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Utilizing zinc oxide nanoparticles to create fabrics with antibacterial properties

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Research Article

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Abstract

An developing field in nanoscience and nanotechnology is the use of materials and structures at the nanoscale, typically between 1 and 100 nanometers (nm). Noble metal nanoparticle synthesis is a field of ongoing attention for uses in biology, electronics, textiles, environmental protection, and catalysis. Antimicrobial fabrics have recently been developed as a result of increased awareness of personal protection, contact disease transmission, and general cleanliness. In this study, zinc oxide nanoparticles have been used to manufacture antibacterial cotton textiles. The pad-dry-cure process was used to directly apply the ZnO nanoparticles, which were made via a wet chemical method, to the 100% cotton woven fabric. The final textiles' antibacterial activity was evaluated quantitatively using the percentage reduction test and qualitatively using the parallel streak technique and agar diffusion. The treated and untreated fabrics' topographical analyses were examined and contrasted. The final cloth showed strong antibacterial activity against S. aureus in both qualitative and quantitative testing, according to the findings. ZnO nanoparticles were embedded in the treated textiles, according to the SEM study. The treated cloth was shown to be able to last up to 25 wash cycles in the wash durability research.

Keywords: Zinc oxide, nanoparticles, antibacterial coating, and washability

Introduction

Over the last ten years, nanoscale science and technology have become the cutting edge of both fields. The fast, diverse growth of modern science and technology is well shown by the crossing branches of research that make up this area of science and engineering. Due to their capacity to endure challenging process conditions, inorganic materials like metal and metal oxides have garnered a lot of interest in the last ten years (Fu et al., 2005; Makhluf et al., 2005). Metal oxides including TiO2, ZnO, MgO, and CaO are of special interest among the inorganic materials since they are typically thought to be safe for both humans and animals, as well as stable under challenging processing circumstances (Stoimenov et al., 2002; Fu et al., 2005). Because of their antibacterial qualities, silver and zinc oxide nanoparticles have been considered a promising way to prevent infectious infections. Size, shape, composition, crystallinity, and morphology are the primary factors that influence a metal nanoparticle's inherent qualities (Dickson and Lyon 2000). Given the history of innovation in the textile business, it is not surprising that nanotechnology has entered this field so rapidly. It is predicted that nanotechnology will be the world's second industrial revolution. The unique qualities and little material usage have sparked attention in a variety of fields and sectors worldwide. This also applies to the textile industry. According to the "European Technological Platform for Textiles and Fashion," the textile sector has to produce new goods for new markets, provide innovative products for old customers, and enhance and lower process costs in order to prosper. In actuality, both public and private research organizations as well as commercial businesses are actively involved in nanotechnology research targeted at applications in the textile industry worldwide. Nanotechnology may play a significant role in achieving these objectives. Technology innovation is essential to staying ahead of the increasing competition. The market for functionally completed textiles is expanding quickly due to consumer satisfaction and health concerns.

The number of antibiotic-resistant bacteria is increasing along with the incidence of diseases caused by these germs due to global population increase and the spread of disease. Many individuals concentrated on learning about and defending themselves against dangerous diseases as a result of this rise in health consciousness. Protecting the user from germs became more crucial for antimicrobially treated textiles than just shielding the clothing from fiber deterioration (Ye et al., 2006). The emergence of resistant bacteria strains is closely linked to the requirement for antimicrobial fabrics. Textiles with antimicrobial finishes, long-lasting or permanent press-finished clothing, self-cleaning qualities, and nanotechnology are all examples of functional textiles. With the background information mentioned above in mind, the current study was conducted with the primary goals of developing a straightforward method for the synthesis of ZnO nanoparticles, designing a technique to finish ZnO nanoparticles onto cotton fabrics to confer antimicrobial function, and ultimately assessing the finished fabrics in terms of antibacterial, wash durability, and topographical function.

