

Spunlaced Cotton and Cotton Blend Cosmetic Pads and Bed Sheets: Study of Fiber Entanglement

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ABSTRACT

Nonwoven webs containing five different blends of bleached cotton with Lyocell rayon, bicomponent core/sheath polyester/polyethylene, or cotton comber noil were prepared by either light needlepunching, or light needlepunching followed by spunlacing (hydroentanglement). We optically acquired fiber bundle size measurements to learn about the pre-needling process, the hydroentangling process and the influence of fiber blend composition on fiber entanglement. Fiber entanglement measurements were compared to basis weight uniformity measurements. One of the bed sheet developments utilized a combination of bonding technologies (spunlacing and thermal bonding) that used low energy. Results from this work indicate that spunlacing produced high quality cosmetic pads and economical short-life bed sheeting.

INTRODUCTION

To achieve adequate properties in nonwoven webs, it is necessary to bond fibers to one another. One form of bonding which is present in every nonwoven is mechanical fiber entanglement. Precursor webs for needlepunching or spunlacing (hydroentangling) generally are a low density, loose assembly of fibers with relatively few contacts between fibers and thus few fiber entanglements. This low level of entanglement provides little web integrity but does provide for fiber mobility during pre-needling or hydroentanglement. Needle punching and hydroentanglement increase web density and fiber entanglement to develop desirable properties such as web strength, durability during use, abrasion resistance and other attributes.

Needling and hydroentanglement increase entanglement by increasing fiber packing density along with fiber twisting and curling to increase the

number of fiber contacts per unit web volume. Numerous structural features and properties related to fiber entanglement have been measured. These include web density [1-3], fiber orientation [1,2], large-scale web texture [2,4], the use of colored tracer fibers to obtain information about orientation, curl, and shape of individual fibers in webs [5], and the length of straight fiber segments in webs [1].

The structure of entanglements themselves have not been studied thoroughly. Fiber staining techniques have been used to observe fiber knots [6] and the size and orientation of fiber bundles have been measured [7]. Fiber entanglements can take many structural forms that range from loosely packed fibers having relatively little contact with one another to tightly packed, intertwined fibers in bundles that act as cohesive units.

Nearly all nonwoven materials contain fiber bundles. Carded webs typically contain few bundles since the carding process separates tufts into individual fibers before forming a loosely packed web. Meltblown webs contain a large number of bundles since dynamic airflow turbulence dynamically entangles and twists hot fibers tightly during web formation.

We produced a series of cotton-containing webs by pre-needling followed by hydroentangling and reported detailed basis weight uniformity measurements for the webs [8]. It was observed that blending a manufactured fiber (Tencel or low temperature thermal-bondable polyester/polyethylene, core/sheath fiber) with bleached cotton and bleached cotton comber noil improved basis weight uniformity in pre-needled webs substantially. We also observed that hydroentangling needled webs significantly improved total and machine direction (MD) uniformities at most size resolutions but

reduced uniformity at small size resolutions in any web direction and in the cross direction (CD) at all size resolutions. Hydroentangling also reduced non-uniformity differences in needled webs that were associated with fiber blending.

We considered two different explanations for our basis weight uniformity observations. First, we thought that fiber mass was redistributed during hydroentangling to improve uniformity on large size scales (e.g. 1-2 mm). At the same time, hydroentangling might very well introduce a periodic basis weight variation in the CD on the size scale of inter-nozzle spacing. Optical microscope images supported this hypothesis since fiber mass variations were observed with a spatial periodicity of 635 μ in hydroentangled webs. Clearly, redistribution of fiber mass on both large and relatively small size scales contributed to some of the web uniformity changes we observed for hydroentangled webs.

Second, we thought that the bending modulus and frictional drag of manufactured fibers were different than cotton and could have affected basis weight uniformity by influencing the amount of fiber entanglement that occurred during processing. However, no experimental evidence was available to test this hypothesis. The overall goal of our current work was to acquire experimental measurements of fiber bundle size to understand the contribution of this type of fiber entanglement to our previous basis weight uniformity measurements. This understanding is important since the nature of fiber entanglement strongly influences web properties. For example, entanglements that produce fiber bundles concentrate fiber mass in a small volume, create voids, and thus reduce web uniformity.

