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DEVELOPMENT OF WASH-DURABLE ANTIMICROBIAL POLYESTER/COTTON FABRICS BY IMPREGNATION WITH ZINC-OXIDE NANOPARTICLES

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Abstract: *Polyester fabrics, frequently utilized in healthcare and sportswear settings, exhibit susceptibility to microbial contamination. This is due to their inherent structural attributes coupled with diverse environmental factors such as humidity and temperature fluctuations. This vulnerability presents notable hygiene and health concerns. To address these issues prompted by healthcare considerations, and the need to design more diverse products, the development of multifunctional antimicrobial polyester/cotton fabrics was accomplished in this work through the impregnation of zinc oxide (ZnO nanoparticles using an aqueous heat attachment method. The fabrics used in this study were polyester/cotton blends. The fabrics were characterized using X-ray Diffraction, and Digital Microscope to determine the chemical composition, morphology, and crystallinity. The antimicrobial performance of the fabric against Escherichia coli, using zone of inhibition (ZOI) test. The fabrics also underwent a wash test to determine the durability of nanoparticle coating. The impregnation with ZnO nanoparticles did not alter the visual appearance of the fabric, as the light gray shade of the ZnO nanoparticles integrated with the fabric's appearance. The coated fabrics demonstrated effectiveness against E. coli achieving a ZOI of 8 mm while no ZOI was observed for the uncoated fabric. After undergoing multiple washing cycles, the fabric exhibited minimal decrease in antimicrobial activity after the first 10 cycles and the performance did not change for 20 and 30 cycles. The ZOI of the ZnO-coated fabrics were 5, 4, and 4 mm after 10, 20 and 30 washing cycles, respectively. Notably, the immobilization of ZnO nanoparticles yielded a robust polyester textile, with elevated antibacterial activity and preserved the fabric's original color and morphology.*

Key words*:* Antimicrobial; Polyester fabric; Zinc oxide; Nanoparticle; Impregnation; *Escherichia coli*

1. INTRODUCTION

Textile materials are susceptible to microbial contamination due to their inherent structural characteristics, compounded by various environmental factors such as humidity and temperature.

The presence and growth of harmful bacteria can lead to several detrimental effects on textiles, including the generation of unpleasant odors, the formation of stains and discoloration, a decline in the mechanical strength of the fabric, and an increased likelihood of contamination for end-users. Consequently, it becomes imperative to employ antimicrobial treatments on textile materials to mitigate the proliferation of bacteria during their use [1, 2].

The textile industry benefits from many uses of the characteristics of nanoparticles, which covers a wide range of applications. The use of different kinds of nanoparticles in the textile industry has been successful in a number of ways. Creating desired textile characteristics, modifying the physical, chemical, and biological characteristics of textiles, and engineering, synthesizing, and changing conventional materials and processes to create newer, better materials, devices, systems, and structures are just a few examples. Deposition of effective and appropriate nanoparticles on the surface of textiles is one of the primary methods for achieving the mentioned attribute [3, 4].

Zinc oxide (ZnO) nanoparticles have gained significant interest due to their stability in diverse environmental conditions and the ability to be produced at low temperatures. ZnO particles have demonstrated antimicrobial effects against both Gram-positive and Gram-negative bacteria, including antibacterial activity against bacterial spores. These nanoparticles are generally considered safe for human use, being non-toxic, biocompatible, and regarded as biosafe [5, 6]. The size of ZnO Nanoparticles (NPs) was determined to be the most relevant parameter when considering antimicrobial activity. Smaller nanoparticles are more harmful to microbes [7].

To ensure the effectiveness of nanoparticle coatings on polyester materials, it is crucial that these coatings exhibit strong adhesion to the fabric's surface. This adhesion is necessary because polyester materials experience both dry and wet friction, undergo wet washing, and may be subjected to dry cleaning during their usage. Furthermore, it's essential that these modified fabrics retain their antimicrobial properties even after multiple washing cycles, maintaining resilience even after 20 rounds of washing [8].

