Synthesis of a Hein–Schiff base compound and its antibacterial activity on cotton fabrics

Wen Wen · Zaixing Zhang · Lingxiao Jing · Tonghua Zhang

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Abstract This work aimed to obtain a highly efficient and durable antimicrobial agent on cotton fabrics by synthesizing a new Schiff base compound called (E)-1-((4-(allyloxy) benzyl) amino) imidazolidine-2,4-dione (AOBYID). Cotton fabrics were finished with Schiff base compound via alkali-free thiol–ene click chemistry. Chlorine were subsequently added to the nitrogen-containing groups on the grafted cotton fabrics through chlorination with sodium hypochlorite. NMR, FT–IR, Raman, and SEM results showed that the target compound (AOBYID) was successfully synthesized and effectively processed on

cotton fabrics. Antibacterial test results showed that the antibacterial rates of the treated fabrics after 1 min of contact reached 97.83% and 94.83% for *E. coli* and *S. aureus*, respectively, and remained above 90% after 24 h contact. In addition, the treated fabrics could retain approximately 79% of the initial chlorine content after 30 days storage, and 60% of the chlorine could be regenerated after 12 h of UV light. These findings revealed the high efficiency and durability of the antibacterial activity of treated cotton fabrics.

W. Wen · L. Jing · T. Zhang
Chongqing Engineering Research Center of Biomaterial
Fiber and Modern Textile, College of Textiles &
Garments, Southwest University, Chongqing 400715,
China

Z. Zhang
Hunan Engineering Laboratory for Preparation
Technology of Polyvinyl Alcohol Fiber, Chemistry and
Material Engineering School of Huaihua University,
Huaihua 418008, China

T. Zhang (✉)
No. 2 Tiansheng Road, Beibei, Chongqing 400716, China
e-mail: zhtonghua@aliyun.com

Graphic abstract

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Introduction

Cotton is an abundant natural fiber consisting of practically pure cellulose (approximately 88–96%) (Rattanaphani et al. 2007). Among the natural fibers, cotton is widely used in daily life due to its good hygroscopicity, soft comfort, and biodegradability. However, cotton fabrics propagate the reproduction of microorganisms, such as bacteria and fungi that will spread diseases, remarkably increase cross-infection risk, and even endanger human health (Küçük and Öveçoğlu 2019). Hence, understanding the antibacterial activities of cotton fabrics is crucial.

Various types of antibacterial agents, such as *N*-halamine (Chen et al. 2020), quaternary ammonium salts (Liu et al. 2019), nanosilver (Rohani Shirvan et al. 2019), and chitosan (Zhang et al. 2018), have been developed to determine antibacterial activity. Among these agents, *N*-halamine has attracted researchers' attention due to its unique structure,

nontoxicity, and highly effective antibacterial properties. *N*-Halamine is a group of compounds containing one or more nitrogen–halogen covalent bonds (N–Cl) normally formed via the halogenation of imide, amide, or amine groups (Qiao et al. 2017). Moreover, *N*-halamine has antibacterial activity against a broad spectrum of microorganisms, including bacteria, viruses, fungi, and yeasts (Ma et al. 2019a, b).

When the oxidative halogen in *N*-halamine is consumed by sterilization, it can be restored through the dilution of household bleach or halogen-releasing agents (Ma et al. 2019a, b). However, poor stability of *N*-Halamine compounds against UV light can limit their practical applications. Ren et al. (2008) confirmed that UV light irradiation could rapidly dissociate the N–Cl bonds in siloxane precursors and cause unrecoverable loss of antibacterial activity related to the cleavage between *N*-halamine functional groups and cotton substrates. However, Sandstrom et al. (2007) reported that *N*-halamine compounds with aromatic structures could partially protect the N–Cl bonds from breakage. Moreover, the Schiff bases with imino groups (RC=N) possessing special structures and variable properties have been widely used in biological activities and functional materials (Naeimi

et al. 2008; Hassan et al. 2018; Yousif et al. 2018). However, most studies were based on the Schiff base complex and only a few used the Schiff base in fabric finishing. Furthermore, the highly efficient introduction of functional molecules on cotton fabric surface by using a facile method continues to be an important research topic.