We carefully measured fiber bundle size for the ten webs previously evaluated for basis weight uniformity. Fiber bundles are generally defined as tight, cohesive groups of two or more fibers. There may also exist a single fiber fibrous bundle. In addition to the number of fibers per bundle, characterization of the bundles can be expanded to include bundle spacing, harshness and other inherent properties. However in this work, bundle size was the focus rather than bundle makeup. *Figure 1* provides an optical image from a lightly needled web and a large bundle is identified with an arrow. Bundles were measured using an instrument which incorporates conventional optical microscopy along with automated web sampling and auto-focusing to focus bundles through the whole web thickness and across the whole web width. After an image was acquired, automated image processing and image

analysis was used to detect focused fiber bundles and measure their diameters. No attempt was made to determine the number of fibers present in the individual bundles.

EXPERIMENTAL

Bleached cotton and comber noil cotton had fiber staple lengths of 0.973 inch and 0.550 inch with micronaire values of 4.0 and 3.9, respectively. Unbleached grey upland cotton (staple length of 1.09 inch with micronaire value of 4.27) was mechanically cleaned but contained natural hydrophobic oils and waxes.

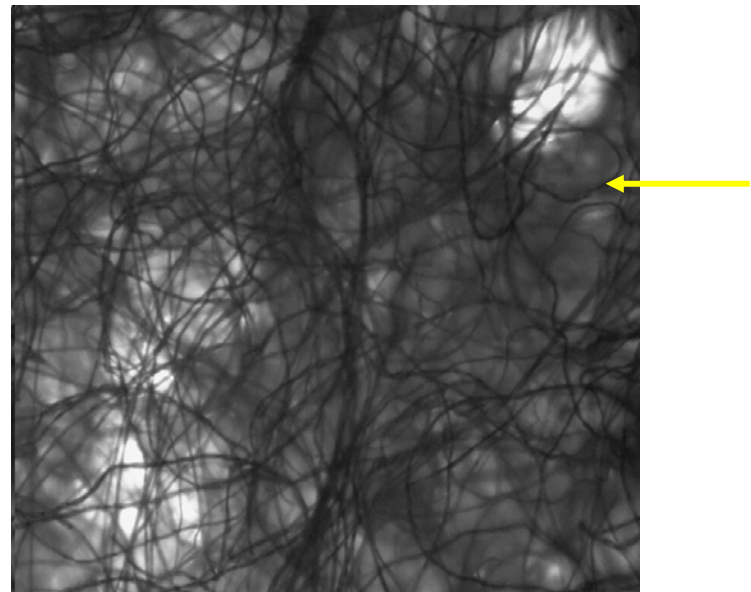


FIGURE 1. Transmitted light image showing fiber bundles in a lightly needled web; web area is 2.84 mm x 2.15 mm.

Good mechanical cleaning was necessary to make grey cotton fiber free from broken seed coats or husks. Three denier, 2" Tencel fiber and a bicomponent core/sheath polyester/polyethylene (2 denier, 1.5 inch; melting point of polyethylene ~ 128C) fiber were used.

The objective of our development was to create economical, high-quality cosmetic pads and semi-durable bedsheets using new cotton blends in nonwoven webs. Precursor webs were prepared by lightly needling fibers to produce webs that could be transported and unwound on the hydroentanglement line. Slight drafting of webs during unwinding was evidence of the low level of needling that was achieved. Using bleached cotton fiber blends, fabrics developed were 1 NH and 2 NH for cosmetic pads, and 3 NH and 4 NH for bedsheets. The bed sheet

TABLE I. Description of Webs.