Materials and methods

Nanoparticle preparation

Zinc nitrate, sodium hydroxide, and soluble starch were used as precursors in the wet chemical approach (Yadav et al., 2006) to create the zinc oxide nanoparticles. Using a microwave oven, various soluble starch concentrations (0.1%, 0.5%, and 1.0%) were dissolved in 500 milliliters of purified water. The solution above was supplemented with 14.874 g of zinc nitrate (0.1 M). The zinc nitrate was then fully dissolved by continuously swirling the solution with a magnetic stirrer. Once the zinc nitrate had completely dissolved, 20 milliliters of 0.2 M sodium hydroxide solution—drop by drop hitting the vessel walls—was added while being continuously stirred. After adding all of the sodium hydroxide, the reaction was let to continue for two hours. The solution was let to settle overnight once the reaction was finished, and the supernatant solution was then properly disposed of. After centrifuging the leftover solution for ten minutes at 10,000 X g, the supernatant was disposed of. Distilled water was used to wash the resulting nanoparticles three times. Washing was done to get rid of the extra starch and byproducts that were attached to the nanoparticles. The nanoparticles were cleaned and then dried for a whole night at 80 degrees Celsius. Zinc hydroxide completely transforms into zinc oxide during the drying process.

1.2 Application to textiles

For the application, a fine-medium weight, 100% cotton woven fabric (plain weave, 75.30 g/m2; ends, 75/inch; picks, 60/inch) was used. The pad-dry-cure process was used to apply ZnO nanoparticles to cotton. After immersing the 30 x 30 cm cotton fabric in the ZnO (2%) and acrylic binder (1%) solution for five minutes, the cloth was run through a padded mangle. For every treatment, a 100% wet pick-up was maintained. The cloth was padded, let to air dry, and then treated at 140°C for three minutes. To get rid of unbound nanoparticles, the cloth was then submerged in 2 g/l of sodium lauryl sulfate for five minutes. After that, the cloth was washed at least ten times to remove all of the soap solution. After washing, the cloth was allowed to air dry. Bulk-ZnO coating was done concurrently for comparison.

Assessment of antibacterial activity

Qualitative tests

Agar diffusion method (Mucha et al., 2002)

Bacteriostasis agar was dispensed in sterile petriplates.24 hours broth cultures of the test organisms (*E.coli* and *S.aureus*) were used as inoculums. Using sterile cotton swab the test organisms were swabbed over the surface of the agar plates. The test fabrics (fabrics treated ZnO nanoparticles) & Control (fabrics treated with ZnO bulk) was gently pressed in the center of the mat culture. The plates were incubated at 37°C for 18-24 hours.

Parallel streak method: (AATCC Test method 147-1992)

Sterile bacteriostasis agar was dispensed in petriplates. 24 hours broth cultures of the test organisms (*E.coli* and *S.aureus*) were used as inoculums. Using 2 mm inoculation loop, 1 loop full of culture was loaded and transferred to the surface of the agar plate by making 7.5cm long parallel streaks 1cm apart in the center of the plate, without refilling the loop. The test specimen (fabrics treated ZnO nanoparticles & Control i.e. fabrics treated with ZnO

bulk) was gently pressed transversely, across the five inoculums of streaks to ensure intimate contact with the agar surface. The plates were incubated at 37°C for 18-24 hours.

Quantitative tests
Percentage reduction test (Mucha et al., 2002)
Specimens of the test material were shaken in a known concentration of bacterial suspension and the reduction in bacterial activity in standard time was measured. The efficiency of the antimicrobial treatment is determined by comparing the reduction in bacterial concentration of the treated sample with that of control sample expressed as a percentage reduction in standard time.
The evaluation of modified Hohenstein test was made on the basis of the percentage reduction of bacteria by the sample. Percentage reduction was calculated using the following formula.

$R = (A\text{-}B) / A$
Where *R* is percentage reduction, *A* is the number of bacteria in the broth inoculated with treated test fabric sample immediately after inoculation i.e., at zero contact time and *B* is the number of bacteria recovered from the broth inoculated with treated test fabric sample after the desired contact period (18 hours).
Topographical analysis by SEM:
The topographical analysis of the test fabrics (finished with ZnO nanoparticles) and the fabrics finished with ZnO bulk were studied comparatively based on the Scanning Electron Microscopic analysis.

