A facile coating with water-repellent and flame-retardant properties on cotton fabric†

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A facile coating consisting of chitosan (CS), phytic acid (PA) and silicon dioxide (SiO2) modified with hexamethyldisilylamine (HMDS) was fabricated with a simple repeated coating technique and applied onto cotton fabric (CF) to achieve both superhydrophobicity and flame retardancy. SEM observation revealed that CS/PA/HMDS–SiO2 CF has a hierarchical rough surface. ATR-FTIR characterization results and XPS spectra verified the structure of the coating on the CF surface. The as-prepared coating on CF showed excellent waterproofing ability, mechanical stability and thermal stability in air. A flame test indicated the coating can protect cotton sample burning off. In particular, the coated CF still retained water-repellent and flame-retardant properties to some extent even after 50 abrasion cycles with sandpaper (400 cW). Hence, the coating on CF possesses potential application in outdoor clothing, equipment and the military.

1. Introduction

Recently, water-repellent properties applied on cotton textile surfaces have been broadly explored and applied in self-cleaning, oil-water separation, anti-condensation and other fields.1,2 Superhydrophobic surfaces with a water contact angle greater than 150° and a sliding angle (SA) below 10° resulted in the prevention of water absorption and a self-cleaning effect.3,4 Nevertheless, most textiles are highly flammable, and this has led to lots of fire disasters, which brings not only massive damage to human properties and lives worldwide but also severe destruction to our surrounding environment.5 The fabrication of a flame-retardant and superhydrophobic fabric is necessary.

Fabrics with waterproof and flame-retardant coatings are widely utilized in civilian and military applications,9 such as automotive interiors, outdoor clothing and tents, firefighter apparel and military garments. Among the many flame-retardant treatments of fabrics, surface modification is the most effective and convenient strategy.7–9 The treatment of the surface of fabrics does not modify the intrinsic properties (e.g., mechanical properties) of the textiles and can be purposely integrated with functional components to achieve multiple functions.10

Various waterproof and flame-retardant coatings on fabric surfaces have been fabricated by researchers in recent years. The Wei group synthesized linear x,ω-di-[4-butoxypiperazin-1-yl]phosphinic acid methyl ether]-terminated polysiloxane and cyclic-shaped poly[tetra(tetramethylcyclosiloxyl)piperazin]phosphinic acid methyl ether] macromolecules as flame retardants.11,12 These multifunctional copolymers have both flame retardant and hydrophobic properties for cotton fabrics, and showed excellent durability. Chen et al. reported flame-retardant and superhydrophobic cotton textiles, which were fabricated with introduction of fluorine–silicon-containing polymer networks and 9,10-dihydro-9-oxa-10-phosphaphenanthrene 10-oxide onto the surface of cotton fabric.13 The Chen team have demonstrated the fabrication of flame-retardant and self-healing superhydrophobic cotton fabric by using a solution-dipping method that involves the sequential deposition of a trilayer of branched poly(ethyleneimine), ammonium polyphosphate, and fluorinated decyl polyhedral oligomeric silsesquioxane.14 These cases involve the participation of organosilicon, which is a smoke suppressor and low surface energy material. The Si–O–Si structure could be incorporated into the flame-retardant isolation layer and enhance stability.15,16 Si–R is a hydrophobic group, which can endow cotton fabric with water repellency.17 However, these approaches still have some disadvantages, such as complicated and time-consuming operations and the use of expensive and toxic compounds.
Considering green chemistry and environmental issues, the coating treatments of textiles that come in close contact with the body have created a desire to use “green” materials. Intumescent coating is a subset of flame-retardant technology with a simple and environmentally friendly preparation commonly used to protect cotton textiles.\(^{18}\) We chose the chitosan (CS)–phytic acid (PA) system as an intumescent flame-retardant coating to apply in our work. CS is an abundant, natural and cationic biopolymer with nontoxicity, biodegradability and antibacterial activity properties.\(^{19}\) The natural, non-noxious, renewable and phosphorus-rich characteristics make PA an attractive green product which can be coupled with CS to form an eco-friendly flame-retardant system.\(^{20,21}\) In this study, we fabricated a flame-retardant and water-repellent coating on cotton fabric (CF) using pollution-free compounds and by the simple repeated coating technique. The flame-retardant coating consists of a bilayer of CS/phosphoric acid (PA) fabricated with the formation of a polyelectrolyte complex (PEC). Subsequently, a hydrophobic layer of –Si(CH\(_3\)\(_3\)) functionalized SiO\(_2\) nanoparticles was deposited on the PEC surfaces. The water-repellent properties of the textile depended on the non-fluorinated hydrophobic SiO\(_2\) nanoparticles.

