Cellulose (2019) 26:9361–9371
https://doi.org/10.1007/s10570-019-02721-5

ORIGINAL RESEARCH

Development of mechanically durable hydrophobic lanolin/silicone rubber coating on viscose fibers

Tawfik A. Khattab · Salwa Mowafi · Hosam El-Sayed

Received: 11 February 2019 / Accepted: 30 August 2019 / Published online: 6 September 2019

Abstract We report on a simple technique for the production of mechanically durable water-repellent layer on viscose fibers via spray-coating of a lanolin-silicon rubber solution in petroleum ether. Depending on the silicon rubber solution concentration, it was achievable to gain surfaces with hierarchical morphology. Extracted lanolin was admixed with a mixture of a room temperature vulcanizing silicon rubber and petroleum ether to afford the silicon rubber-lanolin formulation, which was applied successfully onto viscose fabrics employing spray-coat procedure. The surface characteristics of the spray-coated viscose fibers were studied by scanning electron microscope, energy dispersive X-ray analysis, and static water contact and sliding angle measurements. The alteration in the chemical composition of viscose-treated fabric was studied using Fourier-transform infrared spectroscopy. The wetting behavior was found to be a function of silicon rubber concentration in ether solution affording coatings with high static water contact angle and low sliding angle values. The treated viscose fabric exhibited excellent ultraviolet protection and enhanced hydrophobicity without adverse effect on its inherent physico-mechanical properties. The comfort characteristics of spray-coated viscose fibers were also evaluated by studying their air-permeability and stiffness. The results displayed durable water-repellent properties of the treated viscose, introducing a good opportunity for a large-scale manufacture of water-repellent textiles for a diversity of industrial purposes.

Keywords Viscose · Lanolin · Silicon rubber · Spray coating · Hydrophobic

Introduction

Purified wool wax, known as "lanolin", is a highly viscous natural matter composed of fats and oils. This lubricant represents about 10–25% of the sheared greasy wool (Yao and Hammond 2006; Flockhart et al. 1998). The hydrophobic nature of lanolin makes it valuable in various industrial fields, such as lubricants, plastics, rustproof coatings, paints, and inks. It can easily combine with a variety of materials to be employed for cosmetics and pharmaceuticals due to its strong emulsification and penetration properties. Its adhesion nature makes it an excellent substance to be applied as a plasticizer in adhesives and resins (Edman

T. A. Khattab
Textile Industries Research Division, Dyeing, Printing, and Textile Auxiliaries Department, National Research Centre, Cairo 12622, Egypt

S. Mowafi · H. El-Sayed (✉)
Textile Industries Research Division, Proteinic and Man-made Fibres Department, National Research Centre, Cairo 12622, Egypt
e-mail: hosam@trdegypt.org

and Möller 1989). Spray coating technology has been introduced as a simple, cheap, and non-contact process to coat surfaces with high speed, insignificant agglomeration, and at a decreased quantity of excess coating paste aerosol (Moridi et al. 2014; Huang et al. 2004; Aziz and Ismail 2015; Khattab et al. 2018a, b, c, 2019; Cheng et al. 2018; Girotto et al. 2009). Room Temperature Vulcanizing (RTV) silicone can be cured at ambient conditions employing a catalyst, such as dibutyltin dilaurate. It is distinguished by good resistance to chemicals, temperature, ageing, and acid/base conditions. It also possesses low viscosity and shrinking, high-quality hardness, good mechanical stress, and easy to apply. RTV has been applied in aviation and printing technologies, electronics, and casting procedure of diverse materials, such as epoxy and polyester resins, low melt-temperature alloys/metals and urethane, wax, and gypsum (Sabri et al. 2015; Labouriau et al. 2015a, b; Heredia-Guerrero et al. 2018; Kumar et al. 2016; Labouriau et al. 2015b).

A hydrophobic surface has attracted a significant consideration due to potential applications in maritime industry, such as drag reduction, antifouling and self-cleaning (Zhang et al. 2019a, b; Liu et al. 2019; Zimmermann et al. 2008). In recent years, various publications have been introduced describing several methods, some of which are complicated, for the development of hydrophobic surfaces on a variety of substrates such as metals, wood and textiles (Hoefnagels et al. 2007; Xue et al. 2013; Zhang et al. 2013, 2019; Xue et al. 2008). Hydrophobic coatings have been highly studied through different physical and chemical techniques, such as lithography, electrospinning, plasma or chemical etching, chemical vapor deposition, self-assembly, and sol–gel methods. However, methods able to introduce mechanically durable water-repellent surfaces employing simple and cost-effective techniques are limited. Some of the above mentioned approaches are mainly characterized by being time-consuming and multiple-step process, which are not practical for developing water-repellent coating for engineering purposes (Rehan et al. 2018; Khalil-Abad and Yazdanshenas 2010; Wang et al. 2011; Xue et al. 2017; Abbas et al. 2015; Abdelmoez et al. 2016). A number of attempts describing a facile approach does not introduce satisfactory hydrophobic surface of suitable mechanical durability. Ogihara et al. reported the creation of hydrophobic surfaces by spraying SiO_2 nanoparticles suspended in an alcohol (Ogihara et al. 2011, 2012, 2013).

