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A Green in Situ Synthesis of Zinc Oxide Nanoparticles on a Cotton Fabric Using Orange Peel Extract to Create a Functional Textile with Enhanced Physical Properties

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Abstract

This study explores the green in situ synthesis of zinc oxide nanoparticles (ZnO-NPs) on cotton fabric using orange peel extract. The aim is to create sustainable textile technologies and explore value-added applications like food packaging, and antibacterial medical bandages. Medical textiles are in high demand right now, but the conventional physical and chemical processes are expensive, full of environmental hazards, and vulnerable to chemical reactions. The study aims to develop an efficient green synthesis method for synthesizing ZnO NPs on cotton fabric, focusing on its cost-effectiveness, biocompatibility, eco-friendliness, and ease of handling. Here, the tensile strength of ZnO NPs-coated fabric is higher than uncoated fabric due to hydrogen bonds between the NPs and fabric cellulose. Besides, the tearing strength of the NPs-coated fabric is lower than uncoated fabric, and the ZnO-treated fabric has a decrease. FTIR analysis of ZnO NPs-treated cotton fabric revealed ZnO presence and SEM analysis showed round, spherical NPs with an average size of 70 nm, confirming a valid synthesis process. Besides, ZnO NPs enhance water resistance and surface tailoring in cotton fabric, enhancing breathability and moisture transmission in textiles and packaging. Moreover, the crease recovery angle of ZnO NPs-coated cotton fabric indicates better recovery and better shape maintenance. For these reasons, this method has the potential to be a viable solution for producing functional textiles that have a reduced impact on the environment.

Keywords: Green synthesis, ZnO NPs, Sustainable textile.

1. Introduction

In the current globalized society, consumers want top-notch textile products with multiple uses. Various chemicals for the development of the multifunctional cotton fabric are toxic to human beings and aquatic ecosystems and cannot easily be degraded. Metal oxides' crystalline structure is much more effective at the nanoscale due to their superior physical, chemical, and mechanical capabilities [1]. Textile manufacturers can use metal oxides to protect fabrics from microorganisms, self-clean, repel water, and retard flames, among other things. In-situ growth of zinc oxide nanoparticles (ZnO NPs) onto the fabric is a viable alternative to ex-situ deposition because it has been shown to result in a homogeneous dispersion of NPs. Furthermore, they display high adsorption and adhesiveness, giving long-term functional properties [2]. Green synthesis of NPs can be performed using different biological entities such as algae [2], Microorganisms [3], fungi [4], and different parts of plants [5]. Green synthesis is chosen over physical and chemical methods because it is cost-effective, easy to handle, environmentally friendly, and biocompatible [6].

ZnO-NPs are frequently utilized in the textile sector to impart finished fabrics with increased resistance to the damaging effects of UV rays, as well as antibacterial and deodorant properties [7]. Applying ZnO NPs to biodegradable polymeric metrics has improved food and packaging quality through three mechanisms: antimicrobial ion release, bacterial cell destruction, and ROS formation from light radiation [8]. The production of ZnO NPs by living entities is presumed to be a result of the presence of a variety of metabolites, such as proteins, enzymes, and other biomolecules that function as reducing, capping, and stabilizing agents. The attributes of biodegradability and low toxicity are considered to be highly important properties of ZnO NPs. Zinc (Zn^{2+}) is an essential trace element for adults, playing a crucial role in various metabolic processes. ZnO NPs are used to functionalize polyethylene bags, socks, T-shirts, and sportswear. However, owing to the considerable

danger of contamination associated with surgical suits, the ideal application for ZnO NPs is in the medical field. Fabrication of ZnO NPs functionalized fabrics employs a variety of techniques. This study explored the production of ZnO NPs on 100% cotton fabrics using a one-step green in-situ approach.

2. Materials and methods

Raw materials

One type of. Cotton fabric was used to carry out this work. The fabric was collected from a nearby factory.

Table 1. Fabric Composition

Fabric type	Woven Fabric
GSM	140
EPI	120
PPI	72
Warp Count	40 Ne
Weft Count	40 Ne

Table 2. Chemicals and auxiliaries list

Serial No	Chemical Name	Supplier
01	$[Zn(CH3COO)_2].2H_2O$	Merck Chemical Industries, Germany
02	Orange peel extract	Local Market
03	Distilled Water	Local Market

Preparation of Peel Extract

To acquire the extracts, orange fruits were cleaned and dried before peeling as thinly as possible. After that, the peel had dried completely in a food drier for 12 hours and then it was ground into an almost fine powder. Subsequently, 50 mL of de-ionized water was added to each glass container containing 1 g of the powder, and the mixture was stirred for 3 hours. After mixing, each mixture was placed in a water bath at 60^0c for 60 minutes. Finally, all the mixtures were filtered, and the final extracts were preserved for future use.