### 2. Experimental

#### 2.1 Materials

Tetraethyl orthosilicate (TEOS, 98%), hexamethyldisilazane (HMDS, 98%) and PA (50 wt% solution in H\(_2\)O) were purchased from Shanghai Macklin Biochemical Co. Ltd (Shanghai, China). CS (deacetylation degree \(\geq 95\%\)); the viscosity-average molecular weight \((M_\text{v})\) of CS was 4.7 \(\times\) 10\(^5\) g mol\(^{-1}\) was acquired from Aladdin Industrial Co. Ltd (Shanghai, China). Acetic acid, ammonia solution (25–28%) and ethanol were obtained from Sinopharm Chemical Reagent Co. Ltd (Shanghai, China). Deionized water was used for all the experiments. All reagents were used as received and without further purification. The CF was a commercial product and cut into 3 cm \(\times\) 3 cm pieces before being used.

#### 2.2 Preparation of CS solution and PA solution

0.5 g CS powder was magnetically stirred in 20 mL of 2% (v/v) acetic acid solution for 2 h at ambient temperature until the powder was completely dissolved to form the CS solution. PA solution was prepared at 5.0 wt% concentration using deionized water.

#### 2.3 Preparation of HMDS-modified SiO\(_2\) homogeneous solution

The SiO\(_2\) sol was synthesized by using TEOS as the precursor catalyzed with dilute ammonia in ethanol at room temperature.\(^{22}\) Dilute ammonia solution was prepared by adding 1 mL ammonia solution into 9 mL deionized water. Briefly, TEOS (3.5 mL) was added into 25 mL of ethanol under magnetic stirring with heating to 35 °C in a water bath, and the pH value was adjusted to 8–9 with 5% dilute ammonia solution. After continuously stirring for 3.5 h, HMDS (4.5 mL) and ethanol (4.5 mL) were then added into the above SiO\(_2\) sol dispersion under stirring and the reaction was kept for additional 1.5 h to obtain a dispersion of HMDS-modified SiO\(_2\) (labeled as HMDS–SiO\(_2\)) homogeneous solution (Scheme 1). The resulting white dispersion was cooled to room temperature and aged for 24 h.

#### 2.4 Fabrication process of flame-retardant and water-repellent coating on the cotton fabric

The CF was hyperacoustically rinsed with deionized water and ethanol, and dried in an oven at 60 °C for 20 min before usage. The pristine CF was immersed in CS solution for 10 min to obtain a layer of polycations and dried in an oven at 60 °C (coded as CS CF). The weight per unit area of sample increased about 1.5 \(\times\) 10\(^{-3}\) g cm\(^{-2}\) after this step. Then, the CS CF was soaked in PA solution for 10 min which can pair with CS. The quantity of PA absorbed was about 2.0 \(\times\) 10\(^{-3}\) g cm\(^{-2}\) after measuring. The dried textile was called CS/PA CF after this step. The low-surface-energy material HMDS–SiO\(_2\) was finally deposited on the textile surface to generate superhydrophobicity. The CS/PA/HMDS–SiO\(_2\) CF was prepared by soaking CS/PA CF in HMDS–SiO\(_2\) homogeneous solution for 10 min. The massive HMDS–SiO\(_2\) particles were deposited on the surfaces and the weight per unit area increased about 0.8 \(\times\) 10\(^{-3}\) g cm\(^{-2}\). It is worth noting that the CF became slightly more rigid after the coating treatment. The procedure for fabricating the water-repellent and flame-retardant CS/PA/HMDS–SiO\(_2\) CF is shown in Scheme 1.

