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PROPERTIES OF HYDROENTANGLED NONWOVEN FABRICS MADE WITH GREIGE COTTON LINT, SELECTED MANMADE STAPLE FIBERS, AND THEIR INTIMATE BLENDS WITH THE LINT IN DIFFERENT BLEND RATIOS

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Abstract. *For the first time ever, a preliminary study has been conducted to assess the effects of intimate blending of greige (raw) cotton and certain commonly used manmade fibers on properties of the resulting nonwoven fabrics made with different blend ratios. Implementing the hydroentanglement system of making nonwoven fabrics, twenty one (21) fabrics were made separately, using the selected pre-cleaned Upland greige cotton lint, polyester, polypropylene, Tencel, viscose rayon, bleached cotton, and intimate blends of the cotton lint with the other fibers in 80:20, 50:50 and 20:80 blend ratios. With the exception of 100% polypropylene fiber and its 80:20 intimate blends with cotton, all other fibers and their various blends with the greige cotton were processed on the mill-like equipment available at the Center. The fabrics were not scoured and/or bleached to totally remove the greige cotton's native (hydrophobic) waxes. The results have shown that the improvement of desirable features of absorbency and whiteness of optimally blended greige cotton-based nonwoven fabrics could be significant incentives for rethinking cotton's use in nonwovens, especially in the fem-hygienic products where the consumer's choices of good absorbency, whiteness and comfort indeed matter!*

Key words: *Greige cotton lint, Man-made fibers, Intimate blends, Carding, Hydroentanglement, Nonwoven fabrics*

1. INTRODUCTION

The global growth of classical nonwoven fabrics in a decade has surpassed the growth rate of traditional woven fabrics. In fact, according to the Association of Nonwoven Fabrics Industry (INDA), Cary, North Carolina, USA, the so-called 'technical nonwoven fabrics' are growing even more rapidly than the classical nonwoven fabrics. The most

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common methods for commercially producing nonwoven fabrics today basically consist of two broad, underlying technologies, viz., 1) the melt spinning based on the extrusion of continuous thermoplastic fiber filaments, such as those in spunbonding, melt-blown, and several related, hybrid or even pseudo versions of this technology and 2) the staple-fiber-web-based technology that is mostly involved in producing nonwovens by using a pre-formed dry-laid or a preformed wet-laid web [1,2]. In the melt spinning, certain synthetic, thermoplastic polymeric chips are melted and extruded through a variety of spinnerets to ultimately produce a variety of integrated nonwoven fabrics under a variety of processing metrics and conditions. The extruded material generally is subjected to fast currents of either cold air or hot air or both sequentially to produce a variety of nonwoven roll goods, mostly online. On the other hand, the web-based nonwovens generally are made with staple fibers that are formed into a dry or a wet consolidated web/substrate, such as the one seen in the production of a needlepunched roll of nonwoven fabric or a pulp-based roll of nonwoven fabric, respectively [3,4]. Generally, all types of manufactured nonwoven roll goods are converted into specific end-use products and applications in separate manufacturing entities or facilities.

Cotton, mainly because of its high absorbency and consumer appeal, potentially could have generated good demand-based markets for certain cotton-based nonwovens. But, at the present, the use of greige cotton lint fiber in the dry web-based nonwoven fabrics is very limited. Communications and professional meetings and conferences held with the industry leaders, viz., Association of Nonwoven Fabrics Industry (INDA), Cary, NC; Nonwovens Institute, Raleigh, NC; Cotton Incorporated, Cary NC, Pellon Custom Products, Inc., Petersburg, FL; Ahlstorm Nonwovens, Wisconsin, USA, among others, have indicated that the wipes, diapers, medical devices and other hygiene and personal-care nonwoven products and their markets are stabilized and almost totally established with the use of manufactured fibers - mostly polypropylene, polyester and rayon [5-8]. Depending on the various sources of information, the main reasons for the very limited use (estimated at ~3 wt % of the global nonwovens markets) of greige cotton lint fiber in nonwovens include, among others, 1) the fiber's lack of cost competitiveness and its price volatility; 2) the fiber's lack of reliable supply of consistent quality year after year; 3) the ever-fluctuating non-lint content, e.g., waxes, pectin, coloring matter, etc., and foreign matter such as plant leaves, stem, seed coat fragments, dirt and trash; 4) the lack of certain desirable physical properties, such as the whiteness and absorbency for hygienic and personal care products; 5) lack of certain mechanical properties such as the high strength modulus and the ease of mold-ability for modern technical nonwoven fabrics, and, of course, 6) the absence of the required fiber cleaning equipment at the existing nonwoven roll goods manufacturing entities for thoroughly cleaning classically ginned greige cotton lint as it is supplied in compressed bales to any user facility. The cleaning of classical greige cotton is mandatory in almost every cotton user mill that is involved in manufacturing quality textile products, whether they are made with woven or nonwoven fabrics. Furthermore, the cotton must be thoroughly cleaned at the first opportunity in any user mill.

Since almost all the manufacturing entities of modern nonwovens most predominantly use manufactured fibers that inherently are clean, mostly white, and predictably consistent in quality, these entities neither have any cotton cleaning equipment nor are willing to encounter any potential contamination of their regular, synthetic fiber-based production lines with the regular ginned greige cotton which, as previously mentioned, is always contaminated with some objectionable foreign matter. Commercially bleached cotton, which generally has most of the greige cotton's undesirable and characteristic constituents, such as the (non-white) coloring matter, the non-lint native matter (waxes, pectin, etc.), and the foreign (field) matter, removed in the traditional scouring and bleaching processes, is preferred over greige cotton for certain nonwoven fabrics and end-use applications. However, even the bleached cotton sometimes is considered a bit costly and hence less competitive overall, when it is compared to the most commonly used manmade or manufactured fibers such as the polypropylene and polyester which inherently are hydrophobic in nature and even when it is compared to the rayon which is hydrophilic and closely related to (natural) cotton.

