International Journal for Environmental Rehabilitation and Conservation

essence

ISSN: 0975 6272
XI (1): 1 — 10
www.essence-journal.com

Original Research Article

Application of Zinc Oxide nanoparticles on Cotton fabric for imparting Antimicrobial properties

Mulchandani, Neha and Karnad, Vishaka

Department of Textile and Fashion Technology, College of Home Science Nirmala Niketan, Mumbai, Maharashtra

Corresponding Author: neham.84@gmail.com

ARTICLE INFO

Received: 28 February 2020 | Accepted: 15 June 2020 | Published Online: 30 June 2020

EOI: 10.11208/essence.20.11.1.101

Article is an Open Access Publication

ABSTRACT

The ZnO nanoparticles were prepared using Zinc acetate as a precursor by wet chemical method. The particles were characterized by X-ray diffraction (XRD) analysis, UV-vis spectroscopy and Transmission electron microscopy (TEM). Woven (100%) medical cotton fabric was treated with nano ZnO based finish. The antimicrobial property was assessed quantitatively with test method AATCC 100 against gram positive and gram negative bacteria. The finished samples were characterized by Fourier Transform Infrared (FTIR) Spectroscopy, and Scanning electron microscopy (SEM). The finished sample showed good antimicrobial property showing 97.61% reduction for Staphylococcus aureus and 96.97% reduction for Klebsiella pneumonia after 50 washes. The study indicates that nano ZnO based finish enhances antimicrobial properties of cotton and hence can be used to treat fabric used for medical and hygiene apparel.

KEYWORDS

Nanotechnology | Antimicrobial | Nano ZnO | Nanoparticles | Medical Textiles | Healthcare

CITATION

Mulchandani Neha and Karnad Vishaka (2020): Application of Zinc Oxide nanoparticles on Cotton fabric for imparting Antimicrobial properties. ESSENCE Int. J. Env. Rehab. Conserv. XI (1): 1 — 10.
https://eoi.citefactor.org/10.11208/essence.20.11.1.101

Introduction

Focus on antimicrobial properties in medical textiles have increased more due to increasing incidence of bacterial infections. To impart antimicrobial properties, and to prevent the exposure and transference of micro-organisms, medical textiles have been coated with variety of antimicrobial agents (Murugesh Babu and Ravindra, 2014; Gao and Cranston, 2008). Of these, inorganic antimicrobial agents are gaining more importance for their increased stability at high temperatures and pressures such as TiO_2, ZnO, MgO and CaO (Sawai, 2003; Stoimenov *et al*., 2002). Nanoparticles of especially copper oxide, Zinc oxide and nanosilver are known for their antimicrobial effect.

Zinc oxide is known to have remarkable properties like high thermal conductivity, high refractive index, binding energy, UV protection and antibacterial because of which it is extensively used in biomedicine as anticancer, drug delivery, antibacterial, and diabetes treatment; anti-inflammation; wound healing;, and bio imaging and other industries like cosmetics, solar cells, rubber, concrete, food etc. (Uikey and Vishwakarma, 2016; Jiang *et al*., 2018). Currently nanosilver is being widely used in most of the consumer products including clothing and wound dressings. Silver however causes toxicity and may possess potential environmental problem (Bondarenko *et al*., 2013; Prabhu and Poulose, 2012; Ray *et al*., 2009; Mishra *et al*., 2017; Zhang and Xiong, 2015; Kim *et al*., 2017; Xiong, 2013). ZnO nanoparticles have been found to be nontoxic with good compatibility to human cells (Zvyagin *et al*., 2008; Kachynski *et al*., 2008; Vanheusden *et al*., 1996). They are receiving more preference due to cost effectiveness and white appearance in comparison to nano silver and other metal oxide nano particles (Kathirvelu *et al*., 2010). Also ZnO is found to be chemically stable at higher temperatures and UV (Becheri *et al*., 2007). Recently it is being explored to be used for textile applications. They can be better alternative to triclosan, quaternary ammonium salts, and other synthetic organic compounds that are dominating the market of antimicrobial textiles (Perelshtein *et al*., 2016).

Zinc is also an essential element for body tissues and enzyme systems and has an important role in body metabolism, proteins and nucleic acid synthesis, hematopoiesis, and neurogenesis. Moreover, the US Food and Drug Administration (FDA) has indexed it as GRAS (generally recognized as safe) (Jiang *et al*., 2018; Rasmussen *et al*., 2010).