#### 2.5 Characterization

The surface morphologies of the fabrics were characterized by using a JSM-5601LV scanning electron microscope (SEM) operating at 5 kV. Before analysis, the samples were sputtered with gold under high vacuum to improve their conductivity. Attenuated total reflectance (ATR) Fourier transform infrared (FTIR) spectra were collected at room temperature in the range of 4000–400 cm\(^{-1}\) with a Thermo Scientific Nicolet iS10 FTIR spectrophotometer. X-ray photoelectron spectroscopy (XPS) was conducted with a Thermo Scientific ESCALAB 250 Xi. Contact angle (CA) and SA were assessed by a contact angle meter (POWERRACH JC2000D1), and the corresponding droplet volumes were 5 \(\mu\)L and 10 \(\mu\)L at 25 °C, respectively. Thermal stability tests were conducted with a thermogravimetric analyzer (Mettler 1100LF) under an air atmosphere from 30 to 800 °C at a heating rate of 10 °C min\(^{-1}\). Combustion behavior was determined by a vertical flammability test using an automatic vertical
flammability cabinet (Qingdao SHANFANG ZR-02). Optical photographs and videos were obtained with a Huawei Mate 10.

3. Results and discussion

We aimed to design an environmentally friendly coating system containing CS and PA which can impart flame retardancy, and HMDS–SiO$_2$ acts as a hydrophobic component. CS is a linear natural polysaccharide backbone with abundant functional hydroxyl and amino groups (Scheme 2a). In dilute acid solution, CS displayed a cationic nature and paired with many anion polyelectrolytes to prepare functional PECs with the protonation of NH$_2$ groups. PA contains 6 phosphate groups and 12 hydroxyl groups in very close proximity, enabling it to interact with almost all kinds of positively charged compounds (Scheme 2b). For this reason, PA can interact with CS to form PEC through ionic bonds on cotton surface by a simple deposition method (Scheme 2c).

Under alkaline conditions, hydrophilic SiO$_2$ nanoparticles were obtained from the hydrolysis and the self-condensation reaction of TEOS. These nanoparticles contained abundant –OH groups on their surface. These groups reacted with HMDS to convert some of the hydrophilic silanol groups (Si–OH) to hydrophobic groups through the formation of /C17Si–O–Si(CH$_3$)$_3$/ linkages (Scheme 2d). TEOS and HMDS hydrolytic reaction could lead to the formation of semitransparent hydrophobic SiO$_2$ sols. Based on the large amount of methyl groups covered on the surfaces, the hydrophilic SiO$_2$ nanoparticles were converted into hydrophobic nanoparticles.

3.1 Surface morphology

The surface morphologies of CF were observed by using SEM as shown in Fig. 1. From Fig. 1a, the pristine CF fibers were usually smooth and round, on which was present natural structure of grain and distortion. Due to the excellent film-forming ability of CS, there was an integral film on the surface of CS CF, as shown in Fig. 1b (left). However, this does not cause great changes of the surface morphologies compared to the pristine CF, which is shown in Fig. 1b (right). The SEM image shown in Fig. 1c (left) illustrates that the CS/PA PEC coating deposited and grew on the CS/PA CF surface. This coating changed the surface morphology (Fig. 1c, right). The SEM images of the pristine CF and CS/PA/HMDS–SiO$_2$ CF (Fig. 1d, left) showed no significant differences. However, Fig. 1d (right) illustrates the surface of coated fibers became rough because the fibers were fully covered with spherical particles after treatment with HMDS–SiO$_2$. On the other hand, it is clearly revealed that the last sample has a typical nano- and microscale hierarchical structure. The EDS results indicated that the CS/PA/HMDS–SiO$_2$ CF mainly contains C, O, N, P and Si elements (Fig. 1e). Moreover, the EDS elemental mapping of the CS/PA/HMDS–SiO$_2$ CF is shown in Fig. 1f, in which the abovementioned elements were well detected. The result suggested that CS, PA and HMDS–SiO$_2$ were successfully deposited on the CF surface.

3.2 ATR-FTIR

To confirm the functional groups, the ATR-FTIR spectra of the pristine CF, CS CF, CS/PA CF and CS/PA/HMDS–SiO$_2$ CF were obtained and are presented in Fig. 2a. By comparison of the FTIR spectra of the CF before and after modification, the characteristic peak at 3329 cm$^{-1}$ corresponded to the stretching peak of –OH in cellulose, and the bands at around 1242 cm$^{-1}$ and 1712 cm$^{-1}$ were ascribed to the stretching vibration of C–O and flexural vibration of C=O in cellulose, respectively. The signals of CS CF were difficult to be precisely distinguished from pristine CF due to some similar chemical structures of CS and cellulose. For the spectrum of CS/PA CF, the absorption peaks at 1164 cm$^{-1}$ and 981 cm$^{-1}$ were associated with the stretching vibrations of P=O, O–P–O and P–O groups.