Web ID	Fiber Blend	Process [End use]	Target Basis Weight (g/m ²)	Web Thickness (mm)
1 N	50% bleached No. 1 cotton 50% bleached cotton comber noil	Lightly Pre-Needled	220	3.7
1 NH	50% bleached No. 1 cotton 50% bleached cotton comber noil	Lightly Pre-Needled and Hydroentangled [cosmetic pads]	220	2.9
2 N	40% bleached No. 1 cotton 40% bleached cotton comber noil 20% Tencel (3 den, 2 inch)	Lightly Pre-Needled	220	3.7
2 NH	40% bleached No. 1 cotton 40% bleached cotton comber noil 20% Tencel (3 den, 2 inch)	Lightly Pre-Needled and Hydroentangled [cosmetic pads]	220	2.8
3 N	37.5% bleached No. 1 cotton 37.5% bleached cotton comber noil 25.0% polyester/polyethylene Bico T256	Lightly Pre-Needled	90	1.9
3 NH	37.5% bleached No. 1 cotton 37.5% bleached cotton comber noil 25.0% polyester/polyethylene Bico T256	Lightly Pre-Needled and Hydroentangled [bed sheets]	90	0.7
4 N	32.5% bleached No. 1 cotton 32.5% bleached cotton comber noil 35.0% Tencel (3 den, 2 inch)	Lightly Pre-Needled	90	1.9
4 NH	32.5% bleached No. 1 cotton 32.5% bleached cotton comber noil 35.0% Tencel (3 den, 2 inch)	Lightly Pre-Needled and Hydroentangled [bed sheets]	90	0.7
5 N	65% unbleached greige cotton 35% Tencel (3 den, 2 inch)	Lightly Pre-Needled	90	2.3
5 NH	65% unbleached greige cotton 35% Tencel (3 den, 2 inch)	Lightly Pre-Needled and Hydroentangled [bed sheets]	90	0.7

fabric 5 NH was made with a blend using grey (unbleached) cotton fiber.

The ten webs prepared from five different fiber blends are described in Table I. A 1,500 m sample of each blend was produced by light needlepunching, whereas another 1,500 m sample of each blend was produced by light needlepunching and followed by hydroentangling. Fibers were weighed by blending hoppers and transferred to a conveyor, blend roll (with a 3-lag Kirschner Beater), and the Micro-Tuft Opener. Fiber was subsequently fed into a blending reserve and then conveyed by air to the Flockfeed Fine Opener with pedal-feed feed plates, and a 3-lag Kirschner Beater for fine opening. Finally, fiber was conveyed by air to the chute feed and the card. All five blends were processed on a card line with a 2.5 m MASTERCARD, crosslapper, needle loom, and winder with slit at Hollingsworth On Wheels in Greenville, South Carolina [9]. Needle punching was performed only lightly at a line speed of approximately 8 meters per minute on a Dilo Needle Loom. The loom had two boards of needles, one with straight line pattern and another with random pattern, with 7,375 needles per square meter. Needling was about 250-350 ppsi, at a penetration depth of 0.3mm.

The webs were to be subjected to subsequent hydroentanglement at Fleissener GmbH in Eglesbach, Germany [10-12] using an Aquajet Spunlace line with pre-needling and three-step spunlacing (with individual adjustment of water pressure). Water pressures used depended upon the end product. For cosmetic pads, it was 20 bar, 35 bar and 40 bar. For bed sheet developments, it was 20 bar, 150 bar, 150 bar and 150 bar.

Fiber bundle analysis [13] was measured quantitatively off-line using *WebPro*, an automated image analysis-based instrument [14]. Optical images were acquired by focusing fiber bundles in various thin planes onto the image sensor of the camera. A substantial effort was made to sample web structure adequately by measuring 5,000-6,000 fiber bundles in each web and measuring bundles through the whole web thickness and across the whole web width.

RESULTS AND DISCUSSION

The objective of our development was to use hydroentanglement to create economical, high-quality nonwoven cosmetic pads and short-life bed sheets using cotton blends. In the USA, supermarket store shelves carry the needlepunched cotton

cosmetic pads, but not the spunlaced cosmetic pads. Spunlaced cotton cosmetic pads and short-life bed sheets could be novel introduction to the consumer in the United States.

At TIEHH, Texas Tech University, the surface mechanical properties (friction/smoothness) of the cosmetic pads were evaluated using frictional forces at different loads [15]. The sliding friction apparatus was used on a constant-rate-of-elongation Instron Tensile Tester to obtain frictional forces at different loads [16]. Based on the comparison of the average friction value of each of these fabrics (MD and CD), it was determined that the spunlaced cosmetic pad fabrics (1 NH and 2 NH) were superior to their lightly pre-needled counterparts (1N and 2N). The hydroentanglement process smoothed the protruding fibers of the pre-needled fabrics which in turn provided less resistance to the movement of the friction sled. The spunlaced fabrics had lower friction value providing superior smoothness. Spunlacing improved the fabric quality and performance. Additionally, each of the cosmetic pad fabrics were stamped into round pads, and these round pads were evaluated for the criteria of "edge seal." As expected, the cosmetic pads of spunlaced fabrics were found to be superior to their pre-needled counterparts, and the cosmetic pads of spunlaced (2NH, containing Tencel) superior to those of 1 NH.