With exceptional properties, various methods are being explored to synthesize ZnO. Different methods produce different morphologies and size with unique properties and applications (Gupta *et al*., 2007). The nanostructures can be produced by variety of physical and chemical methods such as nanolithography, physical vapour deposition (PVD), chemical vapour deposition, spray conversion processing, sol-gel process, and precipitation method however size and shape of nanoparticle can be better controlled by chemical techniques(Sirelkhatim *et al*., 2015; Belay *et al*., 2017). Most of the synthesis techniques require either high temperature or high vacuum. In this study, Zinc oxide nanoparticles were produced by a chemical reduction method which is inexpensive, requires low temperature, reproducible and environmental friendly (Borade *et al*., 2016).

It has been discovered in many studies that particle size and concentration of nanoparticle play an important role for antimicrobial activity (Sirelkhatim *et al*., 2015). Submicron sized particles of ZnO react with water to produce reactive oxygen species that destroy the bacteria cell membranes. And, if the size of nanoparticles is made even smaller, the result will be more effective as the particles will reach inside the bacterial cell wall resulting in even higher killing efficiency (Anita and Ramachandran, 2012).The present work is an attempt to investigate the antimicrobial effect of zinc oxide nanoparticles and to find optimum of ZnO concentration to effectively combat bacteria.

Materials and Methodology

Materials

100% medical cotton fabric (Twill weave, GSM-204g/m^2, EPI-120, PPI-60 warp count-25 tex and weft count-27 tex) was used for the study. Before application, the fabric samples were washed in distilled water to remove impurities. Zinc acetate was purchased from Merck. Sodium Hydroxide and PVA was procured from S. D. Fine Chemicals, 99%.

Preparation of zinc oxide nanoparticles

Zinc oxide nanoparticles were prepared by wet chemical method. 2M NaOH was dissolved in 20 ml of deionized water and 0.1M Zinc acetate was dissolved in 200 mL of deionized water. NaOH solution was added dropwise into zinc acetate solution to adjust the pH of solution to 7 under constant stirring. The reaction was continued for 2 hours at 80˚C after the addition of NaOH. The solution was then allowed to settle and supernatant solution was discarded carefully. The obtained nanoparticles were rinsed several times by ethanol, DI water and finally dehydrated at 100˚C for 2 Hrs in ambient conditions.

Characterization of ZnO particles

The XRD of ZnO particles was performed using ShimadzuXRD-6100 X-ray diffractometer using Cu Kα (λ = 1.54 Å) radiation over a range from 20 to 80 2θ angles to study the crystalline structure of the sample.The UV-Vis absorbance spectra of the sample dispersed in DI water was recorded within 200–600 nm wavelength range, using a ShimadzuUV -1800 ultraviolet-visible spectrophotometer.The shape of the nano particles were obtained through TEM, using a FEI Technai G2 apparatus operating at 300kv.

Application of zinc oxide nanoparticles on fabric

Zinc Oxide nanoparticles were applied on medical cotton fabric using pad-dry-cure method. The solution was prepared by mixing ZnO nanoparticles (0.01%, 0.05%, 0.10% and 0.25%) along with PVA (2%) in shaker bath for 5 minutes. The cotton fabric samples were then immersed in the solutions for 5 minutes and passed through a padding mangle. The pressure and speed of padding mangle was adjusted to get approx. 100 % wet pickup for the treatments at four different concentrations. The padded fabric samples were then dried and cured for 3 mins at 140˚C.

Assessment of fabric treated with nano ZnO for antimicrobial activity

The fabrics coated with zinc oxide nanoparticles under different concentrations of nanoparticles namely 0.01%, 0.05%, 0.1% and 0.25% were tested quantitatively by a colony count method by following AATCC 100 norms. Staphylococcus aureus (ATCC 6538), a Gram-positive organism and Klebsiella pneumonia (ATCC 4352) a Gram-negative organism were used as test organisms respectively. Treated sterilized and control samples of 4.8 cm ± 0.1 cm were inoculated with the test organisms. After inoculation, 100 ml of neutralizing solution was added to the bottles containing both the test and control swatches. The bottles were shaken vigorously for 1 min and serial dilutions were made with water followed by standard plate count method in duplicate using nutrient agar. The plates were then incubated for 24 h at 37˚C and the bacterial colonies were counted using colony counter. The antimicrobial activity was evaluated by comparing the percent reduction of bacteria in control and treated samples. The percent reduction of bacteria (R) was calculated using the following formula:

$$\mathbf{R\ (\%) = (B - A) \times 100 / B}$$

Where R = % reduction; A = the number of bacteria recovered from the inoculated treated test specimen swatches in the bottle incubated over the desired contact period; B = the number of bacteria recovered from the inoculated treated test specimen swatches in the bottle immediately after inoculation. The treated fabric showing maximum antibacterial activity was subjected to