Scheme 2 Schematic illustrations of (a) CS and (b) PA. (c) Schematic illustration for the formation of PEC between CS and PA. (d) Schematic illustration for the preparation of HMDS–SiO$_2$. 

Fig. 1 SEM images of (a) pristine CF, (b) CS CF, (c) CS/PA CF, and (d) CS/PA/HMDS–SiO$_2$ CF. (e) EDS spectrum of the CS/PA/HMDS–SiO$_2$ CF. (f) SEM–EDS elemental mapping of the CS/PA/HMDS–SiO$_2$ CF.
In comparison, a new absorption band at 1540 cm\(^{-1}\) corresponded to the NH\(_3\)\(^+\) vibrational mode of the PEC, which is formed between CS and PA.\(^{29,30}\) As shown in the spectrum of the CS/PA/HMDS–SiO\(_2\) CF, the strong characteristic bands appearing at 840 cm\(^{-1}\) and around 1053 cm\(^{-1}\) were attributed to the Si–C and Si–O–Si in HMDS–SiO\(_2\) nanoparticles,\(^{31}\) respectively. Overall, the ATR-FTIR spectra revealed PEC formation between CS and PA. 29,30 As shown in the spectrum of SiO\(_2\) CF surfaces (Fig. 2b) was observed. Si was detected on the PA coating on the CS/PA CF (Fig. 2e) and CS/PA/HMDS–SiO\(_2\) CF (Fig. 2f), which confirmed the presence of hydrophobic SiO\(_2\) nanoparticles which were produced by the hydrolysis-condensation reaction of TEOS and HMDS.

3.3 XPS

The surface composition of the fabric samples was obtained from XPS spectra, and element content (Fig. 2c) was calculated from areas of the bands in the spectra. Fig. 2b indicates that C and O were detected on the pristine CF belonging to the cellulose fibers, whereas N, P and Si originating from the coating were detected on the sample. In the case of CS CF and CS/PA CF, the CS coating was confirmed by the presence of the N 1s peak, which was detected at a binding energy of 402 eV (Fig. 2d). However, the N 1s peak was not apparent in the XPS spectrum of the CS/PA/HMDS–SiO\(_2\) CF. The reason might be related to the following two aspects. The first is the relative decrease of the N element content with the increase in coating of a coating because it is very easy to damage in practical applications.34 In general, the hierarchical micro-/nanostructures of superhydrophobic surface are relatively weak and could be easily destroyed. Therefore, an abrasion test was conducted on the CS/PA/HMDS–SiO\(_2\) CF for validating the mechanical stability. The sample was placed on sandpaper (400 cW) and loaded with 200 g weight, which was dragged by an iron folder for a length of 10 cm (Fig. 3d). This operation was defined as one abrasion cycle. And then, this process was repeated and the CA of the coating measured every five abrasion cycles. As shown in Fig. 3c, the CA of the water droplets of pH from 1 to 14 on the surface of superhydrophobic sample was in the vicinity of 150°. The result indicated that the wettability of CS/PA/HMDS–SiO\(_2\) CF had chemical durability toward corrosive droplets. It is well known that mechanical stability is another significant indicator for the function of a coating because it is very easy to damage in practical applications.34 In general, the hierarchical micro-/nanostructures of superhydrophobic surface are relatively weak and could be easily destroyed. Therefore, an abrasion test was conducted on the CS/PA/HMDS–SiO\(_2\) CF for validating the mechanical stability. The sample was placed on sandpaper (400 cW) and loaded with 200 g weight, which was dragged by an iron folder for a length of 10 cm (Fig. 3d). This operation was defined as one abrasion cycle. And then, this process was repeated and the CA of the coating measured every five abrasion cycles.
phenomenon is attributable to the synergistic effect between the organosilicon and the PA coating on the CS-covered CF. Moreover, the fire-resistant property of the damaged CS/PA/HMDS–SiO2 CF was studied and is discussed later (Fig. 6c). The test indicated the coating can resist friction to some extent.

