Effect of web formation on properties of hydroentangled nonwoven fabrics

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Abstract

The aim of this study was to determine the effects of two popular web-forming technologies, viz., the Rando air-laid technology and the traditional carding and cross-laying technology, on properties of the hydroentangled nonwoven fabrics made therewith. A mill-like fiber processing study was conducted in a commercial-grade pilot plant using a variety of short staple fibers and their blends. The fibers used in the study were greige cotton, bleached cotton, cotton derivatives, and cut-staple polyester. The hydroentangled fabrics produced with the two systems were mainly evaluated for their physical and mechanical properties, absorbency, absorbency capacity, and whiteness. The study has shown that, with the exception of greige cotton linters, the greige cotton lint, greige cotton gin motes, and even greige cotton comber noils, either alone or in blend with the other fibers mentioned, can be mechanically processed into hydroentangled nonwoven fabric structures without any insurmountable difficulties. The drop test and sink time followed each other pretty closely, as the drop test time increased so did the sink times. The “whiteness” of fabric, which is significantly more dependent on the fabric’s constituent fiber content than on the fabric’s surface-based light reflection, obviously varied considerably. However, the whiteness index within the same fiber types and their blends shows no trend of significant difference between the fabric produced with carded fiber web and the fabric produced with random Rando fiber web. Incidentally, the Rando sample of bleached cotton was not available. Since the nonwoven fabrics of this discussion generally are disposable, the optional use of ‘brighteners’ to improve whiteness of certain whiteness-deficient fabrics may be considered as long as the brighteners do not easily bleed from the fabrics.

Key words: Cotton fiber, Polyester fiber, Mechanical web-forming systems, Carding system, Rando system

1. Introduction

Textile staple fibers can be “bonded” in several ways to produce an integrated fabric structure. In traditional textile manufacturing, the fibers are generally bonded by mechanically twisting them together to form a continuous, endless strand of yarn, which, in turn, is used to make woven and knitted fabrics. In the manufacturing of staple-based
nonwoven fabrics (where the fibrous webs are directly converted into fabrics without the yarn spinning), the fibers may be bonded in several different ways, such as by using chemical energy (via. resins and other chemicals), thermal energy (via. adhesives, low-melt fibers, ultrasonic’s, calendaring, microwaves, laser, etc.), and/or mechanical energy (via. needlepunching and/or hydroentangling systems). However, in each of the above different ways of bonding staple fibers into a nonwoven fabric structure, a reasonably manageable fibrous web or batt of certain density and integrity is required and hence must be produced. Although there are quite a few methods or technologies available to form a web of staple fibers, the most predominantly used systems and their diverse sub-avenues today are based on carding and air-laid technologies (Smith, 2008).

In the carding system, a fibrous batt or web is produced using a carding machine. A card basically opens up the randomly tufted feed-stock fibers, uni-directionally individualizes and parallelizes them in the machine direction by means of a combing action of densely-wired card clothing, and finally delivers the carded fibers in a continuous (endless) web of light weight, for example, 10 to 15 g/m². This fibrous web then may either be assembled with other similar webs produced from several other cards in series or be lapped/folded on a crosslapping machine to form a web of desired weight density for the downstream needlepunching and/or hydroentanglement system for fabric formation. A “cotton card” typically has revolving flats that are densely clothed with a wire similar to that of the main cylinder and set very close to the cylinder wire clothing. The flats traveling at a much slower linear speed of around only ~ 13 cm per minute (~5 inches per minute) against the main cylinder’s surface speed of about 2,000 m (78K inches) per minute (at the cylinder speed of 500 + RPM) achieve good “combing” of the fibers, while simultaneously removing any fine non-lint trash and any very short fibers still present in the feed material (Gordon and Hsieh, 2007; Condon, 2010). A “nonwovens card,” on the other hand, generally does not have the revolving flats, since it is normally used to mainly process clean and uniform manufactured fibers, such as polyester, polypropylene, rayon and others like this. Instead it has either a set of rollers or a set of fixed metallic plates, or a combination of rollers and plates, which are set in close proximity to the main cylinder wire clothing (Allen, 1990) Figure 1 shows a view of a typical web made on the roller-top, nonwovens card. The fibers in the web are well individualized, although they, unlike in a typical cotton card web, are not uni-directionally oriented and parallel to each other, because the nonwovens card used in this study also had a pair of “randomizing rollers” to randomize the fiber orientation before the web exit at the end of the card (Fleissner, 2009). Nonwovens cards generally have a pair of randomizing rolls to randomize fiber orientation to achieve more uniform tensile and related properties in both the machine and cross directions of the end product (fabric).

