SUPERIOR NONWOVENS MADE FROM NATURALLY COLORED COTTONS

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Abstract

Naturally colored brown cotton offers several advantages over common white cotton for use in needlepunched nonwoven blankets. Whereas the use of naturally pigmented cotton fibers has been restricted in conventional textiles because the fibers tend to be short and weak, they are well suited for nonwovens. This study evaluates fabrics made from colored cottons and different low-melt polymer additives in fifteen-percent blends by weight. Fiber and fabric properties including weight, thickness, strength, stiffness, air permeability, thermal properties, and flammability are reported for a range of heat treatment conditions. The properties of nonwovens made from colored cotton, and particularly brown cotton, are greatly improved with suitable fusible fibers and treatments. In general, the Hoechst Celanese bicomponent Celbond® 254 and 255 improve the needled nonwoven properties, while the amorphous Foss Fibre 410 does not. The low-melt Foss fiber deteriorates blanket performance as utilized by reducing nonwoven weight, decreasing strength, and increasing permeability. Both of the Hoechst Celanese products enhance nonwoven fabric properties by improving strength, launderability, and abrasion resistance. The green cottons produce the softest blankets that best retain their flexibility and hand after treatment. The brown cottons derive greater benefit from the additives. These nonwovens also prove to be better insulators and to burn more slowly than the green or white cottons. The fabrics containing Hoechst Celanese Celbond® 254 fiber are deemed superior for their combined strength, durability, softness, and flexibility in consumer blankets. The use of the Hoechst Celanese 255 fiber would be superior for applications requiring greater strength and stiffness. It is concluded that soft and attractive needlepunched nonwoven fabrics can be produced readily from short, weak, naturally colored brown and green cottons. Certain pigmented cottons offer several ecological and functional advantages when suitably used in nonwoven materials.

Introduction

Naturally colored cotton by definition refers to cotton cultivars that produce fiber in any shade other than white. Whereas most cotton cultivated today yields white fiber that is chemically dyed for consumer use, colored cotton is more ecological and does not require dyeing. Its lint is pigmented by nature, typically in a range of earthy shades of green and brown [14, 15, 16]. Many varieties of several species have been known to have existed for thousands of years, and several are currently grown in limited quantities domestically and internationally [8, 17]. In general, the fibers of colored *Gossipium hirsutum* varieties tend to be shorter, weaker, and finer than typical white cottons. While these properties tend to restrict the use of pigmented cotton in common textiles they can be desirable for nonwovens. A prior study produced superior needlepunched nonwovens from brown cotton by the inclusion of scrim reinforcement [6]. This study explores the alternative use of low-melt polymers with appropriate heat treatment to improve the strength and performance characteristics of the resultant materials.

Materials and Methods

The white Maxxa and naturally colored brown and green cottons were California grown (Table I). Fiber properties were tested per ASTM methods D5867 (HVI), ASTM D1445 (Stelometer) and ASTM D1448 (Micronaire) as reported in Table I. Three fusible synthetic fibers, all of 1.5-inch staple length were utilized; one was supplied by Foss Fibre (Hampton, NH) and Hoechst Celanese (Charlotte, NC) supplied the others (Table II). The fibers were opened separately and intimately blended in a SpinLab opener/blender (Knoxville, TN) in 85% cotton and 15% fusible fiber proportions. The lots were carded on a Hollingsworth card (Greenville, SC) that had been modified to deliver batt instead of sliver.

Needlepunched fabrics were formed from two layers of fibrous card batt on a Morrison Beckshire needlepunch machine (North Adams, MA) by the penetration of barbed needles. The fabrics were needled four times at 5.9 ft./min using Groz-Beckert (Charlotte, NC) style F222-G92919 needles at 257 cycles/min or 29 penetrations per square inch. A total of twelve nonwoven materials were produced, representing three cottons, three additives and a set of three cotton controls without fusible fiber. Each was subjected to six different heat conditions by traversing through an Ernst Benz (Ròmlang-Zurick, Switerland) throughput oven as follows: 1) unheated, 2) 130ºC for 2.5 min., 3) 160ºC for 1.5 min., 4) 160ºC for 2.5 min., 5) 160ºC for 5.0 min., and 6) 190ºC for 0.5 min. Thermal parameters were selected based on a combination of supplier information and processing trials.