Preparation of Zinc Acetate Dehydrate Solution

To make zinc acetate dehydrate solution first weigh 1 g zinc acetate dehydrate in 100 ml distilled water to make 1% stock solution. For the 8-gram sample liquor ratio was maintained at 1:20. So the total amount of solution taken was 8×20=160 ml. For making 0.25%, 0.50%, 0.75%, and 1% of zinc acetate dehydrate solution below-mentioned data was followed.

Table 3. Zinc acetate dehydrate treatment chart

Sample No	Concentration	zinc acetate solution	Distilled water
01	0.25%	2ml	158ml
02	0.50%	4ml	156ml
03	0.75%	6ml	154ml
04	1%	8ml	152ml

In situ synthesis of ZnO NPs on cotton fabric

Firstly the pretreated cotton fabrics were dipped in a precursor solution of zinc acetate dehydrate [Zn $(CH_3COO)_2$]. $2H_2O$ at room temperature for 10 min. After that, the fabrics were pressed using padder rollers to achieve a 100% wet pick-up. The fabrics were then immersed in a reducing agent solution (peel extract) at 60°C for 60 minutes, ensuring a 20:1 mass ratio between the solution and the fabric. The next step was to rinse the samples with cold deionized water and then let them air dry at room temperature. Finally, the desired product was obtained, which is been shown in Fig. 1.

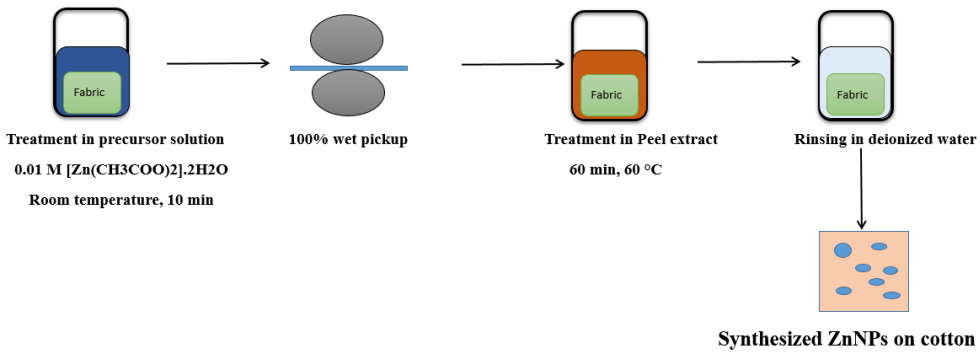


Fig. 1. Graphical representation of the overall in situ synthesis procedure

3. Results and Discussion

After the coating process was completed, several tests were conducted to evaluate the physio-mechanical and multi-functional properties of the Cotton fabric. A comparative analysis was then made. The tests' outcomes and discussions are listed below:

FTIR Analysis

ATR Fourier transform infrared (FTIR) spectrometer was used to investigate functional groups or chemical bonds formed between ZnO Nps and the fabric structure and the existence of any bond can be found in the presence of picks at different wave numbers. The resulting signal detected by the instrument produces a molecular spectrum, from 4000 cm^{-1} to 500 cm^{-1}, that serves as a distinctive fingerprint of the sample. Fig. 2. shows the FT-IR spectra of ZnO NPs treated and untreated cotton fabric. FTIR measurement of ZnO NPs treated cotton fabric was conducted to identify the functional groups present and the peak at 660 cm^{-1} indicates the presence of ZnO [9]. It also indicates that ZnO NPs get attached to the fabric.