Textile industries are as wide and diverse as the goods it affords with inventive applications. There are global competitive manufacturers of textile products, such as yarns, fabrics, furnishings and apparels. High performance textiles can be defined as the textile merchandises that are produced for non-aesthetic purposes, where their functions are the main decisive factor (Khattab et al. 2017, 2018a, b, c; Khattab and Helmy 2019; Aboutalebi et al. 2014; Holme 2007). The major purpose of high performance protecting textiles, such as water-repellent, fire-retardant, and antimicrobial garments, is to improve human safety (Abdelrahman and Khattab 2019; Zimmermann et al. 2008; Chen et al. 2016; Oulton 1995). Hydrophilicity usually reduces the diversity of textile applications, especially in packaging, crafts and transportation. A water-repellent surface with a contact angle $> 150°$ and a sliding angle $< 10°$, forced by lotus phenomenon, has been always a research hot mark for most recent decades due to its remarkable waterproof ability, self-cleaning nature, and antifouling property (Qiang et al. 2017; Chauhan et al. 2019; Ma et al. 2018; Xue et al. 2019). The generation of nano- and micro-hierarchical structures results in a surface roughness and a low surface energy. This nano- and micro-hierarchical morphology can be recognized as sufficient approach to achieve a hydrophobic phenomenon, which is the key function to generate waterproof fabrics. Fluorinated compounds have been used as one of the major applied materials to introduce a hydrophobic surface. However, this approach is not effective due to the toxicity and high cost of those fluorinated materials. Recently, research efforts have been taken into consideration to approve environmentally friendly processing toward water-repellent textiles (Pan et al. 2018; Xu et al. 2013; Si and Guo 2016; Bian et al. 2014; Cao et al. 2017).

In this work, we introduce a cheap and simple process to prepare mechanically durable water-repellent surface on a viscose fabric. In this method, viscose fibers were spray-coated by RTV silicon rubber/lanolin solution. By varying the concentration of RTV silicone rubber solution in petroleum ether, a hierarchical surface with high static contact angle can be produced.

Experimental

Materials

Light-weight 100% plain weave viscose fabrics (150 g m^{-2}) were kindly supplied from Misr Company for Spinning and Weaving, El-Mahalla El-Kobra, Egypt. Purified wool wax (lanolin) was extracted in our labs from wool fleece (Madara and Namango 2014). Decoseal silicon rubber RTV-2540 was supplied by A.D.M. Chemical Industries (ADMICO), Egypt. Petroleum ether (b.p. 60–80 °C; AR Grade) was purchased from Sigma-Aldrich. Reagents were purchased at highest purity available and were employed without further purification.

Spray-coating of viscose fabrics

Lanoline (hereafter LA) 15 wt% (weight of lanoline to volume of petroleum ether) was dissolved in petroleum ether. Silicone rubber (hereafter RTV) was then dissolved in LA/ether solution to prepare solutions with five different concentrations which varied from 3 wt% (RTV-3), 7 wt% (RTV-7), 10 wt% (RTV-10), 12 wt% (RTV-12), to 17 wt% (RTV-17). Viscose substrates were spray-coated by the prepared different concentrations of RTV/LA/ether solution. The spray-coating process of the prepared solutions was carried out under ambient conditions using Lumina automatic spray gun STA-6R (Fuso Seiki Co. Ltd., Tokyo, Japan) bearing spray nozzle with orifice size (1.00 mm). The spray nozzle was moved back and forth over the viscose substrate at a speed of ~ 3 cm/s. It was equipped with pressurized air as a carrier gas at 250 KPa, whereas pressure of inflow air was recorded by a pressure gauge. Distance between viscose fabric and spray nozzle was 20 cm. The solutions were sprayed intermittently with a flow rate of 10 mL/min. In general, the spraying course was conducted until the solution covered the entire viscose fabric. The samples were then air-dried for 30 min on a clean flat surface to evaporate the solvent.

Characterization

Contact angle measurements

Water contact and sliding angles were measured on OCA-15EC (Dataphysics GmbH, Germany) with software. Contact angle properties were carried out with 10 μL drops of triple distilled water. Viscose substrates were connected to glass cover slips using double sided adhesive tape to create a planar surface.

Ultraviolet protection factor

The ultraviolet protection factor (UPF) was automatically calculated according to Australia/New Zealand standard AS/NZS-4399:1996 method employing UPF calculation system of UV/Vis spectrophotometer as reported in the standard AATCC Test Method 183:2010-UVA Transmittance.

Fourier transform infrared spectroscopy

FTIR spectra were measured using the transmission mode on FTIR spectrophotometer (Nexus 670; Nicolet, United States) in the range of 4000–400 cm^{-1} with spectral resolution of 4.0 cm^{-1}. The viscose samples were placed in direct contact with the detector during measurement.

Field emission scanning electron microscope

The morphological properties of both blank and spray-coated viscose samples were tested using field emission scanning electron microscope (FE-SEM) on a Quanta FEG-250 (Czech Republic). The elemental content was investigated by surface Energy-dispersive X-ray analysis (EDAX) unit (TEAM-EDX Model) connected to the electron microscope. The distribution of particles' diameter was measured using Image J software program saved on scanning electron microscope.

Whiteness index

The level of whiteness of untreated and treated samples was determined by studying color strength (K/S) and color coordinates (L^*, a^*, b^*) on a spectrophotometer with pulsed xenon lamp as light source (Ultra Scan Pro, Hunter Lab, United States), and illuminant of D65 with 10° observer, measurement area of 2 mm and d/2 view geometry. An average of five reads at different locations of the tested viscose fabric was recorded and then was taken as the main value.

Bending stiffness

The bending stiffness of viscose fabrics was assessed according to the British Standard method 3356:1961 using Shirley stiffness tester. The bending length was reported as an average of five recorded readings at five different positions for each sample.

Burst strength

The burst strength of both blank and spray-coated viscose fabrics was measured according to the Standard method ASTM 3786, JIKA (Toyoseiki). The burst strength was measured as an average of five recorded readings at five different positions for each sample.

Air-permeability test

The air-permeability exam of viscose samples was reported using the standard ASTM D-737 employing Textest FX 3300 with 100 Pa pressure gradient. The air-permeability was recorded as an average of five readings at five different positions for each viscose substrate.

