Chapter 13

Synthesis of Nanometal Oxide–Coated Cotton Composites

Issa M. El Nahhal, Abdelraouf A. Elmanama and Nadia M. Amara

Additional information is available at the end of the chapter

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Abstract

Several selected studies dealing with the development of novel antimicrobial metal oxide–coated cotton nanocomposites and their antimicrobial applications have been reviewed in this chapter. Synthesis of metal oxide nanoparticles (NPs) and its deposition onto cotton fibers were conducted using various methods. These include the high energy γ-radiation, thermal treatment-assisted impregnation, "pad-dry-cure" of the impregnated fabric in the colloid formulation of metal oxide soluble, and ultrasonic radiation methods. The coated metal oxide nanoparticles have shown an effective enhancement for antimicrobial activity. They reduce the chance of diseases originating from hospital infections. The antimicrobial properties of cotton fabrics finished with metal oxide NPs against a variety of bacterial strains commonly associated with nosocomial infections, caused by *Staphylococcus aureus* and *Escherichia coli*, have been investigated by four different methods. The morphology of the cotton-coated metal oxide nanoparticles and their chemical structure have been analyzed by UV-vis, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray photoelectron spectra (XPS). SEM and XRD analyses revealed that the shape and size of the coated nanoparticles are dependent on the nature of the metal oxide and its preparation conditions.

Keywords: antimicrobial activity, metal oxide–coated cotton, coated cotton nanocomposites, CuO and ZnO nanoparticles, ultrasonic radiations

1. Introduction

Textile fabric, especially those made from natural fibers, provides an excellent environment for the growth of microorganisms because of their large surface area and the ability to retain moisture. A large number of chemicals have been used to impart antimicrobial activity to textile materials. The development of new clothing products based on the immobilization of nanophased materials on textile has recently received growing interest from both academic and industrial sectors [1]. Currently, a wide range of nanoparticles (NPs) with various structures can be immobilized onto the textile fibers in order to bring new properties to the textile product [1]. In this scene, the preparation and applications of nanoparticle coatings onto cotton fibers have received much attention due to its promising applications.

There are three general methods to impregnate metal oxide nanoparticles onto the cotton fibers: the first method is "pad-dry-cure process" while the second method is ultrasonic irradiation, which is an effective method for the deposition of nanoparticles onto the surface of cotton textile fibers and other substrates. The third method is a thermal chemical treatment [2–4]. Among these methods, ultrasonic irradiation represents a promising tool in nanosynthesis and deposition of NPs on/into the natural cotton fiber as it reduces the operation time, allows one-step preparation and deposition of nanomaterials on textile substrates, and enhances the quality of products [5]. In addition, the sonication method results in an appreciable quantity of coating, higher dispersion, and more diffusion of the particles onto the substrate compared to the other coating methods [6]. Moreover, sonication results in a smooth and homogeneous layer of coating, and it is capable of projecting nanoparticles toward the fabric surface at a very high speed, which causes nanoparticles to adhere strongly to fabric surfaces [7]. Abramov and his coworkers [8] have developed a method for introducing copper oxide NPs (CuO-NPs) into cotton fabrics using sonochemical reactor and their antimicrobial activity has been studied.

Gouda and his coworkers [4] have succeeded in the synthesis of some nanometal oxides via microwave irradiation technique and applied them onto cotton fabric to study their multifunctional properties. Antibacterial activity was evaluated quantitatively against Gram-positive bacteria such as *Staphylococcus aureus* and Gram-negative bacteria such as *Escherichia coli*. The antimicrobial activity of cotton fiber coated with zinc oxide (ZnO) and CuO-NPs was investigated against *E. coli* and *S. aureus* cultures by El-Nahhal and his coworkers [2, 3]. In this study, they have prepared crystalline ZnO of hexagonal and CuO of monoclinic phases with an average crystallite size of 12 and 50 nm, respectively. These nanoparticles were physically adsorbed onto the cotton fiber surface by ultrasonic irradiation. These results proved that the coated cotton samples have displayed a high activity with a great reduction in the bacterial growth [2, 3].

Shateri-Khalilabad and Yazdanshenas [9] have synthesized ZnO-NPs on the surface of cotton fabric via a simple wet chemical method to impart antimicrobial activity and ultraviolet (UV) protection. SEM images revealed that significant amounts of hierarchical ZnO-NPs were homogeneously formed on the fibers' surface; most of them were bundle-/flower-like particles having different sizes. It was stated that the ZnO-NP–coated cotton fabric has a good bacteriostatic activity against two representative bacteria, *Klebseilla pneumoniae* and *S. aureus*, which was demonstrated by the zone of inhibition. It was proved that the coated fibers have an excellent ability to block the UV radiation [9]. Several authors have examined and investigated the antimicrobial activity of metal oxide–coated cotton nanocomposites, and they have showed an effective reduction in the bacterial activities [10–16]. ZnO nanoparticle assembly for the multilayer film formation on the cotton fabrics was prepared by layer-by-layer deposition process [17]. Hongjum and others have successfully synthesized ZnO films deposited onto the surface of cotton fibers by a simple two-step process [18]. The growth of ZnO films was carried out in Zn $(CH_3COO)_2$ solution, with NaOH solution [18]. In this chapter, we discussed the synthesis, characterization, and antimicrobial activity of metal oxide nanoparticles with emphasis on CuO and ZnO.

2. Antibacterial agents

Antibacterial agents are classified into two types: organic and inorganic. The organic materials are often less stable than that of the inorganic antibacterial agents with respect to the high temperatures and pressures compared to inorganic antibacterial agents [19]. The inorganic materials such as metal and metal oxides are considered to be stable at harsh processing conditions. Among these materials are the metal oxides ZnO, CuO, and MgO. One of these inorganic materials is zinc oxide (ZnO). ZnO belongs to a group of metal oxides that are characterized by several properties [20]. ZnO is generally regarded as a safe material for human beings and animals, and it has been used extensively in the formulation of many personal care products [21, 22].

CuO-NPs are very efficient in imparting antibacterial effect to fabric [7, 1]. They have been investigated as antibacterial agent against Gram-negative and Gram-positive microorganism *E. coli*. These copper oxide-plated or impregnated synthetic fibers possess broad spectrum biocidal properties: they are antibacterial, antifungal, antiviral, and they kill dust mites. Moreover, animal studies demonstrated that these fibers do not possess skin-sensitization properties [23].