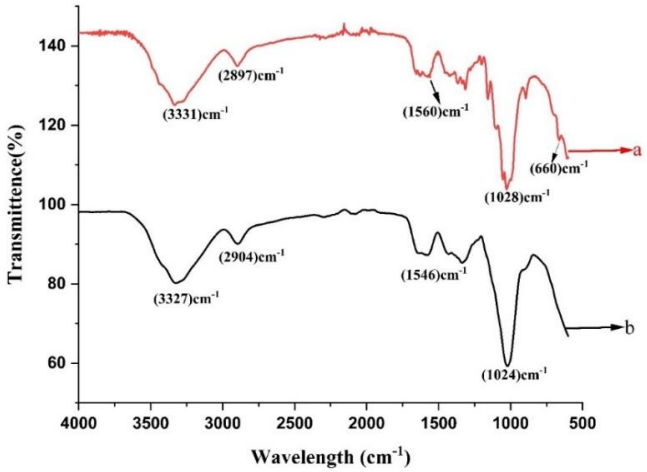


Fig. 2. FT-IR Test result for (a) ZnO NPs treated and (b) untreated cotton fabric.

Table 4. Different wave peaks and corresponding bonds (ZnO NPs Treated)

SL. No.	Absorption Peaks (cm^{-1})	Bond/Functional Groups Present
1	3331 cm^{-1}	O–H
2	2897 cm^{-1}	C=C
3	1560 cm^{-1}	C–O
4	1028 cm^{-1}	C–H
5	660 cm^{-1}	ZnO

SEM Analysis

The surface morphology of treated and untreated fabric was investigated with a scanning electron microscope (SEM), model JCM-7000-JEOL. Various magnifications were used to capture images of the NP's size and coating uniformity. The majority of the particles were seen to have a spherical or rounded form [10]. In Fig. 3(a) it can be observed that the cotton fabric's surface is smooth, and Fig. 3(b) shows the surface of the ZnO-treated fabric which seems to be harsh.

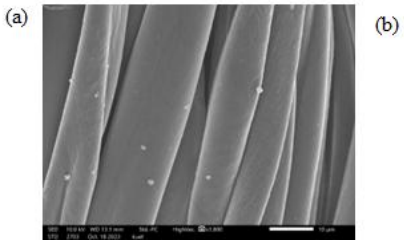


Fig. 3. SEM image of (a) untreated and (b) treated cotton fabric

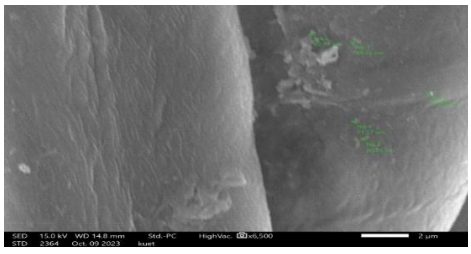


Fig. 4. ZnO Nanoparticles over treated sample

Besides From Fig. 4. It is seen that most particles are between 50 to 96 nm. Therefore, it can be said that the synthesis process of ZnO NPs was valid and showed a good result.

Evaluation of Tensile Strength

The ASTM D638 standard and a Universal Testing Machine (UTM) were used in this study to perform a tensile strength test on cotton fabric samples. From Fig. 5. it is noticed that the tensile strength of the ZnO NPs-coated fabric is higher than that of the uncoated fabric sample. Increased tensile strength is due to the generation of

hydrogen bonds between ZnO NPs and the functional group of fabric cellulose. Orange peel extract is used in textile dyeing and has been found to increase the tensile strength and decrease the elongation of cotton fabric [11].