In the following pages, we will briefly discuss fiber bonding in the webs, then, the general influence of hydroentangling on web structure. Finally, we will evaluate the influence of fiber blend composition on fiber bundle size by comparing data for individual webs.

Fiber Bonding in Webs

A relatively small amount of core/sheath, polyester/polyethylene bicomponent fiber (Cellbond T256 from Hoechst Celanese Corporation and now from KOSA) was added to one fiber blend (3 N and 3 NH) for short-life bed sheets to produce fiber bonding via thermal flow and on cooling, mechanical adhesion. Thermal bonding was achieved economically in drying (without any additional heating) since thru-air drying was used to dry the dewatered fabric after hydroentangling as well as achieve thermal bonding of the bicomponent fiber simultaneously. It is possible that the polyethylene sheath might have been modified with maleic anhydride to improve the adhesion to cotton. Thus, a combination of bonding technologies (spunlacing and thermal bonding) occurred in the bed sheet fabric (3 NH). The bicomponent fiber imparted strength characteristics to the fabric (3 NH) but with a stiffer

hand as compared to that of the bed sheet fabric 4 NH using Tencel.

Figure 2 provides a scanning electron micrograph (SEM) using a secondary electron detector of the needled web (Web 3 NH) containing 37.5% bleached cotton, 37.5% bleached cotton comber noil and 25% polyester/polyethylene bicomponent fiber. The arrow in this figure shows a bicomponent fiber (circular cross sectional shape) that has been thermally bonded to cotton fibers (flat ribbons with twisted convolutions). This indicates that thermal bonding was indeed achieved during thru-air drying. Although the bicomponent fiber contributed to fiber bonding in the web, the majority of bonding in this figure can be seen to be fiber entanglement.

Influence of Hydroentanglement on Web Structure

We previously reported that hydroentanglement improved basis weight uniformity by redistributing fiber mass more uniformly in webs [8]. In that report, however, we did not investigate specific mechanisms that could contribute to improved basis weight uniformity. *Figures 3-5* illustrate one specific example of how web uniformity was improved by hydroentanglement. *Figures 3-4* show that needled webs contain holes which represent local areas of quite low basis weight compared to areas surrounding the holes. Redistribution of fibers in the vicinity of

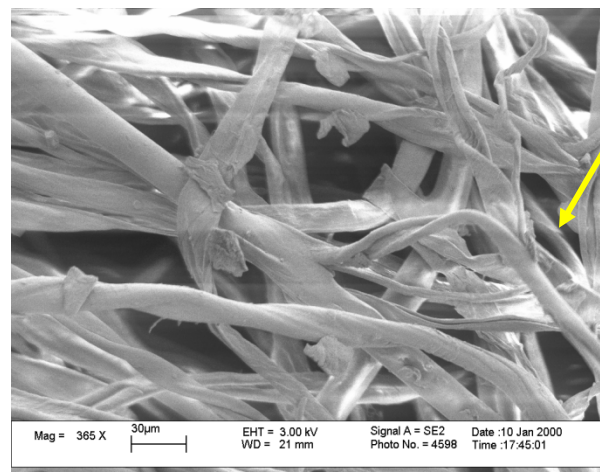


FIGURE 2. SEM of web 3 NH showing thermal bonding.

needle holes during hydroentanglement would be expected to improve web uniformity. *Figure 5* shows that hydroentangling indeed effectively redistributed

fibers in the vicinity of needle holes since needle holes are not visible in webs after hydroentangling.

Figure 6 provides an overall view of the affects of hydroentangling on fiber bundle size distributions. Fiber bundle measurements were averaged for the five needed webs and for the five needed/hydroentangled webs.

