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The Development of ZnO Nanoparticle Coated Cotton Fabrics for Antifungal and Antibacterial Applications

Tanu Shree Roy[1], Siraj Ud Daula Shamim[2], Md. Khalidur Rahman[3], F. Ahmed[4], M. A. Gafur[5*]

[1]Department of Physics, Bangladesh University of Textile, Dhaka, Bangladesh
[2]Department of Physics, Mawlana Bhashani Science and Technology University, Tangail, Bangladesh
[3]Department of Electrical & Electronic Engineering, Prime University, Dhaka, Bangladesh
[4]Department of Physics, Jahangirnagar University, Saver, Dhaka, Bangladesh
[5]PP & PDC, Bangladesh Council of Scientific & Industrial Research (BCSIR), Dhaka, Bangladesh
Email: *dr.abdul.gafur999@gmail.com

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Abstract

In the textile industry, cotton is the most popular choice among all the natural fibers due to its unique properties such as softness, affinity to skin, biodegradability, absorbency, and moisture being comfortable to wear. Zinc Oxide Nanoparticles (ZnO NPs) were produced and coated on cotton fabrics. The concentration of Zinc acetate was varied. 2-methoxy-ethanol has been used as a solvent. Using the dip coating technique, ZnO NPs have been coated on the cotton fabric in different mole concentrations. Scanning Electron Microscopy (SEM), Ultraviolet Visible (UV-VIS) spectroscopy, the antifungal and antibacterial activity of the ZnO NPs was performed on the coated fabrics. The SEM images depicted that the nanoparticles are well dispersed on the fabric at 3M concentration of ZnO solution. It was found that the UV absorbance increases with the increase of concentration up to 2M concentration and after that it decreases. It was also found that maximum antibacterial and antifungal activity is at 2M concentration.

Keywords

Nanoparticles, ZnO, Cotton, SEM, UV-VIS, Antibacterial, Antifungal

1. Introduction

Due to the surface effect and quantum size effect, nanoparticles exhibit exceptional physical, chemical, optical properties from bulk materials [1] [2]. This leads to different applications in drugs and medicines, environment, electronics, food, manufacturing and materials, mechanical industries [3] [4] [5] [6]. From the literature reviews, it has been found that the nanoparticles such as Ag, ZnO, CuO, TiO_2, SiO_2 NPs, etc. are widely used in the textile engineering sector for enhancing the performance of water repellency, flame retardancy [7], breathability, self-cleaning [8], antibacterial effect [9], UV protection [6], etc. Ag NPs has been widely used as an antibacterial agent on fabric against *Staphylococcus aureus* and *Escherichia coli* bacteria [10]. TiO_2 and SiO_2 NPs have been used for imparting for self-cleaning property [11] [12]. Among these nanoparticles, ZnO NPs is widely used for antibacterial properties, photo-catalytic properties, UV blocking properties due to nontoxicity, biosafety, chemically stable under exposure to both high temperature and UV [13] [14]. Although the small doses of UV radiation from the sun provide vitamin D that can contribute to bone development, the intense UV radiation can cause skin cancer, Alzheimer's diseases, inflammatory disorders, etc. which is harmful to our outdoor workers [15] [16]. Therefore, NPs are used to protect the UV rays from the sun by coating on fabrics.

Among the total fibers used in the textile industry, about 48% of cotton fibers are used around the world due to its excellent properties such as hygroscopicity, air permeability, softness, breathability, bio-degradation, regeneration, no static electricity, etc. [17] [18] [19]. It is an abundant natural renewable fiber that consists of about 88% - 96% of pure cellulose [20] [21]. As cotton fabrics have a high specific surface area and have the ability to retain moisture, microorganisms can grow easily into the cotton fabric [22] [23]. To get rid of microorganisms, numerous chemical agents have been coated on the fabrics. Among these chemical agents, ZnO NPs shows strong inhibitory and antibacterial effects against *Staphylococcus aureus* and *Escherichia coli*, etc. [24]. In 2016, Shaban M *et al.* synthesized ZnO NPs by using the sol-gel method and coated ZnO NPs on cotton fabric via a spin coating technique. They found that ZnO NPs showed high photocatalytic activity and self-cleaning property against methyl orange dye under the sunlight and lamp illumination [25]. Becheri Alessio *et al.* synthesized and characterized ZnO NPs and coated on cotton and wool fabrics for UV shielding. They claimed that a significant increment of the UV absorbing activity due to coating ZnO NPs on the cotton and wool fabrics can protect our body from solar radiation [26]. Rajendra R. *et al.* prepared ZnO NPs and coated on cotton fabric by wet chemical method and investigated the antimicrobial property. They clearly confirmed that the ZnO NPs treated fabrics showed a better antibacterial effect than the bulk ZnO against *S. aureus* and *E. coli* [24].

