NATURALLY COLORED BROWN COTTON FOR NEEDLEPUNCHED NONWOVEN FABRICS

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Abstract

Although naturally colored cotton is not new, it remains largely unknown. It is grown in small quantities in the United States and several other countries, but struggles to maintain a tiny market share among common white varieties. Its use in conventional textiles has been restricted to some degree because its fibers are generally short and weak. However, the brown naturally colored cotton fibers offer some distinct advantages for certain nonwoven consumer applications. The fibers are soft and attractive, do not require dyeing, and are inherently more flame resistant than white cotton. Needlepunched nonwoven fabrics are produced easily from a fairly short staple, naturally pigmented, brown cotton. This study compares needlepunched nonwovens made from white and brown colored cottons with and without scrim reinforcements. Fiber and fabric properties are reported, including tests for weight, thickness, strength, stiffness, air permeability, insulation properties and flammability. The pure brown cotton nonwovens are substantially weaker than pure white cotton nonwovens, but the strength and other performance properties are dramatically improved with suitable scrim reinforcement. The naturally pigmented fibers prove to be suitable for use in needlepunched nonwoven fabrics, and demonstrate particular promise for utilization in consumer blankets. Additional studies are planned to use other materials and methods to further enhance the strength and other functional properties of the resulting nonwoven products.

Introduction

Typical cotton produces white fiber that is usually chemically dyed for apparel and other end uses. Yet, there are many varieties of *naturally pigmented* cotton that have existed for thousands of years. Most such cultivars produce lint that ranges in color from shades of cream and tan, to tones of red and brown [13, 14, 15]. The oldest examples of pigmented cotton have been found along the Northern Peruvian coast, but colored cotton has been used since antiquity in parts of India and the former Soviet Union [7, 16]. The fibers have been used by hand spinners and weavers of Acadian (Cajun) communities in Louisiana since the 1700's [3]. Australia, France, Guatemala, Peru, Israel and the United States are among the countries that grow limited quantities of colored cotton today. The colored fibers offer several advantages for certain consumer and household uses, because they are soft and attractive, do not require dyeing, and are inherently more flame resistant [10, 11, 12, 17]. The primary limitation of naturally colored cotton is that the fibers are generally shorter and weaker than white cotton. This makes it somewhat more difficult to commercially process the fibers into woven or knitted fabrics, and results in larger quantities of fibrous waste. The higher cost of colored cotton may justify the use of exceedingly short colored fibers and those reclaimed from conventional textile processing. The objective of this study was to discern if naturally colored fiber could be used to produce viable nonwovens, a category of goods previously overlooked for the fibers.

Materials and Methods

The brown naturally colored cotton and white Maxxa cotton utilized in this study were both California grown. Their fiber properties were tested per ASTM D1447-94 (Fibrograph), D1445-95 (Stelometer), and D1448-97 (Micronaire) as shown in Table I. It should be mentioned that just as white cottons are diverse in their fiber properties, so are the many varieties of pigmented and specifically brown cottons. Some colored cottons have extremely short fiber length, so although the 0.86-inch staple length is very short for white cotton, it is not atypical of colored cotton. Breeders continue to work to improve their properties. The brown fiber used in this study represents a colored cotton with a fairly short staple length but with a micronaire suggestive of good fiber maturity. Both cottons were used to produce nonwoven fabrics with and without reinforcing scrim materials of two types.

The cottons were opened at low speed by a Spin Lab opener/blender (Knoxville, TN) and carded on a Hollingsworth card (Greenville, SC). This was a conventional card that was modified by the addition of a cylindrical drum to collect the fibers as a flat batt instead of sliver. Throughput speed was reduced to allow the filmy webs to maintain their structural integrity as they doffed. Two identical batts were made to produce each nonwoven fabric. These were layered with an intervening scrim layer for needling, as appropriate. Three variations of brown and white nonwovens were made, including those without scrim, those containing a nylon scrim, and those containing an aramid scrim (Tables II and III).