3. Deposition methods

Various methods have been developed for depositing metal oxide nanoparticles on the textiles. There are only a few methods in the literature that describe the coating of fabrics with metal oxide nanoparticles, for example, the "pad-dry-cure" method [24–26], radiation, and thermal chemical treatment [4, 27, 28]. These techniques have some disadvantages: first, they are rather complicated and involve several stages; second, a stabilizer agent is used in order to get small nanoparticles, resulting in the presence of impurities in the final products. A new simple method for coating fabric surfaces with metal oxides is via ultrasound irradiation. Sonochemical irradiation has been proven as an effective technique for the synthesis of nanophased materials [1, 24, 29, 30]. The deposition and insertion of nanoparticles on/into the mesoporous ceramic and polymer supports, fabrics, and glasses is also reported [31–33]. The process involves the formation of metal oxide nanoparticles and subsequent deposition on fabrics in a one-step reaction. This coating process is not only safe and cheap but also shows that even with a low coating concentration of metal oxides in the composite, excellent antibacterial activity is maintained. In other systems, cross-linkers or binder agents are used to increase the adherence of inorganic agents NPs onto cotton fiber [17, 34–36]. In our unpublished research, surfactants were used as catalysts, which increase the homogeneity and adsorption of inorganic NPs onto cotton substrate [37].

3.1. Ultrasonic irradiation method

In this method, metal salt (CuX_2 or ZnX_2) precursor was dissolved in aqueous ethanolic solution. The pH was adjusted to 8–9 by the addition of $NH_3 \cdot H_2O$ or NaOH. The reaction mixture was irradiated with a high-intensity ultrasonic radiation under a flow of Ar. The sonication flask was placed in water bath maintained at a constant temperature of 30°C. The coated fibers were washed thoroughly with water and dried under vacuum at 60°C. The CuO- or ZnO-NPs–coated cotton fiber was obtained by the deposition of the corresponding nanoparticles onto the cotton fibers via the ultrasound irradiation of metal hydroxide according to the reaction in a similar way as previously reported [1–3].

During the formation process, a blue fresh product of $Cu(OH)_2$ is formed immediately after the addition of OH^-, which turns into brown color of copper oxide, after a few minutes of sonication. The CuO nanoparticles produced by the reaction were probably physically adsorbed onto cotton fibers (**Figure 1**).

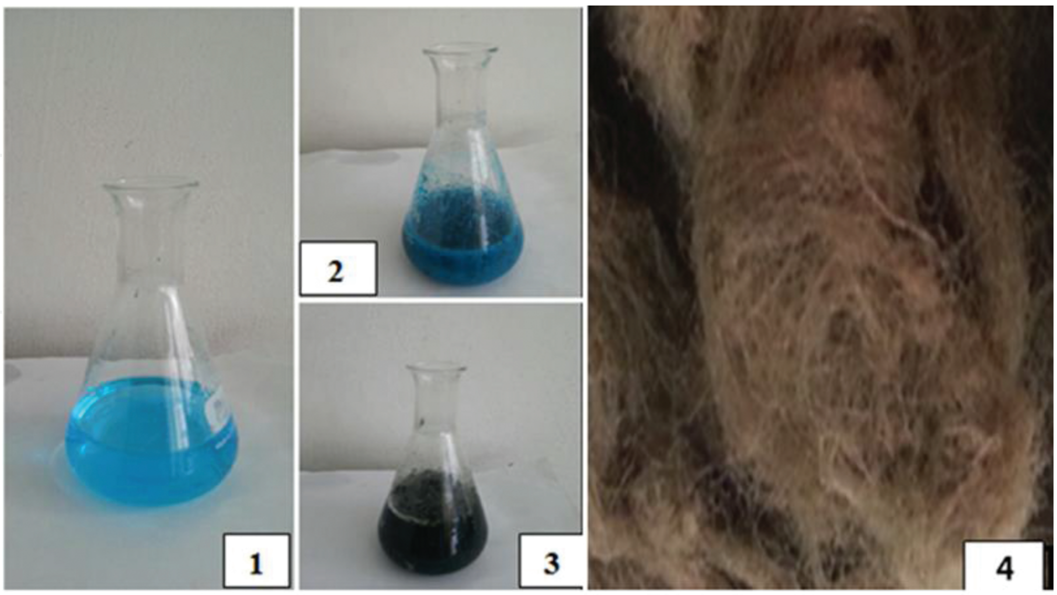

Figure 1. Coating steps of CuO-NPs onto cotton fibers: (1) aqueous solution of copper sulfate, (2) copper hydroxide "dark blue precipitate," (3) CuO-NPs, and (4) CuO-NP–coated cotton. M.Sc. thesis 2016, Islamic University Gaza.

3.2. Pad-dry-cure method

The metal oxide nanoparticles were treated with the fabric by pad-dry-cure method. Two percent of metal oxide nanoparticles were treated with 20% of wet pickup of cotton fabrics. Subsequently, these fabric samples were padded continuously for 15 min using two bowl-padding mangles. Then, the fabrics were cured at 120°C for 3 min. The excess of nanoparticles were removed by washing with sodium lauryl sulfate solution. The coated fabrics were completely washed with water and dried.

3.3. Microwave method

The thiol-modified cotton fabrics chelated with metal salt were prepared [4]. This was done by dipping the modified cotton fabrics into a conical flask containing 100 ml of metal ion solution. The flask was shaken overnight using Bench-top Shaker. Dipped fabric samples were squeezed at 100% wet pickup. Modified cotton fabrics containing metal salt were then placed in the microwave oven (MARS6, CEM microwave systems CEM GmbH, Germany) operating at a power of 1800 W and a frequency of 2455 MHz and subjected to microwave irradiation at 100°C for 5 min. Upon microwave irradiation, the cotton fabric samples gained a color corresponding to the metal oxide nanoparticles. The fabric samples containing metal oxide nanoparticles obtained were washed with double distilled water and then dried in an oven at 70°C for 1 h.