Wash durability of the finished fabric :(Sarkar et al., 2003)
The wash durability testing of the finished fabrics was carried out using a neutral soap at 40º C (+/- 2º C) for 30 minutes, keeping the material : liquour ratio at 1: 50, followed by rinsing washing and drying. After drying the test fabrics and the control were assessed for antimicrobial activity by the methods as described earlier (Sec. 2.4.3)

Results and discussion
The results of the qualitative antibacterial assessment by agar diffusion show that the fabric sample treated with ZnO nanoparticles showed a maximum inhibitory effect against *S.aureus* and is shown (Table 1).

Table 1. Antibacterial assessment by agar diffusion method

Fabric treated	Organism	Zone of Inhibition (in cm)				
		Trial-1	Trial-2	Trial-3	Mean	Range
Fabrics treated with ZnO nanoparticles	*S.aureus*	4.9	5.3	5.4	5.2	0.5
	E.coli	3.4	3.2	3.3	3.3	0.2
Fabrics treated with ZnO Bulk	*S.aureus*	2.3	2.8	2.4	2.5	0.5
	E.coli	1.9	1.5	1.7	1.7	0.4
Fabrics without ZnO nanoparticles (Control)	*S.aureus*	0	0	0	0	0
	E.coli	0	0	0	0	0

When compared to ZnO bulk treated textiles, it is clear that the fabrics treated with ZnO nanoparticles exhibited greater antibacterial activity, while the untreated fabrics did not. Both ZnO nanoparticles and bulk-treated textiles generally have more antibacterial activity against S. aureus than E. coli. Figure 2 displayed the relative antibacterial activity of ZnO nanoparticles, ZnO bulk, and untreated cloth (control) against S. aureus. Zhang et al. (2007) investigated the ZnO particles' antibacterial activity. Although the findings of this research do not directly support this theory, it seems that active oxygen species produced by ZnO particles may be a mechanism. Yamamoto et al. (2000) found evidence of active oxygen species. Both nano-sized and micron-sized ZnO suspensions have been shown to be effective in preventing the development of bacteria; however, the nano-sized ZnO suspension is obviously much more effective than the micron-sized ZnO suspension (Zhang et al., 2009). Both the ZnO nanoparticle-treated textiles and the ZnO bulk-treated fabrics had antibacterial activity,

although the activity in the ZnO nanoparticle-treated fabrics was much greater, which is consistent with our study's findings.

Figure 1 illustrates the ZnO nanoparticle-treated fabric sample's greatest inhibitory effect against S. aureus, with a zone of inhibition of 5.8 cm, and E. coli, with a zone of inhibition of 3.7 cm, when evaluated for antibacterial activity using the parallel streak technique.

The percentage reduction test was used to examine the quantitative bacterial decrease, and Table 2 presents the findings. The parallel streak technique and agar diffusion provide findings that are consistent with this percentage reduction test. The textiles treated with Zno nanoparticles had the highest percentage of decrease, with 94.16% for S. aureus and 86.5% for E. coli. In comparison, the textiles treated with ZnO bulk showed a smaller percentage of decrease. Because there is no bactericidal activity and the end number of cells will be much larger than the beginning number of cells, the textiles without any treatment (control) have negative values for the percentage reduction test and the results are zero. Nagarajan Padmavathy et al. (2008) investigated the increased bioactivity of ZnO nanoparticles. Zinc oxide quantum dots (ZnO QDs), nanoparticles of purified powdered ZnO, were tested for antimicrobial activity against these pathogens by researchers at the US Agriculture Department's Food Safety Intervention Technologies Research Unit (Jin et al., 2009). They discovered that ZnO nanoparticles have antibacterial activity. When the ZnO particles made by the wet chemical technique were examined under a scanning electron microscope (Figure 2), it became clear that they were roughly spherical and ranged in size from 60 to 75 nm. In contrast to the control textiles, or fabrics treated with ZnO bulk, the SEM examination of the treated fabrics revealed embedded zinc oxide nanoparticles (Figs. 3.1 & 3.2). Professor Yong-Chien Ling and his research team also manufactured ZnO of Nanosize and evaluated its antibacterial potential.