A pioneering, exploratory research conducted at the USDA-ARS-SRRC research facility in New Orleans has demonstrated that a so-called mechanically pre-cleaned ***greige*** cotton that is now commercially available as True Cotton^{TM} (P.O. Box 231, West Point, GA 31833, www.tjbeall.com) can be successfully processed to produce a variety of needle-punched and hydroentangled nonwoven fabrics of ~ 35 - 100 g/m^2 density [9-16]. Since the nonwoven roll-goods manufacturing industry today most predominantly uses manmade fibers in their rapidly growing nonwovens markets and since the natural fibers, due to their renewability, sustainability and perhaps even the so-called eco-friendliness, are also growing in popularity in these days, the Agricultural Research Service of the US Department of Agriculture has sensibly and timely directed new research to explore the potential of using the intimate blends of cotton with commonly used manmade fibers in the development of nonwoven fabrics of improved properties, by way of harnessing advantages of both the natural and the manufactured fibers. Since the bleached cotton lint relatively is a bit costlier than the comparable greige cotton lint, the research efforts at the USDA-ARS facility thus far have been mainly, if not almost solely, directed toward using the now commercially available pre-cleaned greige cotton. This study has investigated the (*fabric*) effects of intimate blends of the greige cotton with the manmade fibers in different blend ratios. Successful research and development of the cotton-based nonwoven blended fabrics are expected to promote the use and hence the market share of cotton in the nonwovens. This potentially would increase demand, production and profitable utilization of cotton, which ultimately would serve the ARS-USDA's underlying mission of assisting the US agriculture and its producers.

Accordingly, as a follow-up on the above stated ARS's new initiative of developing the cotton-based blended nonwovens, this research was planned and conducted to develop quite a few featured hydroentangled nonwoven fabrics using the commonly used manmade fibers and their intimate blends with the greige cotton fiber in different blend ratios. Basically, this manuscript presents a preliminary progress report on the comparative evaluations of the nonwoven fabrics made with pure (100%) greige cotton and pure polyester, polypropylene, viscose rayon, Tencel and bleached cotton fibers and the fabrics made with intimate blends of the greige cotton with each of the above manmade/manufactured fibers in 80:20, 50:50 and 20:80 blend ratios.

2. EXPERIMENTAL MATERIALS AND METHODS

2.1. Materials

For the research purpose only, several complementary bales of the following fibers were acquired from the entities indicated below:

1. Pre-cleaned Upland greige cotton (C_g) from: TJ Beall, Greenwood, MS 38930
2. Polyester (PES) from: DAK, Charlotte, NC
3. Polypropylene (PP) from: FiberVision, Covington, GA.
4. Viscose rayon (VR) from: Lenzing, Austria
5. Tencel^{TM} (modified rayon) from: Lenzing, Austria
6. Bleached Upland Cotton (C_{bl}) from: Tintoria Piana US, Cartersville, GA 30120

Classical properties of the fibers used in research are given in Tables 1 and 2 below:

Table 1 Measured properties of the pre-cleaned greige cotton and bleached**** cotton

L (n) cm (inch)	SCN * (count/g)	L (w) cm (inch)	UQL** (w) cm (inch)	SFC*** (w) (%)	Neps (count/g)	Trash (count/g)	Dust (count/g)	Maturity ratio (%)
1.98 (0.78)	8	2.29 (0.9)	2.74 (1.08)	10	293	2	24	92

L (n) and L (w): Fiber length based on the "Number" and "Weight" test methods, respectively.
*SCN: Seed-coat
**UQL: Upper Quartile Length
***SFC: Short Fiber Content.
**** This particular bleached cotton (different from the pre-cleaned cotton) had no specs identified on it. Its SRRC-Lab-measured properties of Linear Density of 2.12 dtex; Tenacity 15.65 cN/Tex; and E-max 6.7 % indicate that it relatively was a weak fiber.

Table 2 Properties of the manmade fibers used*

Fiber type	Staple length (mm)	Linear density (dtex)
Polyester	38	1.7
Tencel (rayon)	38	1.7
Polypropylene	38	1.3
Viscose Rayon	40	1.7

* This information was provided by the respective fiber manufacturers/suppliers.

2.2. Methods Used in Processing the Fibers

Sufficient quantities of each of the selected fibers identified below and about 30 pounds of intimate fiber blends of the greige cotton (C_g) with each of the other fibers in 80:20, 50:50 and 20:80 blend ratios, i.e., a total of the following 21 different fiber compositions or blend samples, were prepared for processing on a full-scale, commercial-grade equipment in the Nonwovens Pilot Plant at the Southern Regional Research Center:

1. Pre-cleaned 100% greige cotton (C_g)
2. 80:20 pre-cleaned greige cotton (C_g) : polyester (PES)
3. 50:50 pre-cleaned greige cotton (C_g) : polyester (PES)
4. 20:80 pre-cleaned greige cotton (C_g) : polyester (PES)
5. 0:100 pre-cleaned greige cotton (C_g) : polyester (PES)
6. 80:20 pre-cleaned greige cotton (C_g) : polypropelene (PP)
7. 50:50 pre-cleaned greige cotton (C_g) : polypropelene (PP)
8. 20:80 pre-cleaned greige cotton (C_g) : polypropelene (PP)
9. 0:100 pre-cleaned greige cotton (C_g) : polypropelene (PP)
10. 80:20 pre-cleaned greige cotton (C_g) : viscose rayon (VR)
11. 50:50 pre-cleaned greige cotton (C_g) : viscose rayon (VR)
12. 20:80 pre-cleaned greige cotton (C_g) : viscose rayon (VR)
13. 0:100 pre-cleaned greige cotton (C_g) : viscose rayon (VR)
14. 80:20 pre-cleaned greige cotton (C_g) : Tencel (TEN)
15. 50:50 pre-cleaned greige cotton (C_g) : Tencel (TEN)
16. 20:80 pre-cleaned greige cotton (C_g) : Tencel (TEN)
17. 0:100 pre-cleaned greige cotton (C_g) : Tencel (TEN)
18. 80:20 pre-cleaned greige cotton (C_g) : bleached cotton (Bl C)
19. 50:50 pre-cleaned greige cotton (C_g) : bleached cotton (Bl C)
20. 20:80 pre-cleaned greige cotton (C_g) : bleached cotton (Bl C)
21. 0:100 pre-cleaned greige cotton (C_g) : bleached cotton (Bl C)

The commercial-grade, one meter wide, nonwovens processing equipment at the Center's textile pilot plant mainly included a basic fiber opening line, a nonwovens card with 4 plates of stationary flats, a cross-lapper, and a needle punch machine for light pre-needling to prepare the required consolidated fibrous web or substrate for its hydroentanglement on a downstream Fleissner (now,Trutzschler's) commercial-grade hydroentanglement system, Fig. 1. The major process metrics of the substrate preparation and the hydroentanglement are given in Table 3 and 4, respectively.