Fabric testing was performed per ASTM methods D3776 for weight, D1777 for thickness, D3787 for bursting strength, D5035 for breaking strength and elongation, and D737 for air permeability. Additional data was obtained using Federal Method 5202 for stiffness, and thermal and horizontal flame testing as described. Thermal testing was performed using static methods in accordance with ASTM D1518. Simultaneous measurements of the temperature gradient and heat flux were made on a FOX 200 thermal conductivity meter from the LaserComp Corporation (Wakefield, MA). Conditioned specimens were tested between "cold" (21.0°C or 69.9°F) and "hot" (36.6°C or 97.9°F) plates. The instrument provides for high control, accuracy, and automatic monitoring of equilibrium conditions. The reported thermal properties represent the mean of two samples subjected to three measurements each.

The horizontal burning test used at the Southern Regional Research Center (SRRC) derives from elements of the Federal Aviation Administration (FAA) Horizontal Flammability Test, Part 25, appendix F, Part I (b) (5), Federal Motor Vehicle Safety Standard (FMVSS 302), and Federal Test Methods 191and 5900 (12-31-68). The method measures the burning rate of a material subjected to a 1.5-inch vertical, natural gas flame while the material is held in a horizontal position. The samples are preheated for 4 hours at 60°C and immediately placed in a test chamber of the same temperature. This eliminates the effect of moisture variation on the burning properties of the specimens. Sample size is within a framed area of 2 x 13 inches. The flame is placed at the edge of one end of the specimen for 12 seconds. The time required for the flame to traverse between two lines marked 10.5 inches apart is measured. The method has proven capable of distinguishing burning differences of modified and unmodified materials.

Results and Discussion

It should be noted that there are many varieties of naturally pigmented cotton and the properties reported herein should not be construed to be representative of all cottons of similar color. In fact, the measurement of colored lint presents difficulties using instruments designed and calibrated for white cotton. The short fiber length of some cultivars precludes or confounds testing. The unique geometry and/or waxiness of others may influence measurements of strength, elongation and fineness. The

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micronaire of the brown cotton is slightly higher than that of the white cotton, whereas it is considerably lower for the green cotton, suggesting the latter is very fine. However, it has not yet been established how these readings relate to the maturity of pigmented cottons. All specimens were observed and photographed by scanning electron microscopy. Photomicrographs reveal some degree of apparent fiber immaturity as evidenced by flat ribbon-like fibers in the brown and particularly in the green cottons (Figures 1 and 2). The strength measurements suggest that the brown cotton is very weak and the green cotton is strong by the standards of domestic white cotton. However, the green fibers were found to be weak as well. Its high tenacity is due to the collective strength of its more numerous very fine fibers in the bundle or beard of fibers that is broken.

All cottons were combined with fifteen-percent fusible fiber of the same circular cross section and length to produce the experimental set of blended specimens. The number of synthetic fibers in the different blends varies because the additives differ in denier and chemical composition. There are fewest of the highest linear density Foss fibers observed in the blends. Needlepunching the intimately blended batts involves displacing fibers from the surface to the interior of the structure, thereby creating a matrix of mechanically entangled fibers and simultaneously increasing the packing density of the fabric. Such fabrics are typically weak and lack dimensional stability. Magnified views of the unheated specimens show the different synthetic fibers, which can be discerned from the cotton fibers by their regularity (Figures 3 to 5). The difference in the fiber diameters is evident. All of the nonwoven fabrics are soft and pliable before heating. The unique properties of the green cotton contribute to its inordinately soft hand.

The low-melt additives soften and melt upon heating, fusing to each other and adjacent cellulosic fibers in a variety of ways (Figures 6 to 8). The Foss fiber dissipates, contracting into sizeable agglomerates of adhesive at distant locations. The Hoechst Celanese fibers are bicomponent materials containing two polymers, a common polyester core and a sheath that melts at a lower temperature, to leave the core intact within the fibrous matrix. The sheath of fiber 254 melts with sufficient heat to form localized bonds where the synthetic fibers contact each other. These spot point adhesions maintain a high degree of relative motion between the fibers, and enhance fabric strength and serviceability while retaining softness and flexibility. By contrast, the sheath of fiber 255 melts to produce more pervasive areas of adhesion between synthetic and cellulosic fibers, forming a weblike structure, and imparting greater strength, less elongation, and considerably greater stiffness in the nonwovens.