4. Influence of surfactants

Several surfactants include sodium dodecyl sulfate (SDS), cetyl trimethylammonium bromide (CTAB), Triton-X (TX)-100%, and HY were used for coating process to form metal oxide (ZnO and CuO)–coated cotton nanocomposites [37]. Surfactants were used as stabilizing agents for the metal oxide controlling their shape and size as encapsulated species within which were interacted with cellulose chain and metal oxide nanoparticles [38] (**Figure 2**).

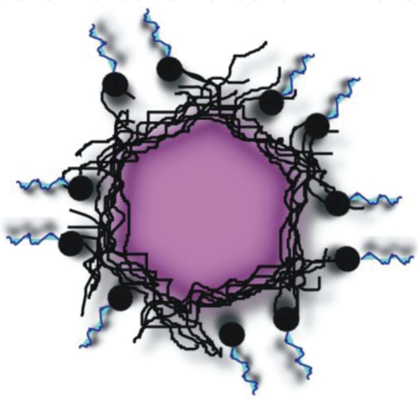

Figure 2. Interaction of ZnO with surfactant and cellulose, Manufacturing Nanostructures, chapter 4 (2014) 109-127.

5. Proposed antibacterial activity mechanism

Several studies have reported the mechanism responsible for the antibacterial action of the coated materials. The results showed that hydrogen peroxide and/or radical species are formed by the metal oxide-modified hybrid polymer, which probably contributes to the antibacterial activity. The generation of highly reactive species such as OH-H_2O_2 and O_2 is explained as follows, since both UV and UV light can activate MO with defects, electron hole pairs can be created. The holes split H_2O molecules into OH^-, H^+ and then they react with hydrogen ions to produce molecules of H_2O_2. The generated H_2O_2 can penetrate the cell membrane and kill the bacteria [39].

6. Wash durability of coated cotton materials

Wash durability test carried out on coated cotton fabrics showed that the different washing cycles resulted in significant release of MO-NPs out of the cotton substrate [37].

The results showed that CuO-NPs are adhered well onto the surface of the cotton fibers compared with ZnO-NPs (**Figure 3**).

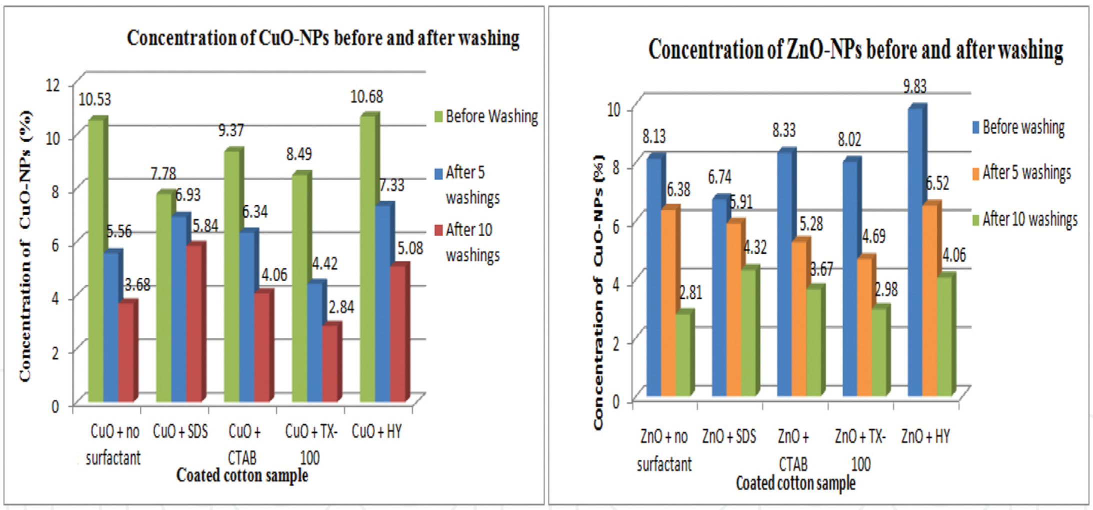

Figure 3. Concentration of CuO and ZnO-NPs before and after washing, M.Sc. thesis 2016, Islamic University Gaza.

7. Characterization methods

7.1. FTIR analysis

The infrared spectra of blank sample showed characteristic absorption peak at 3329 cm^{-1}, which is attributed to OH-stretching vibration; the band at 2887 $cm^{-1}$is assigned to the C-H-stretching vibration peak, and the band at 1427 cm^{-1} is ascribed to C-H bending vibration peak [18]. The strongest absorption peak of pristine cotton samples appears at 1037 cm^{-1}, which is characteristic of the OH-stretching vibration peak. The absorption peak at 1159 cm^{-1} is observed for all samples, which may refer to C-O-C asymmetric-stretching vibrations. The peak at 1643 cm^{-1} indicates the presence of water. FTIR spectra were recorded at room temperature for pristine- and ZnO-coated cotton fibers, respectively (**Figure 4**). Both spectra are characterized by two intense and broad bands in the range of 3300–3500 cm^{-1} and 1400–1500 cm^{-1}, assigned to the existence of hydroxyl groups on the surface [18]. It indicates that both of them show the characteristic bands of cellulose. An additional peak at 464 cm^{-1} is observed for ZnO-coated cotton fibers, which is attributed to the Zn-O vibration band [40].

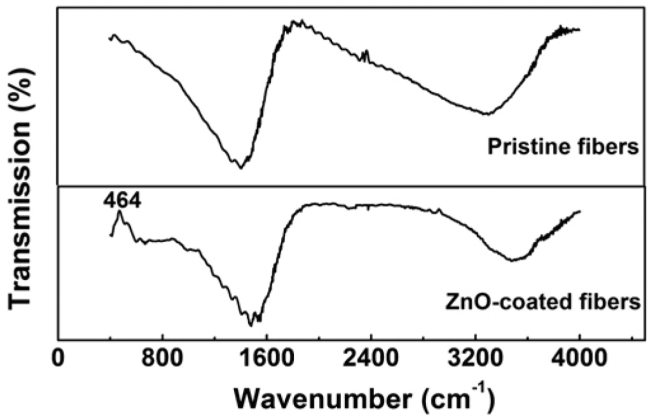

Figure 4. FTIR spectra of pristine fibers and ZnO-coated fibers, Materials Letters 65 (2011) 1316–1318.