The amount of cotton used for each lot was calculated to fabricate fabrics weighing nominally 7 ounces per square yard. Two identical batts of appropriate weight were used with the identified scrim positioned between them, to produce a total of six nonwoven fabrics. Cerex Advanced Fabrics (Cantonment, FL) manufactured the nylon scrim. The aramid scrim was woven into gauze (23W x 15F) from flame-

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resistant Conex fiber (Teijin Ltd, Japan) by Tex Tech Industries (North Monmouth, ME). Each fibrous sandwich was needlepunched four times on a Morrison Beckshire needlepunch machine (North Adams, MA). Sequential passes were needled on alternating sides using a single bed of 575 Groz-Beckert (Charlotte, NC) style F222-G92919 needles (15 x 18 x 40 x 3.5 inches) at 257 cycles per minute and a linear speed of 5.9 feet per minute.

Fabric testing was performed per ASTM methods D3776-96 for mass or weight (estimated by use of two 1 x 1-inch squares of die-cut specimens), D1777-96 for thickness, D3787-89 for bursting strength, D5035-95 for breaking strength and elongation (strip), and D737-96 for air permeability (Frazier). Additional data was obtained using Federal Method 5202 for stiffness (Tinius Olsen), NFPA 702 for flammability (45 degrees), and additional flame and thermal testing as described. Procedural details are omitted for these common methods. All thermal conductivity and thermal transmittance tests were performed using static methods in accordance with ASTM D1518-90, using a new FOX 200 thermal conductivity meter from the LaserComp Corporation (Wakefield, MA).

Thermal conductivity refers to the time rate of unidirectional heat transfer per unit area, in the steady state, between parallel planes *separated by unit distance*, per unit difference of temperature. Thermal transmittance refers to the time rate of unidirectional heat transfer per unit area, in the steady state, between parallel planes, per unit difference of temperature. All specimens were conditioned to 20° C and 65% RH for 24 hours before measurement. The thickness of the samples was measured as referenced previously. The thermal conductivity and thermal transmittance values reported represent the mean of three samples, subjected to three measurements each.

The thermal properties of good insulative materials, such as the subject nonwovens, is based on the simultaneous measurement of the temperature gradient (ΔDT) across the sample and heat flux through the sample. Samples (8 x 8 inch) are placed between "cold" (T_{cp} = 21.0° C or 69.9° F) and "hot" (T_{hp} =36.6° C or 97.9° F) plates. The positions of the corners of these plates are controlled and monitored with high accuracy (± 0.025 mm) by a digital-thickness readout system. The actual heat flow through the sample is measured under equilibrium conditions by precision thin-film heat-flux transducers that are permanently bonded to the surfaces of the plates. The temperature of both plates can be specified to allow for heat flow in either direction. The instrument is equipped with a special digital signal processor that monitors the measured parameters continuously to ensure that readings are taken at true temperature equilibrium for great accuracy.

Flammability testing was initially performed using a 45-degree flammability tester using method NFPA 702. This standard has been officially discontinued but remains in use. The samples were dried in an oven and conditioned in a desiccator before testing. The ignition time was 5 seconds, and the time to burn 5 inches was recorded. Specimens that burned part way were designated as IBE (ignited but extinguished); specimens which did not ignite after 5 seconds were designated DNI (does not ignite). The classification is based on the average for 5 specimens. A horizontal burn test designed to simulate ignition by a lit cigarette was employed as well. This involved observing the burning behavior and outcome of combustion induced by a standard methenamine ignition source (pill), calibrated to burn for 80 seconds (Eli Lilly, Indianapolis, IN). The pill was placed in contact with the specimens while suspended between vertical supports. This method proved capable of distinguishing between the different samples more meaningfully, and was considered more applicable to consumer use and safety.