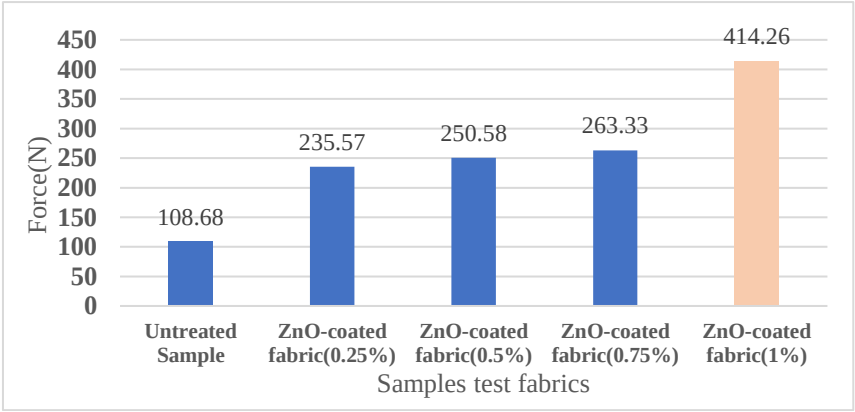


Fig. 5. Change of tensile strength after treatment with ZnO Nps

Evaluation of Tearing Strength

Tearing strength refers to the maximum force required to tear a material. The coating effect of NPs on the tearing strength of the fabric is shown in Fig. 6. The Figure shows that the nanoparticle-coated fabric's tearing strength is relatively lower than the uncoated fabric sample. For ZnO-treated fabric, tearing strength decreased compared to untreated cotton fabric. One possible reason for the decrease in the tearing strength of a fabric treated with orange peel extract as a reducing agent is that these compounds can weaken the fabric's fibers [12]. This weakening effect can occur due to the interaction of the natural compounds in the extract with the fabric's fibers. This interaction can lead to changes in the physiochemical properties of the fibers, causing them to become more brittle and easier to tear [13].

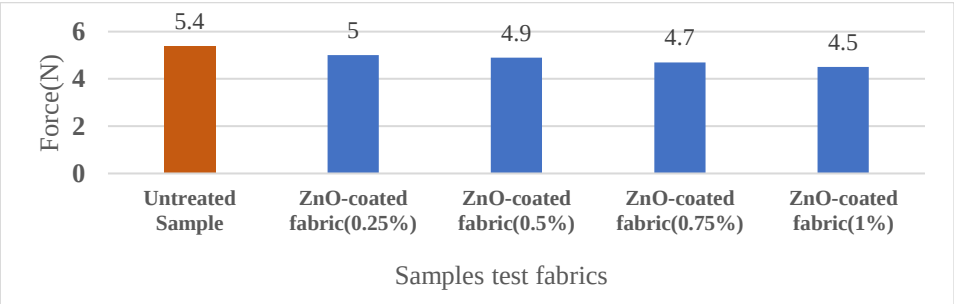


Fig. 6. Change of tearing strength after treatment with ZnO Nps

Additionally, the extract may alter the mechanical and physical properties of the cotton fibers, leading to a decrease in their strength and durability. The extent of the damage to the tearing strength of the cotton fabric will depend on the concentration of the extract, the duration of the treatment, and the specific properties of the cotton fibers [14].

Analysis of Crease Recovery Angle

The crease recovery angle of ZnO NPs-coated cotton fabric can be compared to that of untreated cotton fabric to determine the improvement in increased recovery. The Crease Recovery Angle in both warp and weft direction for each sample was tested using a James Heal Crease Recovery Angle Tester with an angle scale ranging from 0° to 180°. A higher crease recovery angle indicates better recovery of the fabric, meaning that it will appear less wrinkled and maintain its shape better after being folded or creased. ZnO NPs coating on cotton fabric has been shown to improve the crease recovery angle, which can be attributed to the increased stiffness and resilience of the material due to the presence of NPs. This property can be helpful in various applications, such as making wrinkle-resistant clothing or textiles for industrial use requiring frequent folding and unfolding. The crease recovery angle of a fabric can increase with increasing ZnO Nps coating due to the development of a dense network in the fabric's structure and the formation of a thin film on the fabric surface [15]. This improvement in crease recovery angle is essential in determining the fabric's ability to recover its original shape after creasing or folding and enhances its overall mechanical properties [16].

Table 5. Crease recovery angle

Sample No	Warp way	Weft way
Untreated	100°	90°
Treated (0.25%)	105°	94°
Treated (0.5%)	108°	97°
Treated (0.75%)	110°	101°
Treated (1%)	113°	103°

Analysis of Water Vapor Permeability

Water vapor permeability, or water vapor transmission rate (WVTR), is a key property of materials, particularly in textiles and packaging, that determines their ability to allow water vapor to pass through. It quantifies the speed at which water vapor spreads through a substance in controlled circumstances, typically denoted in terms like grams per square meter per day (g/m²/day) or in metric measurements like g/(m²·s). Here, the ASTM E96 cup method was employed to evaluate water vapor permeability. It was utilized to quantify the rate of water vapor transmission perpendicularly through a certain area of cloth in a regulated atmosphere. This approach involves placing a sample over a cup filled with distilled water in a controlled atmosphere at 20°C and 65% relative humidity. By modifying the initial mass of water in the cup to 80 g, the air gap was established at 19 mm. The experiments were conducted over one day, and the weight of each cup was documented daily. The following equation was implemented to calculate the WVTR:

$$\text{WVTR} = \frac{W1-W2}{A\times t}\ \text{g/m}^2\text{/day} \quad (1)$$

Here,
W2 = Final weight of the cup with a fabric sample,
W1 = Initial weight of cup with a fabric sample,
A = Internal area of the cup in m² = 0.44 m²
T = Time interval in hours between weighing.