7.2. UV/vis spectra

UV visible spectrum of ZnO nanoparticle synthesized with 0.5% soluble starch (**Figure 5**) shows an absorption peak at 361 nm. By using effective mass approximation, the size (diameter) was calculated to be 40 nm [38].

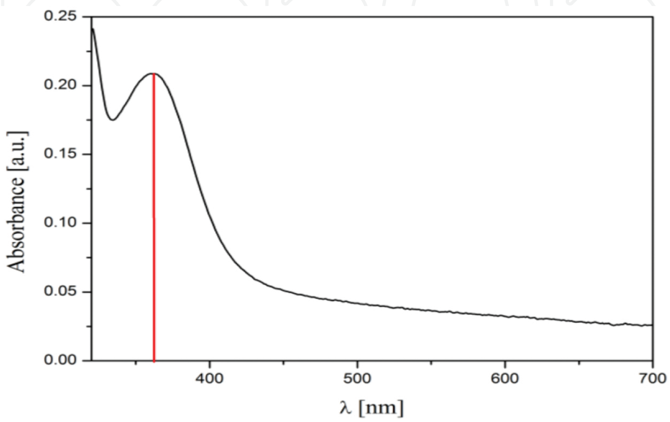

Figure 5. Absorption spectra of ZnO-NPs in ethanol. Manufacturing Nanostructures, chapter 4 (2014) 109-127.

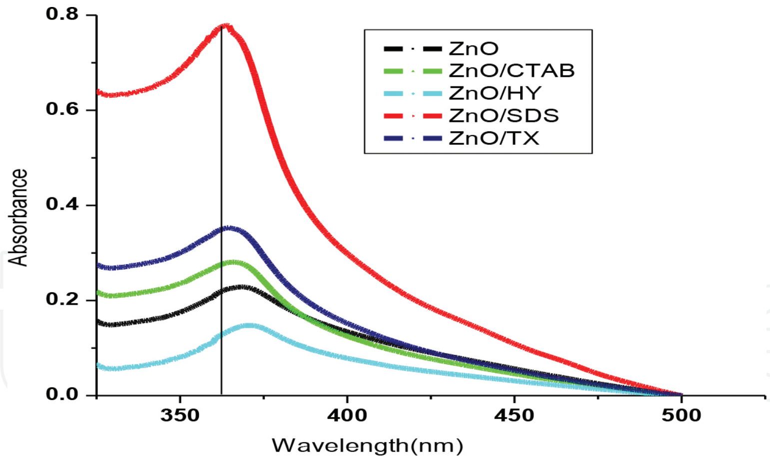

Figure 6. UV-spectra of ZnO-NPs in different surfactants, M.Sc. thesis (2015), Islamic University Gaza.

Figure 6 displays the absorption spectra of ZnO-NPs prepared in different surfactants (CTAB, HY, SDS, and TX-100). There was a blue shift of the peak maximum from 371 for ZnO/HY to 362 nm for ZnO/SDS [37]. It is also shown that the highest peak intensity was obtained when SDS was used whereas the lowest intensity resulted when HY was used. This is in consistence with the fact that smaller particles "in case of using SDS" were bound strongly to the fiber surface compared with the larger particles "in case of using HY" which were not strongly adhered to the surface. This explains why the addition of SDS shows the least leaching of CuO- and ZnO-NPs compared with HY (**Figure 3**).

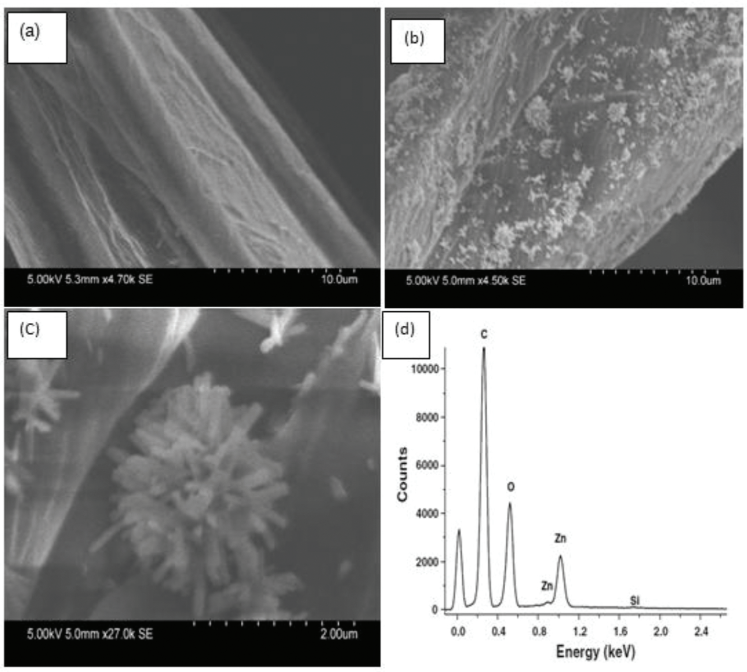

Figure 7. SEM images: (a) blank cotton, (b) ZnO-coated cotton, (c) ZnO nanorods onto cotton fiber (high magnified), and (d) EDX spectra of coated ZnO. J Mater Sci:Mater Electron 24 (2013).

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7.3. SEM results

The morphology of the fiber surface before and after coating with ZnO nanoparticles was reported [3]. **Figure 7a** shows the SEM image of the original cotton fiber before coating where grooves and fibrils could be easily seen on the surface of the fiber. **Figure 7b** presents the SEM image of ZnO-NP–coated fibers, where ZnO nanoparticles can be easily observed. Under these conditions, it is found that nanorod crystals of various sizes as well as assemblies of well-defined flower of nanorods of ZnO are observed (**Figure 7c**). That is in agreement with previously reported results [41]. The chemical composition of the ZnO-coated cotton samples is presented in **Figure 7d**. EDX spectrum of the ZnO-coated cotton composite showed C, Zn, and O components.

Surfactants can play an important role in synthesizing nanomaterials of different interesting morphologies. It has found that surfactants can be used to control the size, shape, and agglomeration among the particles [37].

7.4. XRD results

The crystalline nature of the commercial ZnO and CuO was analyzed by XRD (**Figure 10a** and **b**), respectively. According to the results, the ZnO pattern is assigned to the hexagonal phase of zincite and the CuO pattern corresponds to the monoclinic tenorite phase [1–3, 16].