Metal-free thiol–ene click reactions have attracted researchers' interest because of their unique advantages of simplicity, high efficiency, strong versatility, and mild reaction conditions. Although their applications have been widely studied, such as in compound synthesis, material surface modification, and fabric functional finishing, most works typically focused on the thiol–Michael addition reactions and ignored the antibacterial finishing of cotton fabrics (Liu et al. 2017; Fei et al. 2018; Herwig and Dove 2019). These reactions require the use of nucleophiles, such as strong bases, metals, organometals, and Lewis acids, which hinder environmental protection. By contrast, the thiol–ene click reaction can be initiated by adding even a small amount of photocatalyst, and the reaction is highly efficient.

In this work, a Schiff base compound with Hein, double bond, and benzene ring was synthesized, and an alkali-free thiol–ene click reaction was introduced to the antibacterial finish of cotton fabrics. First, a sulfhydryl group was introduced onto the surface of cotton fibers with a 3-mercaptopropyltriethoxysilane (MPTES) treatment. This group could efficiently react with the terminal olefinic bonds of E-1-((4-(allyloxy) benzyl) amino) imidazolidine-2,4-dione (AOBYID) and form covalent bonds to improve the stability of AOBYID remarkably. Then, chlorine was introduced into the nitrogen-containing groups on the grafted cotton fabric to transform it into a highly effective antibacterial substance via sodium hypochlorite chlorination. The possible reaction between AOBYID and cellulose is presented in Scheme 1. In addition, the antibacterial properties, stability, and rechargeability of the treated samples were explored further.

Experiment

Materials

Bleached cotton fabric (144 g/m^2) was used in this study. P-hydroxybenzaldehyde, 3-bromopropene,

1-aminoheine hydrochloride, *N,N*-dimethylformamide (DMF), petroleum ether, sodium chloride, and sodium thiosulfate solution (0.1000 mol/L) were purchased from Shanghai Aladdin Biochemical Technology Co., Ltd. Sodium hydroxide and ethanol were sourced from Chongqing Chuandong Chemical (Group) Co., Ltd. 3-mercaptopropyltriethoxysilane (MPTES), sodium hypochlorite solution (6–14% active chlorine basis), and beef paste were obtained from Shanghai Macklin Biochemical Technology Co., Ltd. Peptone. Benzoin dimethyl ether (DMPA) was supplied by Shanghai Yuanye Biological Technology Co., Ltd. Agar powder was acquired from Chengdu Kelong Chemical Co., Ltd. AOBYID was synthesized using 3-bromopropene, P-hydroxybenzaldehyde, and 1-aminoheine hydrochloride. All chemicals were analytic grade reagents and used without further purification.

AOBYID synthesis

The synthesis process of AOBYID is shown in Scheme 2. First, sodium hydroxide (4 g, 0.1 mol) and P-hydroxybenzaldehyde (12.212 g, 0.1 mol) were initially added to a round bottom flask (250 mL) containing 100 mL ethanol and stirred at room temperature until dissolved. Second, 3-bromopropene (12.098 g, 0.1 mol) was added dropwise thereto, placed in an oil bath with a magnetic stirrer, and stirred under reflux at 70°C for 16 h. Third, the salt was filtered under reduced pressure, the solvent ethanol was evaporated, and the residue was purified with petroleum ether to obtain a pale-yellow liquid (4-(allyloxy)benzaldehyde). Fourth, 1-aminohydantoin hydrochloride (15.155 g, 0.1 mol) was added to a round-bottomed flask (250 mL) containing 60 mL ethanol, 4-(allyloxy) benzaldehyde (17.700 g, 0.1 mol) was poured into simultaneously, and then stirred under reflux at 70°C for 18 h. After the reaction, the solvent was evaporated under reduced pressure, and deionized water was used to precipitate a solid to obtain a crude product. Finally, a light yellow-solid powder (AOBYID) was obtained with recrystallization in petroleum ether.