Durability test

To study the durability of the finished fabrics, the spray-coated specimens were washed for 1, 5, 10, and 20 laundering cycles according to the standard AATCC 61-1989 method. The treated viscose sample (5 × 15 cm) was placed in a launder-o-meter and accelerated machine laundering with a detergent solution (200 mL) at a temperature of 40 ± 3 °C for 45 min. The UPF efficacy as well as the contact angle measurements was assigned as indicators for the durability of the proposed treatment.

Results and discussion

Treatment of viscose by RTV/LA

This work was devoted to render hydrophobic surface to viscose fabrics using lanolin, extracted from raw wool fleece, in combination with silicon rubber. Mixtures of lanoline (LA) 15 wt% and silicone rubber (RTV) was prepared at five different concentrations of RTV from 3 wt% (RTV-3), 7 wt% (RTV-7), 10 wt% (RTV-10), 12 wt% (RTV-12), to 17 wt% (RTV-17), where the weight percentage was considered to the volume of petroleum ether. Viscose fabrics were spray-coated by the prepared RTV/LA solutions. The spraying process was performed until the solution completely covered the whole surface of the viscose fabric followed by air dying.

Contact and sliding angles

Figure 1 and Table 1 show the results of the static contact angle measurements of untreated viscose (Fig. 1a), lanolin (only)-treated viscose (Fig. 1b), RTV (only)-treated viscose (Fig. 1c), and RTV/LA-treated viscose (Fig. 1d). It was observed that the water contact angle of viscose fabric increased when it was treated with either lanolin or silicon rubber to nearly the same degree from 101.5° for blank/untreated viscose to 131.0° LA (only)-loaded viscose, 134.5° RTV (only)-loaded viscose and 141.8° for RTV-LA. Thus, further increase in contact angle of viscose fabric was attained upon treatment with lanolin followed by silicon rubber; by virtue of a synergetic effect of the aforementioned two hydrophobic reagents. Similarly, the static contact angles of the treated fabrics were measured after 20 washing cycles. We can conclude from Fig. 1e,f,g that washing of viscose-treated fabrics LA (only)-loaded, RTV (only)-loaded and RTV-LA substrates respectively, resulted in acceptable decrease in their water contact angles to 121.7°, 120.8° and 131.0°, respectively.

A rough surface was fabricated via spray-coating of RTV-LA applied on viscose surfaces of RTV-3, RTV-7, RTV-10, RTV-12 and RTV-17 with static water contact angles between 112.7°, 128.6°, 148.1°, 135.8° and 119.8° depending on RTV concentration between 3 wt% (a), 7 wt% (b), 10 wt% (c), 12 wt% (d), and 17 wt% (e), respectively, as depicted in Table 2. At low RTV content (3 wt% and 7 wt%), the surfaces demonstrated a fairly rough morphology compared to uncoated pristine sample. Accordingly, the fibrous surface was covered by a thin layer of RTV-LA. Upon increasing RTV content (12 wt% and 17%), in addition to covering the viscose fibrous surface, the surface pores located among the viscose fibers were also filled by RTV-LA and the roughness was accordingly decreased. Thus the surface roughness at high RTV content was decreased due to increasing RTV-LA film

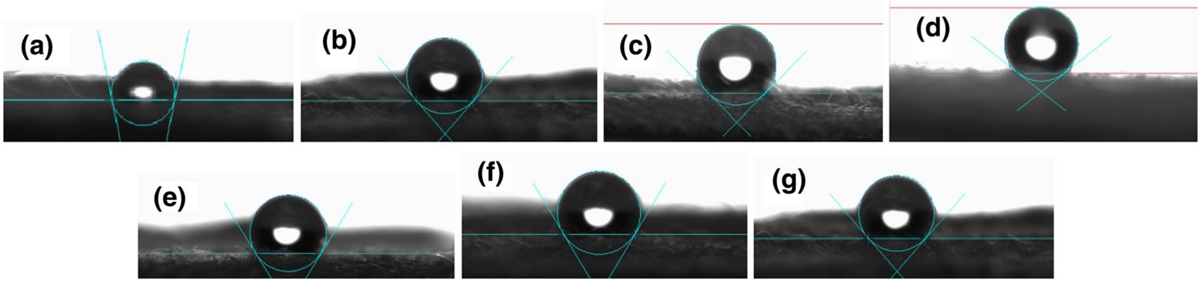

Fig. 1 Static water contact angles of the untreated viscose fabric (**a**), LA-treated fabric (**b**), RTV-10-treated fabric (**c**), LA/RTV -10-treated fabric (**d**), LA-treated fabric, then 20 washing cycles (**e**), RTV-10-treated fabric then 20 washing cycles (**f**), and LA/RTV-10-treated fabric then 20 washing cycles (**g**); LA concentration was fixed at 15 wt%

Table 1 Static water contact angles of treated as well as untreated viscose fabric

Sample	Static water contact angle (°)	SD (for 7 measurements)
Untreated viscose fabric	101.5	0.16
LA-treated viscose fabric	131.0	0.11
RTV-10-treated viscose fabric	134.5	0.06
LA/RTV-10-treated viscose fabric	141.8	0.11
LA-treated viscose fabric, then 20 washing cycles	121.7	0.10
RTV-10-treated viscose fabric then 20 washing cycles	120.8	0.08
LA/RTV-10-treated viscose fabric then 20 washing cycles	131.0	0.58

Table 2 Static water contact angles of the spray-coated viscose at different concentrations of RTV; LA concentration was fixed at 15 wt%

Sample (conc.)	Contact angle		Sliding angle	
	Value (°)	SD (7 measurements)	Value (°)	SD (7 measurements)
RTV-3	112.7	0.08	5	0.05
RTV-7	128.6	0.07	8	0.05
RTV-10	148.1	0.10	11	0.8
RTV-12	135.8	0.11	12	0.7
RTV-17	119.8	0.08	13	0.8

thickness. Because increasing RTV-LA content led to increasing the quantity of particles on the substrate surface and the surface roughness was accordingly reduced, the presence of optimum RTV-LA content was considered (Fig. 2). Consequently, the entire surface of the viscose fibers was fairly covered by hydrophobic RTV-LA, whilst the surface pores among fibers were not filled by RTV-LA (Abdelrahman and Khattab 2019; Nouri and Saadat-Bakhsh 2017; Seyedmehdi et al. 2012).