X-ray diffraction analysis revealed the presence of the crystalline zinc oxide on the cotton fibers (**Figure 8a**). The pattern corresponds to the hexagonal phase of ZnO. The pattern can be indexed for diffractions from the (10 0), (0 0 2), (1 0 1), (1 0 2), (1 1 0), (1 0 3), and (112) planes of wurtzite crystals. The average crystallite size of zinc oxide nanoparticles estimated by XRD data was around 12 nm, which is very close to the reported values of similar ZnO-coated cotton materials, which provides evidence that a sphere crystallite shape of ZnO is more probable.

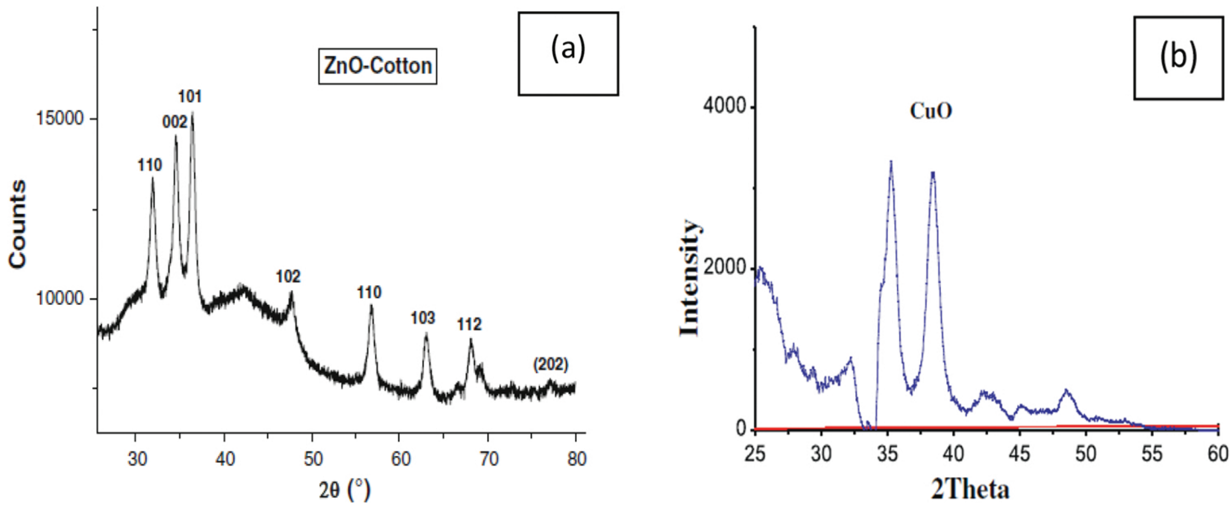

Figure 8. XRD analysis for (a) ZnO, J Mater Sci:Mater Electron 24(2013) and (b) CuO-NP–coated cotton substrate, Intern. Nano Lett. 2, 62 (2012).

The XRD pattern of the coated cotton (**Figure 8b**) reveals that copper oxide is present onto the cotton fibers. The pattern corresponds to the monoclinic phase of CuO; the diffraction peaks match very well with the PDF file 80–1916. The peaks at 2θ = 35.53 and 38.37 are assigned to the (−111) and (111) reflection lines of monoclinic CuO particles. Scherer's equation was used to estimate the mean size of nanoparticles.

7.5. XPS results

X-ray photoelectron spectroscopy was used to examine ZnO nanoparticle film coated onto the cotton fabrics. The survey scan XPS spectrum of cationized cotton fabric showed distinctive peaks at 283.95, 399.6, and 530.11 eV, which indicate the presence of carbon, nitrogen, and oxygen, respectively (**Figure 9a**). **Figure 9b** showed a survey scan XPS spectrum of 16 multi-layer ZnO nanoparticle film deposited on cationized cotton fabrics. Distinctive peaks at 283.95, 530.11, and 1033.7 eV indicate the presence of carbon, oxygen, and zinc, respectively.

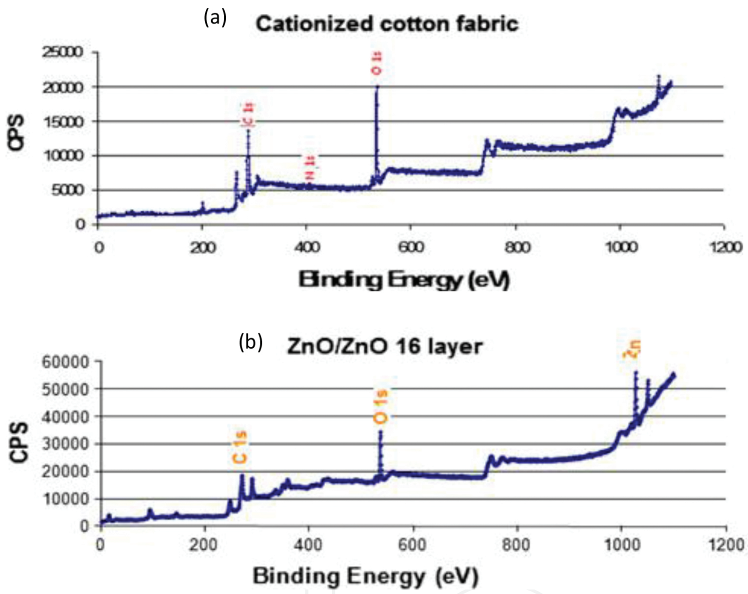

Figure 9. XPS survey for (a) cationized cotton and (b) ZnO/cotton composite, Nanoscale Res Lett 5 (2010) 1204–1210.

8. Antimicrobial activity

8.1. Antibacterial tests

Two different types of cell wall in bacteria, called Gram-positive and Gram-negative, are well known. The Gram-positive bacteria have a thick cell wall and bear many layers of peptidoglycan and teichoic acids, whereas the Gram-negative bacteria are characterized by a relatively thin cell wall with a few layers of peptides surrounded by a second lipid membrane containing lipopolysaccharides and lipoproteins.