Modification of cotton fabric with MPTES

First, the cotton fabric was cleaned with an aqueous solution at 80°C for 20 min to remove the surface impurities and then dried at 60°C . Second, anhydrous

Scheme 1 Mechanism of preparing antibacterial cotton fabric

Scheme 2 Preparation procedure of AOBYID

ethanol and distilled water in the ratio of 4:1 was mixed in the solution, and MPTES (5 wt%) was added. Third, the pH of the mixture was adjusted to 3.5 with acetic acid. Fourth, the mixed solution was continuously stirred at 25 °C for 30 min, and the cotton fabric was immersed into the above solution for 3 min and solidified at 25 °C for 5 min. Finally, the MPTES-modified cotton (cotton-SH) was obtained.

Finishing of cotton fabric via the addition of alkali-free thiol–ene click chemistry

First, the target compound was dissolved in DMF, and then 0.1%wt DMPA was added as a photoinitiator with a bath ratio of 1:20. Second, cotton-SH was dipped into the mixture solution and treated with UV light for 30 min, and AOBYID was grafted onto the cotton fabrics in the form of C–S bonds through the

thiol–ene click reaction. Third, the fabrics were washed thoroughly and dried at 45 °C to obtain the AOBYID-grafted cotton (cotton-SH-AOBYID).

Grafting rate of the cotton fabrics

The average grafting rate percentage (G%) of each sample was calculated as follows:

$$G\% = \frac{M_2 - M_1}{M_1} \times 100\% \quad (1)$$

where M_1 and M_2 are the weights of the sample before and after the MP TES grafting treatment, respectively.

All the samples were placed in 60% relative humidity at 25 °C for 24 h before measurement. According to Eq. (1), the graft ratio of antibacterial cotton fabric was calculated at 15.7%, which was obtained by averaging the results after five measurements.

Chlorination and determination of chlorine loading

To obtain the antibacterial cellulose of N-halamine Schiff base and render the fabrics with high biocidal efficacy, the treated cotton fabric was soaked in 10% sodium hypochlorite solution (pH 7) for 1 h, and then washed with deionized water and dried at 45 °C for 1 h. The chlorine loading on the fabrics was measured using the iodometric/thiosulfate titration method. The amount of oxidative chlorine on the cotton swatches was calculated as follows:

$$\text{Cl}^+\% = \frac{N \times V \times 35.45}{W \times 2} \times 100\% \quad (2)$$

where $\text{Cl}^+\%$ is the wt.% of oxidative chlorine in the samples; N and V are the normality (equiv./L) and volume (L) of titrant sodium thiosulfate, respectively; and W is the weight of the cotton samples (g).

Characterization

Nuclear magnetic resonance (^1H NMR)

Nuclear magnetic resonance (^1H NMR) spectra of AOBYID are obtained via a WNMRI-400 MHz with TMS as the internal standard using DMSO.

Fourier transform–infrared spectroscopy (FT–IR)

The infrared spectra of AOBYID, untreated cotton, cotton-SH, and cotton-SH-AOBYID were obtained using a GX infrared spectrometer (PE Co., USA) under the following test conditions: the ratio of sample to KBr of 1:100, wavenumber range of 4000–500 cm^{-1} , number of scans of 32, and resolution of 4 cm^{-1} .

Raman analysis

The surface functional groups after the MP TES pretreatment were investigated with a spectral range of 2000–3000 cm^{-1} by using the Raman analysis (DXR2, ThermoFisher Scientific, USA).

Scanning electron microscopy (SEM)

The surface morphology images of untreated cotton, cotton-SH, and cotton-SH-AOBYID, and chlorinated (Cl-cotton-SH-AOBYID) samples were observed using SEM (Hitachi S-4800, the Netherlands) at an accelerating voltage of 10 kV.