The objective of this study was to examine the antimicrobial effectiveness of polyester fabrics coated with ZnO nanoparticles against Gram-negative bacteria (*E. coli*) and assess the effect of multiple washing cycles on robustness of the fabrics.

2. MATERIALS AND METHODS

2.1. Materials

Zinc acetate, sodium hydroxide, acetone, and ethanol were obtained from DLA Chemical Reagent Co. Ltd., Nairobi, Kenya. They were used to synthesize ZnO nanopowder and the impregnation process. These reagents were of analytical reagent quality and were employed without any additional purification steps. Deionized water, purchased from Eldo Chemical Reagent Co. Ltd., Eldoret, Kenya, was utilized in all synthesis and treatments. The fabric (65% polyester, 35% cotton) was sourced from the Rivatex Eldoret, Kenya.

2.2. Synthesis of ZnO nanopowder

The method of Wang et al. [9] was employed with some modifications. Initially, 6.23 grams of zinc acetate, 6 ml of deionized water and 80 ml of absolute ethanol were mixed and subjected to magnetic stirring for half an hour. The resulting solution was allowed to age at room temperature until it transformed into a gel. Following this, the gel mixture underwent a drying and calcination process. The calcination process was carried out at temperatures of 450° C, 480° C, 500° C, 550° C, and 600° C, respectively. The duration of calcination was varied (1 hour, 1.5 hours, 2 hours, 2.5 hours, and 3 hours). These sequential steps ultimately yielded the ZnO nanopowder.

2.3. Preparation of the polyester fabric and impregnation of ZnO

Aqueous heat attachment method by Abdel-Wahab et al and Sudrajat [10, 11] were used with modifications. The fabric was washed with detergent at 80°C for 30 minutes and rinsed thoroughly with a substantial amount of water to completely remove the detergent. Subsequently, the PFW was immersed in a 3.75 g/L NaOH solution at 100° C for 20 minutes, then rinsed repeatedly with water and dried at 80° C. Next, the cleaned PFW was immersed in a ZnO suspension at 80° C for 2 hours, with stirring at 200 rpm, and then subjected to 5 minutes of sonication to eliminate any released nanoparticles. This process was repeated three times. The coated PFW was subsequently cured at 150° C for 30 minutes. Finally, the resulting ZnO/PFW was immersed in water at 80° C for 30 minutes to remove loosely attached particles, followed by drying at 80° C for 24 hours and storage in desiccators for use.

2.4. Fabric Characterization

The surface morphology of the coated polyester was determined using a Digital microscope (MSX-500 Di viewer). The chemical composition and the structure of the coated fabrics were determined using X-ray Diffraction (Model: Smartlab X-Ray Diffractometer).

2.5. Washing of coated fabrics

The experiment involved placing three pieces of coated fabric (each measuring 50x50 mm^2) that had undergone impregnation treatment into a wash bottle containing 250 ml of distilled water at a temperature of 40° C. Along with this, three drops of a standard detergent (Sapnol uses for the evaluation of textiles at Rivatex Ltd) and ten steel balls with a diameter of 5 mm were added to the bottle. The mixture was thermally stabilized at 40° C. The washing process was carried out by agitating the bottle at 42 revolutions per minute (rpm) for duration of 30 minutes using a Launder-paramount machine [12].

After the initial washing, the first fabric underwent two rinsing cycles, each lasting 3 minutes, using distilled water. Subsequently, all the fabrics were air-dried in a dark environment at room temperature. This entire procedure was repeated twice more for the second and third fabrics to complete a total of 20 and 30 wash cycles, respectively.