Results and Discussion

The nonwovens that include nylon or aramid scrims contain proportionally less cotton, since the experimental design was to produce fabrics of the same weight. The amount of cotton used for each lot was based on a series of processing trials. The quantity of fiber lost during carding was consistent with expectations, but the fibrous batts spread out to varying degrees during needling, causing some deviation from the target weights and associated thicknesses. The specimens containing the heavier aramid scrim began with the least cotton and lowest bulk batts. These samples also spread the most during needling, producing the thinnest and lightest weight nonwovens (Figure 1). The resulting fabrics ranged from about 6.5 to 7.5 oz/yd^2, but the comparative trends and associated benefits of the scrim reinforcements are evident, nonetheless.

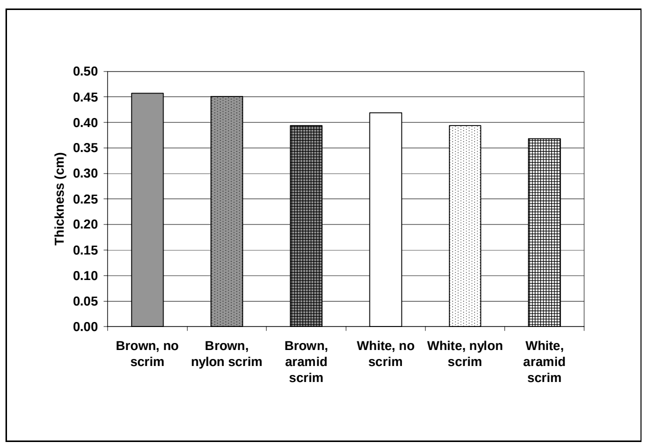

Figure 1. Fabric Thickness

All specimens were mounted on sample stubs for scanning electron microscopy, sputter coated, and photographed. The photomicrographs were examined to compare the constituent fibers and reinforcing scrims. Visual observations cannot be considered conclusive because the samples were not entirely homogeneous (Figures 2 and 3). However, representative images seem to reveal similar fiber geometry, with some degree of fiber immaturity evident in both cottons (Figures 4 and 5). The lower micronaire reading suggests that there may be more, finer fibers in the same mass of brown cotton. There was no discernable difference between the reinforced and non-reinforced fabrics as viewed from their top surfaces.