Table 3 Metrics implemented in preparation of the substrates

Carding production rate	~10 kg/hr.
Card web weight	~ 12.5 g/m²
No. of crosslapping	16 (laps)
Light needling @	115 pts/cm²
Needlepunching production speed	2.3 m/min
Nominal weight of the substrate	65 g/m²

Table 4 Metrics involved in the process of hydroentanglement

Wet-out (low) water pressure @ 0.12 mm diameter nozzle jet strip	30 Bar
Hydroentangling (high) water pressure @ the two heads of jet strips of 0.12 mm diameter nozzles	90 Bar
Nozzle density of each jet strip	16/cm length
Fabric drying (oven) temp	180° C for all fabrics, except 160° C for the fabrics containing polypropylene.
Fabric production speed	10 m/min

All the fabrics were produced in triplicates under the same conditions, in order to ensure their reproducibility. They were tested in-house for evaluating the required properties, viz., the fabric basis weight, the fabric thickness, the fabric tensile strength and breaking elongation in both the machine direction (MD) and the cross direction (CD), the fabric tear strength in both the MD and CD directions, the fabric burst strength, the fabric whiteness index, and the fabric absorbency, using the standard ASTM-I, AATCC, INDA and any other applicable test methods [17-23]. Generally, 3 to 5 lab tests were performed on each test material and their averages with standard deviations have been presented to ensure statistical validity of the test results. However, due to lack of the appropriate instruments for objectively testing the fabric appearance, hand and drape, these fabric characteristics were subjectively evaluated based solely on the research team's expertise.

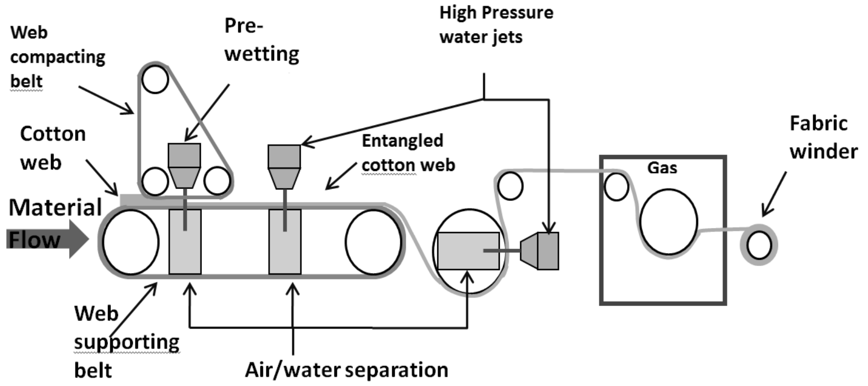

Fig. 1 A schematic of Fleissner Hydroentanglement System at the Southern Regional Research Center, New Orleans, LA 70124.

3. Results and Discussion

With the exception of the fabrics made with 100% polypropylene (PP) fiber and 80:20 polypropylene:cotton blend, the fiber processing involved in producing all the other fabrics (a total of 19 fabrics made with the different fibers and fiber blends) was reasonably satisfactory, throughout. The less-than-satisfactory fiber processing performance of the 100% PP and its 80:20 rich blend with cotton seemed to be due to particular difficulties that were experienced in less-than satisfactory carding performance of the PP fiber. And the reason for the carding difficulties of the PP fiber seemed to be *a pronounced incompatibility of the wire type and spacing* of the card plates and the card cylinder. Although the brand new cylinder and doffer wires especially for processing intimate blends of cotton and manmade fibers had been installed, the card plate wires somehow remained unchanged. Furthermore, the PP fiber is well known to card somewhat differently when compared to the other fibers in this study. Incidentally, the shorter fiber length of cotton, compared to the length of the manmade fibers, did not seem to create any problem in the preparation of the various web substrates required. It may be mentioned that the intimate blends of cotton with the stated manmade fibers have been historically processed quite efficiently in the manufacturing of traditional textiles, viz., yarns and woven fabrics.

Split Tables 5A and 5B below show the summarized data of the selected properties of the various fabrics made with the different fiber blends. Figures 2- 7 represent the graphic views of the same summarized data for ease of observing the underlying trends of the fabric properties in relation to the fabric's constituent fibers and blend ratios.