The needled nonwovens were subjected to a series of six thermal treatment conditions of varied time and temperature to determine the optimal heating conditions to melt the fusible fibers as processed. Selected test results are depicted in Figures 9 to 11. Thermal treatment #3 (160°C for 1.5 min) was deemed the most effective for the Hoechst Celanese 254 fiber, and treatment #4 (160°C for 2.5 min) worked best for the Hoechst Celanese 255 fiber. The Foss fiber required higher temperatures and was subsequently treated at 190°C for 60 seconds. However, this material produced more variable results and generally deteriorated nonwoven properties as employed herein. The Hoechst Celanese fibers successfully improved nonwoven performance. Whereas the non-reinforced nonwovens could not withstand home laundering, the brown cottons containing the Hoechst Celanese fibers survived 10 wash cycles without incident. The green fabrics were less durable than the brown as determined by laundering and abrasion tests.

Further properties are reported for the thermal conditions deemed optimal for each additive. There was some deviation in nonwoven fabric weight and thickness. Whereas the white and brown nonwovens were nominally 7 oz/sq yd, the green nonwovens were thinner and lighter (Figure 12). This is because the green batts tend to spread and flatten more during needling, a consequence of their unique geometric and frictional properties. Other researchers have reported on the high wax content of green cotton that is presumed to contribute to this phenomenon [10]. Since colored fibers are shorter and weaker than the white fibers, it is no surprise that the colored fabrics are weaker than the white fabrics are (Figure 13). More benefit is derived from the fusibles for the brown cotton than the other cottons. Both bicomponent fibers enhance the strength of the brown nonwovens, whereas fiber 255 provides superior adhesion for the green. All additives cause an increase in fabric stiffness (Figure 14). However, the 255 fiber produces a dramatic change in the brown nonwovens, which become too stiff for applications that require some flexibility. The changes in this property are more subdued for the green cotton, which consistently retains its appealing softness and flexibility. The air permeability of the additive reinforced brown and white specimens is higher than the controls. There is a slight decrease in the permeability of the green nonwovens containing the Hoechst Celanese fibers.

A comparison of the thermal conductivity of the two cottons shows that the brown cotton has lower thermal conductivity than the white cotton, and provides better thermal insulation as a result (Table III). The green cotton exhibits superior insulation properties, but has higher heat transmittance than the white or brown cottons. However, these figures do not take into account the differences in fabric weight. The horizontal flammability tests showed that the brown fabrics burn more slowly than the white fabrics, but the green fabrics burn much faster than the others. The flame retardancy of all specimens could be improved further with topical finishes if desired. The flammability data report on an initial set of burn trials and should not be considered conclusive. Additional trials with a variety of other colored cultivars are planned, including those reported to have superior flame resistance [12, 13].

The ASTM standard performance specification D5432-93 outlines the performance requirements of blanket products for institutional and household use. All of the specimens were deemed acceptable for thermal transmittance. Previous work established that the colored nonwovens achieved class I ratings by the 45-degree angle flammability test, which is the requirement of nonwoven materials for household use [6]. The ASTM specification D5432-93 outlines the performance requirements of blankets for this application. The samples were not tested for all of the specification requirements during this initial study.

Conclusions

In general, the Hoechst Celanese fibers improved the needled nonwoven properties, whereas the Foss fiber did not. Soft and attractive needlepunched nonwoven fabrics produced from short, weak, brown and green cottons are weaker than comparable nonwovens made from white cotton, but their properties were substantially improved with suitable fusible fibers and treatments. The green cottons produced the softest and most supple blankets but these were weaker and less serviceable than the brown. The brown cottons were the best insulators and burned considerably slower than the others. The Hoechst Celanese 254 fiber was deemed most suitable for consumer blankets for its combination of strength, durability, softness, and flexibility. Additional studies are planned to further explore the differences in the insulation properties and flammability of these and other naturally colored cultivars. The American Textile Manufacturers Institute (ATMI) recently defined items made from naturally colored cotton as environmentally improved textile products. Further work utilizing naturally colored cotton in nonwovens is recommended and encouraged.

Acknowledgments

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Table I. Cotton Fiber Properties.

	MAXXA	**BROWN**	**GREEN**
Color	White	Brown	Green
Length, HVI UHM (inches)	0.9	0.8	0.9
Length, AFIS UQL (inches)	1.2	0.8	1.0
Strength, HVI (grams/ tex)	30.6	20.1	27.1
Strength, Stelometer (grams/tex)	28.9	17.5	27.2
Elongation, HVI (percent)	10.6	12.4	12.1
Elongation, Stelometer (percent)	7.4	7.3	9.0
Micronaire, HVI	4.0	4.6	2.5
Micronaire, Fibronaire	4.0	4.3	2.7

Table II. Fusible Fiber Properties.