The sliding angle was also employed as an additional factor to assess the quality of the water-repellent viscose surface as summarized in Table 2. When the LA/RTV solutions were applied to spray-coat viscose fabrics, the wetting behavior was shifted as the sliding angle was increased as a function of RTV concentration. There have been a variety of methods in literature reporting the generation of water-repellent surface using toxic and/or expensive materials, which were then applied via sophisticated processing and time-consuming processes (Zhu 2018). Therefore, it is a

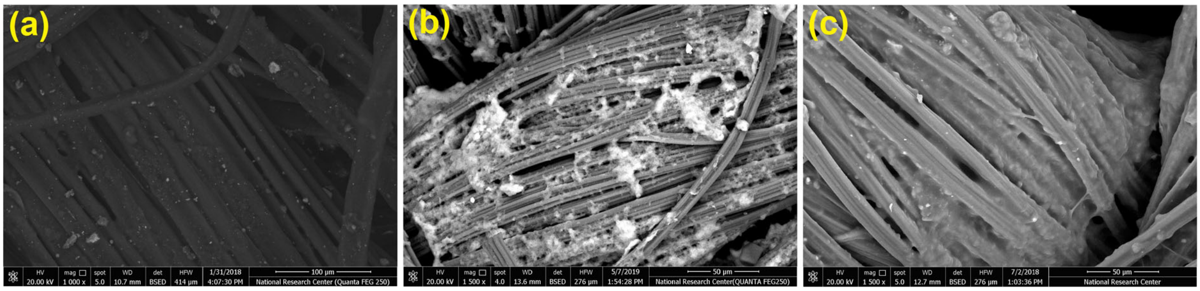

Fig. 2 SEM images demonstrate the surface roughness of the treated viscose fabrics at different RTV concentrations **a** RTV-3, **b** RTV-10, and **c** RTV-17

technical challenge to establish hydrophobic substrates by applying our simple and cheap spray-coating technique in absence of any complicated instrumentations. Moreover, this simple technique can be employed for potential large-scale manufacturing of hydrophobic products for a variety of practical applications, such as water-repellent tents.

Ultraviolet protection factor (UPF)

The protective effect of cloths against the harmful ultraviolet rays is of great importance for people safety. The UPF values of untreated as well as treated viscose fabrics were assessed and the results were summarized in Table 3. Treatment of viscose fabric with lanolin (LA only) or silicon rubber (RTV only) enhanced its resistance to transmission of ultraviolet rays to 30.7% or 38.5%, respectively. The synergetic action of lanolin and silicon rubber (RTV-LA) on viscose fabric enhanced its UPF to 53.8%. A remarkable decrease in the UPF values after 20 washing cycles was monitored for either lanolin(only)-treated samples or silicon rubber(only)-treated viscose fabrics. On the other hand, samples treated with LA/RTV lost only one-third of their UPF efficacy after 20 wash cycles; presumably due to encapsulation of viscose fibrils with LA/RTV layer which can withstand the effect of washing. This indicates that the treatment of viscose with RTV-LA mixture is more durable, particularly when compared to lanolin (only) or silicon rubber (only)-treated fabrics. These findings are in harmony with the results of water contact angle measurements.

Morphological properties of spray-coated viscose

The morphological characterization of RTV-LA incorporated onto viscose surface was investigated by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDAX). Studying the fiber morphology of the treated viscose fabrics in comparison with the untreated fabric would account for the hydrophobic nature of lanolin and or silicon rubber treated fabrics. Figure 3 shows the Scanning Electron Micrographs (SEMs) of untreated as well as treated viscose fabrics. Figure 3a shows the SEM of the normal pattern of untreated viscose fabric. Treatment of viscose fabrics with lanolin resulted in coating of the fiber with an even uniform hydrophobic layer of lanolin; which rationalizes the induced water-

Table 3 The UPF of untreated as well as LA and/or RTV-treated viscose fabric

Sample	Improvement % in UPF (relative to untreated sample) at different washing cycles[a]				
	0 wash	1 wash	5 wash	10 wash	20 wash
LA loaded fabric	30.7	23.0	16.1	15.0	14.8
RTV loaded fabric	38.5	25.0	20.0	18.7	18.4
RTV-LA loaded fabric	53.8	40.0	36.1	35.2	35.2

[a] The standard deviation of each result ranged between 0.05 and 0.66 (5 measurements each)