Table 5A Measured properties, in part, of the blended nonwoven fabrics

Fabric & Fiber ID	Weight (grams/m²)	Thickness (mm)	Drop Test (seconds)	Tensile MD (N/50mm)	Elongation MD (%)
100% Cg	64.5 (3.7)	0.56 (0.02)	>60	74.5 (5.1)	39.4 (2.9)
80% Cg / 20% PES	61.1 (1.6)	0.59 (0.03)	>60	94.5 (3.8)	43.2 (1.9)
50% Cg / 50% PES	62.6 (4.2)	0.6 (0.0)	>60	113.0 (8.8)	48.2 (3.9)
20% Cg / 80% PES	65.6 (2.4)	0.64 (0.030	>60	134.9 (7.6)	57.3 (2.4)
100% PES	61.6 (3.6)	0.61 (0.40)	>60	131.3 (8.9)	60.6 (3.4)
80% Cg / 20% PP	58.0 (2.1)	0.57 (0.02)	>60	81.6 (3.5)	49.7 (2.9)
50% Cg / 50% PP	61.2 (3.8)	0.56 (0.03)	0.6	114.8 (4.5)	57.5 (3.2)
80% Cg / 20% VR	62.3 (4.8)	0.57 (0.03)	>60)	70.8 (4.4)	35.1 (3.2)
50% Cg / 50% VR	66.3 (6.2)	0.55 (0.03)	5.1	74.9 (3.5)	29.2 (2.2)
20% Cg / 80% VR	68.0 (7.0)	0.54 (0.02)	0.9	88.5 (6.5)	21.4 (2.0)
100% V R	71.7 (6.5)	0.54 (0.03)	0.6	85.9 (6.7)	17.6 (1.4)
80% Cg / 20% TEN	64.4 (6.0)	0.57 (0.03)	>60	88.7 (4.6)	37.5 (2.4)
50%Cg / 50%TEN	66.2 (6.9)	0.56 (0.03)	8.0	96.1 (7.2)	28.5 (1.6)
20% Cg / 80% TEN	76.0 (5.6)	0.57 (0.03)	0.9	115.8 (8.2)	23.7 (1.7)
100% TEN	64.5 (4.7)	0.53 (0.05)	0.8	125.7 (8.1)	18.3 (1.1)
80% Cg / 20% Bl C	67.5 (4.0)	0.59 (0.03)	2.6	49.6 (2.9)	33.4 (1.7)
50% Cg / 50% Bl C	68.0 (3.3)	0.57 (0.02)	0.9	53.9 (2.9)	32.8 (2.5)
20% Cg / 80% Bl C	67.4 (4.6)	0.61 (0.02)	0.8	52.5 (3.5)	31.7 (3.8)
100% Bl C	59.6 (3.0)	0.55 (0.02)	1	42.4 (2.4)	35.5 (3.0)

The test values in parentheses present standard deviations.
For the fiber identification from the fiber symbols in the Table, please see Element 2.2.

Table 5B Measured properties, in part, of the blended nonwoven fabrics

Fabric & Fiber ID	Tensile CD (N/50mm)	Elongation CD (%)	Tear Test MD (Newton)	Tear Test CD (Newton)	Burst Strength (Bar)	Whiteness (Index)
100% Cg	64.0 (6.6)	62.1 (1.9)	10.7 (1.1)	11.1 (0.8)	2.2 (0.2)	20.9 (2.0)
80% Cg / 20% PES	72.7 (2.4)	76.7 (3.1)	11.9 (1.0)	13.8 (1.0)	2.2 (0.1)	35.5 (1.0)
50% Cg / 50% PES	84.5 (8.0)	79.6 (2.4)	14.3 (0.9)	15.3 (1.2)	2.9 (0.2)	59.7 (2.3)
20% Cg / 80% PES	153.5(14.4)	72.0 (3.4)	16.8 (1.8)	21.3 (3.2)	3.3 (0.2)	105.2 91.1)
100% PES	101.5 (13.8)	87.6 (3.3)	14.9 (1.4)	14.3 (1.7)	3.2 (0.4)	122.2 (0.3)
80% Cg / 20% PP	86.7 (5.0)	69.5 (2.0)	11.5 (1.2)	12.6 (0.9)	2.4 (0.2)	28.9 (1.1)
50% Cg / 50% PP	146.3 (11.9)	66.6 (4.2)	12.6 (0.7)	14.1 (1.3)	3.0 (0.2)	46.0 (1.1)
80% Cg / 20% VR	61.4 (8.0)	64.5 (2.8)	9.7 (1.2)	9.4 (0.8)	2.0 (0.2)	25.1 (0.8)
50% Cg / 50% VR	56.3 (7.5)	58.1 (4.5)	8.9 (0.7)	8.3 (1.2)	1.6 (0.2)	40.1 (0.7)
20% Cg / 80% VR	58.8 (8.0)	53.2 (2.7)	7.9 (0.6)	5.8 (0.2)	1.6 (0.2)	58.9 (0.7)
100% Viscose Rayon	57.3 (12.1)	43.8 (4.3)	7.0(0.6)	5.7 (0.5)	1.8 (0.2)	75.0 (0.3)
80% Cg / 20% TEN	69.8 (6.6)	64.4 (2.3)	12.2 (0.9)	10.8 (1.0)	2.2 (0.3)	25.0 (1.2)
50%Cg / 50%TEN	66.0 (7.1)	67.0 (3.2)	11.6 (1.9)	9.9 (0.9)	2.2 (0.2)	38.9 (0.6)
20% Cg / 80% TEN	98.4 (10.7)	51.7 (3.0)	10.2 (0.8)	9.3 (1.3)	2.8 (0.4)	58.6 (0.8)
100% TEN	91.1 (12.2)	48.6 (2.3)	10.1 (1.5)	8.1 (0.8)	2.3 (0.4)	79.7 (0.4)
80% Cg / 20% Bl C	38.4 (16.3)	58.6 (21.7)	7.1 (0.9)	5.3 (0.6)	1.3 (0.1)	27.7 (0.6)
50% Cg / 50% Bl C	43.1 (2.2)	58.6 (2.8)	7.2 (0.6)	6.4 (1.0)	1.4 (0.1)	42.1 (1.3)
20% Cg / 80% Bl C	47.5 (4.6)	56.2 (3.6)	7.3 (1.1)	7.0(0.4)	1.6 (0.2)	62.1 (0.5)
100% Bl C	38.2 (3.8)	55.0 (1.9)	6.5 (0.9)	7.7 (0.6)	1.3 (0.5)	81.8 (0.2)

The test values in parentheses present standard deviations.
For the fiber identification from the fiber symbols in the Table, please see Element 2.2

The following are discussions of the individual properties of the various nonwoven blended fabrics:

3.1. Fabric Weight

As seen, most fabrics weighed reasonably well within the intended nominal weight of 65 g/m^2. However, although the overall average weight density of all the fabrics was 65.08 g/m^2, the overall density range of 58 g/m^2 (of the 80:20 C_g : PP fabric) and 76 g/m^2 (of the 20:80 C_g : TEN) was unexpectedly considerable. Beside the inherently and significantly different densities of some of the fabrics' constituent fibers (and their different blend ratios), the observed wide range of the fabric weight or density possibly could have also been due to some minor discrepancies that might have occurred during the fiber processing and handling operations. In any event, the fabric properties, where applicable, were appropriately marginalized by normalizing the fabric weight. As seen, the standard deviations of individual fabric weights were all within acceptable ranges.