Antibacterial activity test

The antibacterial activities of Cl-cotton-SH-AOBYID were evaluated through the zone of inhibition, number of colony-forming units (CFU), and optical density at 600 nm. The control and chlorinated cotton swatches were challenged with *Staphylococcus aureus* (*S. aureus*, gram-positive organism) and *Escherichia coli* (*E. coli*, gram-negative organism).

In the CFU counting method, 25 μL aliquot of bacterial suspension (100 mM phosphate buffer, pH = 7) was added to the center of two 2.54 cm^2 cotton swatches, which were held in place with sterile weights to ensure good contact of the swatches with the inoculum. The number of bacteria is used in the tests for approximately 10^6 CFUs (CFU/mL), and the actual bacterial count was determined through the counting method. After the contact times of 1, 5, 10, and 30 min, the samples were transferred immediately to conical tubes containing 5 mL sterile 0.02 N sodium thiosulfate solution and vortexed for 2 min to remove all oxidative chlorine and rinse off any surviving bacteria. The serial dilutions of the quenched solution samples were made using 100 μM

phosphate buffer (pH 7) and plated on a Luria–Bertani medium. After incubation at 37 °C for 24 h, the viable bacterial colonies were recorded for biocidal efficacy analysis. The same procedure was performed on the untreated aseptis cotton as control but with only 30 min of contact. The antibacterial rate (R, %) was calculated using Eq. (3) (Ma et al. 2013; Rong et al. 2019).

$$R(\%) = \frac{\text{CFU in control} - \text{CFU in sample}}{\text{CFU in control}} \times 100\% \quad (3)$$

In the inhibition zone method, LB agar medium was prepared and autoclaved at 121 °C for 20 min of sterilization before use. The liquid LB agar medium was then cooled to 45 °C and mixed with an *E. coli* or *S. aureus* broth to a concentration of 10^6 CFU/mL and poured on dishes. Each sample was subsequently placed on the dish, which were incubated at 37 °C for 24 h before observation. The zones of inhibition were recorded with a camera (Cai et al. 2018).

In the OD600 measurement, the antibacterial activity of the three sample groups, including untreated cotton, AOBYID-SH-cotton, and Cl-cotton-SH-AOBYID samples, were tested by evaluating the inhibition of the bacteria *S. aureus* and *E. coli*. Then, 100 μL bacterial suspension (10^6 CFU mL^{-1}) was added to the samples. After 4 h, 900 μL of the Luria–Bertani broth was added. The samples were subsequently placed in an incubator at 37 °C with constant agitation. After 24 h, 200 μL of bacterial suspension was collected. The optical density (OD) of the suspension at 600 nm was measured using a microplate reader. The bactericidal ratios of the groups were calculated using Eq. (4) (Gan et al. 2019).

$$\begin{aligned} \text{Bactericidal ratio}(\%) = & \frac{\text{OD of contrastive group} - \text{OD of experimental group}}{\text{OD of contrastive group}} \\ & \times 100\% \end{aligned} \quad (4)$$

Storage stability testing

In the storage stability test, the chlorinated cotton fabrics were stored in the dark at room temperature,

and the chlorine loadings were measured at different periods of times. The samples were rechlorinated and the chlorine loadings were retitrated.

UV light stability testing

The chlorinated cotton fabrics were placed in a UV light chamber for the duration of 1 to 12 h. After the specified time of UV irradiation, the cotton swatches were removed from the UV chamber and titrated or rechlorinated and titrated according to the previously described method.