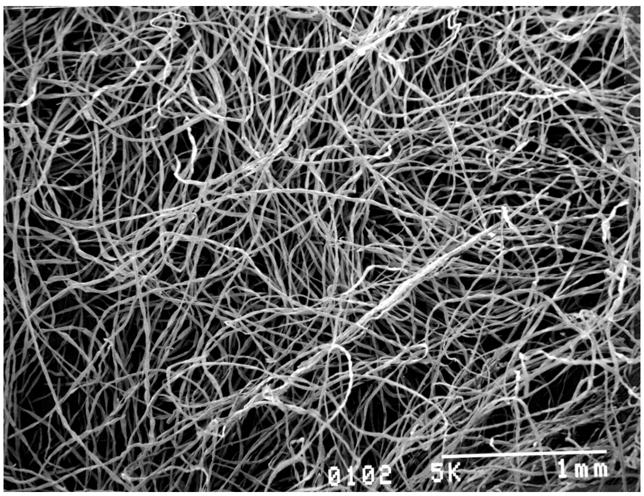

Figure 2. White cotton, no scrim, top view, 30x

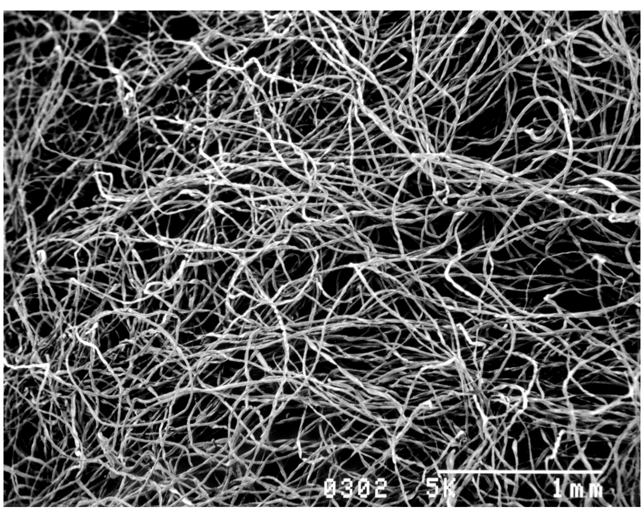

Figure 3. Brown cotton, no scrim, top view, 30x

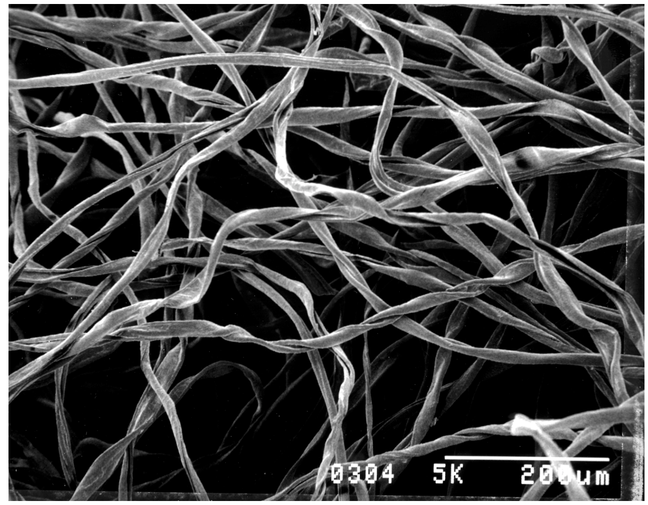

Figure 4. Brown cotton, no scrim, top view, 150x

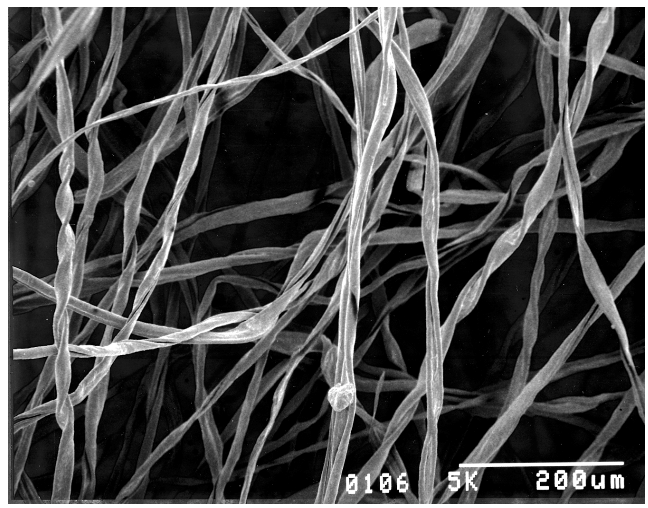

Figure 5. White cotton, no scrim, top view, 150x

The colored fibers were substantially shorter and weaker than the white fibers from the outset, so it was no surprise that the brown nonwoven fabrics were much weaker than those made from white cotton. However, the difference between the bursting strengths of the unreinforced nonwovens was slightly greater than the difference in fiber strength (Figure 6). The greater discrepancies in breaking strengths may possibly be attributed to the weaker colored cotton being more vulnerable to fiber damage than the white cotton (Figure 7). Sequential passes through a mechanical blender proved that more short fiber was generated in the brown than in the white fiber (data not shown). This treatment was meant to simulate the exceedingly short fiber that might be reclaimed from carding. It is likely that the brown cotton incurs more damage during needling as well. The presence of more shorter and finer brown fibers may contribute to the colored nonwovens being slightly stiffer and generally less permeable than their white counterparts (Figures 8 and 9).