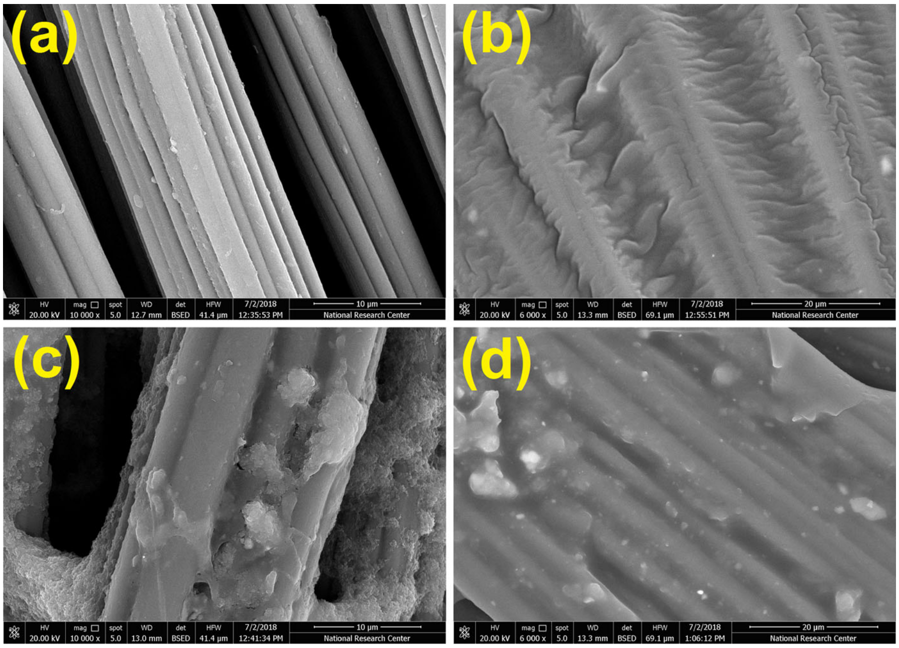

Fig. 3 SEM images of **a** blank, **b** LA-treated, **c** RTV-10-treated, and **d** LA/RTV-10-treated viscose fabrics

repellency to lanolin-treated viscose fabrics (Fig. 3b). Treatment of viscose fabrics with silicon rubber resulted in formation of a heterogeneous layer on the fiber surface, as indicated in Fig. 3c. Comparing SEM images in Fig. 3 proves that the treatment of viscose fabrics with lanolin together with silicon rubber made an even homogenous layer, which is responsible for the water-repellency induced nature of the treated fabrics (Fig. 3d). The elemental content in at% and wt% of the treated viscose substrate RTV-10 concentrations, at three different positions, are demonstrated in Fig. 4 and Table 4. The elemental content of the spray-coated viscose was quite the same confirming the homogenous distribution of RTV-LA on viscose. The creation of nano/micro hierarchical structures led to a surface roughness of low surface energy, and consequently resulted in the hydrophobic phenomenon as shown in Fig. 5.

Fourier transform infrared spectra

FT-IR Spectra was used to prove the substantivity of viscose fabric to lanolin. The characteristic bands within the FT-IR chart of viscose fabric are shown in Fig. 6 shows. The characteristics broad band for the stretching vibration of hydroxyl group appeared at 3313 cm^{-1}. The C–O stretching vibration appears as a sharp intense band at 1017 cm^{-1}.

In the FT-IR chart of lanolin-treated viscose fabric, we can observe that a new sharp weak band appeared at 1736 cm^{-1} which corresponds to the carbonyl group stretching vibration found in the esters found in lanolin.

Physico-mechanical and colorimetric properties

The major reason of using spray-coating procedure was to present a smooth hydrophobic layer with lower optimal surface roughness, while keeping the fabric's breathability and flexibility. Results of air-permeability for treated as well as untreated viscose fabrics, summarized in Table 5, reveals that coating process did not considerably affect on air-permeability by increasing RTV-LA content.

The effect of treatment of viscose fabric with lanoline/silicon rubber system on some of its inherent physical properties was investigated and the results thereof were summarized in Table 6. It is clear from the data in Table 6 that viscose fabrics lost about 20% of its degree of whiteness upon treatment with lanolin/silicon rubber system. On the other hand, no appreciable effect of this treatment on the burst strength of

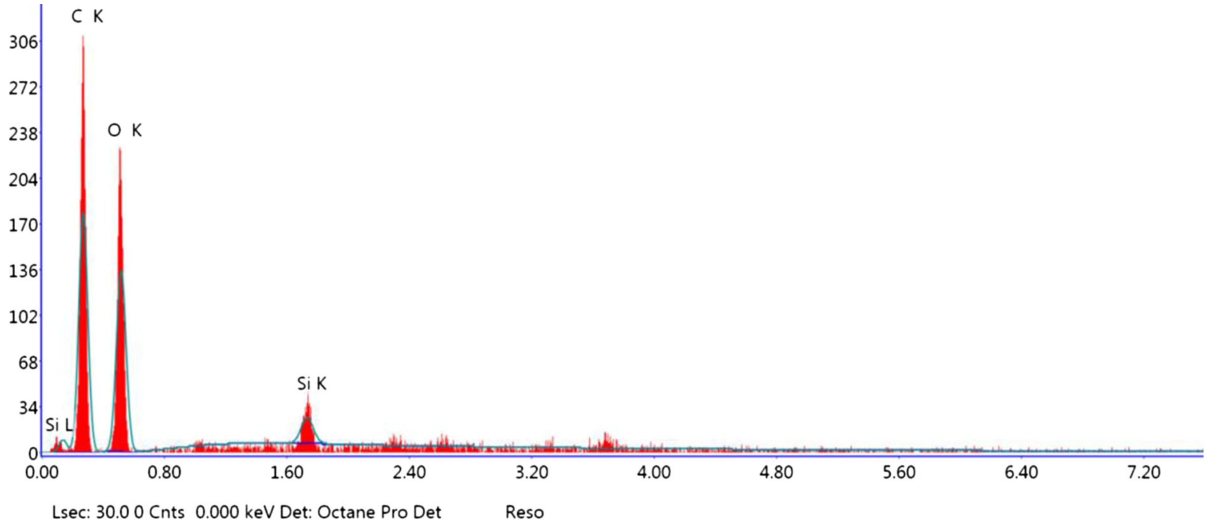

Fig. 4 EDAX diagrams of lanolin/silicon rubber-treated viscose fabric at three different positions on surface of the treated viscose sample (RTV-10); area 1 (top) and area 2 (bottom)

