ELECTROKINETIC PROFILES OF NONOWOVEN COTTON FOR ABSORBENT INCONTINENCE MATERIAL

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Abstract

This paper discusses recent work on cotton/synthetic nonwovens, their electrokinetic analysis, and their potential use in incontinence materials. Electrokinetic analysis is useful in exploring fiber surface polarity properties, and it is a useful tool to render a snap shot of the role of fiber charge on fiber swelling and moisture uptake all of which are important in absorbent incontinence material design. In this study a form of greige cotton termed Ultra Clean^{TM} Cotton (greige cotton processed through a proprietary mechanical cleaning process using no chemicals) was blended with polyester and nylon and subject to a nonwoven hydroentanglement process. The results of this study show a close similarity in the polarity, water uptake, and swelling properties of cotton/synthetic blends of cotton/polyester and cotton/nylon to some of the layers found in commercial absorbent incontinence products. In addition a number of cotton/cotton by-product nonwoven blends are analyzed and show incontinence material potential. Hence this approach is a useful screening and development tool to the discovery of cellulosic and cotton-based materials for absorbent applications. These are all properties that have value in the incontinence materials and wipes market where increasing cotton's share is envisioned.

Introduction

Urinary incontinence, products have continually evolved over the last sixty years (Newman, et al., 2004). Absorbent products may be divided into a variety of structural designs for baby care, feminine hygiene, and adult incontinence management (White, 1999, Parts I-III; Richter, 2011). The size and shape of disposable absorbent hygiene products vary including body worn all-in-one diapers, underwear, pads for light to heavy incontinence episodes (Cottenden, 1988, Fader et al. 2010) and bed pads for immobilized patients (Fader, et al., 2004; Baumgarten, et al. 2006; Cottenden et al., 1998; Biesecker, 1995). Common to these products is a basic design motif that is consistent throughout most absorbent incontinence materials: coverstock, acquisition layer, distribution layer, absorbent core, and back sheet (White, 2003).

The coverstock or top-sheet and its corresponding acquisition/distribution layers (ADL) play a key role in providing comfort, dryness, and moisture distribution, and their design depends on the level of incontinence treated. In recent years the patent and research and development literature for incontinence materials has focused on enhancing the sophistication and cost efficiency of absorbent materials that promote urine uptake, transport and retention in design of absorbent materials. Part of the design process involves evaluating the amphiphilic character or hydrophilic versus hydrophobic balance on the surface of the material's fibers as reflected by the degree of fiber surface polarity. For example the hydrophobic/hydrophilic character of the coverstock and acquisition layer and hydrophilic distribution layer is one aspect of design. This design feature works with material porosity and structural and composition design to promote urine transport, absorption capacity and retention to the absorbent product.

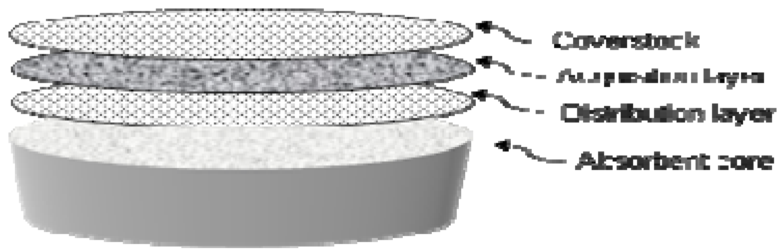

Figure 1: Diagram of the relationship of the absorbent layers of an incontinence material.

Methods used in evaluating hydrophobic/hydrophilic character in the design of incontinence materials have relied principally on water contact angle determinations. The patent literature for nonwoven absorbent materials often cites these values. When analyzed comparatively among fibers, zeta plateau (ζ plateau) can also be viewed as an indication of the relative hydrophobicity and hydrophilicity or fiber surface polarity of the sample as well. For example the rank order of increasing hydrophobicity for four textile fibers has previously been assigned based on zeta plateau as cotton > polyamide > polyester > polyacrylonitrile (Ribitsch and Stana-Kleinscheck, 1998; Grancaric et al., 2005), and it has been previously shown by several studies that the surface of various fibers for textile application may be characterized by their zeta plateau and isoelectric point (IEP) in combination with their water uptake ability and swelling capacity (Bismarck et al., 2002; Reischl et al., 2006; Teli and Rao, 1995). The per cent moisture versus the delta zeta potential (ζ) plotted for the absorbent layers, reflects the degree of swelling and the amount of moisture the material is prone to absorb.

