

Hydroentangled nonwovens made from unbleached cotton

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COTTON FIBERS BRING UNIQUE advantages to many nonwoven products. Because cotton fibers are soft, absorbent, opaque, and biodegradable, they are especially useful in products that contact the skin and in wipers. Cotton is a renewable fiber that has strong appeal to consumers. It is the major fiber marketed in yarn-based consumer apparel and is finding its way into more nonwoven applications.

The bonding technique applied to cotton fibers strongly influences the properties of the final fabric. Latex bonding usually stiffens the cotton fiber web and can reduce its absorbency and biodegradability. Needle punching does not impair the fiber's desirable characteristics. However, the basis weights that can be made by this technique are not acceptable for most medical, protective, wiping, and personal applications. Thermal bonding, using suitable binder fibers or powders, can preserve many of cotton's inherent qualities, although generally at the expense of water-holding capacity (except at higher basis weights) (1). It also results in a loose, bulky fabric that can have excellent comfort qualities, but the fabric can also be difficult to treat as a liquid barrier. Hydroentangling, on the other hand, leaves the fiber in its natural state, preserving softness, absorbency, cover, and biodegradability. It can do this generally at basis weights as low as 30 g/m².

Hydroentanglement is a method of bonding nonwoven fabrics using very fine jets of high-pressure water to drive fibers into the z-direction of

a fiber web, resulting in reorientation and entanglement of the fibers. **Figure 1** illustrates the hydroentanglement process. Because the structure is bonded by friction, the resulting fabric is soft yet strong and tear resistant. It has an additional advantage in that the fibers within the web can be washed off the knuckles of an open supporting wire fabric, producing an apertured or even lacelike fabric. Hence the term "spunlaced" is commonly applied to hydroentangled fabrics.

Hydroentanglement can provide excellent physical and aesthetic properties, and it is becoming an increasingly popular bonding technique for cotton. Japan is producing 4300 tons/year of spunlaced cotton (2), while the UK is manufacturing semidurable bed sheets, napkins, and tableware from spunlaced cotton fabric (3). An Israeli nonwovens producer is marketing 100% spunlaced cotton fabrics, and a Mexican nonwovens producer is making hydroentangled fabrics from unbleached cotton (4). A North American manufacturer is marketing unique surgical gauze fabrics based on spunlaced bleached cotton (4).

Little research has been reported on hydroentangling cotton, although a number of patents have issued. Bertram (5) investigated hydroentangling cellulosic fibers and found that spunlaced cotton had superior retained wet strength compared with rayon. That work also found that cotton fiber produced spunlaced fabrics with superior wet and dry properties. Recent patents have focused on low-linting products for clean-room wipers (6) or products

ABSTRACT

Bleached cotton fibers are commonly used in nonwoven fabrics. This paper examines the use of unbleached cotton as a raw material for nonwovens. Nonwoven fabrics were produced by hydroentangling raw cotton fibers. Fabric mechanical properties and weight loss were measured as a function of the total specific energy applied during the hydroentanglement process. The results suggest that hydroentangling removes waxes and oils from raw cotton while preserving its valuable fiber attributes. The hydroentangled fabrics were very strong and showed excellent tear resistance. Weight loss on treatment was minimal.

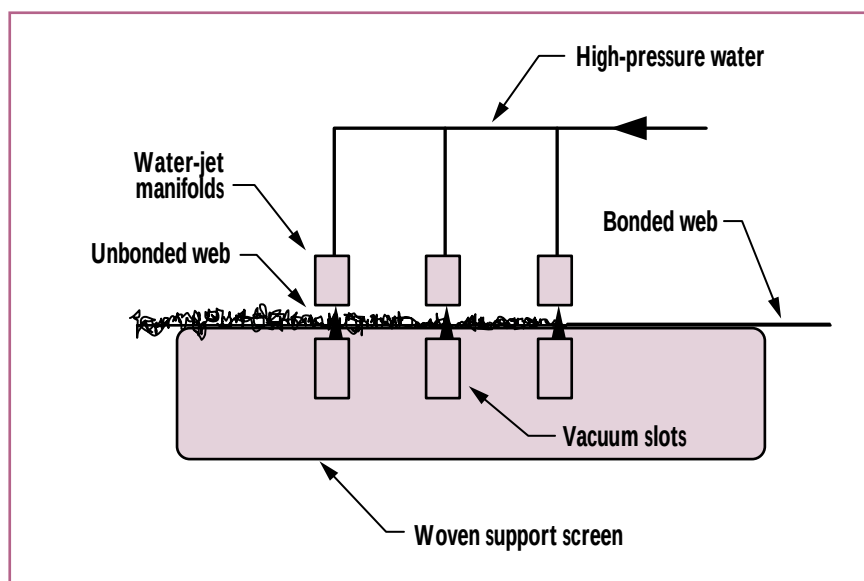
Application:

The energy applied during hydroentanglement apparently removes waxes and oils from raw cotton fibers, thus narrowing the quality gap between bleached and raw cotton fibers.

that can be washed and reused (7). Of particular significance is the finding that unbleached cotton can be made hydrophilic by hydroentangling (8). These inventors found that above a minimum energy level, the unbleached cotton changed from hydrophobic to hydrophilic, probably because of the mechanical removal of the fibers' waxy coating. The minimum energy level of 0.7 kW·h/kg_m (0.43 hp·h/lb_m) that is claimed to be required appears to be well below that required to achieve a useful fabric in most cases.

The objective of this ongoing study is

1. To learn more about the hydroentangling of bleached and unbleached cotton



1. Hydroentangling process

2. To characterize and compare the mechanical and aesthetic properties of fabrics obtained from bleached and unbleached cotton.

Bleached cotton used in nonwovens is usually keir bleached, i.e., bleached in a large vessel or keir. However, continuous bleaching lines are now in limited use. In the batch process, the cotton is taken from bales and packed into the keir. When the keir is full, it is sealed and filled with bleaching chemicals. After bleaching, the keir is opened, and the cotton is removed, dried, and rebaled. Bleaching removes the waxes and oils in the fibers of raw cotton and bleaches the fibers.

Unbleached cotton is an attractive material because it is less expensive than bleached cotton. Current mechanical methods of cleaning raw cotton produce excellent results and leave less trash remaining in the raw fiber. Unbleached cotton contains oils and waxes, and the fibers generally have a yellow-brown cast. Spunlaced unbleached cotton fabrics (greige fabrics), if adequately entangled, can be bleached on conventional scouring and bleaching equipment, which is less expensive (on a per-pound basis) than keir-bleaching the cotton. However, many applica-

tions for spunlaced cotton do not require bleaching. Spunlaced fabrics made of unbleached cotton can be conventionally dyed and finished to provide useful fabrics at lower cost. Protective clothing, other disposable garments, and wipes for many applications may not require the use of bleached fiber, thus reducing their cost.

EXPERIMENTAL

Raw materials

The unbleached cotton used in this study had been processed in an opener-cleaner (Lint Master™) for maximum fiber opening and minimum lint.

Opening and web forming

Webs consisting of 100% cotton fiber were produced at specified target weights. The cotton fibers were processed through the Cotton Incorporated Nonwovens Processing Laboratory in the College of Textiles to form carded/crosslapped webs. The fibers passed through the following process sequence: fine opener (Fiber Controls), chute feed (Fiber Controls Snow Flaker II), revolving-flat cotton card, cross lapper, and needle tacker. The needle-tacked webs were layered with tissue paper and wound into manageable rolls. The tissue paper facilitated unwinding the fiber

webs with minimal distortion and web damage.

Hydroentangling

The needle-tacked webs were hydroentangled on a laboratory hydroentangling unit (Honeycomb) at specific energy levels using a 60 x 40-mesh support wire. Specific energy values were obtained by varying the water pressure in the manifolds, the number of manifolds, and the line speed. Specific energy, SE, in kW·h/kg or hp·h/lb applied to the web by water by each manifold is given by Eq. 1.

$$SE = K[(Cd^2NP^{3/2})/(WS)] \quad (1)$$

where

K = constant obtained using conversion factors, with a value of 27.9 kW·h·in²·g·ft/kg·lb_f^{3/2}·m²·min (17.0 hp·h·in²·g·ft/lb_m·lb_f^{3/2}·m²·min)

C = orifice coefficient (assumed constant = 0.595)

d = diameter of jet orifice, in.