Figure 1. Antimicrobial assessment by Parallel Streak Method (AATCC147)

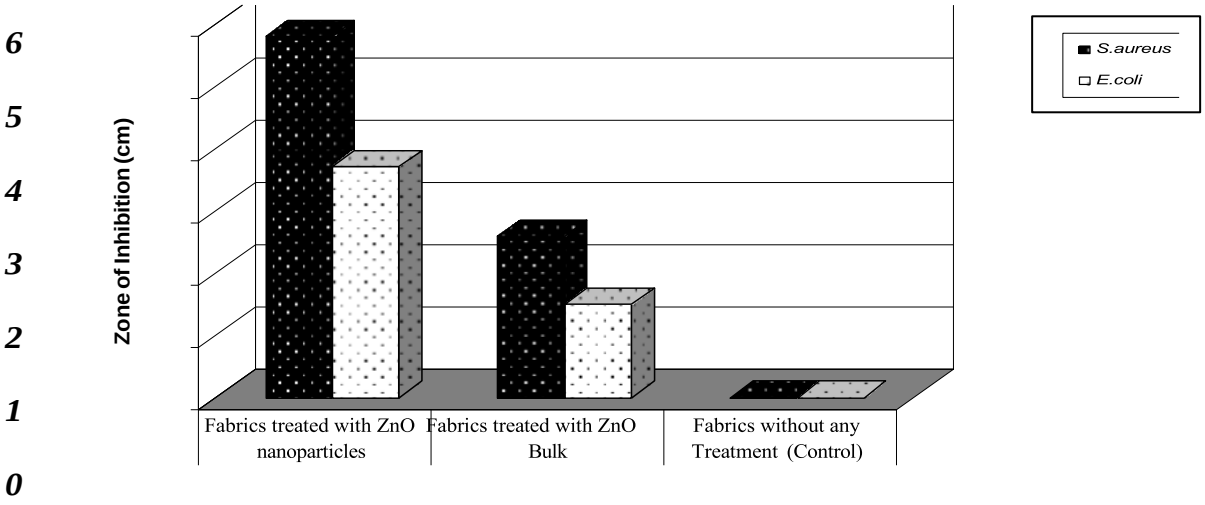


Table-2: Antibacterial Assessment by Percentage Reduction Test (AATCC 100)

Fabric tested	Organism	Initial number of bacterial cells/ml	Final number of bacterial cells/ml	% Reduction
Fabrics treated with ZnO nanoparticles	*S. aureus*	$6x10^6$	$0.35 x10^6$	94.16
	E.coli	$6x10^6$	$0.81 x10^6$	86.5
Fabrics treated with ZnO bulk	*S. aureus*	$6x10^6$	$3.1 x10^6$	48.33
	E.coli	$6x10^6$	$3.5 x10^6$	41.66
Fabrics without any treatment (control)	*S. aureus*	0	0	0
	E.coli	0	0	0

Wash durability

Wash durability test carried out with the test fabrics showed that the significant antimicrobial activity was actively retained in the ZnO nanoparticles treated fabrics upto 10 washes (Table-3) even after repeated wash cycles. After 10 washes the % bacterial reduction was very low and there was no activity found in the fabrics after 20 washes.Whereas the ZnO bulk treated fabrics retained the antimicrobial activity only upto 5 repeated wash cycles. The untreated control fabrics were not subjected to any wash durability test as it has no antibacterial activity.

Table-3. Wash durability testing

No. of Washing cycles	Fabrics treated with ZnO nanoparticles		Fabrics treated with ZnO bulk	
	% Bacterial Reduction		% Bacterial Reduction	
	S.aureus	*E.coli*	*S.aureus*	*E.coli*
1	94.05	86.28	47.27	40.22
2	93.62	85.94	37.59	32.52
5	89.42	81.38	19.49	11.24
10	74.36	69.54	0	0
15	40.25	34.96	0	0
20	12.05	9.85	0	0
25	0	0	0	0
30	0	0	0	0