The three categories listed below describe incontinence absorbent materials in the context of an analytical descriptor of surface polarity characterized through zeta potential (Edwards et al., 2012).

1. ***Characteristics of Heavy and Adult Absorbent Materials:*** The coverstock swells more than acquistion layer, and the coverstock is hydrophobic whereas the acquisition/distribution layer is hydrophilic (20 mV increase from coverstock to distribution layer).

2. Characteristics of Moderate Absorbent Materials: The acquisition layer swells more than the coverstock, or a dense high swelling coverstock is coupled to a porous one layer acquisition layer.

3. Characteristics of Light Absorbent Materials: In light incontinence materials there are very hydrophilic isoelectric layers, and the acquisition layer swells more than the coverstock and distribution layer.

Electrokinetic analysis and absorbency have been employed in our lab to characterize the role of material hydrophobic/hydrophilic character or fiber surface polarity. As listed above surface polarity design motifs have been described using this approach based on the charge difference between the coverstock and acquisition/distribution layers. Commercial incontinence products previously evaluated in our lab have been divided into design motifs between the coverstock and acquisition distribution layer in to two-layer or three-layer polarity gradients, and their relevant amphiphilic properties (Edwards, et al., 2012).

Cotton has a variety of absorbent applications which render it advantageous as a medical and hygienic textile. Cotton has found applications in nonwoven medical products including surgical gowns, swabs and drapes, gauze, disposable patient gowns, bandages, wound dressings, sheets, and bed pads (Karthik, 2010). In recent years the preference to use cotton fibers in nonwoven absorbent products has increased due to its characteristic soft hand, hypoallergenic properties, absorbency, and eco-friendly cellulosic character. An increase in commercial applications of cotton nonwovens in non-implantable and hygienic products has been reflected in new product lines, renewed research and development pursuits as well as consumer preferences.

Synthetic fibers of polyester and nylon are also employed in a variety of medical textiles and when combined with cotton increase the spectrum of fiber surface polarity, swelling, and moisture content properties yielding a broader range of absorbent applications.

In recent years the effects of blends of cellulosic and synthetic fibers have been assessed as a way of regulating fluid imbibitions. It has been proposed that improving the resiliency of the web based on the use of synthetic and cellulosic fibers together improves absorbency by increasing web interstitial space and modulating pore size (Gupta, 2000).

It has also been recently reported that Ultra Clean Cotton (greige cotton processed through a proprietary mechanical cleaning process using no chemicals) possesses some attractive properties of absorbency and wickability when made into a hydroentangled nonwoven fabric. Thus, this uniquely produced form of greige cotton is worthy of exploring potential benefits in medical textile applications (Condon, et al., 2010, Sawhney, 2010).

We report here the preparation and electrokinetic analysis of UltraClean Cotton and two different ratio blends of UtraClean/ polyester and UltraClean/polyamide as well as some cotton/cotton by-product blends.

Materials and Methods

Hydroentangled blends of ultraclean cotton with synthetic fibers including polyester and nylon were prepared by first blending the synthetic and natural fibers on a tandem card modified at the ARS/Clemson facility. Subsequently, the cotton/synthetic blended web via conveyor belt were transported to a commercial cross-lapper for producing a multilap assembly, fed to a pre-needling machine for a light needling impact. The needle-punched substrates were subjected to hydroentanglement to produce a number of greige cotton/synthetic fabrics. The cotton/cotton by-product blends were processed in much the same way. The cotton by-products were derived from ginning waste in the form of combers, linters, and motes.

Streaming zeta potential experiments were carried out with the Electro Kinetic Analyzer (Anton Paar, Ashland Va.) using the Cylindrical Cell developed for the measurement of fibrous samples. For each measurement a fiber plug was placed between the Ag/AgCl hollow cylindrical electrodes of the Cylindrical Cell. The pH dependence of the zeta potential was investigated with the background electrolyte of 1 mM KCl solution. The evaluation of zeta potential is based on the Smoluchowski equation (Zeta Potential web site, 2009; Grahame, 1947).