Table 4 Elemental analysis (wt%) at three different positions of the treated viscose sample (RTV-10)

RTV-LA viscose	C	O	Si
Area 1	50.29	48.38	1.33
Area 2	50.62	48.09	1.29
Area 3	50.43	48.21	1.36

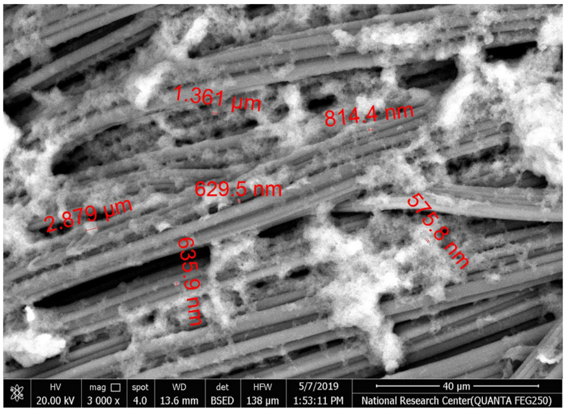

Fig. 5 SEM image of LA/RTV-10-treated viscose fabric displaying the nano/micro-hierarchical morphology

viscose fabrics, was traced after being treated with lanolin and silicon rubber. On the contrary, the bending length of the treated fabrics in the warp and weft direction was significantly enhanced relative to the untreated sample. In general, the hydrophobic property imparted to the treated viscose fabrics has had no negative impact on the inherent physic-mechanical properties of viscose.

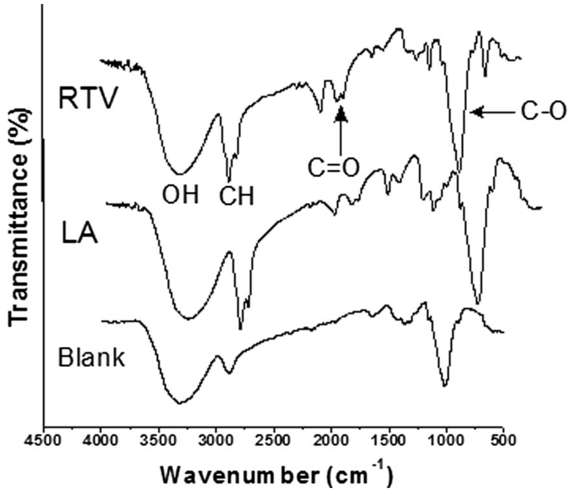

Fig. 6 FT-IR chart of untreated viscose fabric, lanolin-treated viscose fabric, and RTV-treated viscose fabric

To evaluate the color changes owing to LA-RTV layer, both of CIE Lab color coordinates (L^*, a^*, b^*) and color strength (K/S) were reported and presented in Table 7. As was anticipated, only negligible color shifts were monitored after treating viscose with the said reagents. This was verified by the very close

Table 5 Air-permeability of treated viscose samples at different total content of RTV (concentration of LA is 15 wt%)

Sample (conc.)	Air-permeability ($cm^3\ cm^{-2}\ s^{-1}$)	
	Value	SD (out of 5 measurements)
Blank viscose	59.30	0.04
RTV-3	58.71	0.01
RTV-7	58.36	0.03
RTV-10	58.07	0.05
RTV-12	57.90	0.01
RTV-17	56.43	0.02

Table 7 Coloration measurements of untreated as well as treated viscose fabrics at different concentrations of RTV (concentration of LA is 15 wt%)

Treatment	*K*/*S* (λ_{max}: 430 nm)	L^*	a^*	b^*
Blank	0.03	96.12	0.02	2.87
RTV-3	0.07	95.82	− 0.10	2.73
RTV-7	0.13	95.61	− 0.09	2.56
RTV-10	0.17	95.44	− 0.02	2.18
RTV-12	0.18	95.35	0.05	1.75
RTV-17	0.21	94.87	0.17	1.49

The standard deviation of each result ranged between 0.05 and 0.18 (5 measurements each)

values of both color strength and color coordinates which were recorded for treated and untreated viscose fabrics.

Conclusion

Intumescing coating was incorporated onto viscose fabric employing a mixture of the environmentally friendly RTV silicone rubber and lanoline to impart water-repellent property. The results were demonstrate by investigating the surface morphological properties of the spray-coated viscose using Fourier transform infrared spectroscopy, scanning electron microscopy, and energy-dispersive X-ray spectroscopy. The static water contact angles were monitored in the range between 112.7° and 148.1°, while the sliding angles were between 5° and 13°. Lanolin, extracted from wool sheep, was found to be an appropriate candidate for imparting hydrophobicity to viscose fabric; a property which is obliged in definite textile applications. The hydrophobocity is even enhanced by post treatment of lanolin-treated viscose fabric with silicon rubber. This new application of lanolin would open the door to new era of utilization of lanolin in industries other than cosmetics. The obtained hydrophobic viscose fabrics exhibited adequate protection against ultraviolet rays as well as enhanced comfortability, without adverse deterioration in the inherent physico-mechanical properties of viscose. The lanolin/silicon rubber-treated viscose fabrics lost less than one-fifth of its ultraviolet protection efficacy after 20 wash cycles. The comfort features of spray-coated viscose were also evaluated to show satisfactory stiffness and air-permeability.

Table 6 Physico-mechanical properties of untreated as well as LA/RTV-treated viscose fabrics (concentration of LA is 15 wt%; and that of RTV is 10 wt%)

Viscose fabric	Whiteness index	Burst strength (KPa)	Bending length (cm)	
			Warp	Weft
Untreated	33.4	290.5	2.4	2.8
LA-treated	28.6	288.2	3.1	3.3
RTV-treated	29.0	287.4	3.3	3.5
LA/RTV-treated	27.9	289.0	3.8	3.9

The standard deviation of each result ranged between 0.01 and 0.26 (3 measurements each)

Acknowledgments The authors are indebted to the National Research Centre of Egypt for the financial support through Project Number 11070204.