Results and discussion

Characterization of AOBYID

The FT–IR and ^1H NMR spectra were used to investigate the synthesis of the target compound of the Hein–Schiff base. The characterizations of the synthesized AOBYID were first carried out via ^1H NMR spectroscopy (Fig. 1a). The following results were obtained. ^1H NMR (DMSO) δ_{H} : 11.15 (s, 1H, HN) (a1), 7.75 (s, 1H, HC-10) (a2), 7.63 (d, $J = 8.68$ Hz, 1H, HC-2) (a3), 7.63 (d, $J = 8.68$ Hz, 1H, HC-6) (a3), 7.02 (d, $J = 8.88$ Hz, 1H, HC-3) (a4), 7.02 (d, $J = 8.88$ Hz, 1H, HC-5) (a4), 6.05 (m, $J = 27.84$ Hz, 1H, HC-8) (a5), 5.41 (dd, $J = 17.3$ Hz, 1H, HC-9) (a6), 5.27 (q, $J = 11.8$ Hz, 1H, HC-9) (a7), 4.61 (d, $J = 5.12$ Hz, 1H, HC-7) (a8), and 4.33 (s, 2H, HC-13) (a9). These signals indicated that the Hein–Schiff base compound might have been successfully synthesized.

The structure of the target compound was further verified through its FT–IR spectra (Fig. 1b). The two peaks around 3196 and 3075 cm^{-1} are due to the N–H stretching vibration in hydantoin. The weak peaks at 693 and 618 cm^{-1} correspond to the out-of-plane rocking vibration of N–H and O=C–N in hydantoin, respectively. Furthermore, the absorption peak in the 1790–1765 cm^{-1} region was generally ascribed to the symmetrically coupled vibration of C=O in hydantoin, whereas the signal at the 1755–1690 cm^{-1} region was related to the asymmetrically coupled vibration of C=O. The peaks appearing at 1513 and 1248 cm^{-1} belong to the bending vibration of C–N–H and the

Fig. 1 **a** ^1H NMR spectrum, and **b** FT-IR spectra of AOBYID; **c** FT-IR spectra of a: untreated cotton, b: cotton-SH, and c: cotton-SH-AOBYID; **d** Raman spectra images of untreated cotton and cotton-SH

telescopic vibration of C–N in hydantoin, respectively. The weak peaks at 2936, 2859, and 2742 cm^{-1} were assigned to the C–H stretching vibration in the benzene ring. The absorption peaks in the 1500–990 and 860–790 cm^{-1} regions were generally attributed to the in-plane bending vibration and out-of-plane bending vibration of C–H in the benzene ring. In addition, the peak in the 1700–1610 cm^{-1} region was usually ascribed to the C=C telescopic vibration. Therefore, the absorption band detected at 1651 cm^{-1} should belong to the terminal alkenyl group of AOBYID. Meanwhile, the peak appearing at 1606 cm^{-1} belongs to the characteristic active group C=N of the Schiff base. These results are in accordance with the ^1H NMR spectroscopy analysis.

Therefore, the Hein–Schiff base compound was successfully synthesized.

FT-IR and Raman spectroscopy analysis

Figure 1c shows the FT-IR spectra of untreated cotton, cotton-SH, and cotton-SH-AOBYID. Compared with the untreated cotton sample, cotton-SH essentially remained unchanged. However, two characteristic absorption peaks were observed near 1768 and 1724 cm^{-1} associated with the stretching vibration of C=O groups of AOBYID molecules in the curve of the treated cotton. The skeleton vibration peaks of phenyl ring appeared at 1612, 1550, and 1513 cm^{-1} . The two peaks observed around 1337 and 1250 cm^{-1} in the cotton-SH-AOBYID fabrics

indicated that a characteristic absorption peak of the C–N bond occurred in imide (Xu et al. 2017). The absorption peak at 829 cm^{-1} demonstrated the C–H stretching vibration of phenyl in the cotton-SH-AOBYID fabrics. The peak at 664 cm^{-1} exhibited the vibration absorption peak of the C–S bond, which was generated by the reaction of AOBYID with -SH. Based on these analyses, a reaction occurred between AOBYID and a thiol group through click chemistry.

The molecular identities of MPTES on the cotton fabrics were assessed through their Raman spectra. As shown in Fig. 1d, the characteristic signal around 2570 cm^{-1} could be found in the curves of the treated cotton fabric due to the -SH vibration band (Xu et al. 2017). This result proved that hydroxyl in the cotton fabric reacted with MPTES to generate the -SH group, which was ready for the thiol–ene click reaction in the following step.