5, 10, 25 and 50 washes according to ISO 6330 standard procedures to evaluate the durability of the fabric coated with nanoparticles. The respective specimen was treated with non-ionic detergent at concentration of 1 gpl at the temperature of 40˚C for 30 min in the machinery, after which the antimicrobial property of washed samples was studied according to AATCC 100 norms.

Characterization of fabrics treated with nano ZnO

The FTIR spectroscopic analysis was performed on the nanoparticle ZnO treated fabric. Bruker FTIR spectrophotometer in the range of 400-4000cm with potassium bromide (KBr) Pellet method was used. Surface morphology and size of nano particles of treated fabrics were studied by Scanning Electron Microscope (Philips XL30 SEM, Netherlands) at 10 kV. Fabric sample was placed on the sample holder and air dried for coating. Sample was then vacuum sputtered with gold–palladium mixture to improve its conductivity and viewed under SEM.

Results and discussion

XRD patterns, UV vis spectra and TEM morphologies of zinc oxide nanoparticles

The XRD pattern of the ZnO. particles prepared is shown in Figure 1.The XRD pattern show evident peaks at 2θ =31,34,36,47,62,67 and 69 typical of hexagonal ZnO wurtzite structure according to JCPDS card number 04-0831

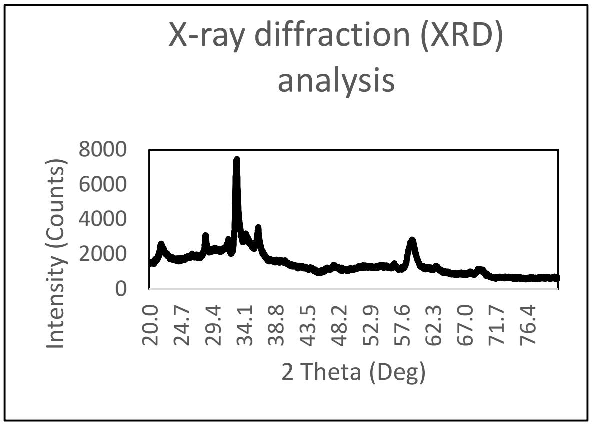


Fig. 1: XRD Pattern of ZnO Particles

indicating crystallinity in nanoparticles corresponding to diffraction planes (100), (002), (101), (102), (110), (103), (112), and (201) respectively.

UV-Vis spectroscopy was also performed to further confirm the formation of ZnO NPs. The absorption spectrum of the particles is shown in Figure 2. From the figure, one can notice absorption band at 381.5nm which attributes to the intrinsic band-gap of Zn-O absorption.

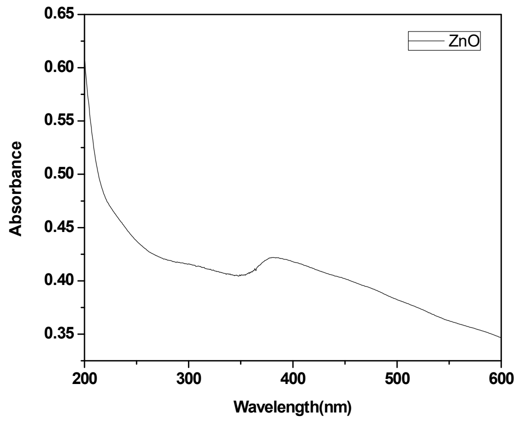


Fig. 2: The particles were subjected to TEM analysis shown in Figure 3 where it clearly revealed the dumbbell shaped ZnO particles.