3.5 Thermal stability in air

Thermal stability of the uncoated and coated cotton fabrics was investigated by thermogravimetric analysis in air, as shown in Fig. 4. This process was done in air atmosphere at a heating rate of 10 °C min⁻¹ from 30 to 800 °C. For the pristine CF, it exhibited weight loss of 5.9% at 30–336 °C and 80.2% at 336–448 °C (Fig. 4a), which was mostly due to the stage of cellulose degradation.35 The thermal degradation of CS/PA/HMDS–SiO2 CF started at about 200 °C, which is the temperature at which the sample weight loss began (Fig. 4b). Onset weight loss of 7% occurred in the temperature range of 200 °C to 250 °C due to decomposition and oxidation of the CS main chain.36,37 The sample exhibited weight loss of 21.3% at 250–400 °C, and the rate of weight loss showed a distinct decline compared with the uncoated fabric. This might be due to the phosphoric acid produced by the PA layer with increasing temperature, which can accelerate the dehydration of cellulose and CS to form a char layer and inhibit volatile production.38 In addition, the large amount of water formed in this process will tend to quench the flame. The remaining residues at 600 °C were 10.72% and 29.66% for the pristine CF and CS/PA/HMDS–SiO2 CF samples, respectively. It is evident that the residues of the coated samples were about 3 times higher than that of the uncoated sample. This phenomenon is attributable to the synergistic effect between the organosilicon and the PA coating on the CS-covered CF. Moreover, the sample coating affected by temperature was tested. The CS/PA/HMDS–SiO2 CF was placed into an oven with different temperature (20 °C to 120 °C for 1 h). The wettability of the sample surface was measured soon after heating. Fig. 4c shows that, at under 120 °C, temperature cannot generate any huge effect on the wettability of the coating which means that this CS/PA/HMDS–SiO2 coating can maintain its surface characteristic at under 120 °C. Observed from the TG curve (Fig. 4b), the coating can maintain its surface characteristics at 200 °C. And this is enough for everyday needs.

3.6 Water repellence, self-cleaning, and delaying-icing properties

As a superhydrophobic surface, a spherical water droplet could slide from the CS/PA/HMDS–SiO2 CF surface if the rolling angle was less than 10°. Besides the water droplet, the surface also presents a great resistance for a water column. Fig. 5a (Movie S2, ESI†) shows that, when the water column ejects to the surface (sample was put on glass with an inclination angle of about 30°), it was bounced out without any spread and did not wet the surface of the sample. This phenomenon indicated the CS/PA/HMDS–SiO2 CF surface has excellent water repellence. In practical applications, the CF is often contaminated with sand, clay, and muddy water. As a superhydrophobic surface, air pockets get trapped in the interface between solid and liquid, which lead to the water droplets easily carrying away contaminants, resulting in self-cleaning property. As shown in Fig. 5b–d and Movies S3, S4 (ESI†), we dropped muddy water onto the surface of the pristine CF and the CS/PA/HMDS–SiO2 CF which were tilted at 30°, to confirm that the CS/PA/HMDS–SiO2 CF was able to remain clean. Muddy water was added dropwise onto the surface by a dropping pipette. The pristine CF was contaminated by the polluted water rapidly and the clay stuck on the surface (Fig. 5e). As shown in Fig. 5d, the muddy water could effortlessly roll off along the CS/PA/HMDS–SiO2 CF surface which took away the pollutant. Comparing with the pristine CF, the superhydrophobic surface was not wetted and was clean in the whole process (Fig. 5b). These antifouling experiments tested the self-cleaning and antifouling properties of the CS/PA/HMDS–SiO2 CF. Moreover, the delaying-icing performance of the superhydrophobic sample was tested under the overcooled condition in a fridge freezer (below 10 °C). In order to ensure the sample temperature was consistent with the environment, the samples were stuck on glass and placed in the freezer for 5 minutes before depositing the water droplet (10 μL) on the surface. For the pristine CF, water slowly wetted the cotton and completely iced after 133 s, whereas the droplet

![Fig. 4](https://example.com/f4.png)  
Fig. 4 TG and DSC curves of (a) pristine CF and (b) CS/PA/HMDS–SiO2 CF. (c) CA changes after thermal treatment.

![Fig. 5](https://example.com/f5.png)  
Fig. 5 (a) Water repellency of the CS/PA/HMDS–SiO2 CF surface. (b) The pristine CF and the CS/PA/HMDS–SiO2 CF after antifouling experiments. (c) Muddy water was dripped on the pristine CF surface. (d) Muddy water was dripped on the CS/PA/HMDS–SiO2 CF surface. (e) The process of delaying icing on the CS/PA/HMDS–SiO2 CF surface (inset is a magnified icing image).
on the coated cotton took about 520 s to become a spheroidal ice, as shown in Fig. 5e. For the CS/PA/HMDS–SiO$_2$ CF, more than double the time was required to freeze the water droplet compared to the uncoated cotton. Due to the extremely small contact area between the water droplet and the superhydrophobic substrates, the air layer can greatly impede heat transfer, which delayed the freezing process.