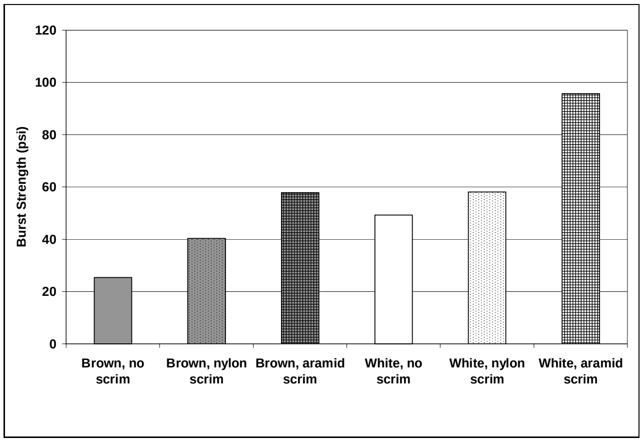

Figure 6. Bursting Strength

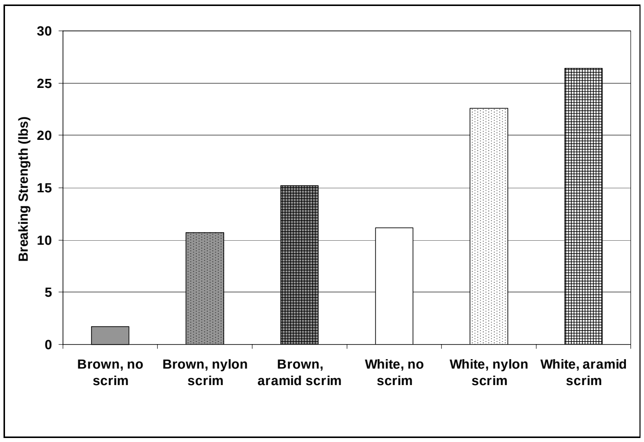

Figure 7. Breaking Strength

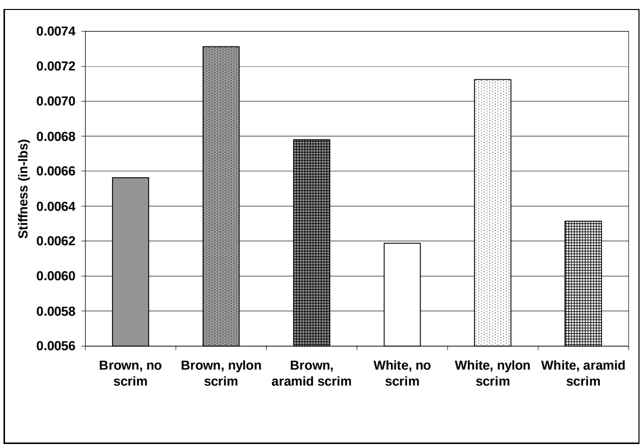

Figure 8. Stiffness

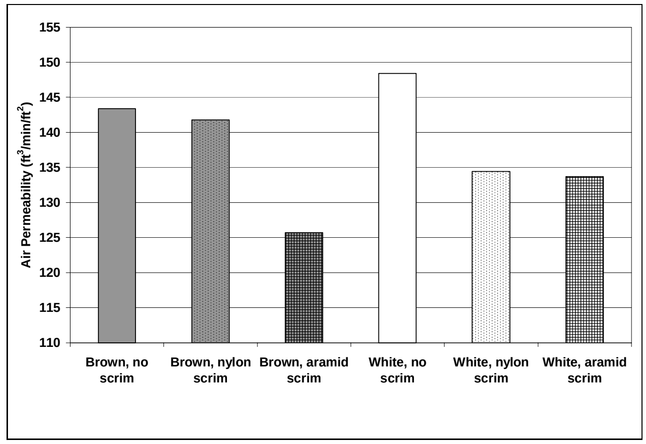

Figure 9. Air Permeability

The addition of the spun-bonded nylon reinforcement nearly compensates for the difference in strength between the brown and white cottons. The inclusion of this lightweight scrim increases the bursting strength of the white cotton nonwovens by only 18%, but improves the brown nonwovens by 59%. A bond point is visible in the nylon scrim in the cross section of the fabric in Figure 10. A cluster of fibers is seen oriented in the direction they were pulled through the scrim in Figure 11. The nylon scrim-reinforced fabrics are stiffer than the controls. The elongation is essentially unchanged, and is similar for both cottons. The inclusion of the nylon also makes these fabrics more conductive, reducing their insulative value.