References

Abbas R, Khereby M, Sadik W, El Demerdash A (2015) Fabrication of durable and cost effective superhydrophobic cotton textiles via simple one step process. Cellulose 22:887–896

Abdelmoez S, Abd El Azeem R, Nada A, Khattab A (2016) Electrospun PDA-CA nanofibers toward hydrophobic coatings. Zeitschrift für Anorganische und Allgemeine Chemie 642:219–221

Abdelrahman MS, Khattab TA (2019) Development of one-step water-repellent and flame-retardant finishes for cotton. ChemistrySelect 4(13):3811–3816

Aboutalebi S, Jalili R, Esrafilzadeh D, Salari M, Gholamvand Z, Yamini S, Konstantinov K et al (2014) High-performance multifunctional graphene yarns: toward wearable all-carbon energy storage textiles. ACS Nano 8:2456–2466

Aziz F, Ismail A (2015) Spray coating methods for polymer solar cells fabrication: a review. Mater Sci Semicond Process 39:416–425

Bian P, Dai Y, Qian X, Chen W, Yu H, Li J, Shen J (2014) A process of converting cellulosic fibers to a superhydrophobic fiber product by internal and surface applications of calcium carbonate in combination with bio-wax post-treatment. RSC Adv 4:52680–52685

Cao G, Zhang W, Jia Z, Liu F, Yang H, Yu Q, Wang Y, Di X, Wang C, Ho S (2017) Dually prewetted underwater superoleophobic and under oil superhydrophobic fabric for successive separation of light oil/water/heavy oil three-phase mixtures. ACS Appl Mater Interfaces 9:36368–36376

Chauhan P, Kumar A, Bhushan B (2019) Self-cleaning, stain-resistant and anti-bacterial superhydrophobic cotton fabric prepared by simple immersion technique. J Colloid Interface Sci 535:66–74

Chen X, Guan Y, Wang L, Sanbhal N, Zhao F, Zou Q, Zhang Q (2016) Antimicrobial textiles for sutures, implants, and scaffolds. In: Sun G (ed) Antimicrobial textiles. Woodhead Publishing, Sawston, pp 263–285

Cheng Q, Liu M, Li Y, Zhu J, Du A, Zeng B (2018) Biobased super-hydrophobic coating on cotton fabric fabricated by spray-coating for efficient oil/water separation. Polym Test 66:41–47

Edman B, Möller H (1989) Testing a purified lanolin preparation by a randomized procedure. Contact Dermat 20:287–290

Flockhart I, Steel I, Kitchen G (1998) Nanoemulsions derived from lanolin show promising drug delivery properties. J Pharm Pharmacol 50:141-141

Girotto C, Rand B, Genoe J, Heremans P (2009) Exploring spray coating as a deposition technique for the fabrication of solution-processed solar cells. Sol Energy Mater Sol Cells 93:454–458

Heredia-Guerrero A, Ceseracciu L, Guzman-Puyol S, Paul Uttam, Alfaro-Pulido A, Grande Chiara, Vezzulli L et al (2018) Antimicrobial, antioxidant, and waterproof RTV silicone-ethyl cellulose composites containing clove essential oil. Carbohyd Polym 192:150–158

Hoefnagels H, Wu D, With G, Ming W (2007) Biomimetic superhydrophobic and highly oleophobic cotton textiles. Langmuir 23:13158–13163

Huang K, Yeh J, Shun T, Chen S (2004) Multi-principal-element alloys with improved oxidation and wear resistance for thermal spray coating. Adv Eng Mater 6:74–78

Holme I (2007) Innovative technologies for high performance textiles. Color Technol 123:59–73

Khalil-Abad M, Yazdanshenas M (2010) Superhydrophobic antibacterial cotton textiles. J Colloid Interface Sci 351:293–298

Khattab TA, Helmy H (2019) Industrial and filtration textiles. In: Paul R (ed) High performance technical textiles. Wiley, Hoboken, pp 215–237

Khattab T, Elnagdi M, Haggag K, Abdelrahman A, Abdelmoez S (2017) Green synthesis, printing performance, and antibacterial activity of disperse dyes incorporating arylazopyrazolopyrimidines. AATCC J Res 4:1–8

Khattab T, Abou-Yousef H, Kamel S (2018a) Photoluminescent spray-coated paper sheet: write-in-the-dark. Carbohyd Polym 200:154–161

Khattab T, Rehan M, Hamouda T (2018b) Smart textile framework: photochromic and fluorescent cellulosic fabric printed by strontium aluminate pigment. Carbohyd Polym 195:143–152

Khattab T, Rehan M, Hamdy Y, Shaheen T (2018c) Facile development of photoluminescent textile fabric via spray coating of Eu(II)-doped strontium aluminate. Ind Eng Chem Res 57:11483–11492

Khattab TA, Fouda MM, Abdelrahman MS, Othman SI, Bin-Jumah M, Alqaraawi MA, Al Fassam H, Allam AA (2019) Development of illuminant glow-in-the-dark cotton fabric coated by luminescent composite with antimicrobial activity and ultraviolet protection. J Fluoresc 29(3):703–710

Kumar V, Lee D, Lee J (2016) Studies of RTV silicone rubber nanocomposites based on graphitic nanofillers. Polym Testing 56:369–378

Labouriau A, Cady C, Gill J, Taylor D, Zocco A, Stull J, Henderson K, Wrobleski D (2015a) The effects of gamma irradiation on RTV polysiloxane foams. Polym Degrad Stab 117:75–83