Figure 2 shows a typical web made on the air-laid system. As seen, the fibers are very much randomized, compared to those of the carded web. In an air-laid system of preparing a fibrous web,
the feed stock, after a thorough opening of its fibrous tufts, is pneumatically transported and piled into layers of fibers and ultimately formed into a desired-weight web of randomized fiber orientation. Such a web may be desirable, if not ideal, for producing a nonwoven fabric, but it may not be desirable in the traditional textile processing, viz., yarn spinning and weaving. For the traditional textile processes and products, it is generally required, if not imperative, to spin a yarn that has well oriented fibers in the machine direction, in order to attain maximum yarn/fabric strength in the machine direction, while also attaining the desired uniformity and luster of the end product (such as, a sewing thread, a knitted fabric, or a woven fabric) (Sawhney et al., 2007). In case of the nonwoven fabrics, a randomized fiber orientation in the fibrous web attains the desired, more uniform properties of the fabric in both machine and cross directions, although the overall fabric strength (in any direction) and luster may not be the maximum attainable with well oriented (crystalline) fibers.

Since staple fibers, particularly the natural fibers such as cotton and its derivative byproducts, can vary considerably in staple length and other properties, it was interesting to investigate the effects of the two commonly adopted web-formation systems, described above, on the properties of the nonwoven fabrics made with different types of staple fibers and their blends. Commercial-grade equipment and mill-like procedures and conditions were used to process the fibers and standard test methods were chosen to test and evaluate the various materials involved in the study. This manuscript basically describes the properties of the fibers used, the metrics of the various processes involved, and the properties of the fabrics produced using the two different systems of web formation.

2. Materials and methods

A commercial bale of post-gin, pre-cleaned greige (raw) cotton lint was procured from wildwood gin in Mississippi. Quantities of bleached cotton lint, greige cotton gin motes and linters and greige cotton comber noils were obtained from the available sources. Dacron T 54 polyester, 1.5-inch staple and 1.5-denier fine was obtained from DAK (made in USA).

The proper amount of each fiber was separately weighed and initially hand blended for preparing specific blends for the study. These hand-blended fibers of each blend were processed through a stand-alone volumetric hopper to produce a rather more uniform, intimately homogeneous fiber mix or blended for further processing to form carded as well as rando webs, using the prevalent carding and Rando fiber preparatory systems and conditions, respectively.

2.1. Formation of carded webs

In this system, the various fibers and fiber blends were separately fed into a meter-wide Rando fiber opener, which further opened and blended the fibers. The output from the opener flows into a chute feed system that, in turn, feeds its output material in a mat form to a 20-inch wide Befama roller-top card equipped with two fiber randomizing rolls at the exit. The carded web thus produced feeds to a 20-inch wide befama crosslapper and is continuously lightly needled on a 20-inch wide automax needlepunch machine, using a foster needle No. 15 18 32 3.5 RB F20 9-6NK and inserting 17 punches per m². The needlepunched output substrate, exiting from the machine, was rolled in a continuous sheet of paper and taken to a remote hydroentanglement system for producing a nonwoven fabric structure. It may be mentioned here that the crosslapper was intentionally set to its lowest setting for the least number of laps, in order to meet the desired low basis-weight of the various materials. Therefore, when the fiber properties (viz., density, length, etc.) of the various materials changed, the resulting web densities also changed.

2.2. Formation of rando webs

In this system, the various fibers and fiber blends were separately fed into a meter-wide Rando fiber opener to further open and blend the fibers. The opened fibers from the opener were directly fed into a 12-inch wide rando web former that formed an isotropic randomized web. The rando web was rolled in paper for the downstream hydroentangling system referred earlier. Again, it may be noted that the rando web former also was set at its lowest web-weight formation and, as such, the web weights attained from the various fibers and fiber blends varied to an extent, depending on the properties of the fibers involved.