Time-Dependent/Swell Behavior: The swell behavior of the incontinence products was measured using the Anton Paar analyzer with the cylindrical cell template. A 0.65 gram sample is loaded into the cell, and quickly rinsed with electrolyte solution. The flow rate was adjusted in the range of 60-100 ml/min by compression of the sample to remove trapped air. The pH of the sample was about 5.5 and was adjusted to 9.0 with 0.1N NaOH solution.

Moisture Content: The moisture content of the incontinence products was measured using a modified ASTM D629-99 and the AATCC 20A-2000. The sample was conditioned overnight in a humidity chamber with the hygrometer reading at 70% and a room temperature of 23^0C. The moisture measurements were taken with an Infrared Moisture Balance (Kett FD 240, manufactured by Kett Electric Laboratory in Tokyo, Japan). The balance was set for automatic wet-based moisture with a drying temperature of 110^0C. Approximately a one gram sample was used for each measurement on the Kett FD 240.

Swell tests and pH titrations were carried out on the hydroentangled nonwoven fabrics and natural (select) incontinence products. The nonwoven fabrics tested were either cotton-polyester blends, cotton-nylon blends or cotton and cotton by-products. Swell tests were performed during which the zeta potential, ζ, was measured vs time (not shown here).

Results and Discussion

Figure 2 shows the functional value of fluid acquisition due to swelling properties based on percent moisture versus Delta Zeta for the range of cotton/synthetic blends (black dots) and cotton ginning by-products (red dots). The per cent moisture versus the delta zeta potential (□□□ for all ratios of cotton to synthetic blends reflects the degree of swelling and the amount of moisture the material is prone to absorb. It should be noted that as the delta zeta value (x-axis) increases, swelling of the material increases. On the other hand there is a concomitant decrease in moisture uptake. These two properties (moisture uptake and swelling) are key to the efficient performance of incontinence products. It can be seen that a linear relationship is evident suggesting that cotton and synthetic blends can be used together to tune in varying degrees of absorbance and swelling capacity required for moisture absorption and transport with incontinence materials.