Labouriau A, Robison T, Meincke L, Wrobleski D, Taylor D, Gill J (2015b) Aging mechanisms in RTV polysiloxane foams. Polym Degrad Stab 121:60–68

Liu K-F, Li P-P, Zhang Y-P, Liu P-F, Cui C-X, Wang J-C, Li X-J, Qu L-B (2019) Laboratory filter paper from superhydrophobic to quasi-superamphiphobicity: facile fabrication, simplified patterning and smart application. Cellulose 26(6):3859–3872

Ma Y, Cao C, Hou C (2018) Preparation of super-hydrophobic cotton fabric with crosslinkable fluoropolymer. In: Zhao P, Ouyang Y, Xu M, Yang L, Ren Y (eds) Applied sciences in graphic communication and packaging. Springer, Singapore, pp 955–962

Madara D, Namango S (2014) Wool grease recovery from scouring effluent at textile mill. J Agric Pure Appl Sci Technol 10:1–9

Moridi A, Gangaraj S, Guagliano M, Dao M (2014) Cold spray coating: review of material systems and future perspectives. Surf Eng 30:369–395

Nouri NM, Saadat-Bakhsh M (2017) Fabrication method of large-scale and mechanically durable superhydrophobic silicon rubber/aerogel coating on fibrous substrates. J Coat Technol Res 14(2):477–488

Ogihara H, Okagaki J, Saji T (2011) Facile fabrication of colored superhydrophobic coatings by spraying a pigment nanoparticle suspension. Langmuir 27:9069–9072

Ogihara H, Xie J, Okagaki J, Saji T (2012) Simple method for preparing superhydrophobic paper: spray-deposited hydrophobic silica nanoparticle coatings exhibit high water-repellency and transparency. Langmuir 28:4605–4608

Ogihara H, Xie J, Saji T (2013) Factors determining wettability of superhydrophobic paper prepared by spraying nanoparticle suspensions. Colloids Surf A 434:35–41

Oulton P (1995) Fire-retardant textiles. Chemistry of the textiles industry. In: Carr CM (ed) Blackie academic and professional, chapter 3. Springer, Singapore, pp 102–124

Pan G, Xiao X, Yu N, Ye Z (2018) Fabrication of superhydrophobic coatings on cotton fabric using ultrasound-assisted in situ growth method. Prog Org Coat 125:463–471

Qiang S, Chen K, Yin Y, Wang C (2017) Robust UV-cured superhydrophobic cotton fabric surfaces with self-healing ability. Mater Des 116:395–402

Rehan M, Khattab T, Barohum A, Gätjen L, Wilken R (2018) Development of Ag/AgX (X = Cl, I) nanoparticles toward antimicrobial, UV-protected and self-cleanable viscose fibers. Carbohyd Polym 197:227–236

Sabri F, King D, Lokesh A, Hatch C, Duran R (2015) Thermal, optical, and electrical characterization of thin film coated RTV 655 bilayer system. J Appl Polym Sci 132:41396–41407

Seyedmehdi SA, Zhang H, Zhu J (2012) Superhydrophobic RTV silicone rubber insulator coatings. Appl Surf Sci 258(7):2972–2976

Si Y, Guo Z (2016) Eco-friendly functionalized superhydrophobic recycled paper with enhanced flame-retardancy. J Colloid Interface Sci 477:74–82

Wang L, Zhang X, Li B, Sun P, Yang J, Xu H, Liu Y (2011) Superhydrophobic and ultraviolet-blocking cotton textiles. ACS Appl Mater Interfaces 3:1277–1281

Xu F, Liu Y, Lin F, Mondal B, Lyons A (2013) Superhydrophobic TiO2–polymer nanocomposite surface with UV-induced reversible wettability and self-cleaning properties. ACS Appl Mater Interfaces 5:8915–8924

Xue C, Jia S, Zhang J, Tian L, Chen H, Wang M (2008) Preparation of superhydrophobic surfaces on cotton textiles. Sci Technol Adv Mater 9:035008

Xue C, Ji P, Zhang P, Li Y, Jia S (2013) Fabrication of superhydrophobic and superoleophilic textiles for oil–water separation. Appl Surf Sci 284:464–471

Xue C, Li M, Guo X, Li X, An Q, Jia S (2017) Fabrication of superhydrophobic textiles with high water pressure resistance. Surf Coat Technol 310:134–142

Xue C, Fan Q, Guo X, An Q, Jia S (2019) Fabrication of superhydrophobic cotton fabrics by grafting of POSS-based polymers on fibers. Appl Surf Sci 465:241–248

Yao L, Hammond G (2006) Isolation and melting properties of branched-chain esters from lanolin. J Am Oil Chem Soc 83:547–552

Zhang M, Wang C, Wang S, Li J (2013) Fabrication of superhydrophobic cotton textiles for water–oil separation based on drop-coating route. Carbohyd Polym 97:59–64

Zhang Y-P, Yang J-H, Li L-L, Cui C-X, Li Y, Liu S-Q, Zhou X-M, Qu L-B (2019a) Facile fabrication of superhydrophobic copper-foam and electrospinning polystyrene fiber for combinational oil-water separation. Polymers 11(1):97

Zhang Y-P, Li P-P, Liu P-F, Zhang W-Q, Wang J-C, Cui C-X, Li X-J, Qu L-B (2019b) Fast and simple fabrication of superhydrophobic coating by polymer induced phase separation. Nanomaterials 9(3):411

Zhu J (2018) A novel fabrication of superhydrophobic surfaces on aluminum substrate. Appl Surf Sci 447:363–367

Zimmermann J, Reifler F, Fortunato A, Gerhardt L, Seeger S (2008) A simple, one-step approach to durable and robust superhydrophobic textiles. Adv Func Mater 18:3662–3669