3.2. Fabric Thickness

The fabric thickness varied between 0.53 mm (of the 100% Tencel fabric) and 0.64 mm (of the 20:80 C_g : PET fabric). This range of the fabric thickness was relatively narrower than that of the fabric weight observed above. The fabric thickness variations, although they likely were due to the different densities and blend ratios of the fabrics' constituent fibers as mentioned above, could also be partly due to the aforementioned small discrepancies occurring in the fiber processing and handling.

3.3. Drop Test

Although the Drop Test in itself does not directly represent the absolute absorbency of the fabric, the test results at least do indicate that the fabrics made with viscose rayon, Tencel and bleached cotton were quickly and highly absorbent, compared to the fabrics made with polyester and polypropylene. Surprisingly, however, the fabric made with the 50:50 C_g: PP blend somehow also exhibited the Drop Test time of 0.6 second, which could be desirable for many end uses, provided this low time of 0.6 seconds indeed could always be attained with any type of greige cotton and any PP fiber, since both of these fibers generally are hydrophobic by nature and are not easily absorbent. The only explanation that the authors possibly could have given for this rather uniquely low Drop Test time of only 0.6 seconds for the 50:50 C_g: PP blended fabric is that the greige cotton component of the particular samples had little wax content, which probably enhanced the absorbance of the resulting blended fabric.

3.4. Tensile Strength and Elongation-at-Break

The MD tensile breaking strength of the fabrics varied from as low as 42.4 N/50mm for the 100% bleached cotton fabric to as high as 131.3 N/50mm for the 100 % polyester fabric. Generally, the polyester blended fabrics had greater MD tensile strength compared to the other blended fabrics and, as seen in Figure 2, the MD strength of the polyester blended fabric increased as its greige cotton component decreased. This mainly was due to the fact that the polyester fiber inherently is much stronger and more uniform than the greige cotton fiber. As also seen from the figure, the MD tensile strength of the blended fabrics made with PET, PP and TEN progressively increased as the fiber blend ratio of these manmade fibers increased from 20% to 50% and to 80% (except PP). As seen from

Table 5A, the tensile strength of the fabric made with 100% polyester was > 60% greater than that that of the fabric made with 100% greige cotton fiber. This was so because the manmade fibers generally are stronger and, more importantly, much more uniform in their characteristics and quality, especially when compared to the greige cotton. The uniformities of properties of textile fibers ultimately play critical roles in the properties of their resulting fabrics. The MD strength of the 80:20 PET: C_g blended fabric surprisingly was slightly greater than the MD strength of the fabric made with 100% PET fiber. This could not be reasonably explained, except that it perhaps was due to some unknown phenomenon relating to certain impact of inter- and intra- fiber friction and consequently to the actual 'load sharing' of the fabric's constituent fibers during tensile testing.

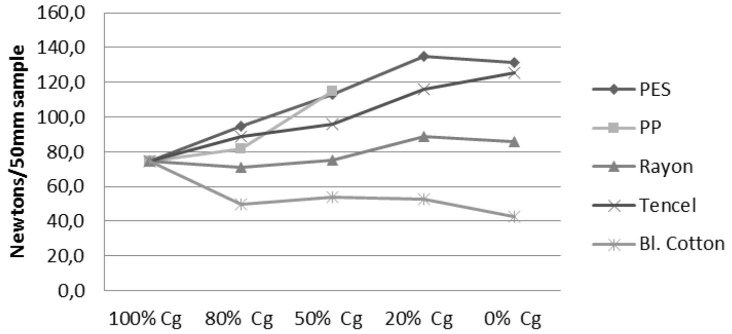

Fig. 2 The MD breaking strength of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis).

The MD elongation-at-break of the various fabrics, Figure 3, varied from 60.6% of the 100% polyester fabric to 17.6% of the 100% viscose rayon fabric. As seen from Table 5A, the breaking elongation of the fabric made with 100% polyester was ~ 50% greater than that of the fabric made with 100% greige cotton fiber. The breaking elongation of textile fibers and fabrics generally depends on the type of material involved/tested, the

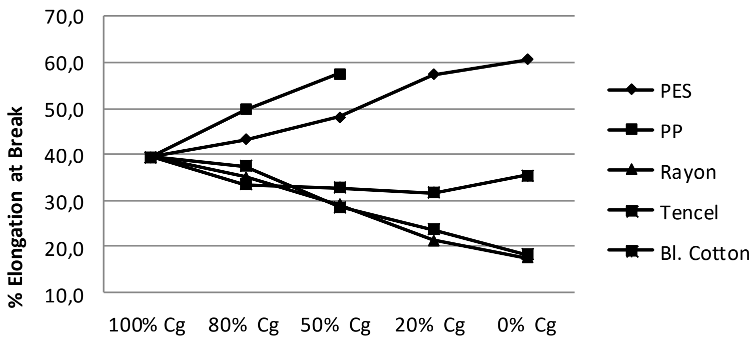

Fig. 3 The MD breaking elongation of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis).

test method used, and the tensile breaking strength of the material. For example, a polyester fiber could be of high tenacity, mid tenacity and low tenacity (that, ~ 4g/denier, is usually blended with cotton fiber of comparable or compatible tenacity). The low tenacity fiber generally has very high breaking elongation (up to 50% +), whereas a high tenacity polyester fiber may have its breaking elongation %age only in teens or even less.