Table 6. Evaluation of comfort/water vapor permeability test

Serial No	W1	W2	WVTR
Untreated	178.839	178.765	0.169 g/m²/hr
Treated (0.25%)	178.683	178.765	0.166 g/m²/hr
Treated (0.5%)	178.590	178.519	0.162 g/m²/hr
Treated (0.75%)	178.486	178.415	0.161 g/m²/hr
Treated (1%)	174.425	174.357	0.155 g/m²/hr

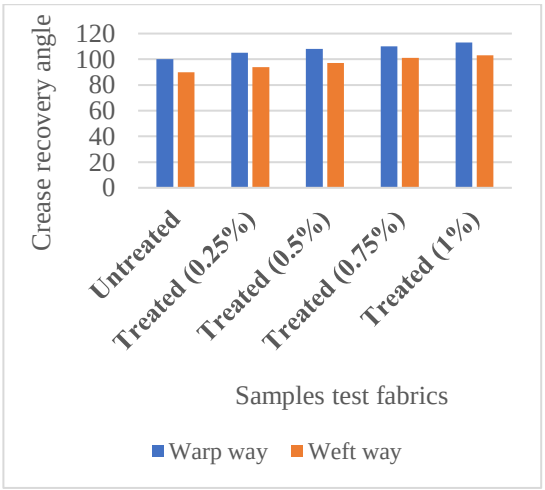


Fig. 7. Effect of ZnO NPs treatment on crease recovery property of the cotton fabric

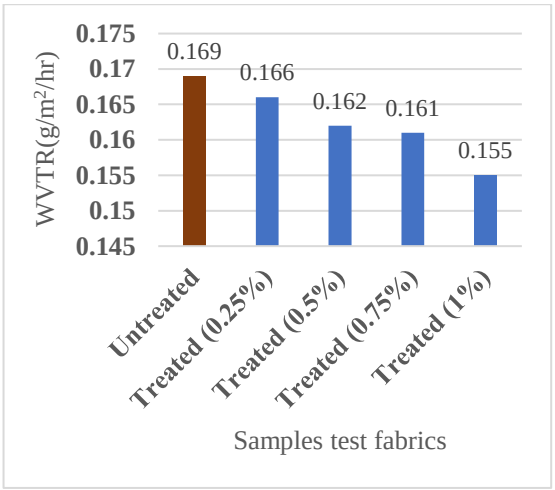


Fig. 8. Water vapor permeability of sample test fabrics

Here it is seen that when the concentration of chemicals increases on treated fabric then water vapor permeability decreases because of the compactness of the cloth. In packing materials, higher water vapor permeability can affect the quality of food badly. Applying ZnO on cotton fabric can lead to a decrease in water vapor permeability due to forming a barrier layer on the fabric surface, therefore this study highlights the potential of ZnO for

enhancing the surface tailoring and water barrier attributes of cotton fabric[17]. ZnO application on cotton fabric led to a decrease in water vapor permeability, which is attributed to the hydrophobic nature of ZnO. This property is essential in numerous applications where moisture management and control are crucial, including breathable apparel, medical dressings, food packaging, and construction materials [18].

5. Conclusion

This study investigates how green synthesis methods can produce ZnO NPs coated cotton fabric. Its tensile strength, tearing strength, crease recovery angle property, and comfort (water vapor transmission rate) were tested. To learn about the coated cloth's qualities, FTIR and SEM were used for analysis. Ultimately, this result thoroughly examines the capacity of environmentally friendly synthesis techniques to create ZnO NPs and their utilization in the production of versatile cotton fabric. Moreover, the cotton fabric coated with ZnO exhibited superior performance relative to the untreated fabric, suggesting that this technique may serve as a feasible approach for creating functional textiles with diminished environmental effects. This research establishes a robust basis for subsequent investigations focused on enhancing sustainable textile technologies and addressing the changing requirements of the textile industry for functional, comfortable, and eco-friendly materials. Nonetheless, there exists an opportunity for more exploration of various functional attributes; forthcoming research will concentrate on analyzing the antibacterial efficacy of the manufactured cotton fibers, which may be utilized in the creation of masks, aprons, and similar items to safeguard against bacteria.

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