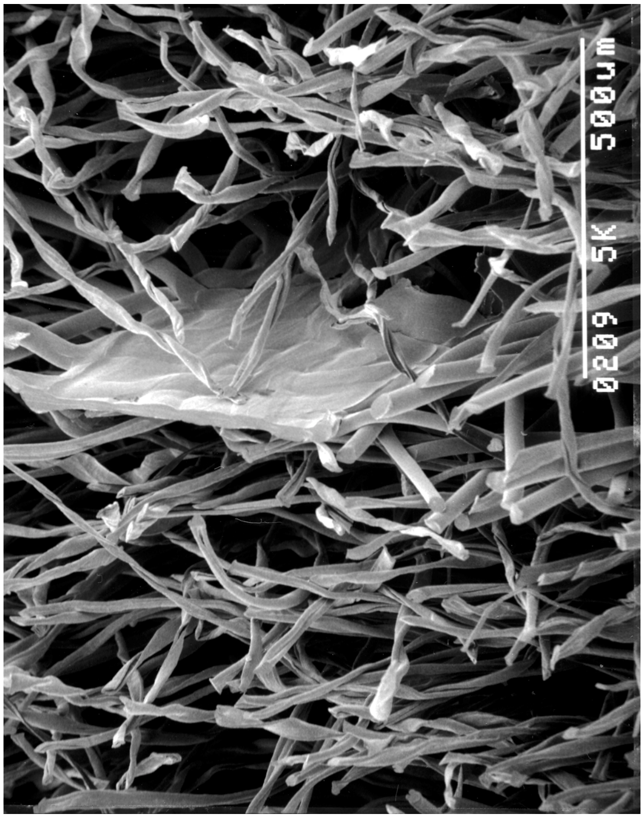

Figure 10. White, nylon scrim, cut edge view, 100x

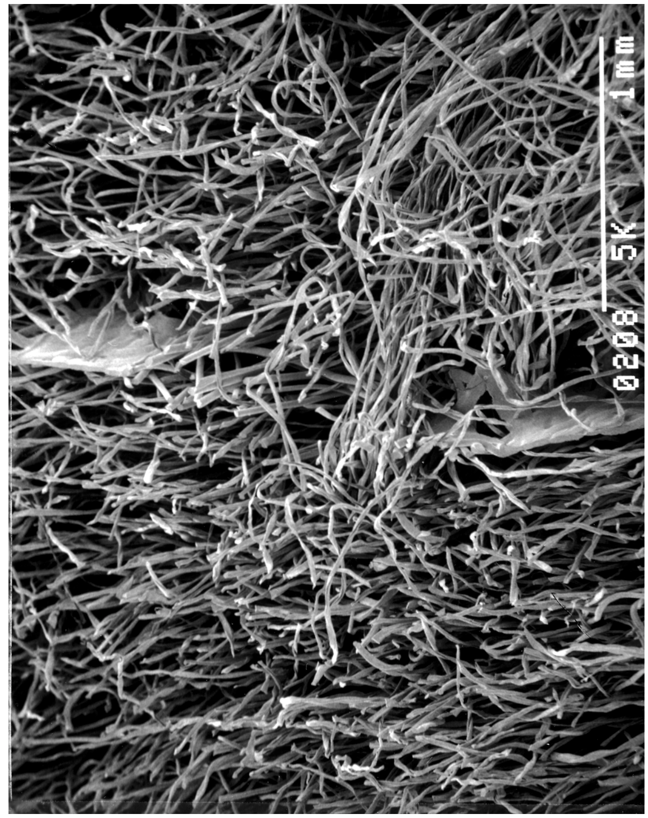

Figure 11. White, nylon scrim, cut edge view, 40x

The use of aramid scrim further enhanced the functional properties of the brown nonwovens. The brown aramid-reinforced fabrics equalled the bursting strength of the white nonwovens containing nylon (Figure 6). The aramid scrim doubled the bursting strength of the brown nonwovens and improved its breaking strength by a factor of six. The aramid specimens were more flexible than those containing nylon. Both scrims reduced air permeability. The nylon scrim did not affect the elongation of the specimens; the aramid scrim reduced elongation substantially (Figure 13). Figure 12 reveals a warp yarn at the center of the fabric cross section.