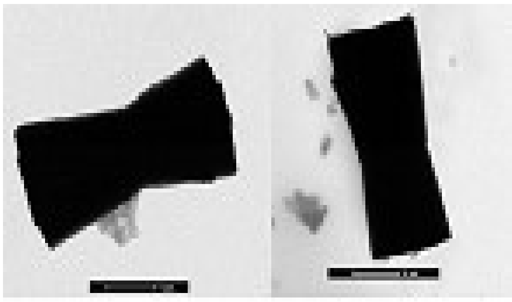


Fig. 3: TEM micrographs of ZnO nanoparticles

Effect of ZnO concentration on antimicrobial performance of treated fabric

Fabric samples treated with nano ZnO under different concentration levels such as 0.01%, 0.05%, 0.1% and 0.25% were assessed quantitatively for antimicrobial efficacy shown in Table 1.

Fabric sample treated with nano ZnO at different concentrations	Initial inoculum (CFU/ml)	Survival Cells (CFU/ml)	Antibacterial activity (% reduction)	Initial inoculum (CFU/ml)	Survival Cells (CFU/ml)	Antibacterial activity (% reduction)
	Staphylococcus aureus			**Klebsiella pneumoniae**		
0.01	1.79×10^5	6.10×10^2	99.65	1.85×10^5	8.20×10^2	99.55
0.05	2.03×10^5	7.60×10^2	99.62	2.07×10^5	8.20×10^2	99.60
0.10	1.78×10^5	<10	>99.99	1.89×10^5	40	99.97
0.25	2.07×10^5	80	99.96	2.15×10^5	90	99.95
0.10 Bulk	1.93×10^5	1.80×10^2	99.90	1.80×10^5	2.30×10^2	99.87
Control	1.75×10^5	3.20×10^5	00	1.89×10^5	4.10×10^5	00

Table 1: Antibacterial activity of fabric samples treated with nano and bulk ZnO

It can be observed from Figure 4, that fabric samples treated with concentrations 0.10 and 0.25 showed almost 100% antimicrobial activity whereas samples treated with 0.01 and 0.05 concentration showed less than 100% activity.

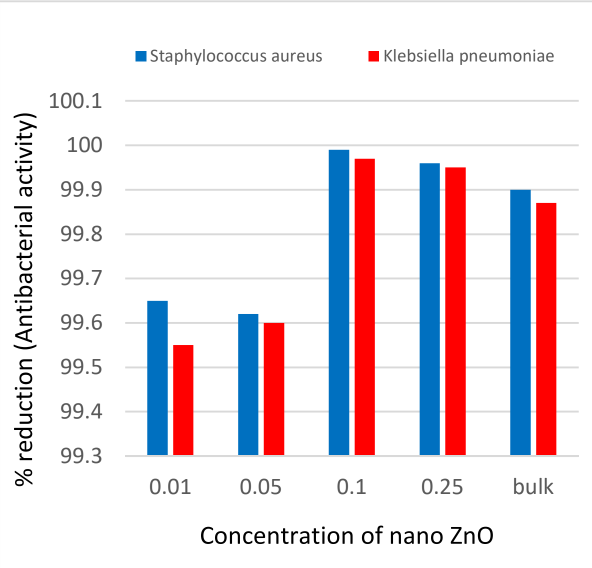


Fig. 4: Antibacterial activity of fabric treated with 0.1% ZnO at 0 and 24 hours

It is seen that with increase in concentration of nano ZnO from 0.05, the inhibition percentage remains more or less in same range against both Staphylococcus aureus and Klebsiella pneumoniae. From the results, nano-ZnO coating with 0.10% uptake of ZnO showed excellent antibacterial activity (reduction > 99.99%), even better than bulk ZnO.

The treated fabric was also subjected to wash durability test. Fabric treated with 0.10% sustained antimicrobial activity until 50 washes as shown in Table 2.The results correspond to similar results reported in Zhang *et al.*, 2009 where nano-sized and micron-sized ZnO suspensions were found to be active in inhibiting the bacteria growth although nanosized were to be more effective than micro sized.

Microorganisms	%Reduction of Microorganism			
	Washing cycles			
	5	10	25	50
Staphylococcus aureus	98.70	98.58	98.52	97.61
Klebsiella pneumoniae	98.68	97.84	97.55	96.97

Table 2: Durability of antimicrobial activity against laundering

(A). S aureus (0hrs and After 24 hrs) **(B).** K. pneumoniae (0hrs and After 24 hrs)

Fig. 5: Antibacterial activity of fabric treated with 0.1% ZnO at 0 and 24 hours.