Regarding the CD tensile strength of the fabrics, the test results show that the CD tensile strength, Table 5B and/or Figure 4, varied from 38.2% of the bleached cotton fabric to (an unrealistic) 153.5% of the 80:20 PET: C_g fabric. Realistically, the CD strength of the 100% polyester was > 60 % greater than that of the 100% greige cotton fabric, as it was also seen in case of the fabrics' MD strengths above. The abnormally high value of CD strength (153.5 N) of the 20:80 blend of greige cotton and polyester fibers is totally unreasonable and hence cannot be explained, other than what already has been hypothesized above in case of the same fabrics' MD strengths. However, as previously indicated, the inherent characteristics and properties of constituent fibers of the fabrics, the fiber processing metrics involved in the preparation of various substrates, and, above all, the actual composition of the substrates influence the load sharing by the constituent fibers and ultimately determine properties of the resulting fabrics. As seen from Table 5B and/or Figure 4, the blended fabrics containing the relatively stronger fibers, viz., PET, PP or Tencel, had greater CD strength compared to the fabrics containing 100% cotton, either the greige or the bleached. The CD strength of the blended fabrics generally increased as the percentage of the greige cotton content decreased, which was also observed above in case of the blended fabrics' MD strengths. The CD strength of the rayon blended fabrics somehow did not show the same trend as observed with the other four fibers. In general, the CD strength of the viscose rayon blended fabrics did not provide the same kind of information or trend as did the CD strength of the PP, PET and even TEN blended fabrics. This likely was due to a relatively lower tensile strength of rayon fiber (especially when it is wet) and bleached cotton fiber, compared to the tensile strengths of the other fibers investigated in this study. Also, any amount of natural cotton waxes and pectin that still had remained on particular test samples of the (*hydroentangled*) fabrics possibly could affect the fabrics' tensile properties. Furthermore, as it previously has been mentioned, any small discrepancies occurring in the fiber processing and handling and even in testing could also affect some divergences in the fabric test data. In any event, the overall test data and the statistical controls in place do not indicate any significant stray from the norms. For example, the MD:CD ratios of all the fabrics were calculated and found within a generally acceptable range of 1 to 1.5 for the so-called balanced nonwoven fabrics. The intimately blended fabrics' MD:CD ratio within the stated normal range of 1 to 1.5 (which is also considered normal for most cotton-based nonwoven fabrics) had been attained by optimum manipulation of the various metrics involved in the carding, crosslapping, and light needlepunching processes of preparing a uniform substrate of the required integrity and fiber orientation for the downstream hydro-entangling process. In other words, by properly adjusting the card web weight, the number of cross-laps, the production speed, the needlepunching parameters, and the material draft, the appropriate fiber orientation in the various fiber substrates likely had been achieved to attain the acceptable MD:CD ratios of the resulting fabrics. The fabrics' CD breaking elongation of the Bl Cotton, Tencel (TEN) and rayon (VR), blended fabrics, Figure 5, seemed to follow the respective fabrics' CD strength, while the breaking elongation of the polyester (PET) and polypropylene (PP) fabrics somehow seemed to be having a sharply opposite trend to that of their CD tensile strength and somewhat contrary to what was observed in case of their MD breaking elongation. Again, this likely was due to the actual fiber orientation in the respective substrates.

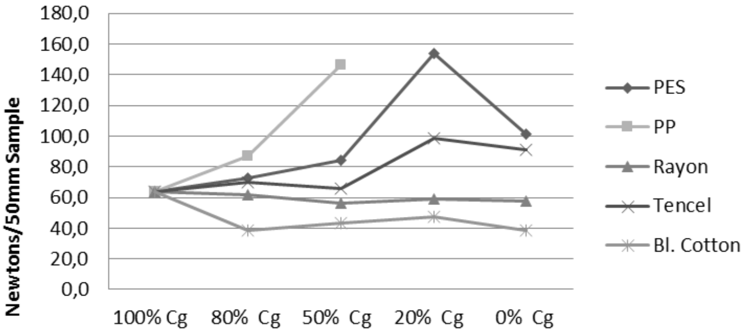

Fig. 4 The CD breaking strength of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis).

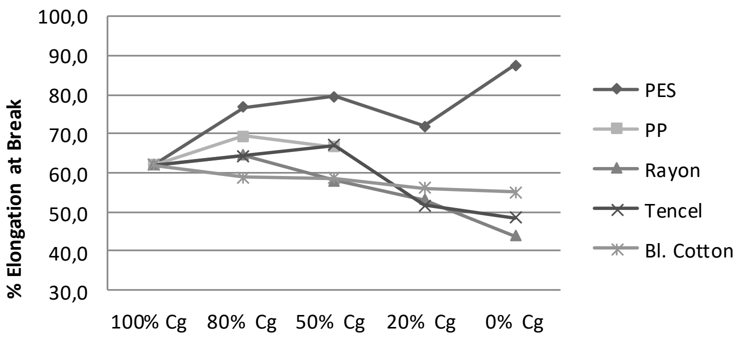

Fig. 5 The CD breaking elongation of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis).

3.5 Tear Strength

The MD tear strength, Table 5B and/or Figure 6, of the fabrics varied from 16.8 Newton for the 80:20 PET:C_g fabric to 6.5 Newton for the 100% bleached cotton fabric. With the exception of the polyester-containing blends, wherein the fabric tear strength in the MD direction increased as the cotton content in the fabric decreased, the MD tear strength of all the other blended fabrics mostly did not show considerable impacts of their fiber blend ratios. The CD tear strength varied from 5.3 N (for the 80:20 C_g:bleached cotton) to 21.3 N (for the 80:20 PET:C_g). Again, the polyester and cotton blended fabrics in all the blend ratios yielded increased CD tear strength and generally greater than that of all the other fabrics including the fabric made with the 100% cotton, whether the greige or the bleached. Again, except for the polyester, polypropylene and Tencel fabrics, the fiber blend ratios of the rayon and bleached cotton fabrics did not make appreciable differences in their CD tear strength.