A comparison of the thermal conductivity of the two cottons shows that the naturally brown cotton has lower thermal conductivity than the white cotton, and provides better thermal insulation as a result. Both scrims increase the thermal conductivity of the materials (Table 3 and Figure 14). The 45-degree flame test proved inconclusive because the burning behavior was inconsistent among specimens. The horizontal flammability showed that the brown fabrics burned more slowly than the white fabrics. The nonwovens containing nylon scrim burned the most rapidly and the specimens containing aramid scrim performed the best. All specimens burned entirely, but only the aramid scrim specimens left some char, while the others left only ash. The flame retardancy of all specimens could be further improved with topical finishes if desired.

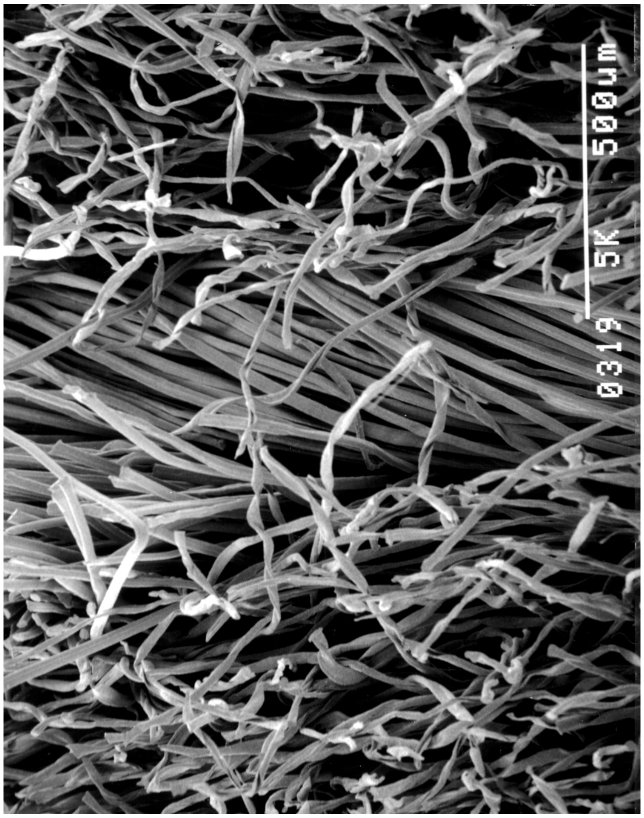

Figure 12. Brown cotton, aramid scrim, cut edge view, 100x

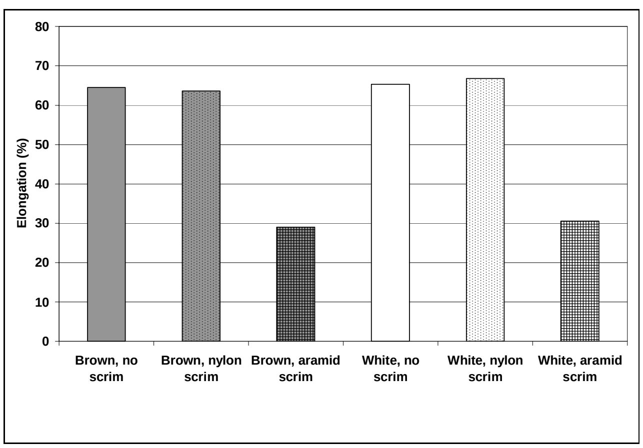

Figure 13. Elongation

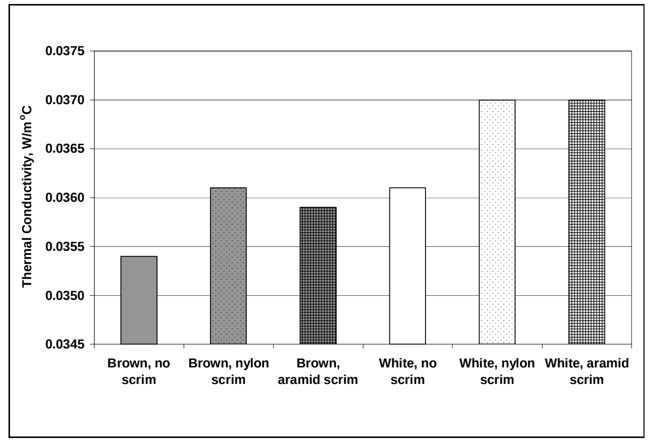

Figure 14. Thermal Conductivity

The ASTM standard performance specification D5432-93 outlines the performance requirements of blanket products for institutional and household use. The samples were not tested for all of the specification requirements, as this was a first look into the viability of naturally colored cottons for use in nonwovens. All of the specimens were deemed acceptable for thermal transmittance. The 45-degree flammability tests resulted in a class I rating for all of the specimens, which is the required rating for nonwoven materials for household use. The Maxxa samples with nylon or aramid scrims passed the breaking strength test and bursting strength for household use. However, the brown naturally colored cotton nonwoven fabric containing aramid scrim met these specifications, while also exhibiting other advantages over the white fabrics for use in consumer blankets. Laundering tests have not been conducted on these samples as of this report.

<u>Conclusions</u>