Many studies have indicated that active oxygen species such as superoxide anion, hydroxyl radicals, and hydrogen peroxide production generated by ZnO particles could be possible mechanism for antimicrobial action (Sawai *et al*., 1996; Yamamoto *et al*., 2004; Zhang *et al*., 2006). UV or visible light activates ZnO generating electron-hole pairs ($e^- h^+$). These electrons /holes split H_2O molecules into OH^- and H^+ present in suspension of ZnO. Electrons reduce dissolved oxygen to superoxide ($^{\bullet}O_2^-$) which react with H^+ to generate ($HO_2^{\bullet}$) radicals. These radicals produce hydrogen peroxide anions (HO_2^-) after subsequent collision with electrons. The peroxide ions then react with hydrogen ions to produce molecules of H_2O_2 which can penetrate the bacterial cell wall and kill the bacteria.

$$ZnO + h\nu \rightarrow e^- + h^+;$$

$$h^+ + H_2O \rightarrow {}^{\bullet}OH + H^+$$

$$e^- + O_2 \rightarrow {}^{\bullet}O_2^-;$$

$${}^{\bullet}O_2 + H^+ \rightarrow HO_2^{\bullet}$$

$$HO_2^{\bullet} + H^+ + e^- \rightarrow H_2O_2$$

Zinc ions released from nano Zinc Oxide and abrasive surface of ZnO are also suggested as possible mechanisms for antimicrobial function. Zinc ions released can cause bacterial cell membrane disintegration, membrane protein damage, and genomic instability, resulting in the death of bacterial cells (McCarthy *et al*., 1992; Jiang *et al*., 2018). The surface roughness of ZnO particles causes the damage of cell membrane E coli (Padmavathy and Vijayaraghavan, 2008). ZnO particles are more active against gram negative bacteria than gram positive. The negative charge on cell wall of gram negative bacteria leads to intense electrostatic interaction with Zn ions on bacterial surface which blocks or inhibits the bacteria in lag phase itself (Shaban *et al*., 2018).

The exact antimicrobial mechanism is still not well established although its considered to be promising antimicrobial agent against different bacterial species which can be coated on various substrates to prevent bacteria from adhering, spreading, and breeding in medical devices (Jiang *et al*., 2018).

Characterization of nano finished fabric using FTIR and SEM

3.2.1 Analysis of Zinc oxide finished fabrics using FTIR

FTIR analysis technique was used to recognize the materials chemical bonding. It is used to identify the elemental constituents of a material. Typically, cellulosic materials show two main absorbance regions in IR spectrum. The first one at low wavenumbers in the range 700 − 1800 cm^{-1}, and the second one at higher wavenumbers in range 2700 − 3500 cm^{-1}.The characteristic peaks exhibited by FTIR spectrum of zinc oxide nanoparticles treated fabric was investigated in Figure 6.Peaks were observed at wavelength 3277.66, 2887.14, 2361.99, 1704.19, 1240.24, 1014.21, 714.14, 660.89, 513.21, 484.28, 469.82, 464.68, 447.37 and 440.01 for the treated fabric. Absorption band at 3277.66 illustrates characteristics of OH functional groups in cellulose. The peaks located at around 3237–3410 cm^{-1} is due to the O–H stretching of the hydroxyl groups of –Zn $(OH)_2$and/or physically adsorbed water molecules (Ghotbi, 2010).

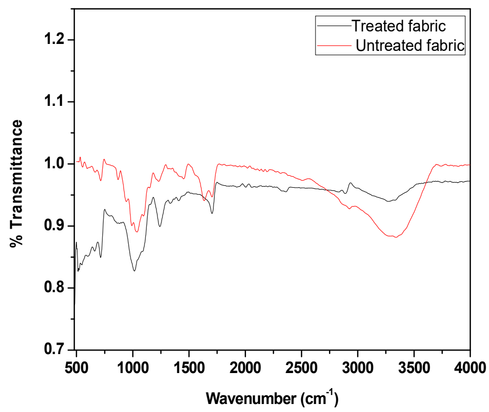


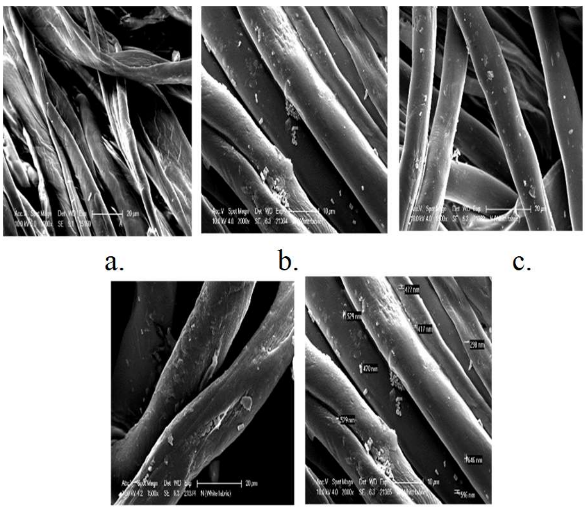
Figure 6: FTIR spectra of Treated and control fabric

