Development of multi-layered cellulosic nanostructure to be used in chemical protective clothing for agricultural applications

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Background and Problem

Chemical protective clothing (CPC) is the last line of defense in chemical handling operations to safeguard the wearer from hazardous environments (Bhuiyan, Wang, Shaid, Shanks, & Ding, 2019). However, due to the discomfort associated with the recommended chemical protective clothing (CPC) ensembles, agricultural pesticide handlers risk themselves to pesticide exposure by choosing typical woven work clothing over the recommended clothing (Lee & Obendorf, 2007). The typical woven work clothes are usually woven in plain, twill, or rib structures in a varied range of weight; ranging up to 500 g m^{-2}. This implies that these fabrics are also bulky. This research aims at development of lightweight multi-layered nano-structured cellulosic fabrics suitable to provide comfort and increase safety via hydrophilic/hydrophobic interaction.

Experimental Design

Materials

Cellulose acetate (CA) with 39% acetyl content and weight average molecular weight (M_w) of 30,000 was purchased from Sigma-Aldrich (St. Louis, MO, USA). Poly (lactic) acid pellet, Ingeo™ biopolymer 6201D, was purchased from Nature Works (Minnetonka, MN, USA). Sodium hydroxide, Redi-Dri™ anhydrous ACS reagent grade (≥ 97%) pellets were purchased from Sigma-Aldrich. Certified ACS grade Chloroform and acetone were purchased from Fisher Scientific (Fair Lawn, NJ, USA). 300 mm X 300 mm copper gauze (30 mesh), made of 0.15 mm diameter copper wires, were purchased from Alfa Aesar (Ward Hill, MA, USA).

Methods

15 % (w/v) cellulose acetate (CA) solution was prepared in Acetone. 8 % Solution of PLA was prepared in a binary solvent of 1:3 acetone to chloroform. Electrospinning was carried out under ambient atmospheric conditions at a fixed potential difference of 25kV, and at a tip to collector distance of 12 cm. To maintain uniform thickness of fabric, 10mL solution was spun each time at a feeding rate of 0.05 mL min^{-1} on a 30 mesh copper collector. Deacetylation of CA into regenerated cellulose (RC) was done using 0.1M NaOH in a 4:1 NaOH: EtOH solution. Multi-layer sandwich structures were created by sewing together the fabrics with PLA filament fibers (Figure 1).

Characterization

Functional group analysis was done by a Thermo Scientificic Nicolet iS10 Fourier transform infrared (FT-IR) spectrometer. Field emission scanning electron microscope (FEI Quanta 250 FE-SEM) was employed to study the surface morphology of the electrospun non-woven fabrics. The dynamic contact angle measurements were done at room temperature following the Wilhelmy plate technique using a tensiometer (DCAT 11, DataPhysics, Germany) interfaced to a computer using built-in DCATS software (V.4.1.14). All measurements were taken in triplicate, and the average is reported.

Summary of Results

Based on the preliminary research on various copper collectors including copper foil, 10 mesh, and 30 mesh copper, electrospinning was carried out on a 30 mesh copper collector for this study. Complete deacetylation of CA to RC after alkaline treatment was confirmed by FT-IR analysis. RC's and PLA's exhibited different surface morphology (size and roughness) under SEM (Figure 1). Due to extreme hydrophilicity of RC's, water contact angle of pristine layers could not be measured in static contact angle mode. However, dynamic contact angle measurements exhibited a water contact angle of 40.2 ± 1.8. On the other hand, pristine layer of hydrophobic PLA electrospun fabrics exhibited a water contact angle of 96.6 ± 1.4. The triple layered assembly exhibited a water contact angle of 72.1 ± 1.5, meaning hydrophobicity increased due to the presence of sandwiched PLA layer between the top and bottom RC layers. The presentation of the polar against dispersive components of surface energy, commonly known as wetting envelope (Figure 2), revealed that the assembly shifted their dispersive nature to polar in presence of PLA layer, meaning wetting became unfavorable in multilayer structures. This shift might be attributed due to the change in topography and microclimate within the sandwich structure.

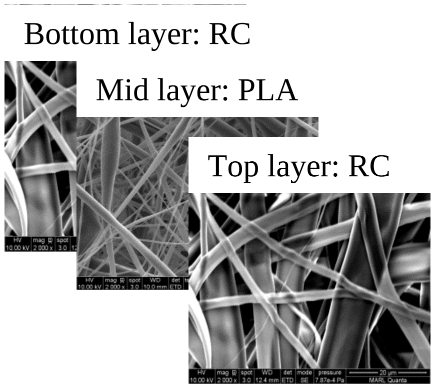

Figure 1. Construction of 3 layered sandwich structure. SEM images were captured at 1000x magnification.

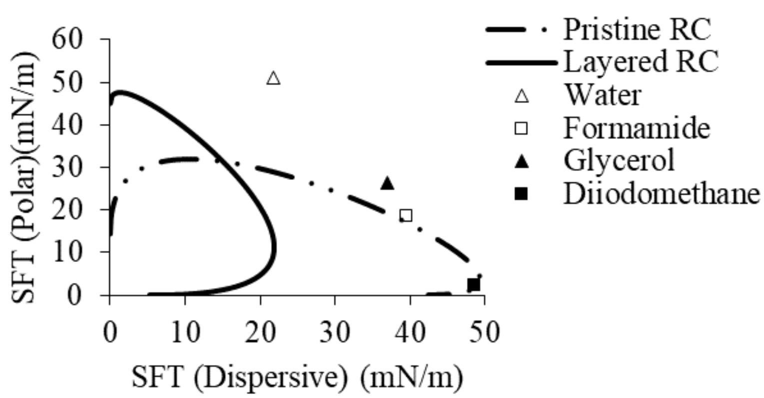

Figure 1. Wetting envelopes of multi layered non-woven fabrics.

Implications

Exposure to pesticides has been associated with adverse health effects including cancer, respiratory dysfunction, hormone disruption, asthma, parkinson's, chronic cough, and dermatitis (Patel, Syamlal, Henneberger, Alarcon, & Mazurek, 2018). Not wearing appropriate CPC lead to this exposure and associated problems. Therefore, we employed electrospinning technique to create a lightweight fabric structure based on RC which would be equally comfortable as cotton. We employed hydrophobic PLA layer in the sandwich structure to manipulate the wetting behavior. This study provides an important insight into the tunability of the wetting behavior by using multilayer structure made of the cellulosic fibers, enabling a comfortable while safe CPC ensemble. Future endeavor is envisioned to incorporate an optical sensor based on RC material to be used in CPC assembly.

References

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