In this study, the ZnO solution has been prepared by using a chemical method. Different mole concentrations (1M, 1.5M, 2M, 2.5M, and 3M) have been prepared and dip-coated on the cotton fabric for enhancing the UV-VIS spectroscopy, antifungal, and antibacterial properties. We have investigated the change of properties with varying mole concentrations. The morphological characteristic, UV-VIS spectroscopy, antifungal and antibacterial properties of ZnO solution coated cotton fabric has been examined by Scanning Electron Microscopy (SEM), Ultraviolet-Visible (UV-VIS) spectroscopy, disk diffusion methods respectively.

2. Experimental Details

2.1. Materials

Zinc acetate dehydrate ($Zn(CH_3COO)_2 \cdot 2H_2O$), 2-methoxyethanol ($C_3H_8O_2$) and monoethanolamine ($C_2H_7NO$) were purchased from Merck-chemicals (Germany). Woven and scoured cotton fabric was obtained from a testing laboratory of BUTEX, Bangladesh. *Aspergillus niger*, *Staphylococcus aureus* and *Escherichia coli* were obtained from WAFFEN Research Laboratory, Dhaka, Bangladesh. Distilled water was utilized throughout the whole research work.

2.2. Washing of the Cotton Fabric

To remove the impurities such as wax and fat, the cotton fabric was washed first with water and detergent at 80˚C for 30 min. Then it was washed 3 times with a sufficient amount of deionized water and further cleaned with acetone at 60˚C - 70˚C about 30 min. The same cleaning was performed with ethanol flowed by drying at room temperature for 24 h [25].

2.3. Preparation of ZnO Solution

Zinc acetate dihydrate, 2-methoxyethanol, and monoethanolamine were used as a precursor, solvent and stabilizer respectively. The molar ratio of monoethanolamine to zinc acetate dihydrate was maintained at a 1:1 molar ratio where solvent 2-methoxyethanol was used as much as needed to prepare 1M, 1.5M, 2M, 2.5M and 3M concentrations [25]. For example, 5.4875 gm Zinc acetate dihydrate, 1.527 gm monoethanolamine and 25 ml 2-methoxyethanol were used for preparing 1M concentration ZnO Solution. Similarly, different concentration solutions were prepared and the solutions were acquired after stirring at 60˚C for 2 h at 500 rpm stirring rate. Then the solutions were aged for 24 hours at room temperature before the coating process on the cotton fabric. **Figure 1** shows the flowchart of the preparation of ZnO NPs.

2.4. Coating Process

In this study, dip coating has been carried out for coating ZnO solution on the cotton fabric. In this process, fabric was dipped at room temperature for 60 sec into the ZnO solution. Then it was dried at 80˚C for 30 min in a drier to get rid of the excess 2-methoxyethanol and monoethanolamine residuals in vacuum oven at 150 mbar pressure. The process was done by dip coater (TL0.01 Dip Coater, MTI Corporation, USA). The process is composed manually dipping and withdrawing at speed of 30 cm/min [26]. The dipping is a manual operation. These coating steps were repeated for ten times and finally the dried fabrics were annealed in a furnace at 150˚C in air for 2 h [25].

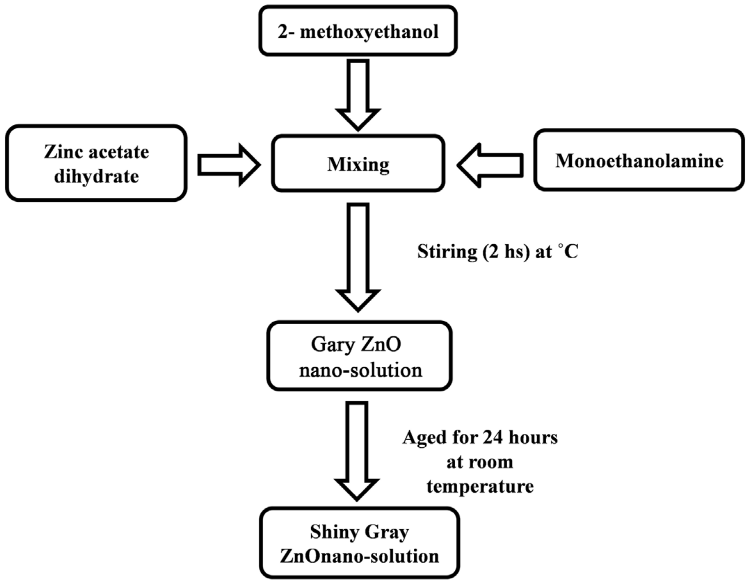

Figure 1. Flowchart of preparation of the ZnO nano solution from Zinc acetate dihydrate, 2-methoxyethanol and monoethanolamine.