The peak at 2887.14 is assigned to stretching vibration of C-H group. Also, the peak at 2361 which is close to 2357 reported by Shaban *et al*., 2018 indicates O-H stretching, which is ascribed to carboxylic acid due to oxidation of primary hydroxyl sites. The peaks at 1704.19, 1240.24, 1014.21 belong to –C=O stretching.

The absorbance bands of zinc oxide lie between 400-700 indicating the presence of Zn-O vibrational modes confirmed by characteristic peaks at 469 and 484 (Shaban *et al*., 2018; Vigneshwaran *et al*., 2006; Rajagopalan and Khanna, 2013).

3.2.2 Analysis of Zinc oxide finished fabrics using scanning Electron Microscope (SEM)

The surface observation of zinc oxide nanoparticle-finished fabric was carried out with a scanning electron microscope. The observations in Figure 7 revealed that the size of the zinc oxide NPs coated on the fabric were in the range between 200-600 nm and distributed. The untreated cotton fabric seems to have smooth fibers without any particles as seen in Figure 7, while the cotton fabric treated with ZnO nanoparticles showed deposition on surface. In some areas agglomerates of the particles are visible.



a. b. c.

d. e.

Figure 7: (a) SEM of pristine fabric; (b), (c), (d) SEM Micrographs of fabric treated with nano ZnO at 0.1 %; (e) SEM with size of the particles

Conclusion

The prepared nanoparticles of ZnO were deposited on cotton fabric for imparting antimicrobial activity. The results show excellent antimicrobial activity when treated with 0.1% of nanoparticles against gram positive and gram negative bacteria. The durability of finished fabric was found to be excellent as it was able to withstand 50 washes with 97.61% reduction for Staphylococcus aureus and 96.97% reduction for Klebsiella pneumonia. The FTIR results indicated the presence of Zn-O vibrational modes in treated fabric. The SEM results indicate the deposition of particles with size ranging from 200nm to 500nm. Nano ZnO which is cost effective and nontoxic can be of immense use in medical textiles for their antimicrobial functionality.

5. Acknowledgements

The authors express deep gratitude towards Dr. S Jejurikar and Mr. P Borade, National Centre for Nanoscience and Nanotechnology, University of Mumbai, Kalina Campus, Santacruz (E), Mumbai, India for the preparation of ZnO nanoparticles.

References

Agrawal, Eashverya and Rastogi, Shivi (2018): A study on properties of union fabrics developed with sisal fibre for textile application. ESSENCE Int. J. Env. Rehab. Conserv. IX (1): 01—05. https://doi.org/10.31786/09756272.18.9.SP1.151. https://eoi.citefactor.org/10.11208/essence.18.9.SP1.151.

Anita, S. and Ramachandran, T. (2012): Preparation, Characterization and Functional Analysis of Zinc Oxide Nanoparticles Coated Single Jersey Cotton Fabric. J. Textile Sci. Eng., 2(114).

Becheri, A., Dürr, M., Lo Nostro, P. and Baglioni, P. (2007): Synthesis and characterization of zinc oxide nanoparticles: application to textiles as UV-absorbers. Journal of Nanoparticle Research, 10(4): 679–689.

Belay, S, G., Reddy A., AR, C. and Z, B. (2017): Synthesis and Characterizations of Zinc Oxide Nanoparticles for Antibacterial Applications. Journal of Nanomedicine and Nanotechnology, s8.

Bondarenko, O., Juganson, K., Ivask, A., Kasemets, K., Mortimer, M., and Kahru, A. (2013): Toxicity of Ag, CuO and ZnO nanoparticles to selected environmentally relevant test organisms and mammalian cells in vitro: a critical review. Archives of Toxicology, 87(7): 1181–1200.