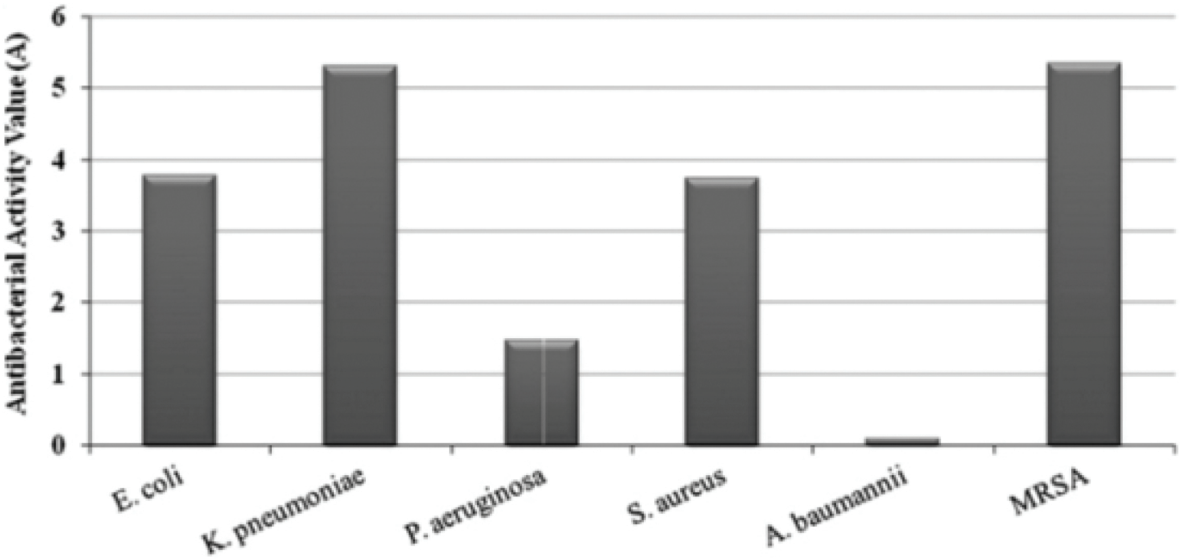

Figure 10. Antimicrobial activity of cotton coated with CuO-NPs, Applied Material Interface, 2 (2010) 1999-2004.

Coated cotton with antimicrobial activity materials (metal oxides) showed good antibacterial activity against *E. coli, K. pneumoniae, S. aureus*, and methicillin-resistant *Staphylococcus aureus* (MRSA). Less antibacterial activity was also observed against *Pseudomonas aeruginosa* and no activity was observed against *Acinetobacter baumannii* [8]. The antibacterial activity of the CuO-NP–coated fabrics was assessed using the absorption method from BS EN ISO20743:2007. The results of the analysis are shown in **Figure 10**.

The antimicrobial activity of cotton coated with ZnO-NPs and CuO-NPs was tested against *E. coli* and *S. aureus* cultures by El-Nahhal and his coworkers [3]. Their results have reported that coated cotton samples displayed high activity with a great reduction in the bacteria population. The antibacterial activity of ZnO-NPs coated onto cotton against *E. coli* is shown in **Figure 11**. No growth was observed in the tubes containing the ZnO-coated cotton as evident by the clear appearance of the tubes and the absence of growth from the subcultured samples. Similar results were observed against *S. aureus*.

Shateri-Khalilabad and Yazdanshenas [9] have confirmed that the ZnO-NP–coated cotton fabric have a good bacteriostatic activity against two representative bacteria, *K. pneumoniae* and *S. aureus*, which was demonstrated by the zone of inhibition and it was proved that the coated fibers have an excellent ability to block the UV radiation.

Singhand and his coworkers [10] have characterized the antimicrobial properties of cotton fabrics finished with ZnO-NPs against a variety of bacterial strains commonly associated with nosocomial infections, *S. aureus* and *E. coli*. In their work, they have investigated the antibacterial properties by four different tests including semi-quantitative testing: agar diffusion method, shake-flask method, quantitatively by the shake-flask method (saline), and the absorption method. The results showed a very high antimicrobial activity of ZnO-coated material against both types of bacteria, with a slightly higher activity for *S. aureus* than for *E. coli* [10].

The antibacterial activity of ZnO nanoparticles was assessed using four different methods in order to investigate the efficacy under different conditions. The ability of the antibacterial agent to inhibit bacterial growth was first tested using a disk diffusion method. Cotton disks (10 mm) with or without the ZnO nanoparticle coating were examined. **Figure 12** shows a clear zone of inhibition around ZnO-treated fabric disk, with higher inhibition zone against *S. aureus as compared with E. coli*.

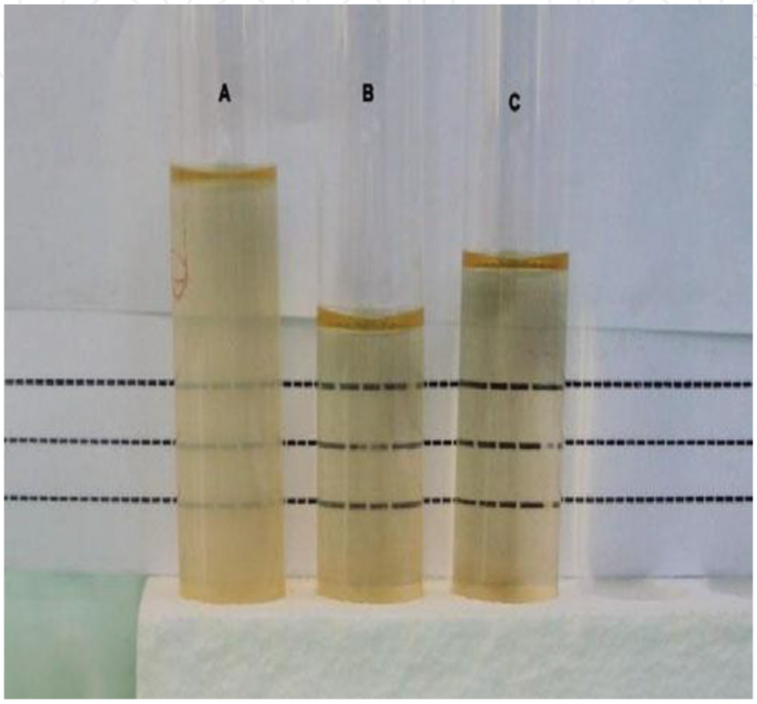

Figure 11. Photos of antimicrobial activity of ZnO-NPs/cotton, J Mater Sci:Mater Electron 24 (2013) 3970–3975, (middle sample; right negative control).

