat, ultrasonics can also be used to melt the fibers. Calendered fabrics are flat and stiff (high bonding areas) or flexible (low bonding areas). They are lightweight (0.5 to 2.0 oz/yd^2) because the time the web spends in the heated area of the calender rolls is very short. By far, the largest market for calendered thermal bonded fabrics is coverstock. There is very little cotton in current use by this method.

Stitchbonding

A filament or yarn is inserted into a web of fibers by warp knitting (Figure 17). Fabrics created by this method have good strength and durability. Stitchbonded fabrics are used as shoe components, vertical blinds, wall and floor coverings. There is little or no cotton used in this method.

U.S. Cotton Nonwovens Market

In 1997, there was an estimated 80 million pounds of bleached cotton used in nonwoven products. This does not include raw cotton. The primary markets are absorbent products, personal hygiene products, home products, and medical fabrics.

Summary

The unique gross and fine morphological structure of the cotton fiber as well as the chemical versatility of the cellulose polymer provide cotton with its outstanding qualities, such as comfort, breathability, absorbency, wicking and chemical reactivity. Cotton is a readily renewable resource with long term supply assurance. Bleached cotton is becoming more available for nonwovens as producers increase their production capabilities. Some nonwoven products can be manufactured from raw (unbleached) cotton where absorbency, whiteness and chemical purity are not important. Or, some nonwovens made from unbleached cotton can be scoured, bleached, dyed and finished in fabric form. Cotton lends itself to many nonwoven bonding techniques, which combined with its unique properties (see appendix), makes it a valuable fiber for use in manufacturing nonwoven goods.

Appendix

Table 1. Properties of Bleached Cotton Fiber.

1.	Length (inches)	
	A. Commodity Staple:	1.0 – 1.2
	B. Gin Motes:	0.5 – 0.75
	C. Comber:	<0.5
	D. First Cut Linters:	0.25 – 0.5
2.	Fiber Diameter:	
	A. Micronaire (μg/inch):	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 .H_2O/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:	9,000 – 15,000
10.	Crystallinity By X-Ray Diffraction (average):	73%
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 decomposition.	
	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:	

Table 1. Properties of Bleached Cotton Fiber. Continued

A. Swelling in NaOH above 18% , but no damage.

15. Organic Solvent Resistance:
Resistant to most common industrial and household solvents.

16. Web Formation:
- A. Dry lay (carding, garnetting)
- B. Air lay

17. Bonding Mechanisms:
- A. Needlepunching
- B. Hydroentanglement
- C. Stitchbonding
- D. Chemical Bonding
- E. Thermal Bonding when blended with thermoplastic fibers

18. General Properties:
Absorbent, Breathable, High Wet Modulus (stronger when wet), Biodegradable (under certain conditions), Excellent Wicking, Wipe Dry Performance, Sterilizable by All Industrial Methods, Low Static Potential, Printable, Dyeable, Chemically Modifiable, Renewable Resource.

19. Potential Applications:
Wipes, Coverstock, Filters, Personal Hygiene Products, Interlinings, Insulation, Absorptive Media, High Loft Products, Composites, Disposable Garments, Medical/Surgical Components, Home Furnishings.

NOTE:Bleached cotton is exempt from OSHA cotton dust regulations.

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TABLE I. TYPICAL GIN MACHINERY ARRANGEMENT

Equipment	Harvest Method	
	Machine Stripped	Machine Picked
Boll Separator	X	X
Airline Cleaner	X	
Tower Drier	X	X
Cylinder Cleaner	X	X
Extractor	X	X
Tower Drier	X	X
Cylinder Cleaner	X	X
Extractor	X	
Gin Stand	X	X
Lint Cleaner	X	X
Lint Cleaner	X	X
Bale Press	X	X

TABLE II. COTTON BLEACHING STAGES

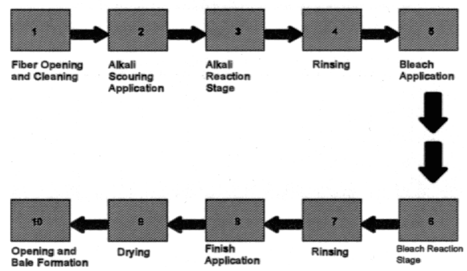

TABLE III. FIBER-TO-FIBER FRICTION VALUES FOR RAW AND BLEACHED COTTON WITH FINISHES

Index	Fiber I.D.	Finish	Force (grams)
A	Raw	Natural	750
B	Bleached	1.0% Ucarsil 1.0% Sodium Acetate	950
C	Bleached	1.5% Sonostat 668 1.0% Sodium Acetate	1270
D	Bleached	3.0% Sonostat 668 1.0% Sodium Acetate	948
E	Bleached	0.5% BES 1.0% Sodium Acetate	1820
F	Bleached	1.0% BES 1.0% Sodium Acetate	1860
G	Bleached	No Finish	2200