Borade, P., Joshi, K. U., Gokarna, A., Lerondel, G., Walke, P., Late, D. and Jejurikar, S. M. (2016): Synthesis and self-assembly of dumbbell shaped ZnO sub-micron structures using low temperature chemical bath deposition technique. Materials Chemistry and Physics, 169: 152–157.

Deepti Bhargava- and Deeksha Bhargava (2018): Blood Repellent finishes for Healthcare Textiles: An overview. ESSENCE Int. J. Env. Rehab. Conserv. IX (1): 45—53. https://doi.org/10.31786/09756272.18.9.SP1.156. https://eoi.citefactor.org/10.11208/essence.18.9.SP1.156

El-Nahhal, I. M., Zourab, S. M., Kodeh, F. S., Elmanama, A. A., Selmane, M., Genois, I. and Babonneau, F. (2013): Nano-structured zinc oxide–cotton fibers: synthesis, characterization and applications. Journal of Materials Science: Materials in Electronics, 24(10): 3970–3975.

Gao, Y. and Cranston, R. (2008): Recent Advances in Antimicrobial Treatments of Textiles. Textile Research Journal, 78(1): 60–72.

Ghotbi, M. Y. (2010): Synthesis and characterization of nano-sized ε-Zn(OH)2 and its decomposed product, nano-zinc oxide. Journal of Alloys and Compounds, 491(1-2): 420–422.

Gupta, K. K., Jassal, M. and Agrawal, A. K. (2007): Functional Finishing of Cotton Using Titanium Dioxide and Zinc Oxide Nanoparticles. Research Journal of Textile and Apparel, 11(3): 1–10.

Hassan, M. S., Ali, H. E. and Ali, N. M. (2017): Antibacterial Activity of Cotton Fabrics Treated With Poly (Vinyl Alcohol)/ZnO Nanocomposites, Photocatalyzed by UV Irradiation. Journal of Vinyl and Additive Technology, 23:E34–E39.

Jiang, J., Pi, J. and Cai, J. (2018): The Advancing of Zinc Oxide Nanoparticles for Biomedical Applications. Bioinorganic Chemistry and Applications, 2018:1–18.

Kachynski, A. V., Kuzmin, A. N., Nyk, M., Roy, I. and Prasad, P. N. (2008): Zinc Oxide Nanocrystals for Nonresonant Nonlinear Optical Microscopy in Biology and Medicine. The Journal of Physical Chemistry C, 112(29).

Kathirvelu, S., D'Souza, L. and Dhurai, B. (2010): Study of stain-eliminating textiles using ZnO nanoparticles. Journal of the Textile Institute, 101(6): 520–526.

Kim, S., Lee, S. Y. and Cho, H. J. (2017): Doxorubicin-Wrapped Zinc Oxide Nanoclusters for the Therapy of Colorectal Adenocarcinoma. Nanomaterials, 7(11):354.

McCarthy, T. J., Zeelie, J. J. and Krause, D. J. (1992): The antimicrobial action of zinc ion/antioxidant combinations. Journal of Clinical Pharmacy and Therapeutics, 17(1): 51-54.

Mishra, P. K., Mishra, H., Ekielski, A., Talegaonkar, S. and Vaidya, B. (2017): Zinc oxide nanoparticles: a promising nanomaterial for biomedical applications. Drug Discovery Today, 22(12):1825–1834.

Murugesh Babu, K. and Ravindra, K. B. (2014): Bioactive antimicrobial agents for finishing of textiles for health care products. The Journal of the Textile Institute, 106(7): 706–717.

Padmavathy, N. and Vijayaraghavan, R. (2008): Enhanced bioactivity of ZnO nanoparticles—an antimicrobial study. Science and Technology of Advanced Materials, 9(3):035004.

Perelshtein, I., Perkas, N. and Gedanken, A. (2016): Ultrasonic Coating of Textiles by Antibacterial and Antibiofilm Nanoparticles. Handbook of Ultrasonics and Sonochemistry, 967–993.

Prabhu, S. and Poulose, E. K. (2012): Silver nanoparticles: mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. International Nano Letters, 2(1).

Rajagopalan,N. and Khanna, A. S.(2013): Effect of size and morphology on UV-blocking property of nanoZnO in epoxy coating. International Journal of Scientific and Research Publications, 3(4).