2.6. Antimicrobial Test

To evaluate the antimicrobial properties of polyester/cotton fabric coated with ZnO nanoparticles, a series of washing cycles (10, 20, and 30 cycles) were conducted. The antimicrobial effectiveness of this fabric against Escherichia coli was assessed through a zone of inhibition (ZOI) test [13, 14]. This experiment utilized five Petri dishes, each filled with nutrient media and *E. coli* [15]. The first dish functioned as a control, containing uncoated fabric. The second dish contained the coated fabric without any additional treatment, while the remaining three Petri dishes held the fabric after undergoing 10, 20, and 30 washing cycles, respectively. This experiment was conducted in triplicate, and following a 24-hour incubation period, the results were analyzed.

3. RESULTS AND DISCUSSIONS

3.1. Fabric Characterization

Fig.1 shows the microscope (MSX-500 Di viewer) image for coated polyester/cotton with ZnO (a) and uncoated polyester/cotton (b). The microscope photos showed that there is no significant change on the fabric morphology and the impregnation with ZnO nanoparticles did not alter the fabric's color, as the light gray shade of the ZnO nanoparticles integrated with the fabric's appearance.

The X-ray diffraction (XRD) patterns of various fabric samples are presented in Fig.2 In all samples, distinct peaks characteristic of polyester/cotton (65/35%) composition were evident. In the case of the uncoated fabric, specific peaks at 2θ = 25.5 and 34.5 were identified, corresponding to crystallographic planes (101) and (002), respectively[16]. Additionally, a series of notable diffraction peaks within the 20 to 40° range were attributed to the semicrystalline nature of polyester fibers [17]. Furthermore, reflection peaks at 2θ = 16.4 and 22.4, indicative of (101) and (002) planes, were attributed to the presence of cotton fibers. On the other hand, for the coated fabric, a set of characteristic peaks at 2θ = 34.5, 36.5, 36.2, 47.4, 62.8, and 68.2 were observed, corresponding to (002), (101), (102), (103), and (112), respectively. These values aligned with the standard card JCPDS 36-1451, confirming the presence of hexagonal wurtzite ZnO phase [18]. These findings suggest the successful deposition of ZnO onto the surface of the polyester/cotton fabric under the specified conditions.

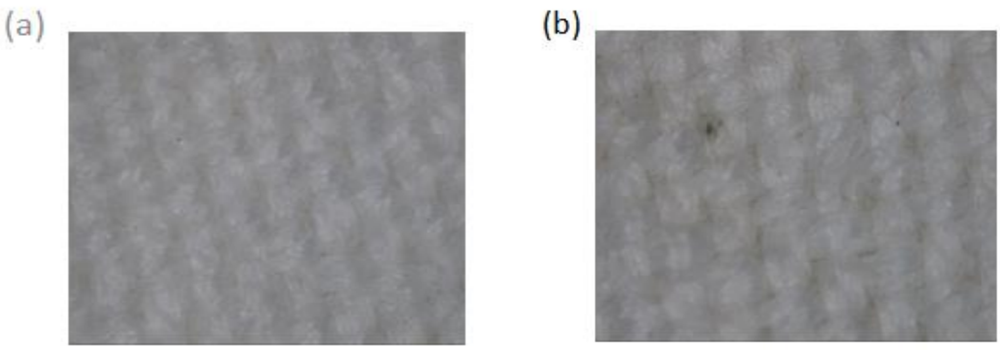

Fig.1. *Microscope (MSX-500 Di viewer) for coated polyester with ZnO (a) and uncoated polyester (b)*