There are several methods for preparing nanosized ZnO powders such as spray pyrolysis (Liu *et al.,* 1986), precipitation (Trindade *et al.,* 1994), thermal decomposition(Verges *et al.,* 1992), hydrothermal synthesis (Chen *et al.,* 2000)and electrochemical growth(Mahamuni *et al.,* 1999). Different methods yield different particle sizes of ZnO, depending on the type of precursor, the solvent, the pH and the temperature of the reacting solution. The choice of method depends on the final application. From the above results we clearly came to know about the enhanced bioactivity of ZnO nanoparticles by studying the antimicrobial activity of ZnO nanoparticles treated fabrics. The enhanced bioactivity of smaller particles is attributed to the higher surface area to volume ratio. For smaller ZnO nanoparticles, more particles are needed to cover a bacterial colony (2μm) which results in the generation of a larger number of active oxygen species (released from ZnO on the surface of the colony), which kill bacteria more effectively. ZnO nanoparticles were found to be more abrasive than bulk ZnO, and thus contribute to the greater mechanical damage of the cell membrane and the enhanced bactericidal effect of ZnO nanoparticles.

Figure 2. Antibacterial activity of (a) ZnO nanoparticle treated fabric, (b) ZnO bulk treated fabric and (c) untreated fabric (control) against *s.aureus* by Disc diffusion method



a b c Figure 3.1. SEM images showing ZnO Nanoparticles

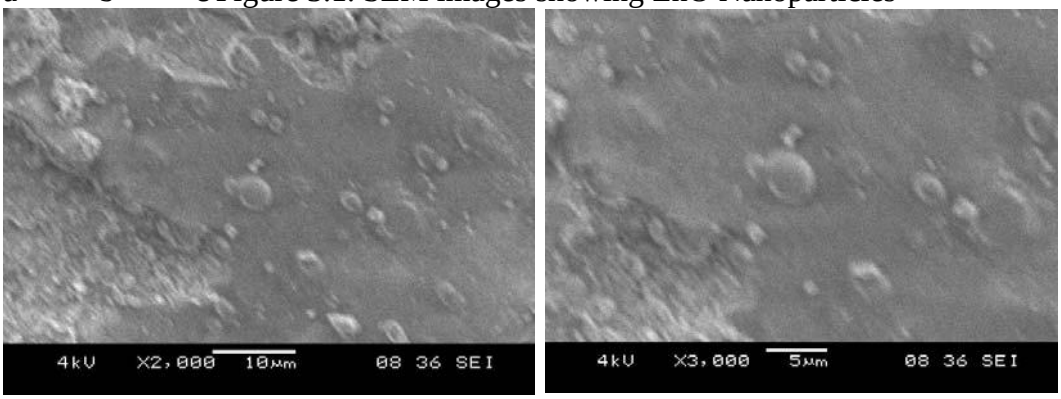
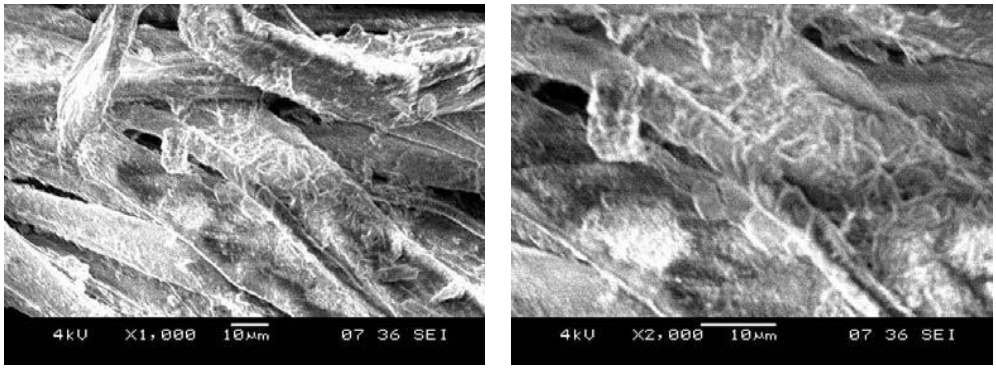