Soft and attractive needlepunched nonwoven fabrics can be produced readily from comparatively short and weak, naturally pigmented brown cotton. Brown nonwovens are weaker than white nonwovens, but their strength and other applicable performance properties can be substantially improved with suitable reinforcement. The aramid scrim is superior to the spun-bonded nylon scrim from the perspective of improved tensile and bursting strength, greater flexibility, and superior flame resistance. Brown nonwoven fabrics demonstrate advantages over white nonwovens for possible utilization as consumer blankets, since they are better insulators and appear to be more flame resistant. The brown cotton burned more slowly despite its lower char integrity. Additional testing, analysis, and microscopic observation are planned following laundering trials. The American Textile Manufacturers Institute (ATMI) has recently defined anything made from organic cotton or transitional cotton, naturally colored cotton, recycled or reprocessed fibers, lyocell, stone-free denim, and unbleached or undyed products as "environmentally improved textile products." Additional work utilizing naturally colored cotton in nonwovens is recommended and encouraged.

Acknowledgments

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Table I. Measured Fiber Properties

COTTON FIBER	MAXXA	BROWN
Color	White	Brown
Length, 2.5% span (inches)	1.12	0.86
Strength, 1/8-inch gage (grams per denier)	3.29	1.73
Elongation (percent)	4.6	3.4
Micronaire	4.0	3.7

Table II. Scrim Fabrics

SCRIM	TYPE #1	TYPE #2
Fiber Type	Nylon	Aramid
Construction	Spun-Bonded	Woven
Weight (oz/yd^2)	0.5	1.5
Supplier	Cerex	Tex Tech

Table III. The Coefficient of the Thermal Conductivity and the Thermal Transmittance of the Samples

Cotton	Scrim	Thickness (cm)	Coefficient of Thermal Conductivity (λ, W/m °C)	Heat Transmittance (W/m^2 °C)
Brown	None	0.457	0.0354	7.77
Brown	Nylon	0.451	0.0361	8.01
Brown	Aramid	0.394	0.0359	9.14
White	None	0.419	0.0361	8.65
White	Nylon	0.394	0.0370	9.43
White	Aramid	0.368	0.0370	10.07