	# 410	**# 254**	**# 255**
Supplier	Foss Fibre	Hoechst Celanese	Hoechst Celanese
Structure	Homogeneous Amorphous	Bicomponent Polyester core	Bicomponent Polyester core
Polymer	Polyester	Polyester sheath	Polyolefin sheath
Denier	3.6	2.0	3.0

Table III. Thermal and Flammability Data.

Cotton	**Thickness (cm)**	**Coefficient of Thermal Conductivity (λ ,W/m°·C)**	**Heat Transmittance (W/m² °C)**	**Time of Burning (min)**
White	0.419	0.0361	8.65	2.08
Brown	0.457	0.0354	7.77	2.92
Green	0.353	0.0327	9.39	1.02

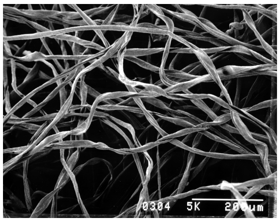

Figure 1. Brown, Unheated No additive, 150X.

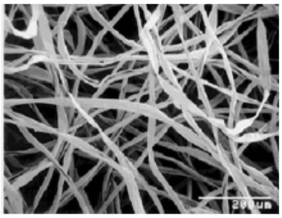

Figure 2. Green, Unheated No additive, 150X.

Figure 3. Brown, Unheated w/ Foss #410, 150X.

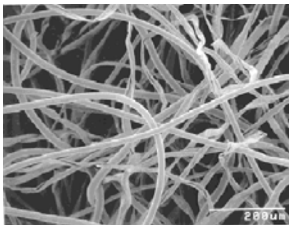

Figure 4. Brown, Unheated w/ HC #254, 150X.

Figure 5. Brown, Unheated w/ HC #255, 150X.

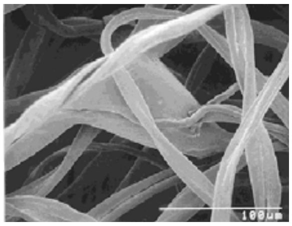

Figure 6. Maxxa, Heated w/ Foss #410, 500X.

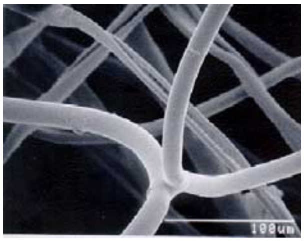

Figure 7. Maxxa, Heated w/ HC #254, 500X.

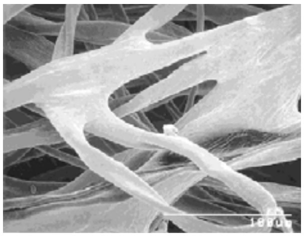

Figure 8. Maxxa, Heated w/ HC #255, 500X.

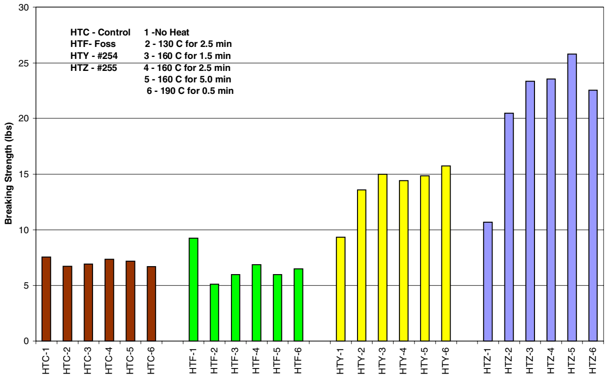

Figure 9. Heat Treatment Trials, Breaking Strength.

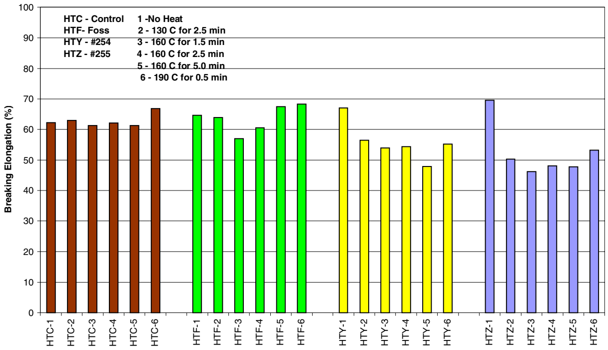

Figure 10. Heat Treatment Trials, Breaking Elongation.