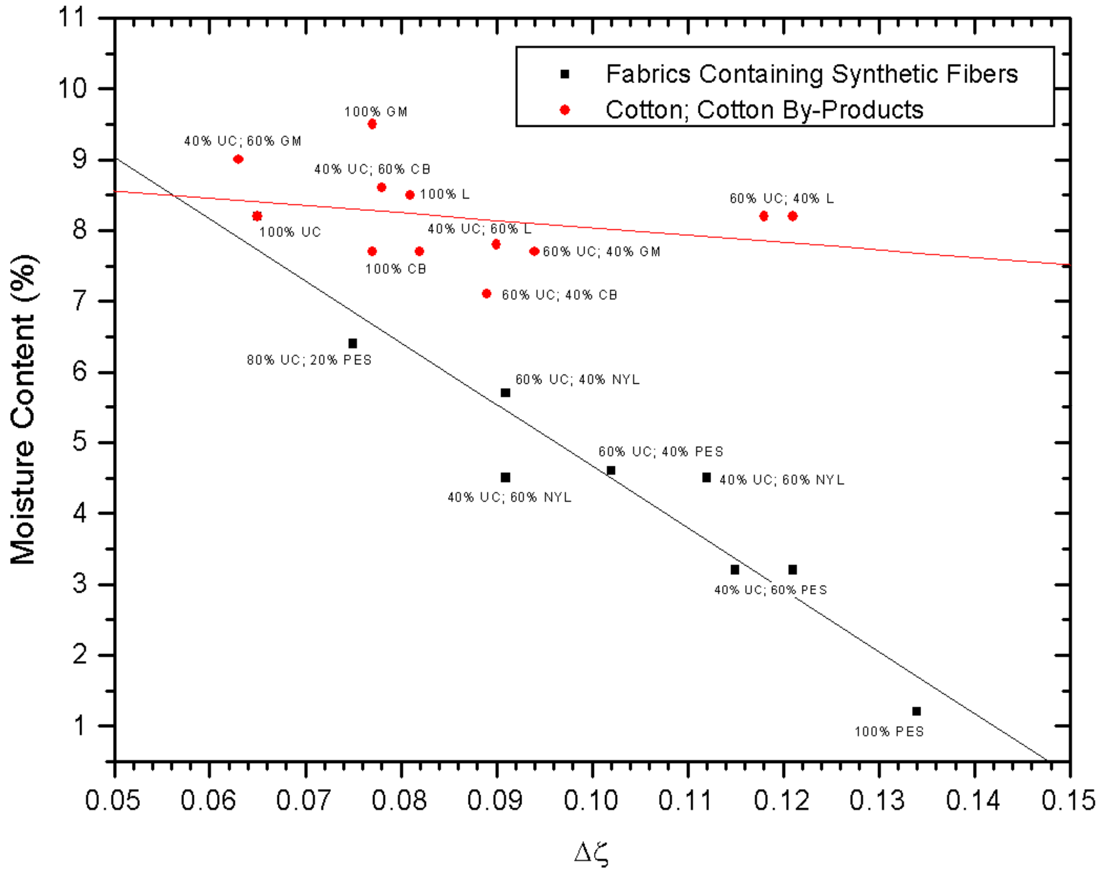

Figure 2: Plot of moisture content % versus □□□for cotton/synthetic blends and cotton and cotton by-products.□□□
This relationship can be explored for its functional value in developing cotton-based incontinence products where the coverstock and acquisition/distribution layers can be designed with the appropriate fiber surface polarity properties. UC = Ultra Clean^{TM} Cotton, PES = Polyester, NYL = Nylon, CB = Combers, GM = Gin motes, L = Linters.

The corresponding moisture uptake, fiber polarity and swelling similarities of commercial coverstock and acquisition layers are compared here in Table 1 with cotton/synthetic blends. It is interesting that similar fiber polarity, moisture uptake and swelling was found among the cotton/synthetic blends with coverstock and acquisition layers from commercial products. All of the blends have similar water uptake, polarity and swelling properties to heavy incontinence material coverstocks. It is also noteworthy that the 40/60 (UC/PES) was comparable to a commercial moderate incontinence acquisition layer, and the 60/40 (UC/NYL) is similar to the coverstock found for a bed pad. In addition it was found that some of the cotton/cotton by-products (60% UC/40% L and 40% UC and 60%CM) also showed similarities to the acquisition layers of heavy and moderate incontinence products.

This paper has focused on the screening of cotton/synthetic blends as incontinence materials. It is apparent from the results of the electrokinetic studies that some of these blends are applicable as absorbent incontinence material layers. We are evaluating this approach in the development of enzyme-based wipes for decontamination and antimicrobial applications. For this purpose lysozyme has been attached to cotton covalently using a low-cost efficient process, and is currently available for licensing. The use of electrokinetic analysis is also useful here in demonstrating the effect of charge as well as moisture and swelling with enzyme-cotton conjugates.

Table 1. Values of percent moisture uptake (% MC) reflecting the ability to take up moisture, zeta plateau ($□_{plateau}$) reflecting the fiber polarity, and □□□ reflecting the swelling capacity of the material. The table compares some values taken from measurements on commercial coverstocks (both Heavy and Light incontinence materials), acquisition layers (Heavy Incontinence) and a bedpad coverstock. UC/PES = Ultra Clean™ Cotton/Polyester.

Composition	**%MC** ***Water Uptake***	**Plateau Potential (mV)** ***Polarity***	**□□□** ***Swelling***	**Density (g/cm^3)**
100%UC	8.2	-26	0.065	0.147
60/40 UC/PES	4.6	-44	0.102	0.110
40/60 UC/PES	3.2	-27	0.115	0.112
60/40 UC/Nylon	5.7	-46	0.091	0.117
40/60 UC/Nylon	4.5	-29	0.112	0.133
Coverstock -Heavy Inct.	3.6	-36/-50	0.15/.2	0.020
Coverstock -Light Inct.	5.4	-35	0.062	0.025
Acquisition -Heavy Inct.	8.89	-20	0.113	0.023
Coverstock -Bedpad	6.67	-48	0.019	0.013

Summary

This paper has discussed our recent work on cotton/synthetic nonwovens, their electrokinetic analysis, and their potential use in incontinence materials. The results of the work demonstrate that greige cotton and greige cotton synthetic blends have fiber polarity, moisture uptake, and swelling capacity properties appropriate for use in absorbent incontinence materials.

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