2.5. Samples Characterization

The surface morphology of ZnO nanoparticle coated cotton fabrics was measured by scanning electron microscopy (EVO18, Carl Zeiss AG, Germany). The absorption spectra of ZnO solution and ZnO NPs coated cotton fabrics were obtained from ultraviolet-visible (UV-VIS) spectrometer (UV-VIS-1601, Shimadzu, Japan) with a wavelength range from 300 to 920 nm. The antifungal activity against aspergillusniger and antibacterial activity against *Staphylococcus aureus* (gram positive) and *Escherichia coli* (gram negative) of the ZnO NPs were performed on the coated fabrics by disk diffusion method.

3. Results and Discussions

3.1. Scanning Electron Microscopy (SEM)

Figure 2 shows the SEM micrographs of ZnO coated cotton fabric at various concentrations of ZnO. From the figure, it is found that concentration of ZnO has a significant effect on the morphology of the ZnO coated cotton fabric. In case of 1M, 2M and 2.5M ZnO solutions coated cotton fabric, the nanoparticles are not well dispersed on the cotton fabric and the surface of the fabric is smooth in comparison with 3M ZnO solutions coated cotton fabric. It has appeared that the nanoparticles are aggregated on the cotton fabric in case of 1M, 2M and 2.5M ZnO concentration. The size of nanoparticles plays a vital role in the fibers. The larger the size of nanoparticles, lesser adhesion to the cotton fabric and easily removed from the fabric during washing. And smaller particles strongly adhere and penetrate deeper into the fabric [27]. The SEM image of 3M ZnO-coated cotton fabric indicates that it is completely different. For 3M ZnO solution, the SEM image depicts that the ZnO nanoparticles are adsorbed

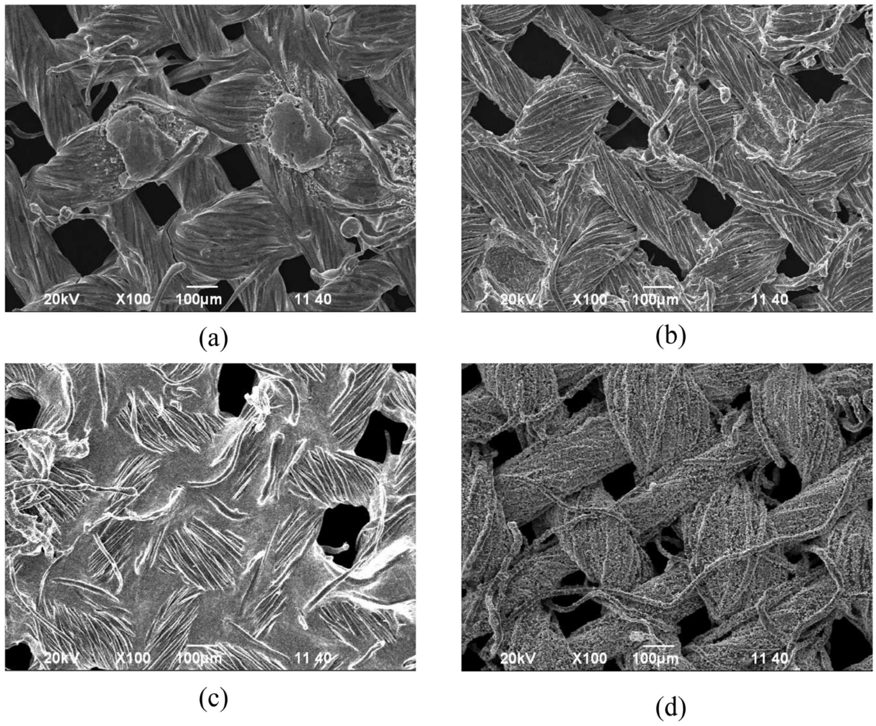

Figure 2. SEM images of the (a) 1M, (b) 2M, (c) 2.5M and (d) 3M ZnO-coated cotton fabrics respectively.

on cotton fabric homogeneously as compared with other mole concentrations due to hydroxyl group present in cotton fabric *i.e.* the nanoparticles are well dispersed on the fabric [28].