2.3. Hydroentanglement of webs into nonwoven fabric structures

The various fibrous webs described above were uniformly hydroentangled using a fleissner minijet system, Figure 3, equipped with one low water pressure jet head for wetting out the feed material...
and two high water pressure jet heads—the first one impacts the substrate material on its top face and the other on its bottom face (Fleissner, 2009). For all fabrics, the low water pressure head was set to inject the water at 50 bar and the two high water pressure heads were set at 125 bar. The fabric production speed was 5 meters per minute. The hydro-impacted/entangled material/fabric was dried using a meter-wide, gas-fired fleissner through-air drum dryer and finally wound on to a tube to form a compact roll of at least 50 meters of the fabric. Incidentally, the hydroentangling line was flushed and cleaned after each fabric production trial.

2.4. Fabric absorbency measurements

The AATCC drop test measures the time it takes for one drop of water applied to a fabric held in an embroidery hoop to be absorbed (when the sheen disappears). The ATSM method uses a sample of fabric that 76 mm wide and cut to a length that equals $5.0 \pm 0.1$ grams. The sample is rolled in to a cylinder shape, upon itself and placed in a basket of standardized weight and size. The basket is dropped from a height of 25 mm into a water bath and the time it takes the sample and basket to sink is measured (Sink Time). After sinking the sample is then allowed to remain submerged in the water for 10 seconds. The basket is removed and allowed to drain 10 seconds and the sample is weighed. The weight of the water is reported as the absorptive capacity (grams of water held by one gram of fabric).

2.5. Test methods

The test methods used to obtain the reported results were (ASTM Standards, 2008):

1. ASTM D 6,242- Mass per Unit Area (Weight) of Nonwoven Textile Fabrics
2. ATSM D 5,035- Breaking Force and Elongation of Textile Fabrics (Strip Method)
3. AATCC 110- Whiteness of Textiles
4. AATCC 79- Absorbency of Textiles (Drop Test)
5. ASTM D 1,117 Section 5- Absorbency Time and Absorptive Capacity Nonwovens

3. Results and discussion

Table 1 shows the measured properties of the various fibers involved in the study. As seen and as expected, all the fibers vary considerably in all the tested metrics. However, since all of the fibers, with the exception of linters as stated previously, processed reasonably satisfactorily without encountering any serious problem, it may be documented that greige cotton lint, greige gin motes, and greige comber noils, either alone or in blend with other fibers, can be mechanically processed into hydroentangled nonwoven fabric structures without any insurmountable difficulties. Now, from the end-use application standpoint, one could logically argue that the neps, visible foreign matter, and/or trash content of especially the gin motes and comber noils could be perceived a consumer concern. Well, let us make this concern a bit consoling by stating that even the (costly) bleached cotton (which is partly, but most often, used in the existing nonwoven products such as wipes) may actually have even more neps and perhaps even more foreign particles than the greige cotton lint and/or its various derivatives.
investigated in this study. The only difference is that the bleaching process of cotton also bleaches greige cotton’s foreign contaminants white, as well. Since the existing wipes and other similar disposable products are invariably white in appearance, this whiteness-induced perception of consumer somehow hides the referenced contaminants and thus befools the consumer by way of her/his inability to recognize the underlying said concern. As far as the main functional performance, i.e., the absorbency characteristics, of these products is concerned, we shall later see that some hydroentangled nonwoven fabrics, which are optimally made with greige cotton and/or its blends with the greige cotton derivatives (gin mote and comber noils) and polyester, could be nearly comparable with the equivalent fabrics made with bleached cotton.

Tables 2 and 3 below show the properties of the hydroentangled fabrics made with the different fibers and fiber blends, using the carded and cross-laid systems of web formations, respectively. As seen, the air-laid webs, when compared to carded webs, consistently have a considerably higher tensile strength in the machine direction, but there doesn’t seem to be much of a difference in the cross direction. This is expected since the card web was crosslapped (multi-folded), which redirected the fiber orientation from the machine direction (MD) to the cross direction (CD). If the card web was not crosslapped, the MD strength would have been much higher and the CD strength obviously would have been much lower of an equivalent basis-weight web. And even a greater difference between the two strengths, e.g., MD and CD, would have been observed had the randomizing rolls on the card were not present.

The standard deviation of the MD and CD tensile strengths appear to be higher when using 100% natural fiber (viz., 100% cotton, comber noils, and gin motes) than when fibers are blended and carded. Also, the standard deviation in the CD is significantly higher than that observed in the MD of carded samples. The standard deviation in the MD and CD tensile strengths of the air-laid samples are lower and there is less of a difference between the CD and MD values. This likely has to do with the fact that the air-laid web is more random than the carded web. Increasing the blending amount of cotton fiber with polyester does not appear to have a significant effect on the strength of the final nonwoven fabrics made with either web forming system. For instance, 60/40 and 40/60 cotton/polyester blends have similar strengths. However, the absorbency difference with respect to the sink time (140 v/s 240 in favor of cotton-rich blend) between the two blends, as seen from the Table 4, is significant.