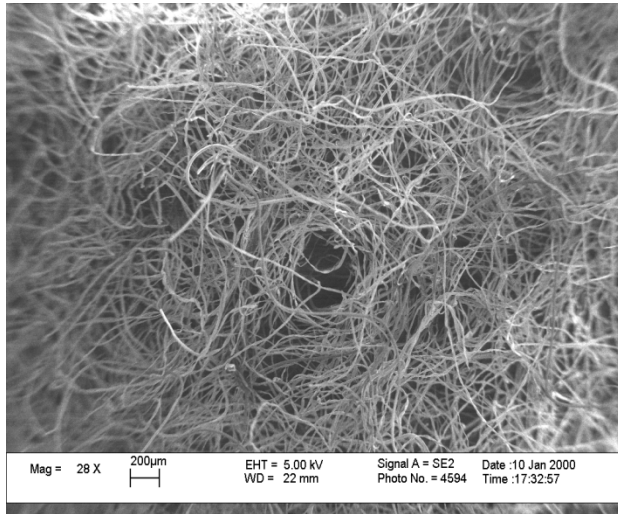


FIGURE 3. SEM of pre-needled web showing a needle hole.

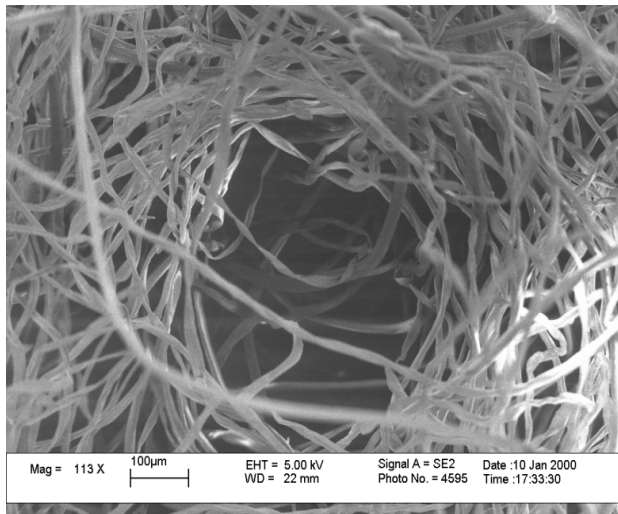


FIGURE 4. Higher magnification view of the needle hole shown in Fig. 3.

This figure provides another specific example of how web uniformity is improved by hydroentanglement

since we see that hydroentangling changed the nature of fiber entanglement by reducing the size of fiber bundles. That is, hydroentangling increased the percentages of fine fiber bundles and decreased the percentages of coarse fiber bundles. Figure 6 also shows that hydroentangling influenced smaller bundles more than larger bundles.

The differences in bundle size distributions in Figure 6 would be expected to influence measures of the

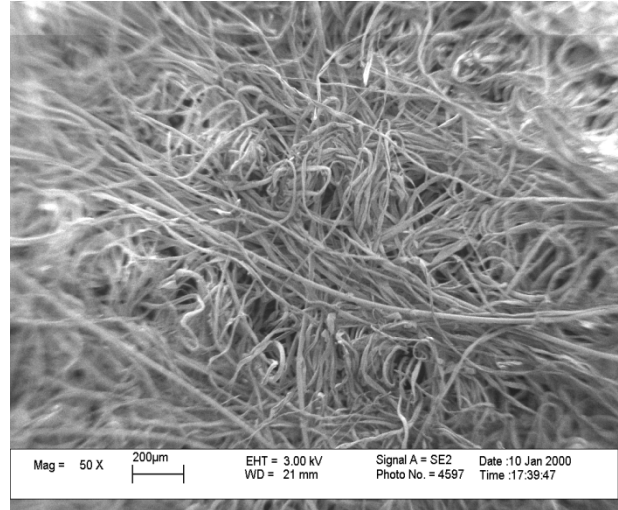


FIGURE 5. The web from Fig. 3 after hydroentanglement.

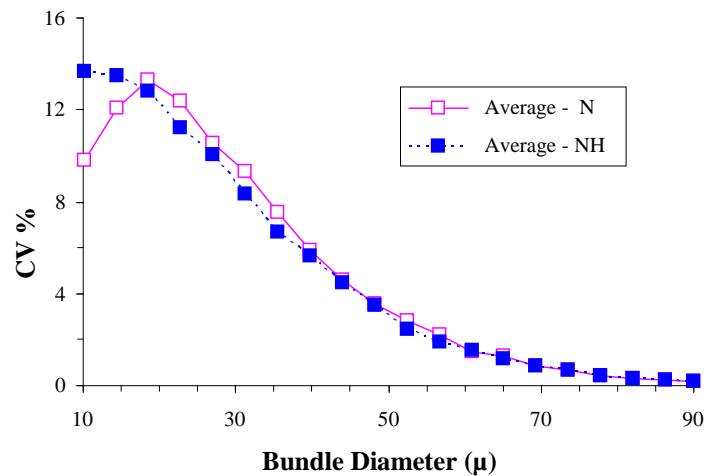


FIGURE 6. Fiber bundle measurements averaged for all needed (N) and all pre-needled/hydroentangled (NH) webs.