N = number of jets per inch of manifold

P = water pressure, psig

W = web basis weight, g/m²

S = line speed, ft/min.

The total specific energy, TSE, expended on each fabric was calculated using Eq. 2:

$$TSE = \sum_{i=1}^p \sum_{j=1}^m SE_{ij} \quad (2)$$

where

SE = specific energy applied to the web by each manifold calculated by Eq. 1, kW·h/kg or hp·h/lb

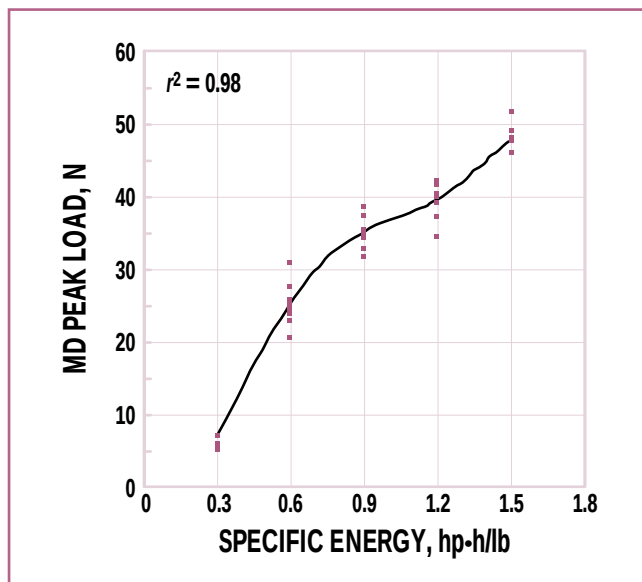
i = manifold number

p = number of manifolds in a pass

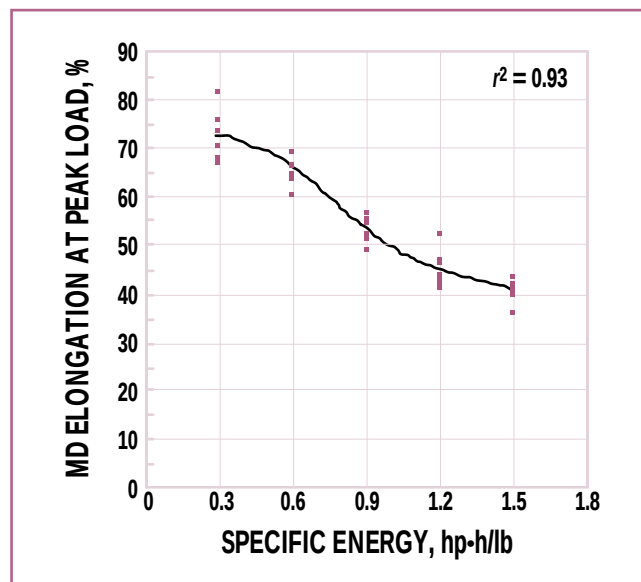
j = pass number

m = total number of passes.

The webs were hydroentangled by passing them under the manifolds using specific speed and water pressure settings. They were entangled on both sides by turning the fiber webs over. The ratio of total specific



2. MD peak load vs. specific energy



3. MD elongation at peak load vs. specific energy

energy (SER) for the two sides is an important operating variable and is calculated using Eq. 3.

$$\text{SER} = \text{TSE}_{\text{side 1}} / \text{TSE} \quad (3)$$

Physical property development

The objective of this set of experiments was to determine the effect of TSE on the mechanical properties of the fabric. The mechanical properties of interest were machine-direction (MD) peak tensile and elongation, trapezoid tear, ring stiffness, and flexural rigidity. Rolls for this purpose—made by the described procedure and with a target basis weight of 73 g/m²—were hydroentangled at five specific energy levels using a specific energy ratio of 35% (low TSE on the first side).

Peak load and elongation were measured using ASTM D 5035 (specimen width 25.4 mm, gauge length 76 mm, jaw speed 305 mm/min). A minimum of eight specimens were tested for each experimental condition. Trapezoid tear was measured using ASTM D 1117 (Section 14) using five specimens for each experimental condition. Flexural rigidity was measured using ASTM D 1388, (Option A, cantilever test) using five specimens for each experimental condition. Ring stiffness was deter-

mined using ASTM D 4032 using five specimens for each experimental condition.