Table 4 shows the absorbency attributes of the various fabrics made from the two different types of fibrous webs. As expected, the addition of synthetics increase sink times of the fabric in the case of both carded and Rando web forming systems. The drop test and sink time followed each other pretty closely, as the drop test time increased so did the sink times. However, there are a few cases where this trend was not rigidly followed and that possibly could be due to any non-uniformity in the fabric. Another observation from the data in Table III is that the sink time (whether fast or slow) does not seem to affect the capacity. In other words, once the fabrics took on the water they held it about the same capacity. However, there is one anomaly where the Rando 40% UC and 60% PES did not sink at all.

Looking at the absorbency data for the same fiber blends, the drop test and the capacity were very similar for both the card and Rando webs. However, looking at the sink time, the fabrics produced from
the Rando webs were significantly lower (fast) in all fiber types and blends, except the 100% GM blend. This observation and finding indeed could be a significant factor and useful in a real world scenario, where the end-use products require fast absorbency times (sink-time).

Table 5 shows the whiteness of the fabrics made with the several different fibers and fiber blends. As seen and as expected, the whiteness of fabrics, depending on their fiber content, varies considerably. The 100% greige cotton lint fabric’s whiteness index of ~35; however polyester fiber, well known for its optical whiteness, considerably improves whiteness of the fabric when blended with greige cotton. In fact, the 40% greige cotton 60% polyester blend exhibited a whiteness index~73—approaching the whiteness of the bleached cotton fabric (included only for the carded web and as a benchmark, since a Rando sample of bleached cotton was not available). For other blends, where the whiteness may need to be improved, the use of optional, relatively much less expensive optical brighteners may be considered, since the nonwoven fabrics of this discussion...
generally are disposable, anyway. So, as long as the brighteners do not easily bleed from the fabrics, they may be considered as a viable option to improve whiteness of whiteness-deficient fabrics. The data in Table 5 also show that the whiteness index, within the same fiber types and blends, shows no trend of significant difference between the fabric produced with carded fiber web and the fabric produced with random Rando fiber web. However, since the whiteness index basically is measured by reflectance of light from the fabric surface and since the fabric surface/texture of hydroentangled fabrics is influenced by the impacting water jets and the forming belt of the hydroentanglement system, it is possible that the likely differences in the surface geometry of the two different web configurations have some influence on the final texture of the fabrics made thereof. And that may be a possible explanation for some insignificant differences observed in the

Table 3.
Mechanical properties of the various hydroentangled nonwoven fabrics made with the air-laid webs