broadness of the fiber bundle distribution. *Figure 7* provides a measure of the broadness of all bundle distributions using the coefficient of variation ($100 \times \text{Standard Deviation} / \text{Mean}$). Although five different fiber blend compositions using four different amounts of manufactured fiber were evaluated in this study, *Figure 7* shows that hydroentanglement increased bundle size coefficients of variation in each case.

Figures 6-7 clearly indicate that hydroentanglement improved basis weight uniformity by disentangling fiber bundles.

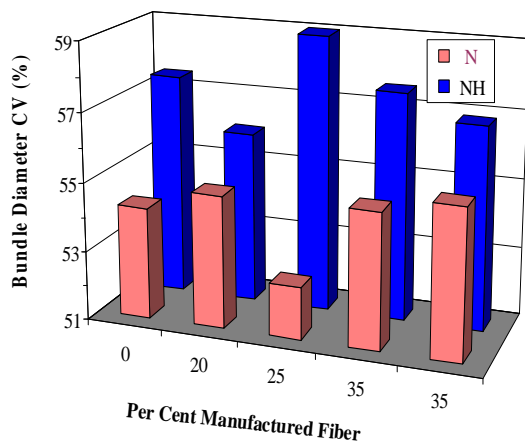


FIGURE 7. Bundle diameter coefficients of variation for pre-needled (N) and pre-needled/hydroentangled (NH) webs; see Table I for web descriptions.

It might seem odd that fiber bundle size is reduced during hydroentanglement since it is known that fibers become entangled during hydroentanglement. However, we must carefully focus on the exact structures measured during analysis. Only tight, cohesive fiber bundles were measured by us and *Figures 6-7* clearly indicate that the size of bundle structures was reduced by hydroentanglement. This observation is not inconsistent with the view that hydroentangling increases fiber entanglement. We learn that hydroentanglement forms loosely entangled structures at the same time tightly entangled bundles are disentangled. *Figure 5* indeed shows that fiber segments are relatively individualized in loosely packed arrays rather than in tight, cohesive bundles which act as a single unit.

Influence of Blend Composition

Next, we evaluated the influence of fiber blend composition on fiber bundle size. The amount of manufactured fiber in our webs varied from 0% to

35%. In the following section, we analyzed our measurement data only using four blends that contained bleached cotton/cotton comber noil (Webs 1-4) and we did not use the blend containing unbleached grey cotton (Web 5). First, we will discuss pre-needled webs and then discuss pre-needled/hydroentangled webs.

Lightly Needled Webs

Figure 8 provides fiber bundle size distributions for needled webs which contained cotton and cotton comber noil along with various amounts of manufactured fiber (Tencel or polyester/polypropylene, bicomponent fiber). This figure shows that the overall affect of blending manufactured fibers with bleached cotton/cotton comber noil and then subjecting fibers to light needling was to increase fiber bundle size. That is, blending larger amounts of manufactured fiber with cotton generally decreased percentages of fine bundles and increased percentages of coarse bundles. In the 10 through 30 micron diameter range, it can be seen that statistically, the differences are accentuated between the higher and lower manufactured fiber levels.

Figure 9 provides total basis weight uniformity (uniformity without regard to web direction) spectra for the same needled webs. We see that blending larger amounts of synthetic fiber with cotton generally improved web uniformity. That is, the variation of basis weight (represented as % coefficient of variation) was reduced when the amount of synthetic fiber was increased. *Figures 8-9* together lead us to conclude that blending manufactured fiber with cotton improved web overall uniformity because manufactured fibers reduced the formation of tight, cohesive fiber bundles. Instead, our data show that the addition of manufactured fibers improved web uniformity in needled webs in spite of the tendency of blends to form larger fiber bundles. As with all dry laid nonwovens, within the larger basis weight sample, there are short-term variations. This notwithstanding, the observed improvement in uniformity is both a desirable and important finding.