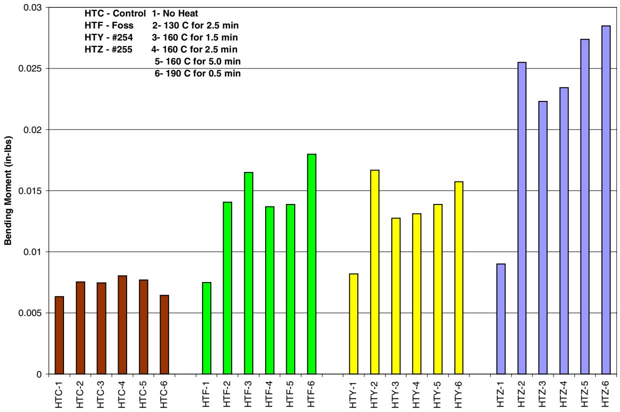

Figure 11. Heat Treatment Trials, Stiffness.

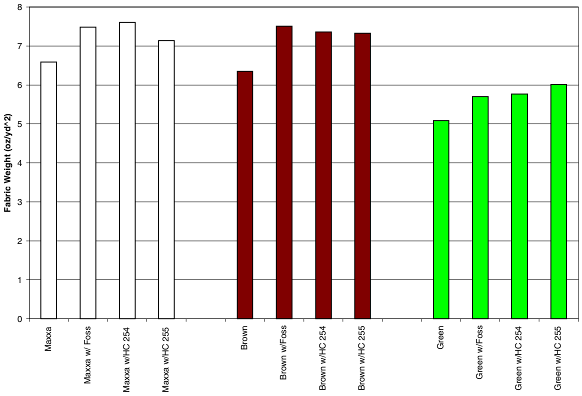

Figure 12. Nonwoven Fabric Weight.

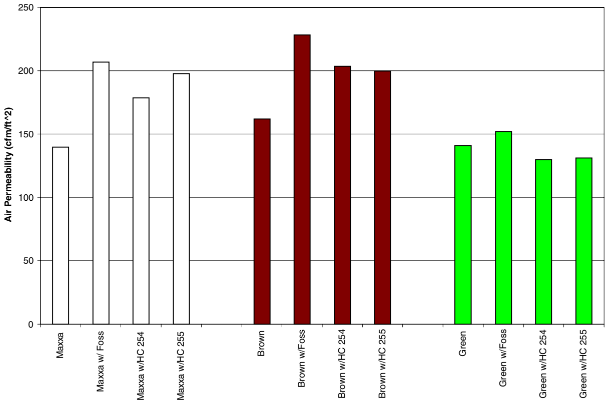

Figure 15. Nonwoven Air Permeability.

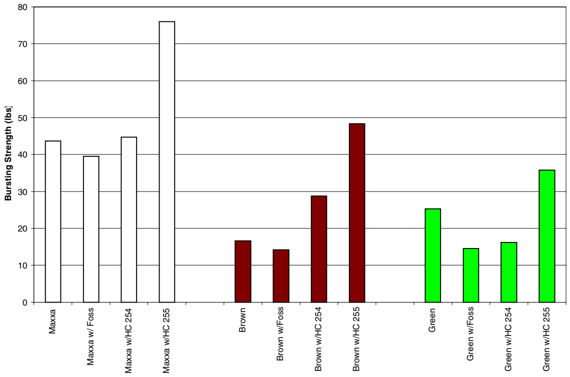

Figure 13. Nonwoven Bursting Strength.

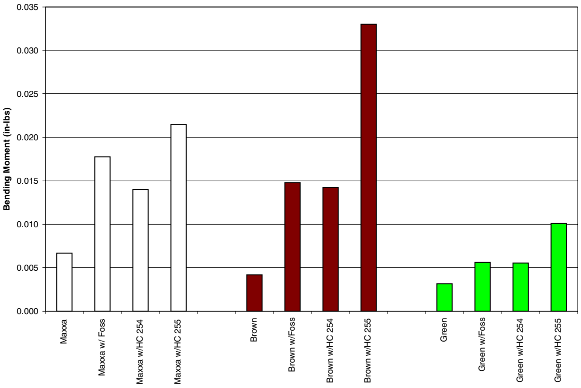

Figure 14. Nonwoven Stiffness.