Weight loss on hydroentangling

The objective of this set of experiments was to determine the weight loss occurring during hydroentangling as a function of specific energy used. Carded and cross-lapped unbonded webs (nominal basis weight 99 g/m²) were made and wound on cardboard cores to make rolls of about 23 m. Tissue paper was inserted between the adjacent layers of the rolls to facilitate cleaner unwinding of the rolls prior to hydroentangling. The rolls were conditioned to constant weight in a laboratory maintained at standard conditions (70±2°F and 65±2% RH). They were then hydroentangled at various TSEs, dried on the through-air dryer, and returned to the conditioned lab to be conditioned to constant weight, along with the original core and tissue paper. Weight-loss fraction was calculated using Eq. 4.

$$\Delta m / m_{\text{gu}} = (m_{\text{gu}} - m_{\text{f}} - m_{\text{c}} - m_{\text{tp}}) / (m_{\text{gu}} - m_{\text{c}} - m_{\text{tp}}) \quad (4)$$

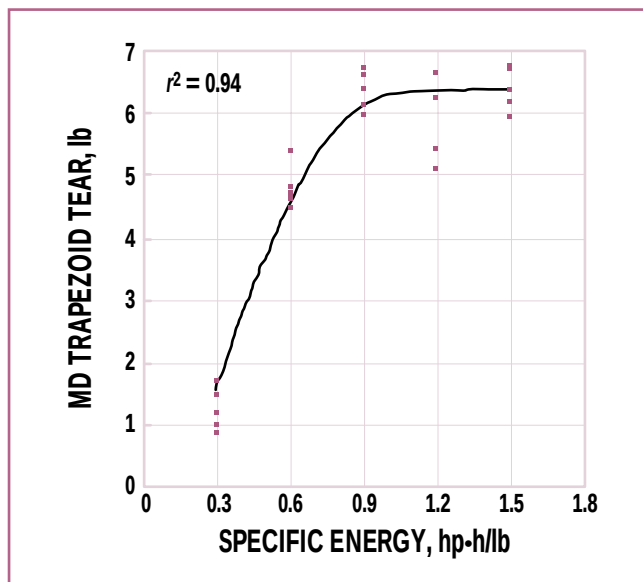
where m is the mass and the subscripts gu, f, c, and tp represent gross unbonded fiber web, hydroentangled fabric, core, and tissue paper, respectively.

RESULTS AND DISCUSSION

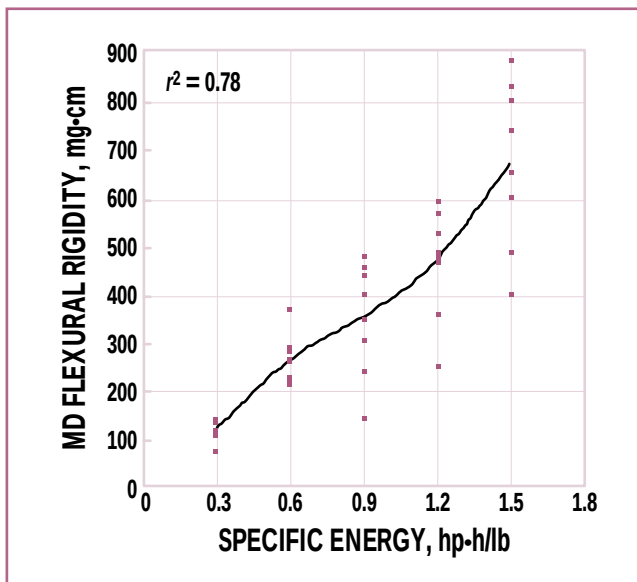
Peak load and elongation in the MD responded as expected to the specific energy applied to the web, as seen in **Figs. 2 and 3**, respectively. Increasing the total specific energy increased strength and reduced elongation. A maximum tensile strength was not achieved within the range of TSE applied. The fabrics are quite strong, considering that the basis weight was around 70 g/m². Trapezoid tear strengths were also extremely high, as seen in **Fig. 4**. High tear strength combined with high tensile strength is a very useful combination.