3.2. Ultraviolet-Visible (UV-VIS) Spectroscopy Analysis

Figure 3 illustrates the variation of absorption spectra with wavelength. In case of ZnO solutions, it shows UV-VIS absorption properties and typical peaks have been found in the region of 330 to 350 nm wavelength range which is similar with the previously reported ZnO samples [27]. With the increasing concentrations, the absorption of UV rays is increased drastically. Herein, 1M ZnO has provided lowest absorbance while 2M ZnO has given highest absorbance. Interestingly, the absorption property is greatly enhanced from 1M to 2M, 2.5M and 3M solutions. 2M, 2.5M and 3M ZnO solutions have been shown comparable absorption properties. Thus the UV absorbance increases with the increase of concentration up to 2M concentration and after that it decreases. It occurs due to that up to 2M concentration, the solution remains homogeneous but above 2M concentration, the nanoparticles in the solution aggregate to form larger radius particles and may falls down. Thus, the absorbency slightly decreases.

But after coating with different concentrations of ZnO solutions on the cotton fabric, it is found that, 2M and 2.5M ZnO coated cotton fabric have shown significant absorbance properties. Among these various concentrations, 2.5M ZnO coated cotton fabric has absorbed highest UV-VIS rays while 3M ZnO coated

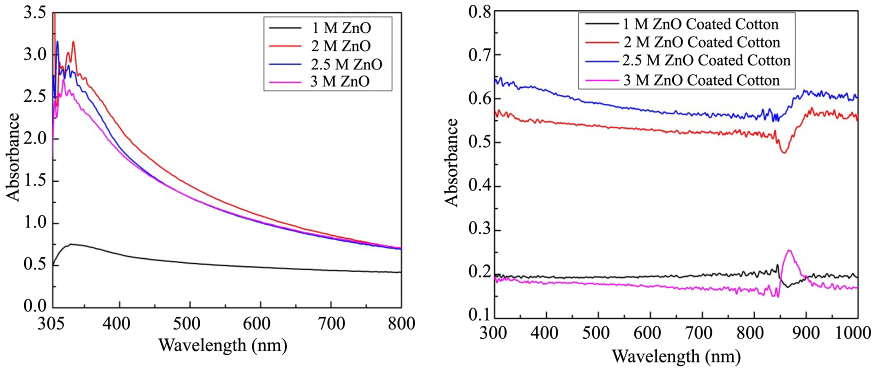

Figure 3. Absorption spectra of (a) 1M, 2M, 2.5M and 3M ZnO nanoparticles containing solutions and (b) 1M, 2M, 2.5M and 3M ZnO-coated cotton fabrics.

cotton fabric has absorbed the lowest UV-VIS rays. So, it can be concluded that 2.5M concentration of ZnO nanoparticle is the optimum concentration for the ZnO nano particle coated cotton fabrics to absorb UV-VIS rays.

3.3. Antifungal and Antibacterial Activity Analysis

Zone of inhibition indicates a circular area where bacteria or fungal do not grow. In our study, we have taken one fungal (*Aspergillus niger*) and two bacteria (*Staphylococcus aureus* and *Escherichia coli*) to test antifungal and antibacterial effect by "Disk Diffusion Method".

Figure 4 depicts the effect of concentration of ZnO NPs on the zone of inhibition for coated cotton fabric and Figure 5 shows the pictorial view of inhibition zone for the same. In this study, pure cotton fabric do not exhibit zone of inhibition. But after coating ZnO nanoparticles on the cotton fabric, strong zone of inhibition have been found against *Aspergillus niger*, *Staphylococcus aureus* and *Escherichia coli*. It means, ZnO nanoparticles act as antifungal and antibacterial agent [29] [30].

In case of antifungal effect, according to this graph, pure cotton has shown no zone of inhibition where 2M ZnO coated cotton fabric has shown the highest zone of inhibition (14 mm). The 2.5M ZnO coated cotton fabric has shown a lower zone of inhibition with comparison to 2M ZnO coated cotton fabric and the 3M ZnO coated cotton fabric has shown a lower zone of inhibition with comparison to 2.5M ZnO coated cotton fabric. So, 2M is the optimum concentration of ZnO for the ZnO coated cotton fabrics for the antifungal effect against *Aspergillus niger*.