Hydroentangled Webs

Figure 10 provides fiber bundle size distributions for hydroentangled webs. This figure shows that the overall affect of blending manufactured fibers with bleached cotton/cotton comber noil and then subjecting lightly needled webs to hydroentanglement was to reduce fiber bundle size. That is, blending larger amounts of synthetic fiber with cotton generally increased percentages of fine bundles and

decreased percentages of coarse bundles in hydroentangled webs. This effect is opposite to that observed for needled webs (Fig. 8). This was a little unexpected.

Figure 11 provides total basis weight uniformity spectra for the same hydroentangled webs. Comparison of Figures 9 and 11 show that hydroentangling needled webs improved their basis weight uniformity (reduced CV%) except at the

smallest size resolution where nozzle spacing introduced periodic structural variations in the webs. Figures 10-11 together lead us to believe conclude that blended improved the uniformity of hydroentangled webs because synthetic fibers reduced the formation of tight, cohesive fiber bundles. In addition to this specific mechanism, Figures 3-5 indicated that redistribution of fibers in the vicinity of needle holes also improved uniformity in hydroentangled webs.

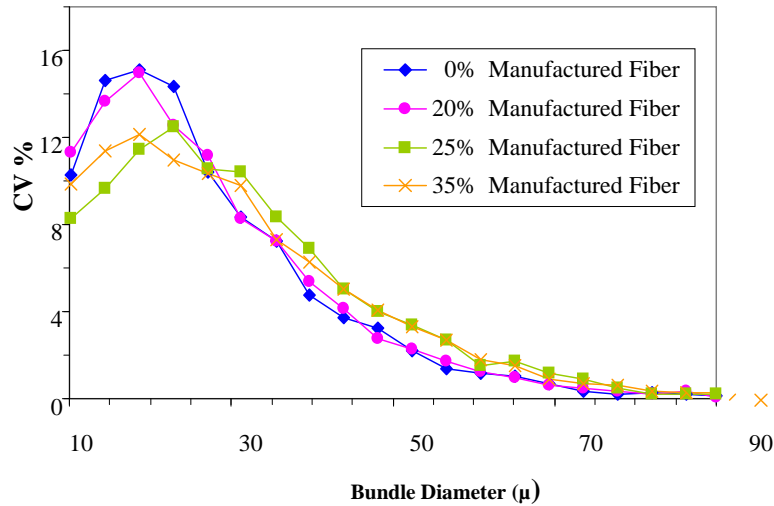


FIGURE 8. Fiber bundle measurements for pre-needled webs.

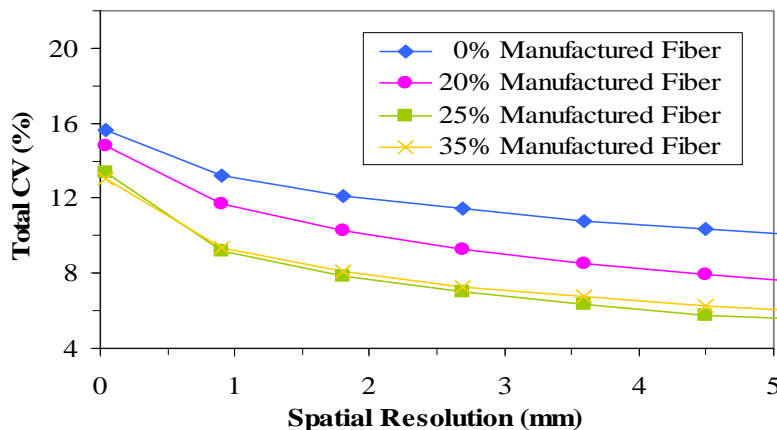


FIGURE 9. Total basis weight uniformity spectra for pre-needled webs.