Rasmussen, J. W., Martinez, E., Louka, P. and Wingett, D. G. (2010): Zinc oxide nanoparticles for selective destruction of tumor cells and potential for drug delivery applications. Expert Opinion on Drug Delivery, 7(9):1063–1077.

Ray, P. C., Yu, H. and Fu, P. P. (2009): Toxicity and Environmental Risks of Nanomaterials: Challenges and Future Needs. Journal of Environmental Science and Health, Part C, 27(1):1–5.

Saranya, R. (2017): Zinc Oxide Nanofilms Prepared By Sol-Gel Method. Journal of Chemical and Pharmaceutical Sciences (JCHPS), Special Issue 1:45-49.

Sawai, J. (2003): Quantitative evaluation of antibacterial activities of metallic oxide powders (ZnO, MgO and CaO) by conductimetric assay. Journal of Microbiological Methods, 54(2):177–182.

Sawai, J., Kawada, E., Kanou, F., Igarashi, H., Hashimoto, A., Kokugan, T. and Shimizu, M. (1996): Detection of active oxygen generated from ceramic powders having antibacterial activity. Journal of chemical engineering of Japan, 29(4):627–633.

Shaban, M., Mohamed, F. and Abdallah, S. (2018): Production and Characterization of Super hydrophobic and Antibacterial Coated Fabrics Utilizing ZnONanocatalyst. Scientific Reports, 8(1).

Shwetambri1 and Verma, Chhaya (2017): Printing of cotton and silk fabric with marigold flower dye and gum Arabic. ESSENCE Int. J. Env. Rehab. Conserv. VIII (SP1): 26—36.

Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N. H. M., Ann, L. C., Bakhori, S. K. M. and Mohamad, D. (2015): Review on Zinc Oxide Nanoparticles: Antibacterial Activity and Toxicity Mechanism. Nano-Micro Letters, 7(3):219–242.

Stoimenov, P. K., Klinger, R. L., Marchin, G. L. and Klabunde, K. J. (2002): Metal Oxide Nanoparticles as Bactericidal Agents. Langmuir, 18(17): 6679–6686.

Uikey, P. and Vishwakarma, K., (2016): Review of Zinc oxide (Zno) Nanoparticles Applications and Properties. International Journal of Emerging Technology in Computer Science and Electronics (IJETCSE), 21(2):239-242.

Vanheusden, K., Warren, W. L., Seager, C. H., Tallant, D. R., Voigt, J. A. and Gnade, B. E. (1996): Mechanisms behind green photoluminescence in ZnO phosphor powders. Journal of Applied Physics, 79(10): 7983–7990.

Vigneshwaran, N., Kumar, S., Kathe, A. A., Varadarajan, P. V. and Prasad, V. (2006): Functional finishing of cotton fabrics using zinc oxide–soluble starch nanocomposites. Nanotechnology, 17(20): 5087–5095.

Webster, T. J. and Seil, I. (2012): Antimicrobial applications of nanotechnology: methods and literature. International Journal of Nanomedicine, 2767.

Xiong, H. M. (2013): ZnO Nanoparticles Applied to Bioimaging and Drug Delivery. Advanced Materials, 25(37): 5329–5335.

Yamamoto, O., Komatsu, M., Sawai, J. and Nakagawa, Z. (2004): Effect of lattice constant of zinc oxide on antibacterial characteristics. Journal of Materials Science: Materials in Medicine, 15(8): 847–851.

Zhang, L., Jiang, Y., Ding, Y., Daskalakis, N., Jeuken, L., Povey, M. and York, D. W. (2009): Mechanistic investigation into antibacterial behaviour of suspensions of ZnO nanoparticles against E. coli. Journal of Nanoparticle Research, 12(5):1625–1636.

Zhang, L., Jiang, Y., Ding, Y., Povey, M. and York, D. (2006): Investigation into the antibacterial behaviour of suspensions of ZnO nanoparticles (ZnO nanofluids). Journal of Nanoparticle Research, 9(3): 479–489.

Zhang, Z. Y. and Xiong, H.M. (2015): Photoluminescent ZnO Nanoparticles and Their Biological Applications. Materials, 8(6): 3101– 3127.

Zvyagin, A. V., Zhao, X., Gierden, A., Sanchez, W., Ross, J. A. and Roberts, M. S. (2008): Imaging of zinc oxide nanoparticle penetration in human skin in vitro and in vivo. Journal of Biomedical Optics, 13(6): 064031.