TABLE IV. AVERAGE DEGREE OF POLYMERIZATION FOR CELLULOSIC FIBERS

Fiber	Degree of Polymerization
Cotton	9,000 - 15,000
Viscose Rayon	
Regular Rayon	250 - 450
High Tenacity Rayon	500 - 650
High Wet Modulus Rayon	400 - 550
Wood Pulp	600 - 1,500

Source: Introduction to Textile Science, 5th Edition

TABLE V. AVERAGE CRYSTALLINITY MEASURED BY X-RAY DIFFRACTION FOR CELLULOSIC FIBERS

Fiber	Average Crystallinity Value (%)
Cotton	73
Viscose Rayon (Regular)	60
Wood Pulp	35

Source: Shirley Institute

TABLE VI. PROPERTIES OF MATERIALS USED IN ABSORBENCY TESTS

Fiber	Denier (micronaire)	Length (mm)	Density (g/cc)
Cotton	1.77 (5.0)	27.0	1.5
Rayon	3.0	38.0	1.5

TABLE VII.

Fiber	Dry			Wet		
	σ (gf/den)	ε (10^2)	σ/ε (gf/den)	σ (gf/den)	ε (10^2)	σ/ε (gf/den)
Cotton	3.60	8.36	42.9	4.17	10.52	39.6
Rayon	2.85	33.21	8.6	1.85	20.04	9.2

VALUES OF BREAKING STRESS (σ), BREAKING STRAIN (ε) AND SECANT MODULUS (σ/ε)

Average of 100 measurements on each fiber type.

TABLE VIII. FIBER PROPERTIES FOR HIGH AND LOW MICRONAIRE COTTONS

Micronaire	Length (in)	Length Uniformity (%)	Strength (g/tex)	Elongation (%)
4.5	1.0	79.4	25.0	7.0
3.0	1.0	78.8	25.0	7.4

TABLE IX. INFLUENCE OF PROCESSING HIGH AND LOW MICRONAIRE COTTON ON NEP CONTENT

Sample Location	AFIS Neps/Gram	
	High Micronaire	Low Micronaire
Original Bale	375	674
Mechanical Cleaned	714	1177
Bleached	1550	1788
Card Web	1196	5508

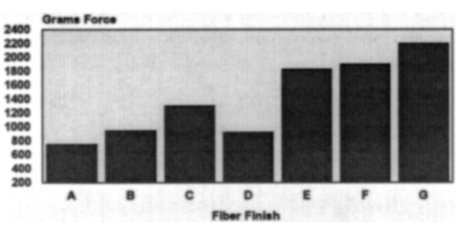

Figure 1. Fiber-to-Fiber Friction.

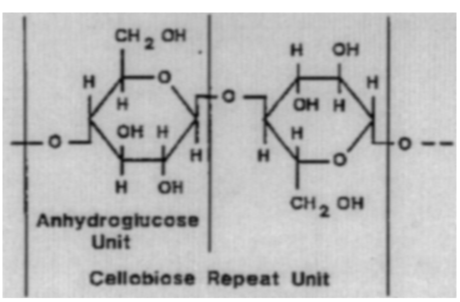

Figure 2. Chemical stucture of Cellulose.

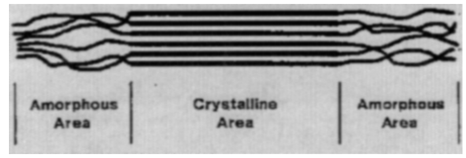

Figure 3. Amorphous and Crystalline areas of Polymers.

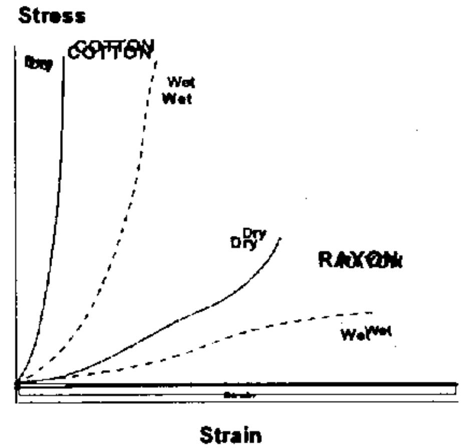

Figure 4.