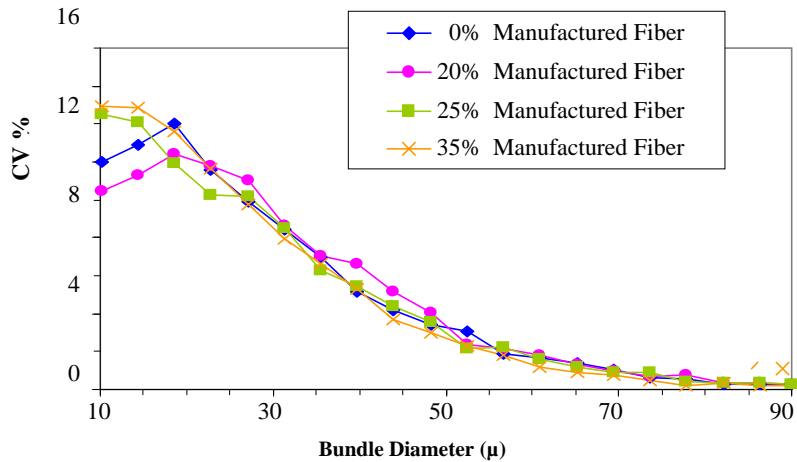


FIGURE 10. Fiber bundle measurements for hydroentangled webs

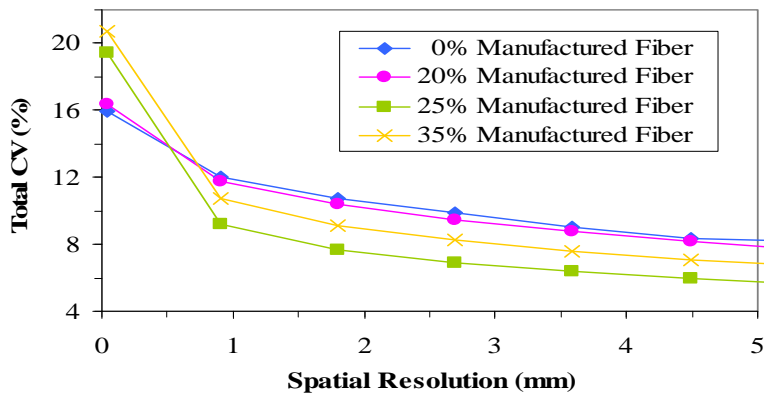


FIGURE 11. Basis weight uniformity spectra for hydroentangled webs.

CONCLUSIONS

The development of high quality hydroentangled cosmetic pads and short-life bed sheets was carried out via light pre-needling the carded webs. Spunlacing produced high quality cosmetic pads, and the fabric (2 NH) produced the best cosmetic pads. The spunlaced bed sheets of grey unbleached cotton (5 NH) will have great economic advantage over the bed sheets of 3NH and 4 NH because of significantly reduced cost of grey cotton fiber (cost is \$0.60/lb vs. \$1.25/lb of bleached cotton). Spunlacing imparted absorbency to make the bed sheets absorbent, although the whiteness of this development (5 NH) was inferior to bed sheets (3 NH and 4 NH) using bleached cotton fiber. The economic advantages of the developments of cosmetic pads (1 NH and 2 NH) and bed sheets (3 NH and 4 NH from bleached cotton) are discussed in more detail by Parikh [8].

We evaluated basis weight uniformity, the local uniformity of fiber distribution and fiber entanglement in cotton-containing webs. Web uniformity and fiber bundle size were influenced substantially by processing (needling vs needling/hydroentanglement). Needled webs were less uniform, contained larger fiber bundles and contained needle holes with local areas of quite low basis weight compared to hydroentangled webs.

Hydroentangling needled webs improved web uniformity except at the smallest size resolution where nozzle spacing introduced periodic structural variations in webs. Hydroentanglement also reduced fiber bundle size and redistributed fiber mass in the vicinity of needle holes. Disentanglement of fiber bundles during hydroentanglement was not inconsistent with the view that the overall effect of

hydroentangling is to increase fiber entanglement. Our measurements indicated that hydroentanglement forms loosely entangled structures at the same time it disentangles tightly entangled bundles.

Blending a manufactured fiber with bleached cotton/cotton comber noil and producing lightly needled webs increased fiber bundle size but improved basis weight uniformity in the webs. That is, the addition of manufactured fibers improved web uniformity in needled webs in spite of the tendency of blends to form larger fiber bundles during needling. Consequently, uniformity improvement did not occur because manufactured fibers reduced the formation of tight, cohesive fiber bundles. Instead, blending must have influenced other structural changes in webs such as fiber redistribution and/or the formation of loosely entangled fiber structures. The stiffness of the manufactured fibers may also have played a part here.

Blending a manufactured fiber with bleached cotton/cotton comber noil and producing pre-needled webs which were subsequently hydroentangled reduced fiber bundle size and generally improved basis weight uniformity in the webs. This leads us to conclude that at least part of the improvement in web uniformity we observed from hydroentangled fiber blends must have resulted because the formation of tight, cohesive fiber bundles was reduced.

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