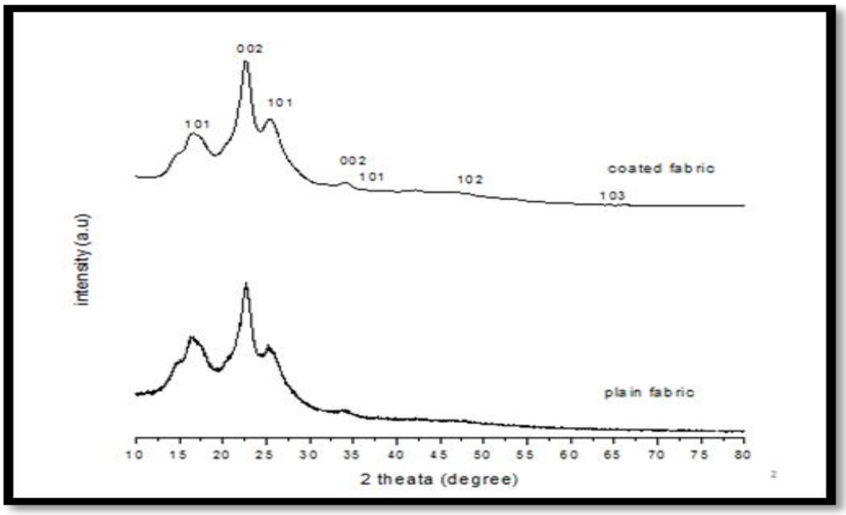

Fig.2 *X-ray diffractometer (XRD) patterns for coated polyester with ZnO and uncoated polyester*

3.2. Antimicrobial Test

The outcomes of the zone of inhibition (ZOI) test for uncoated and coated membranes against *E. coli* as shown in Fig.3. It was observed that there were no inhibition zones around the uncoated fabric as expected. In contrast, distinct zones of inhibition were evident around the ZnO coated fabrics. There was a slight reduction in antimicrobial activity after the initial 10 cycles, and this performance remained consistent through the subsequent 20 and 30 cycles. This demonstrated that the impregnation of the ZnO on the polyester/cotton was effective and could withstand friction and mechanical forces which agree with the literature studies [8].

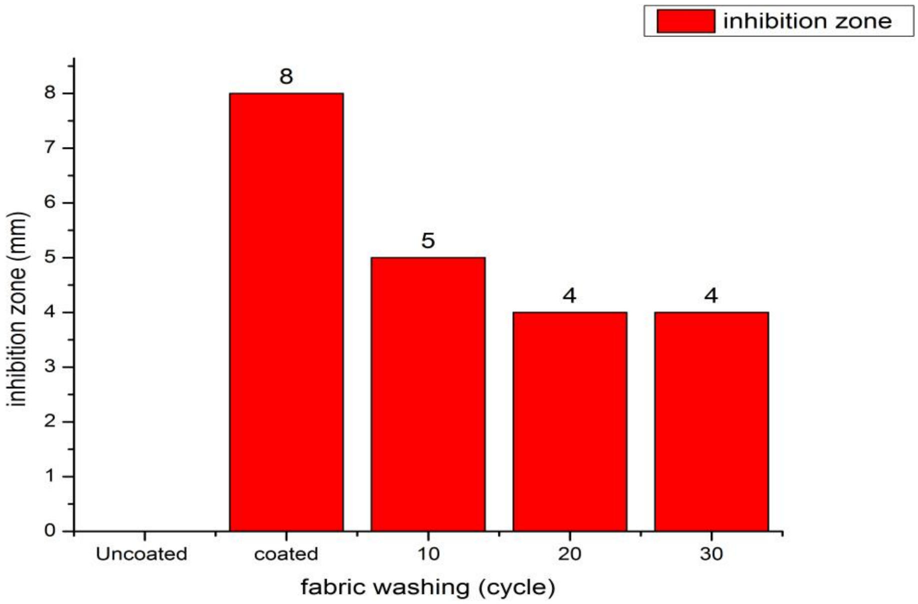

Fig.3. *Inhibition zones around the coated, uncoated and washed fabric fabric*

4. CONCLUSIONS

In this study, ZnO nanopowder was successfully synthesized and applied to polyester/cotton fabric using an aqueous heat attachment method. The antimicrobial efficacy of the coated fabric was investigated against *Escherichia coli*, initially and after multiple wash cycles, through zone of inhibition (ZOI) tests. The findings indicated that the coated membranes demonstrated remarkable antimicrobial ability even after 30 washing cycles. More studies can be done to assess broader antimicrobial activity against gram-positive bacteria and fungi.

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