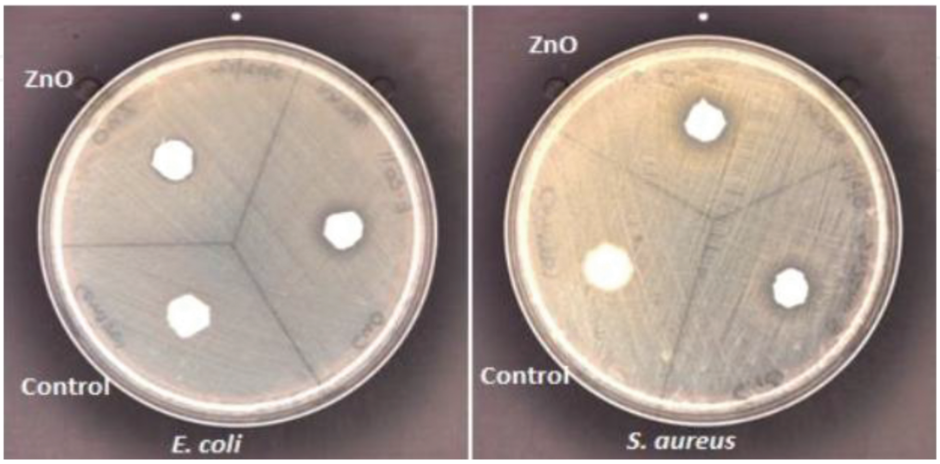

Figure 12. Antibacterial activity of ZnO-NP-treated fabrics by a disk diffusion method, J Microbial Biotechnol Food Sci 2(2012) 106-120.

The antibacterial activity of ZnO-coated cotton was determined using two shake-flask methods, with nutrient broth, and saline as media. The bacterial growth was monitored by measuring the optical density of the medium versus time. **Figure 13** shows the change in absorbance over time. A very high antimicrobial activity was seen against both bacteria.

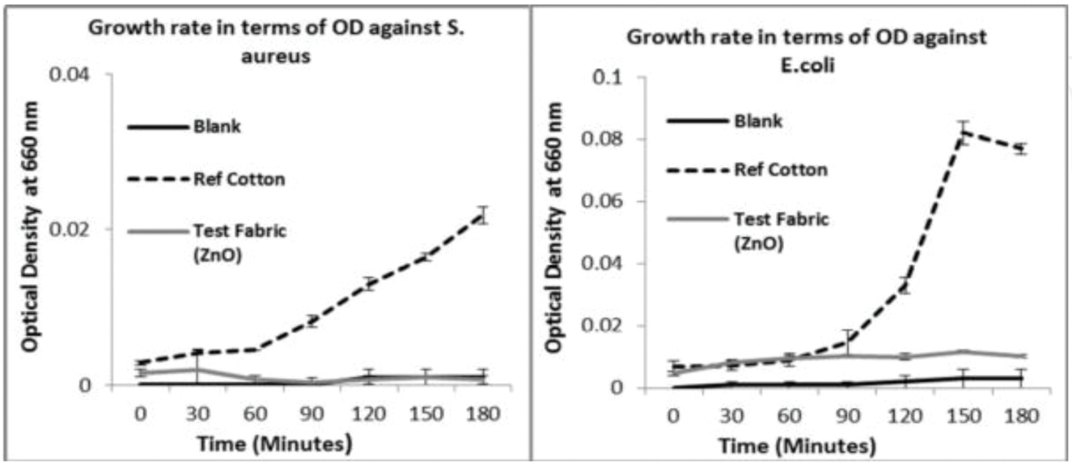

Figure 13. Graphs showing change in absorbance over time (3 h) for nutrient broth shake and flask tests, J Microbiol Biotechnol Food Sci 2(2012) 106-120.

The antibacterial activity of the finished fabrics was assessed against *S. aureus* and *E. coli*, qualitatively by agar diffusion, parallel streak method, and quantitatively by percentage reduction test. The results demonstrated that ZnO-NP–coated cotton fabrics showed higher antimicrobial activity against *S. aureus* in both qualitative and quantitative tests [11]. The results of the qualitative antibacterial assessment by agar diffusion show that the fabric sample treated with ZnO-NPs showed a maximum inhibitory effect against *S. aureus*. It is observed that the ZnO-NP-treated fabric showed higher antibacterial activity when compared with ZnO bulk-treated fabrics, whereas the untreated fabrics showed no antibacterial activity (**Figure 14a–c**).

Figure 14. Antibacterial activity of (a) ZnO-NP-treated fabric, (b) ZnO bulk-treated fabric, and (c) untreated fabric (control) by disk diffusion method, International Journal of Engineering, Science.

Perelshtein and his colleagues [42] have prepared CuO-NP–coated cotton bandages and tested their antimicrobial activity against *E. coli* and *S. aureus*. The viable bacteria were monitored by counting the number of colony-forming units from the appropriate dilution on nutrient agar plates. As shown in **Figure 15**, treatment for 1 h with the coated cotton leads to the complete inhibition of *E. coli* and *S. aureus* growth [42].

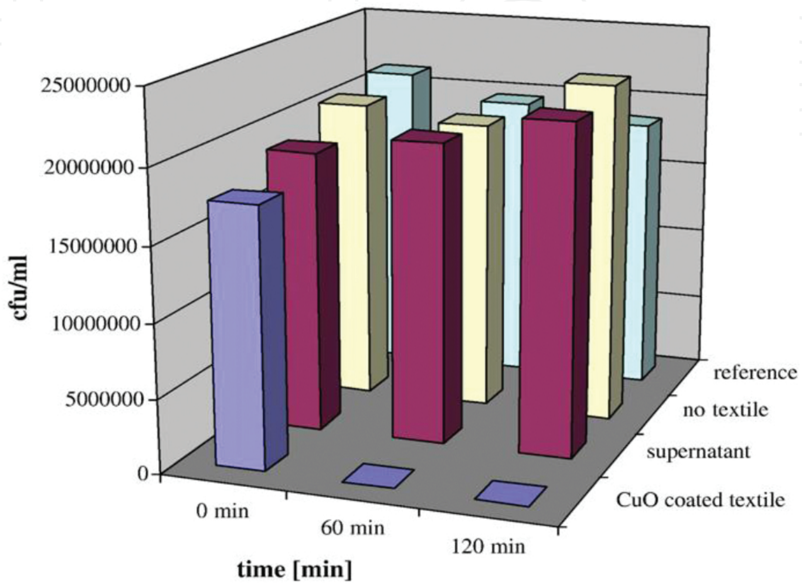

Figure 15. Antimicrobial activity of the CuO-coated bandages against *E. coli* and *S. aureus*, Surf Coat Technol204, 1-2, (2009) 54-57.