Flexural rigidity followed the same trend, with stiffness increasing with TSE, as seen in **Fig. 5**. There are likely two factors influencing stiffness: Higher TSE increases the level of bonding and probably increases the removal of waxes and oils, resulting in a higher level of hydrogen bonding. Ring stiffness also increased with TSE, as seen in **Fig. 6**.

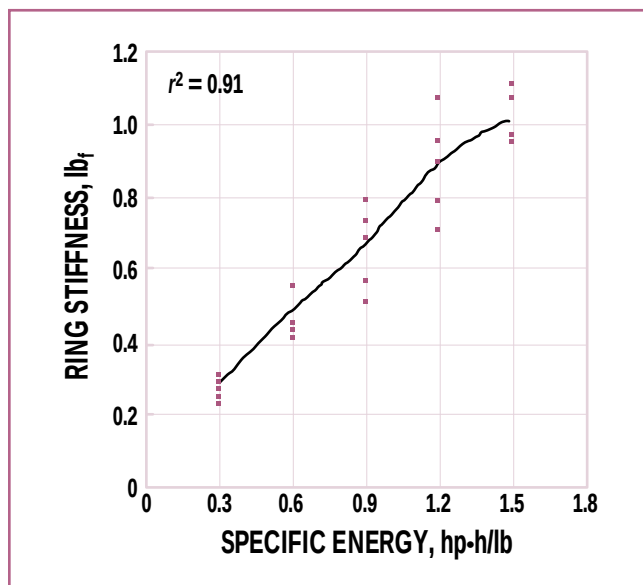
Weight loss on hydroentangling is an important factor influencing the economics of the process, since it represents a loss of raw material. More importantly, it represents contamination of the process water that must be filtered out before the water can be reused for hydroentangling.



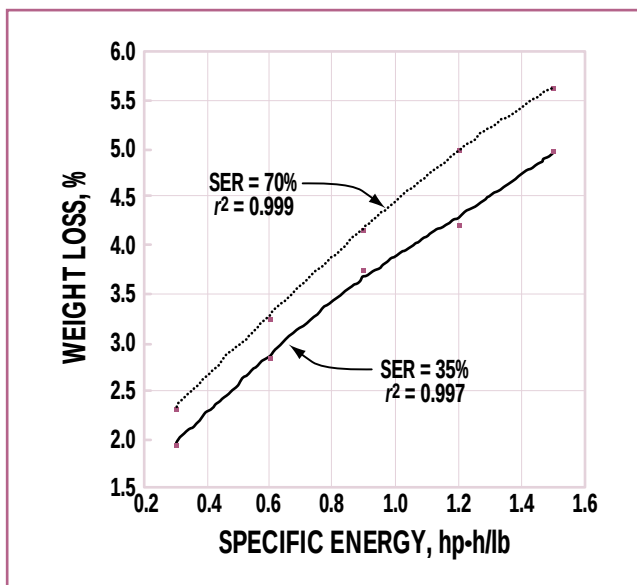
4. MD trapezoid tear vs. specific energy



5. MD flexural rigidity vs. specific energy



6. Ring stiffness vs. specific energy



7. Weight loss vs. specific energy

KEYWORDS

Angiosperms, cotton, energy, fabric, farm crops, fiber entanglement, hydroformers, losses, mechanical properties, natural fibers, nonwood fibers, nonwood plants, nonwovens, plant fibers, properties, seed fibers, sheet formers, spun laced fabric, textile fibers.

In the case of unbleached cotton, we have intentionally used the term “weight loss” instead of “fiber loss,” since the weight loss represents not only fiber loss, but loss of waxes, oils, and “trash.” Weight loss was dependent on the SER, with the lower ratio providing the lower weight loss, as seen in **Fig. 7**. Weight loss at the highest energy treatment condition was 5% for an SER of 35%. Weight loss appears to continue

increasing with increasing specific energy, and one would not expect a maximum. **TJ**

Gillmore was codirector and a visiting associate professor at the Nonwovens Cooperative Research Center, North Carolina State University, Raleigh, NC 27695. Timble is a research associate. Morton is director of product and process research at Cotton Inc., Raleigh, NC 27612-3883.

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