3.7 Flame-retardant property

In general, cotton fabric can be burned easily by fire and the process is irreversible. Hence, flame-retardant property of the uncoated and coated cotton fabrics was assessed using the vertical flame testing method. The test was carried out on samples with 25 mm × 130 mm size. A 40 mm-high fire from a gas burner was applied to ignite the tested fabrics for 3 s while recording the afterflame and afterglow time and then removed. It was clear that the pristine CF was consumed by the bright flame quickly and only the edges of the holder retained a few ashes with afterflame for 17 s (Fig. 6a, f and Movie S5, ESI†). Upon exposure to direct flame, the CS CF ignited immediately and the flame quickly spread as for the uncoated CF. The flame on the CS CF was vigorous and bright after ignition, as shown in Fig. 6b. The coated CS fabric was completely burned within 21 s and remained with black ash (Fig. 6f and Movie S6, ESI†). When the CF was coated with CS and PA, no afterflame appeared during the test, which indicates that the coating has a certain flame-retardant effect, but was not sufficient to stop the spread of the fire (Fig. 6c, f and Movie S7, ESI†). For the CS/PA/HMDS–SiO$_2$ CF, it exhibited a less vigorous flame than the CS/PA CF. Afterflame time was also reduced and afterglow was eliminated (Fig. 6d and Movie S8, ESI†). After burning, the char length and black area of the CS/PA/HMDS–SiO$_2$ CF were the smallest among the coated CF samples, whereas most of the top of the fabric remained intact (Fig. 6f).

The flame retardancy of this cotton was attributed to high efficiency of the CS/PA layer in hindering the transportation of heat and oxygen during the whole process and to the non-flammable property of SiO$_2$ particles. Since pristine CF does not possess such properties, it was easily burned. In this work, CS and PA were employed to fabricate intumescent flame-retardant coatings on CF. Typical intumescent systems contain three components: carbon donor, acid source, and gas source. These components react upon heating to generate a swollen multicellular insulating layer that protects the underlying material from heat and flame.\textsuperscript{18} In the combustion process, CS can be easily carbonized and release inert gases, which enable it to act as a carbon source and a blowing agent for the intumescent flame-retardant system.\textsuperscript{20,40} From a flame-retardant perspective, PA with 28 wt% P can serve as an acid source and deliver more active flame-retardant atoms per molecule.\textsuperscript{41,42} During combustion, combination of nitrogen and phosphorus has synergistic inhibitory effects to protect cotton sample from burning off.\textsuperscript{43,44}

The CS/PA/HMDS–SiO$_2$ CF after 50 abrasion cycles was further confirmed to have flame retardancy. The CF with abrasive coating also completely stopped the flame almost immediately after ignition leaving most of the fabric preserved, as for the CS/PA/HMDS–SiO$_2$ CF (Fig. 6e and Movie S9, ESI†). It was remarkable that the damaged sample still maintained a flame-retardant character. This phenomenon demonstrates the residual coating after abrasion still protected the cotton from burn out. The results manifested that the CS/PA layer and HMDS–SiO$_2$ particles of the coating can endow the cotton with flame retardancy.

4. Conclusions

In summary, we have successfully fabricated functional CF with superhydrophobic surface and excellent fire-resistance property by coating with CA/PA layer and hydrophobic silicon dioxide nanoparticles. The fabrication process can be accomplished in a beaker and without any usage of toxic reagents. The CA of coated CF reached 150 ± 2°, and the SA was about 5°. For the coated sample, the fire spread more slowly and the burning process only lasted 3 s. In addition to this, the coated CF exhibited considerable self-cleaning and anti-fouling characteristics. In particular, the coated CF still retained water-repellent and flame-retardant properties to a certain extent even after 50 abrasion cycles with sandpaper (400 cW). The coating on the cotton satisfies the requirements of real-life applications and displayed relatively good survivability under mechanical friction, cold and hot natural environments. Hence, the material possesses application potential in outdoor clothing, equipment and the military. This work provided an eco-friendly way to prepare water-repellent and flame-retardant CF. Further improvement in mechanical properties is required for practical applications.

Conflicts of interest

There are no conflicts to declare.
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Notes and references