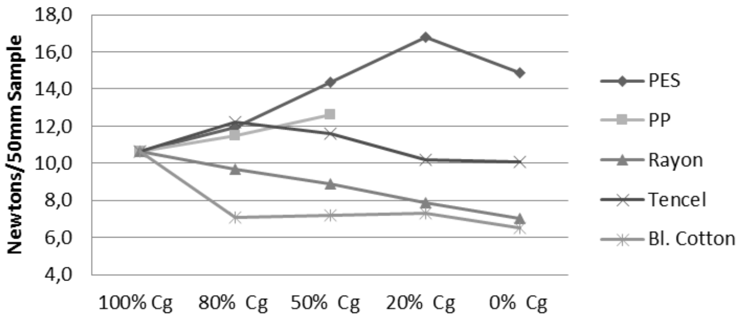

Fig. 6 The MD tear strength of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis)

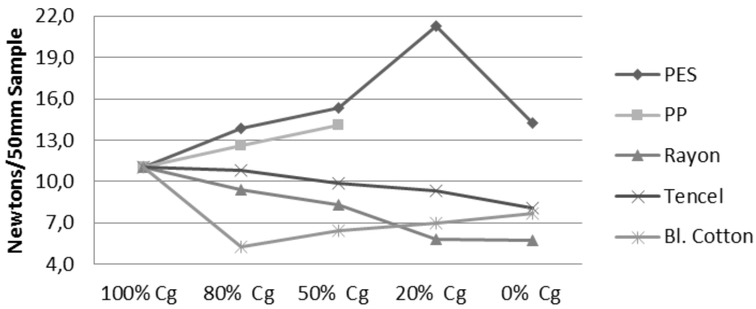

Fig. 7 The CD tear strength of the fabrics made with the different fibers (as shown in their different shapes in the legend) blended with the different %age of greige cotton (as indicated on the horizontal axis).

3.6. Burst Strength

The burst strength of the fabrics, Table 5B, varied from 1.3 bars for the bleached cotton and its 80:20 blend with greige cotton to 3.3 bars with the polyester-rich, 80:20, blended fabric. Even though the burst strength range (1.3-3.3 bars) of the fabrics overall seemed to be wide, the absolute tear strength of all the fabrics was lower compared to that of traditional woven fabrics of equivalent composition and structure. In fact, a previous USDA-ARS research on cotton-based nonwovens had also shown that the 100 percent greige cotton nonwoven fabrics, made via the hydroentanglement process, exhibited a relatively low burst strength that generally was not much affected even by the major process metrics involved in the hydroentanglement system.

3.7. Whiteness

The 100% greige cotton fabric had the whiteness index of only 20.9, whereas the fabric made with a blend of 80:20 polyester:greige cotton had the whiteness index of 105.2, a five-fold increase. The 100% polyester fabric had the whiteness index of ~125. Since the manmade fibers, including those used in this study, generally are very white with their whiteness index ranging from 80 to >125 (*with optical brighteners*), all the blended fabrics, as expected, exhibited increased whiteness as the white fiber content increased and the greige cotton component proportionately decreased. The whiteness indices of the blended fabrics ranged from 25 to 105. However, the fabrics made with 80 % manmade fibers exhibited the whiteness index of at least ~60. This least whiteness index or level of an intimately blended nonwoven fabric possibly could make such a fabric (*without the traditional bleaching process*) quite acceptable as a bleached cotton-like white fabric for many nonwoven end-uses and applications, such as wipes, medical gadgets, diapers and the like.

3.8. Absorbency

Table 6 shows the overall absorbency capacity (that includes absorption and adsorption) of the various blended fabrics. The absorbency of a fiber is a desirable attribute for certain end-use products such as apparel for bodily comfort, wipes, certain medical devices, and the like. The PET and PP fibers inherently are hydrophobic, i.e., their absorbency generally is very low, if any. However, the VR, TEN and Bl C, on the other hand, are highly hydrophilic and hence very absorbent. As seen from Table 6, the PET- and PP- containing blended fabrics exhibit at least some absorbency, especially with their greige cotton content of even 50%. This may be an interesting development considering that the PP, PET and even greige cotton (that is not easily absorbent) fibers generally are mostly hydrophobic. This study has shown that the hydro-entanglement of these intimately blended, non-absorbent fibers could develop at least some absorbency in their resulting nonwoven fabrics.

Table 6 Absorbency Capacity, *g. H_2O per g. of fabric,* of the Nonwoven Fabrics

C_g content		PET	PP	VR	TEN	Bl C
100%	4.49					
80%		3.20	1.84	5.69	4.59	8.82
50%		3.68	1.22	9.29	9.14	9.85
20%		Error	N.A.	8.61	9.82	9.02
0 %		Error	N.A.	8.27	9.28	10.37

Our previous work at the USDA-ARS had also shown that the hydroentanglement process of making a nonwoven fabric removed some or most of greige cotton's natural waxes, sugars and pectin, depending on the process metrics. However, the fabrics made in the earlier work involved relatively high hydroentangling water pressure that impacted the greige cotton substrates at the fabric production rate of only 5 m/min [24]. Under those hydroentangling metrics or conditions, most fabrics generally became considerably hydrophilic due to high impact of the hydraulic energy involved in the hydroentanglement process. Since the hydroentangling water pressure implemented in this study was only 90 bars and, more importantly, the fabric production rate was 10 m/min (i.e., twice as fast as the one in the previous studies), the impact of the hydroentangling energy involved in the present study obviously was much less and perhaps insufficient to remove the greige cotton's natural waxes and other impurities to any significant extent. Since the actual content of these native impurities of the greige cotton was not determined in this study, it is possible that the content slightly varied in each substrate/fabric. And this possibly could also have influenced the observed spread of the absorbency data of the fabrics, although the data, based on the standard deviations, still appeared to within the acceptable confidence. As expected, the blends of greige cotton with TEN, VR and Bl C have all shown much greater absorbencies compared to that of the 100% greige cotton fabric, mainly because of the latter's partly hydrophobic character.