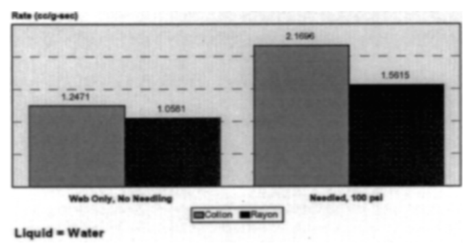

Figure 5. Absorbency rate (12 gf/cm^2)

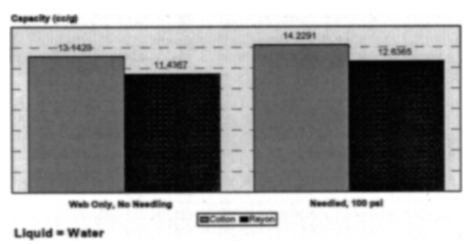

Figure 6. Absorbency capacity (12 gf/cm^2)

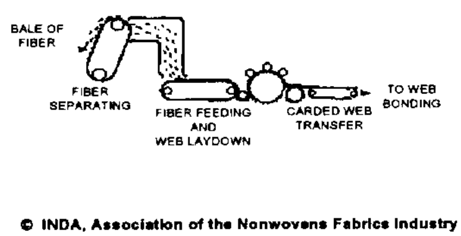

Figure 7. Web forming, Dry Laid, Carded.

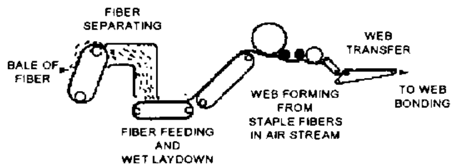

Figure 8. Web forming air laid-Random.

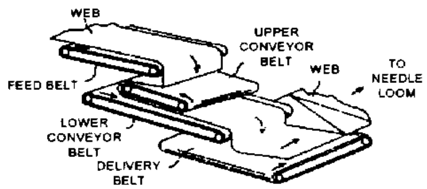

Figure 9. Horizontal Crosslapper.

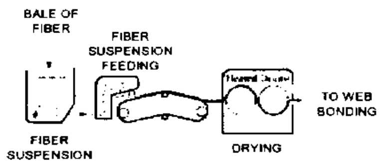

Figure 10. Web forming-wet laid.

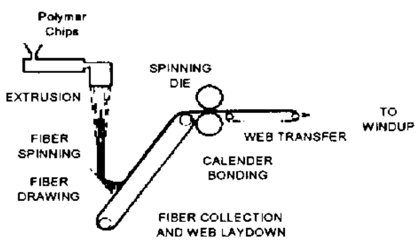

Figure 11. Web forming and bonding-spubonded.

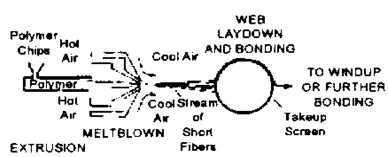

Figure 12. Web forming and bonding-melt blown.

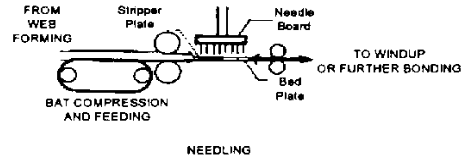

Figure 13. Web forming and bonding--needlepunched.

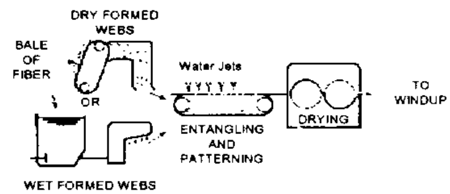

Figure 14. Web forming and bonding-spunlaced.

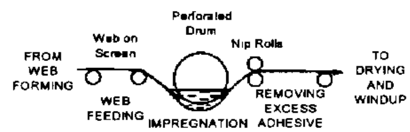

Figure 15. Methods of latex bonding-Saturation bonding.

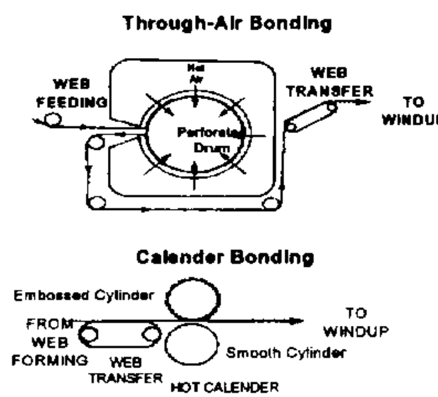

Figure 16. Two methods of thermal bonding.

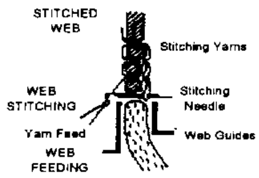

Figure 17. Stitchbonded.