Vigneshwaran and his team [12] have prepared ZnO-soluble starch nanocomposites using water as a solvent and soluble starch as a stabilizer. The synthesized ZnO-NPs of 38 ± 3 nm were then impregnated onto cotton fabrics and its antibacterial and UV protection functions of ZnO-NP–coated cotton fabrics were studied. It was reported that the ZnO-NP–coated cotton fabrics showed an excellent antibacterial activity against two representative bacteria, *S. aureus* and *K. pneumoniae*. In addition, nano-ZnO impregnation enhanced the protection of cotton fabrics against UV radiation in comparison with the untreated cotton fabrics [12].

The antibacterial properties of nanometal oxides (ZnO, CuO) are based on the formation of reactive oxygen species (ROS). This work reveals that the antibacterial properties of these nanometal oxides are strongly dependent on their crystalline structure. The sonochemically prepared nanometal oxides are better antimicrobials than commercially available metal oxides with the same particle size range [16].

8.2. Antifungal test

The ZnO and CuO NP–coated cotton composites were assessed and investigated for antifungal activity against *Candida albicans* and *Microsporum canis* [37]. The results showed that both CuO-NP- and ZnO-NP–coated cotton showed greater antifungal activity against *C. albicans* compared with *M. canis* and that CuO-NP–coated cotton has greater activity against both

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fungal species (*C. albicans* and *M. canis)* compared with ZnO-NP–coated cotton (**Figure 16**). It was also shown that NP-coated cotton fabric was able to retain the antifungal activity against both fungal species even after 10 washes. However, this activity (expressed as % reduction) was reduced as the number of washes increased.

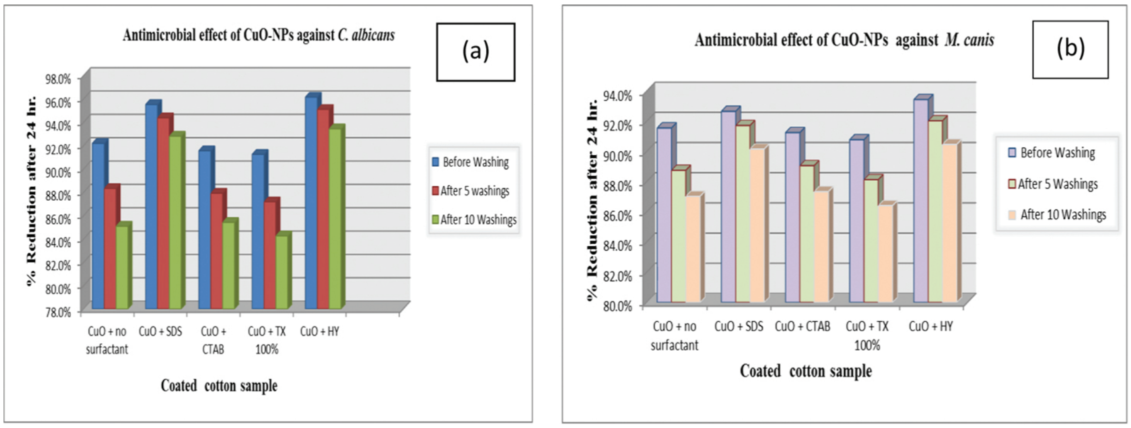

Figure 16. Antifungal activity of CuO-NPs against (a) *Candida albicans* and (b) *Microsporum canis*, M.Sc. thesis 2016, Islamic University Gaza.

9. Conclusion

In this chapter, selected studies dealing with the development of antimicrobial metal oxide–coated cotton nanocomposites and their antimicrobial applications have been reviewed with respect to the synthesis of metal oxide NP–coated cotton composites and their application for antimicrobial activities. The deposition onto cotton fibers was conducted in various methods: high-energy γ-radiation, thermal treatment-assisted impregnation, and "pad-dry-cure" of the impregnated fabric in the colloid formulation of metal oxide nanocomposites; these methods are mostly based on long-duration multistage procedures and require some binding agents for the anchoring of the nanoparticles onto the substrate. A third effective method was used for the synthesis and deposition of nanoparticles onto the substrate in a one-step process without using any type of binding agents. This method was based on using ultrasonic radiations. It has been demonstrated that the use of surfactants increased the durability of the NPs and its activity in the coated fabric. The results showed that there was subsequent decrease in the concentration of the adsorbed NPs accompanied with reduction in the antibacterial efficiency as the number of washes increased. SDS was the most effective surfactant in minimizing the leaching of both MO-NPs and it helped in getting the smallest size for CuO and metal oxides. The physical and chemical characteristics of the cotton-coated material prepared in the presence of surfactants were markedly different from those prepared in the absence of surfactants. It is also shown that the size of the MO-NPs, which were obtained when surfactants were used, is smaller than that obtained in the absence of surfactants.

The coated metal oxide nanoparticles have shown an effective enhancement for protection against UV radiation and antimicrobial activity, and they reduce the chance of disease originating from hospital infections. In this work, the antibacterial and antifungal activities were examined by several different methods. The results showed a very high antimicrobial activity of metal oxide–coated material against both types of bacteria, with a slightly higher activity for *S. aureus* than for *E. coli*. The morphology of the cotton-coated metal oxide nanoparticles and their chemical structure. Several methods have been employed for their chemical and structural characterization, and these include UV-vis spectrophotometer, FTIR, SEM, XRD, and XPS.

Author details

Issa M. El Nahhal[1*], Abdelraouf A. Elmanama[2] and Nadia M. Amara[2]

*Address all correspondence to: issanahhal@hotmail.com

1 Al-Azhar University of Gaza, Gaza, Palestine

2 Islamic University of Gaza, Gaza, Palestine

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