4 CONCLUSIONS

A preliminary and yet a kind of pioneering study has been conducted to determine the effects of intimate blending of pre-cleaned greige cotton lint with certain manmade/ manufactured staple fibers, viz., polyester, polypropylene, viscose rayon, Tencel and even bleached cotton, in the 80:20, 50:50 and 20:80 blend ratios, on properties of the hydroentangled nonwoven blended fabrics made thereof and to compare these properties with those of the fabrics made separately with 100% of each of the various fibers investigated in the study.

The study has shown that the intimate blends of pre-cleaned greige cotton and certain manmade fibers can be efficiently processed on existing commercial mill equipment and converted into their respective substrates that can be efficiently hydroentangled into viable nonwoven fabrics of likely improved properties for certain end-use products. For example, the study has shown that a small (say, ~ 20 - 50%) content of pre-cleaned greige cotton in the hydroentangled, blended nonwoven fabrics made with polyester, polypropylene or Tencel may yield satisfactory physical and mechanical properties, including the improved strength and whiteness and even somewhat satisfactory absorbency especially in the blends of PET and PP fibers that generally are non absorbent. These fabric properties are especially critical in many personal care, hygienic, and medical-grade nonwoven products that presently are made mostly, if not all, with the manmade fibers. The fabrics made with the 80:20 intimate blends of PET:cotton and Tencel:cotton particularly showed considerable improvements also in the fabric appearance, drape and uniformity that generally were difficult to attain in any previous cotton-based nonwoven fabric structures developed at the Center. Overall, considering only the most relevant and beneficial fabric properties, such as the fabric strength, whiteness and absorbency, the polyester-rich blended fabrics seemed to be superior among all the blended fabrics studied. Although the 80:20 PP:Cotton blend did not process well, likely due to the difficulties encountered in its carding operation and subsequently in its substrate preparation, the 20:80 and even the 50:50 PP:Cotton blends processed reasonably well and yielded somewhat encouraging results, especially in the fabric absorbency.

In general, the MD and CD tensile and tear strengths and the burst strength of the blended fabrics increased as the manmade fiber content increased from 20% to 50 % and to 80%. At the 80% level, these fabric strengths almost reached the strengths of the respective fabrics made with the 100% manmade fibers and, surprisingly, they even exceeded in the case of the polyester blend fabric. Although most of the fabrics seemed to have reasonably acceptable physical and mechanical properties, the 20:80 cotton and Tencel and 50:50 cotton and polypropylene blended fabrics particularly exhibited satisfactory (as never seen before) appearance, drape, resilience or crease resistance, as indicated by their subjective evaluations. With the exception of the fabrics containing PP, all the other blended fabrics generally showed increased absorbency as the percent content of greige cotton decreased. The fabrics made with the pure viscose rayon, Tencel and bleached cotton had, as expected, the highest absorbance capacity - ranging, respectively, from 8.3 to 10.37 times their fabric weight. Even the blends of these highly hydrophilic fibers containing 20% or even 50% greige cotton still exhibited sufficiently high fabric absorbency that may be suitable for many end-use applications. The increased (80 %) addition of the (*partly hydrophobic*) greige cotton to the totally hydrophobic polypropylene fiber even made the resulting hydroentangled fabric slightly absorbent. Furthermore, the whiteness index of the cotton-blended fabrics could be considerably improved by adjusting the fiber blend ratio of the constituent manmade fibers. Hence, the desired absorbency and whiteness features alone of these (non-scoured and non-bleached) hydroentangled fabrics containing greige cotton could be significant incentives for rethinking the cotton's use in nonwovens, especially in the fem-hygienic products where the consumer's choices of absorbency, whiteness and comfort really matter considerably!

In summary, the study for the first time has shown that the hydroentanglement system of making nonwoven fabrics is an efficient method for producing cotton-based *blended fabrics in different blend ratios*. The hydroentanglement system today is the most widely used method of producing nonwoven fabrics and is expected to produce 4.6 million tones or 136.9 billion square meters of fabrics valued at $ 15.6 billion in the global market [25]. However, most of these fabrics (~96%) are currently made with the manmade fibers, mostly, polyester, polypropylene and rayon. Hopefully, this work supported by USDA-ARS research will bring rethinking of cotton in modern nonwovens.

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Notes:

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2. *USDA is an equal opportunity provider and employer.*

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KARAKTERISTIKE FILTRIRAJUĆIH NETKANIH TEKSTILNIH MATERIJALA OD NEOBRAĐENOG PAMUKA, VEŠTAČKI SORTIRANIH VLAKANA I NJIHOVIH MEŠAVINA SA PREDIVIMA U RAZLIČITIM PROPORCIJAMA

U radu je predstavljena inovativna i preliminarna studija koja ima za cilj da proceni efekat mešanja neobrađenog (sirovog) pamuka sa pojedinim vrstama veštačkih tkanina na karakteristike dobijenih netkanih tekstilnih materijala u različitim proporcijama. Implementacijom sistema vodenog sloja pri izradi netkanih tekstilnih materijala, dobili smo 21 vrstu tkanine, koristeći prethodno očišćena neobojena pamučna prediva, poliester, polipropilen, Tencel, viskozni rajon, izbeljeni pamuk i mešavine pamuka sa drugim vlaknima u odnosu 80:20, 50:50 i 20:80. Osim u slučaju 100% polipropilenskih vlakana i mešavine pamuka 80:20, sve tkanine i njihove mešavine sa pamukom obrađene su posebnim tehnikama. Tkanine nisu bile očišćene i/ili izbeljene kako bi se potpuno uklonili prirodni (hidrofobni) voskovi pamuka. Rezultati su pokazali da poboljšanje karakteristika apsorpcije i beline optimalnih mešavina netkanih tkanina na bazi pamuka može biti značajan podsticaj za ponovno razmišljanje o upotrebi pamuka u netkanom tekstilu, posebno u slučaju ženskih higijenskih proizvoda kod kojih apsorpciona moć, belina i udobnost utiču na izbor potrošača.

Ključne reči: *neobrađeno pamučno predivo, veštačka vlakna, mešavine vlakana, češljanje, sistem vodenog sloja, netkani tekstilni materijali*