Surface morphology

SEM tests were carried out to observe the surface morphological characteristics of the samples. As shown in Fig. 2a, the original surface of cotton fibers presented a typical morphology of the natural structures of grain and ravines, which are slightly rough but relatively smooth with irregularly shaped fibers (Fan et al. 2019). After the MPTES treatment, a slight change occurred on its surface, and the change is unclear (Fig. 2b). Furthermore, Fig. 2c also shows that the surface of the AOBYID-treated cotton fibers appear to have a thin coating, thereby suggesting the occurrence of grafting of the AOBYID compound onto the MPTES-modified cotton fabrics. After chlorination (Fig. 2d), the cotton fibers became slightly rough and a layer of ribbon-like material covered the surface of the original cotton fibers, thereby

Fig. 2 SEM images of the **a** untreated cotton, **b** cotton-SH, **c** cotton-SH-AOBYID, and **d** Cl-cotton-SH-AOBYID fabrics

suggesting that the AOBYID-grafted cotton was successfully chlorinated.

Antibacterial efficacies

Figure 3 presents the results of *E. coli* and *S. aureus* living on the Petri dishes when the sample is in contact with the inoculum at a concentration of 10^6 CFU/mL at different times.

The original data are listed in Table 1. Figure 3a–l illustrate the results of the antibacterial properties against *E. coli* and *S. aureus*, respectively. As shown in Fig. 3f and l, compared with the untreated cotton-added antibiotics, untreated cotton and Cl-cotton-SH-AOBYID did not produce zones of inhibition against *E. coli* or *S. aureus*. The results revealed that the

antibacterial agents had a slight or no dissolution. The antibacterial abilities of Cl-cotton-SH-AOBYID were investigated through the CFU counting method, which is an effective quantitative antibacterial test that analyzes the inhibitory activity.

The bacteriostatic rates of Cl-cotton-SH-AOBYID against *E. coli* and *S. aureus* reached 97.83% and 94.83%, respectively, after a contact period of only 1 min (Fig. 3b, h). Notably, the antibacterial efficiency was above 99% (Fig. 3c, i) after 5 min of contact and achieved 100% against *S. aureus*. This finding confirmed that Cl-cotton-SH-AOBYID obtained highly effective antibacterial properties. In conclusion, the results indicated that G[−] and G⁺ bacteria were efficiently and remarkably inhibited.

Fig. 3 Antibacterial properties of samples against *E. coli*: **a** untreated cotton with contact of 30 min, **b–e** Cl-cotton-SH-AOBYID with contact of 1, 5, 10, and 30 min. Antibacterial properties of samples against *S. aureus*: **g** untreated cotton with contact of 30 min, **h–k** Cl-cotton-SH-AOBYID with contact of

1, 5, 10, and 30 min. Inhibition zone experiments on the samples: **f** *E. coli* and **l** *S. aureus*. Note: A, B, and C are untreated cotton-added antibiotics and untreated cotton used as the positive and negative controls and antibacterial cotton, respectively

Table 1 Biocidal efficacy against microorganisms

Sample	Contact time (min)	Bactericidal ratio	
		<i>E. coli</i> ^a	<i>S. aureus</i> ^b
		% reduction	% reduction
Untreated cotton	30	—	—
Cl-AOBYID-cotton ($0.38\% \pm 0.01$ Cl ⁺)	1	97.83	94.83
	5	99.28	100
	10	100	100
	30	100	100

^aInoculum concentration was 5.56×10^8 CFU/sample

^bInoculum concentration was 2.76×10^8 CFU/sample

Fig. 4 Antibacterial activity of the treated cotton fabrics **a** images of the *E. coli* and *S. aureus* solutions that were cocultured with the treated cotton fabrics after 24 h.

b Bactericidal ratio of the treated cotton fabrics with *S. aureus* and *E. coli* (The error bar indicates the standard deviation)