Figure 3.2. SEM images showing ZnO Nanoparticles embedded onto the fabrics



Conclusion

In conclusion, a straightforward technique for creating nano-ZnO and applying it to cotton textiles to impart functional qualities has been devised. It is discovered that the cotton cloth treated with nano-ZnO has antibacterial properties. Additionally, it was evident that, as compared to the untreated fabric, the ZnO nanoparticle-treated textiles exhibited a stronger antibacterial activity than the ZnO bulk-treated fabrics.The findings also showed that, in both qualitative and quantitative testing, S. aureus had more antibacterial activity than E. coli. By adjusting the particle size and concentration, the wash's durability may be improved. The entrapment of ZnO nanoparticles in the treated textiles is shown by the SEM investigation of the treated fabric. To further improve the antibacterial effect in cotton textiles, the ZnO particle size and padding conditions must be optimized. Polyester, silk, and other textiles may be added to the technique. The health and hygiene textile industry may make extensive use of this kind of antimicrobial coating. Before a firm conclusion can be reached, the findings of this work highlight other areas that should be the focus of future research to address a number of problems.

References

Hydrothermal synthesis of zinc oxide powders with various morphologies, Chen D., Jiao X., and Cheng G. (2000). Solid State Communication, Vol.113, pp. 363-366.

Lyon L.A. and Dickson R.M., 2000. Journal of Physical Chemistry, Vol. 104, pp. 6095-6098, Unidirectional plasmon propagation in metallic nanowires.

Beaded Cobalt oxide nanoparticles along carbon nanotubes: toward more highly integrated electrical devices, Fu L., Liu Z., Liu Y., Han B., Hu P., Cao L., and Zhu D., 2005, Advanced Materials, Vol.17, pp.217-221.

In 1986, Liu T. Q., Sakurai O., Mizutani N., and Kato M. Using ultrasonic atomization methods, spherical tiny ZnO particles were produced by spray pyrolysis, Journal of Material Science, Vol. 21, pp. 3698-3702.

In 1999, Mahamuni S., Borgohain K., Bendre B.S., Valene J.L., and Subhash H.R. Spectroscopic and structural analysis of ZnO quantum dots generated electrochemically, Journal of Applied Physics, Vol. 85, pp. 2861.

In 2005, Makhluf S., Dror R., Nitzan Y., Abramovich Y., Jelnek R., and Gedanken A. Nanocrystalline magnesium oxide production with microwave assistance and its use as a bacteriocide, Advanced Functional Materials, Vol. 15, pp. 1708-1715.

In 2008, Padmavathy N. and Vijayaraghavan R. Improved ZnO nanoparticle bioactivity: an antibacterial investigation, Science and Technology of Advanced Materials, Vol. 9, 035004 (7pp).

Marchin G.L., Klabunde K.J., Stoimenov P.K., and Klinger R.L. (2002). Metal oxide nanoparticles as bactericidal agents, Langmuir, Vol. 18, pp. 6679–6686.

Pedrosa Jesus J. D., Trindade T., and O'Brien P. (1994). Zinc oxide and zinc sulfide powder preparation using controlled precipitation from aqueous solution, Journal of Materials Chemistry, Vol. 4, pp. 1611-1617.

Gallego M.M. and Verges M.A., 1992. Zinc oxide powder's shape and particle size are affected by hydrothermal conditions, Journal of Materials Science, Vol. 27, pp. 3756–3762.

In 2006, Yadav A., Virendra Prasad, Kathe A.A., Sheela Raj, Deepti Yadav, Sundaramoorthy, and Vigneshwaran N. Zinc oxide nanoparticle functional finishing in cotton textiles, Bulletin of Material Science, Vol. 29, No. 6, pp. 641–645.

Sawai J., Yamamoto O., and Sasamoto T. (2000). Variation in antibacterial properties with ZnO doping concentration in MgO–ZnO solid solution, International Journal of Inorganic Materials, Vol. 2, pp. 451–454.

In 2009, Zhang L., Jiang Y., Ding Y., Daskalakis N., Jeuken L., Povey M., Alex J. O'Neill, and York D.W. Mechanistic analysis of ZnO nanoparticle suspensions' antibacterial activity against E. coli, Journal of Nanoparticle Research,.