<table>
<thead>
<tr>
<th>Fabric ID and fiber content</th>
<th>Weight g/m²</th>
<th>Tensile MD N/1&quot;</th>
<th>Elongation MD %</th>
<th>Tensile CD N/1&quot;</th>
<th>Elongation CD %</th>
<th>Normalizing Factor</th>
<th>Tensile MD N/1&quot;</th>
<th>Tensile CD N/1&quot;</th>
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<tr>
<td>Fabric ID and fiber content</td>
<td>79.0</td>
<td>154.56</td>
<td>41.87</td>
<td>110.66</td>
<td>48.87</td>
<td>0.89</td>
<td>136.87</td>
<td>98.00</td>
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<td>100% UltraClean Cotton</td>
<td>std. dev.</td>
<td>4.01</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>100% Gin Motes</td>
<td>54.3</td>
<td>69.63</td>
<td>32.13</td>
<td>46.35</td>
<td>56.20</td>
<td>1.29</td>
<td>89.72</td>
<td>59.72</td>
</tr>
<tr>
<td>std. dev.</td>
<td>10.37</td>
<td>1.52</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>100% Comber Noils</td>
<td>74.9</td>
<td>107.49</td>
<td>29.13</td>
<td>101.16</td>
<td>46.74</td>
<td>0.93</td>
<td>100.43</td>
<td>94.51</td>
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<tr>
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<td>4.06</td>
<td>3.30</td>
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<tr>
<td>100% Polyester</td>
<td>103.9</td>
<td>266.76</td>
<td>54.20</td>
<td>198.87</td>
<td>73.40</td>
<td>0.67</td>
<td>179.77</td>
<td>134.02</td>
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<td>40% UltraClean 60% Comber Noils</td>
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<td>15.73</td>
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<td>3.55</td>
<td>2.85</td>
<td></td>
<td></td>
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<tr>
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<td>85.6</td>
<td>128.46</td>
<td>33.27</td>
<td>103.20</td>
<td>53.33</td>
<td>0.82</td>
<td>105.03</td>
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<td>40% UltraClean 60% Polyester</td>
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<td>10.15</td>
<td>0.97</td>
<td>8.19</td>
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<td>60.9</td>
<td>116.13</td>
<td>34.73</td>
<td>68.78</td>
<td>49.53</td>
<td>1.15</td>
<td>133.39</td>
<td>79.00</td>
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<td>94.82</td>
<td>30.47</td>
<td>70.80</td>
<td>49.33</td>
<td>1.08</td>
<td>102.10</td>
<td>76.23</td>
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<td>141.11</td>
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<td>74.13</td>
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<td>16.73</td>
<td>4.04</td>
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<tr>
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<td>55.5</td>
<td>136.39</td>
<td>44.87</td>
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Fiber Codes:
UC = UltraClean, GM = Pre-Cleaned Gin Motes, CB = Comber Noils, PES = Polyester Staple, BC = Bleached Cotton.
whiteness index of the fabrics made with the same
types of fibers and fiber blends using the two
different methods of web preparation. At any rate,
the fabrics of same fiber content, whether produced
from carded or Rando webs appear to be similar in
whiteness when viewed by the naked eye.
4. Conclusions

A fiber processing study conducted to determine the effect of web formation on performance of the hydroentangled nonwoven fabric made thereof has shown that, with the exception of greige cotton linters, the greige cotton lint, greige cotton gin motes, and greige cotton comber noils, either alone or in blend with other fibers, can be mechanically processed into hydroentangled nonwoven fabric structures without any insurmountable difficulties. Further, the air-laid webs, when compared to the carded webs, consistently have a significantly higher tensile strength in the machine direction (MD), but there doesn’t seem to be much of a difference in the cross direction (CD). The standard deviation of the MD and CD tensile strengths appear to be higher when using 100% natural fiber (viz., 100% cotton, comber noils, and gin motes) than when fibers are blended and carded. Also, the standard deviation in the CD is significantly higher than that observed in the MD of carded samples. The standard deviation in the MD and CD tensile strengths of the air-laid samples are lower and there is less of a difference between the CD and MD values.

Regarding the fabric absorbency, the drop test and the capacity were very similar for both the card and Rando webs. However, the addition of synthetic fibers increase sink times of the fabric in the case of both carded and Rando web forming systems. The drop test and sink time followed each other pretty closely, as the drop test time increased so did the sink times. However, there are a few cases where this trend was not rigidly followed and that possibly could be due to any non-uniformity in the fabric. Also, the sink time (whether fast or slow) does not seem to affect the capacity. In other words, once the fabrics took on the water they generally held it at about the same capacity.

The fabrics produced from the Rando webs were considerably lower (fast) in all fiber types and blends, except the 100% gin motes blend. This unique finding indeed could be a significant factor and useful in a real world scenario, where the end-use products require fast absorbency times (sink time).

The whiteness of fabrics, depending on their constituent fiber content, varies considerably. However, the whiteness index, within the same fiber types and blends, shows no trend of significant difference between the fabric produced with carded fiber web and the fabric produced with random Rando fiber web. The whiteness index of the 100% greige cotton lint fabric in either case was ~35. However the polyester fiber, well known for its optical whiteness, when blended with greige cotton considerably improves whiteness of the resulting blend fabric. In fact, the 40% greige cotton and 60% polyester blend exhibited a whiteness index of 73 which almost approaches the whiteness of the bleached cotton fabric made only with the carded web (since the Rando sample of bleached cotton was not available). For other blends, where the whiteness, especially when viewed by the naked eye, may need to be improved, the use of optional, relatively much less expensive optical brighteners may be considered. Since the nonwoven fabrics of this discussion generally are disposable, the brighteners, as long as they do not easily bleed from the fabrics, may indeed be considered as a viable option to improve whiteness of certain whiteness-deficient fabrics.

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