The antibacterial activity of the treated cotton fabric with prolonged contact was further explored. The AOBYID-treated cotton fabrics displayed antibacterial activities likely due to the presence of the Schiff base, whereas the chlorinated cotton fabrics demonstrated strong antibacterial activities likely due to the antimicrobial broad spectrum of *N*-halamine. Figure 4a shows the image of bacterial suspensions that were cultured with samples. The suspensions of the blank and untreated cotton samples were turbid during the 24 h culture, whereas those of cotton-SH-AOBYID and Cl-cotton-SH-AOBYID were relatively clear. The bactericidal ratio of cotton-SH-AOBYID for *E. coli* and *S. aureus* were 78% and 89%, respectively, possibly due to the presence of the Schiff base structure. However, the bactericidal ratios of Cl-cotton-SH-AOBYID for *E. coli* and *S. aureus* were 92% and 95%, respectively, probably because the chlorinated sample had increased antibacterial activity

(Fig. 4b). These results were consistent with previous reports (Table 1).

Storage stability and UV stability

The stability of Cl-cotton-SH-AOBYID was evaluated, and the results are presented in Fig. 5a. Although the Cl⁺ content of the tested samples gradually decreased with the increase in storage time, nearly 79% of the initial chlorine loading still remained after 30 days of storage (oxidative chlorine decreased from 0.38 to 0.30%). The stability combined with the antibacterial efficacy result were sufficient to support its application. Chlorine loss could have been caused by the hydrolysis of N–Cl bonds (Zhang et al. 2019). Notably, after 30 days of storage, rechlorination of the sample could restore the original content of chlorine oxide.

The UVA light stability of the chlorinated cotton fabric was further tested. Figure 5b shows that active

Fig. 5 **a** Storage and **b** UV stability of active chlorine on the treated fabric (The error bar indicates the standard deviation)

Table 2 Washing durability of the antibacterial finish cotton fabric

Washing cycles	<i>E. coli</i> ^a Bacterial reduction (%)	<i>S. aureus</i> ^b Bacterial reduction (%)
0	91.35	94.80
5	85.58	87.35
10	78.71	80.70

^aInoculum concentration was 7.67×10^8 CFU/sample

^bInoculum concentration was 4.82×10^8 CFU/sample

chlorine on the cotton fabrics decreases with the increase in irradiation time. The fastest increase occurred in the first hour of irradiation, and approximately 45% of chlorine oxide remained on the fabric. After 12 h of UV irradiation, active chlorine was almost completely lost. However, 60% of chlorine could be regenerated through contact with the diluted sodium hypochlorite solution. Therefore, the results showed that Cl-cotton-SH-AOBYID demonstrated good rechargeability.

Washing durability

According to the standard of AATCC 61–2006, the antibacterial finish fabrics were washed repeatedly, and then the antibacterial durability was evaluated. Table 2 shows the test results. After 5 and 10 washing cycles, the antibacterial fabric still maintained an antibacterial rate of 85.58 and 78.71% against *E. coli*, 87.35% and 80.70% against *S. aureus*, respectively. Consequently, the antibacterial cotton fabrics still maintained a high antibacterial rate after repeated washing.

Conclusions

¹HMR, FT-IR, and Raman results indicated that the Hein–Schiff base compounds were successfully synthesized and grafted onto the cotton fibers. Antibacterial activity test revealed that the prepared antibacterial cotton fabric had high efficiency and good antibacterial activity against *S. aureus* and *E. coli*, and its antibacterial performance was slightly better against *S. aureus*. The presence of the Schiff base structure in the finishing agent enhanced the antibacterial activity, and the introduction of halogenated amine bonds in the grafted cotton fabric also significantly improved the antibacterial properties of the treated cotton fabric. The stability test results of storage and UV presented that the presence of aromatic rings effectively enhanced the stability, and the treated fabric exhibited good rechargeability. The antibacterial fabric still retained high antibacterial performance after repeated washing.

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