Similarly, antibacterial activity of the ZnO coated cotton fabrics has been investigated for the "*Staphylococcus aureus*" (gram positive) and "*Escherichia coli*" (gram negative) bacterias. For antibacterial effect against "*Staphylococcus aureus*", pure cotton has shown no zone of inhibition where 2M ZnO coated cotton fabric has shown the highest zone of inhibition (24.5 mm). The 2.5M ZnO coated cotton fabric has shown a lower zone of inhibition with comparison

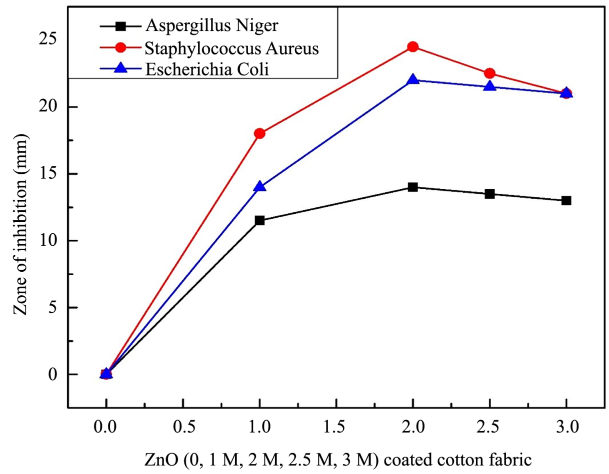

Figure 4. Zone of Inhibition is plotted against different concentrations of the ZnO coated Cotton Fabrics for the *Aspergillus niger*, *Staphylococcus aureus* and *Escherichia coli*.

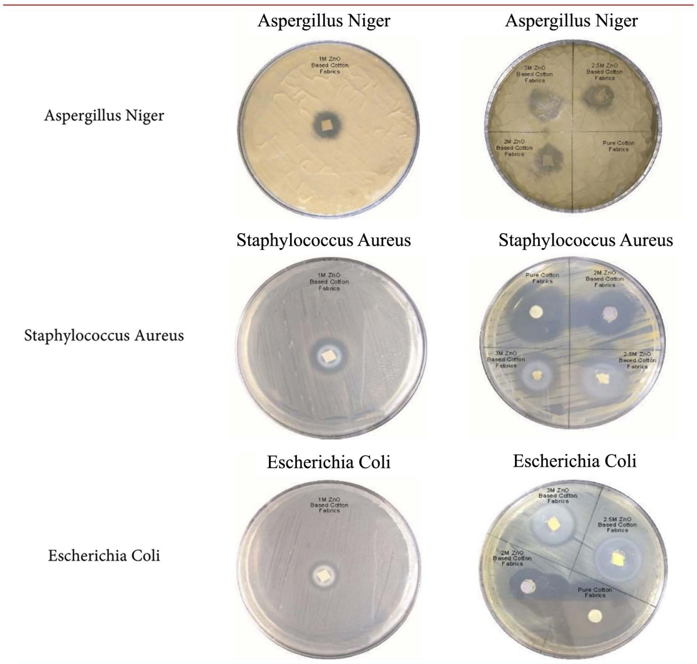

Figure 5. Zone of inhibition of pure, 1M, 2M, 2.5M and 3M ZnO nano-solution coated cotton fabric against *Aspergillus niger*, *Staphylococcus aureus* and *Escherichia coli*.

to 2M ZnO coated cotton fabric and the 3M ZnO coated cotton fabric has shown a lower zone of inhibition with comparison to 2.5M ZnO coated cotton fabric. So, 2M is the optimum concentration of ZnO for the ZnO coated cotton fabrics for the antibacterial effect against *Staphylococcus aureus*. Similar results have been found for *Escherichia coli* bacteria. Here in, 2M, 2.5M and 3M ZnO coated cotton fabrics have shown an analogous zone of inhibition about 22 mm, 21.5 mm and 21 mm respectively. But 2M ZnO coated cotton fabric has shown the highest zone of inhibition. So 2M is the optimum concentration of ZnO for the ZnO coated cotton fabrics for the antibacterial effect against *Escherichia coli*. Therefore, with increasing the concentration of ZnO nano-solution, the antifungal and antibacterial activity increased upto 2M with significant zone of inhabitation which is consistent with previous works [31] [32], such as Valery Svetlichnyi *et al.* found highest ~27 mm and ~18 mm zone of inhabitation for *Escherichia coli* and *Staphylococcus aureus* bacteria [30]. Therefore, it is expected that the ZnO nano particle coated cotton fabric can be used in medical applications such as disposable bedding linen, antibacterial bandage and uniforms for health worker etc. since it exhibits bacterial effect [29] [30].

4. Conclusion

This work describes the methods and results obtained in the development of ZnO nanoparticle coated cotton fabrics for antifungal and antibacterial applications. Characterization of nanoparticles obtained and incorporated into the cotton fabric is shown using Scanning Electron Microscopy (SEM) and Ultraviolet-Visible (UV-VIS) Spectroscopy Analysis methods, to different concentrations of ZnO. Zone of inhibition is found in samples of cotton fabrics with different bacteria, using the disk diffusion method. It was also found that maximum antibacterial and antifungal activity is at 2M concentration of ZnO.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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