Functional Finishes of Textiles Using Zinc Oxide Nano Particles – A Review of the Current Trends

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Abstract

The article comprehensively reviews some of the current research trends in the nano finishes of textiles using zinc oxide. The ZnO nanoparticles solution was directly applied on to the 100% cotton knit & woven fabric to impart antibacterial property using both spin coater & pad-dry-cure method. Then, the disc diffusion method was used to assess the antibacterial activity of the finished fabrics. The topographical analysis of untreated, treated, and washed fabrics of different structures (knit and woven) were studied and compared. A liquid precipitation method was used to prepare zinc oxide nanoparticles in three diverse media: water, methanol, and ethylene glycol. The studied materials were examined by scanning electron microscopy, X-ray diffraction, Fourier transform infrared spectroscopy, and ultraviolet-visible spectroscopy. X-ray diffraction patterns showed a hexagonal Wurtzite structure of zinc oxide with a nanocrystalline size. Acquired powders showed different morphologies (rod, star, and spherical structures), which were affected by the nature of the solvent in the reaction. The different zinc oxide powders have varied optical band gaps. Scanning electron microscopy examinations confirmed the arrangement of nano-zinc oxide on the surfaces of the materials. The zinc oxide-covering procedure was carried out on cotton, polyester, and 50/50 wt% polyester/cotton blended fabrics using a simple dip and curing system.

Keywords: Antimicrobial property, Nano particle, Spin coater, Zinc oxide, UV protection, defence clothing.

Introduction

The nano-world is the intermediary between the atom and the solid, from the large molecule or the small solid object to the strong relationship between surface and volume [1]. The term nano originated from the Greek nanos which suggests 'dwarf'. It is one billionth of a meter [2]. Nanotechnology is the science that deals with matter at the scale of 1 billionth of a meter. It is also the study of manipulating matter at the molecular and atomic scale. Nanoparticle, the most fundamental component in the fabrication of a nanostructure is far smaller than the world of everyday objects, and is described by Newton's laws of motion. However, it is bigger than an atom or a simple molecule that are governed by quantum mechanics [3].

When conventional materials formed from nanoparticles, many of its properties changed. Nanoparticles are reactive and effective than other molecules because of having a greater surface area per weight than larger particles. Nowadays, a very promising scientific research is nanoparticle research because of the wide range of potential and promising applications especially in electronic fields, optical, and biomedical. This new concept changes the use of such material in microscale size to be used in absolutely new and advanced applications by using a nanoscale size of the same material [4]. The structure of the nano materials can be classified by their dimensions. The zero-dimensional nanostructures are called nanoparticles [5]. Recently, one-dimensional nanostructures with different morphologies (such as nanowires, nano-rods (NRs), and nanotubes) have become the focus of intensive research, because of their unique properties with potential applications. Among them, zinc oxide (ZnO) nano materials has been found to be highly attractive, because of the remarkable potential for applications in many different areas such as solar cells, sensors, piezoelectric devices, photodiode devices, sun screens, anti-reflection coatings, and photo catalysis [6].

Defense textiles have an extraordinary potential for cross-infection because they are often used by groups living in numerous camps and risky climates. The principal challenges faced by the defense clothing industry are not only inventing and improving the current functionalities of textiles, but also preservation of the look, flexibility, comfort, washability, and feel of the fabric [7-12]. To protect defense personnel from microbes and cross-infection, a special antimicrobial finish has become a necessity on clothing [13-17]. It is predicted that defense clothes used in military applications will be able to help examine the hazards of the wearer's environment and provide permanent updates on their health status. Cotton is the most commonly used fabric in the manufacture of defense clothing [18].

Recently, zinc oxide has been found highly attractive because of its remarkable application potential in solar cells, sensors, displays, piezoelectric devices, electroacoustic transducers, photo-diodes and UV light emitting devices, sun-screens, UV absorbers, anti-reflection coatings, photo-catalysis, and catalyst [13-25]. Zinc oxide is a modifier in textile industry because of its use for the production of safety garments and all kinds of fabrics for the construction industry. It has a high UV blocking and antibacterial properties [26-31]. Zinc oxide (ZnO) ultrafine particles are well known as UV blocking materials, which make it feasible to be widely used in polymers, fabrics, and cosmetic materials [16,18]. Zinc oxide has a band gap at around 3.37 eV corresponding to 376nm and thus it absorbs light that matches or exceeds this band gap energy [32-36]. UV-range of solar spectrum lies within this range and thus UV light gets absorbed by zinc oxide particles. The UV-blocking property of zinc oxide is only enhanced when it comes to nano-sized ultra-fine ZnO particles.

Influence on antibacterial properties of cotton fabrics

Zinc oxide nanoparticles (ZnO NPs), as one of the most important metal oxide nanoparticles, are popularly employed in various fields due to their peculiar physical and chemical properties [37,38]. Zinc oxide nanoparticles (ZnO NPs) are used in an increasing number of industrial products such as rubber, paint, coating, and cosmetics [39]. In addition, ZnO NPs have superior visible light resistance, antibacterial deodorant, antibacterial, antimicrobial, and excellent UV-blocking properties [40]. Due to their potential for reducing the transmission of infection in medical and health care environments, antimicrobial textiles have attracted a great interest in recent years. In addition, in these fabrics, the formation of unpleasant odors is reduced. Therefore, it is possible to have a pleasant and fresh smell from those textiles still after use. Therefore, antimicrobial products have long been used in health care environments for hospital gowns, patient clothes, curtain, bed cover, infection control, wound healing, hygiene, etc. The effectiveness of antimicrobial action on textiles depends on the antimicrobial, the concentration, and the application method of the antimicrobial on the textile [41]. Microbes are very small lives on the earth which can't be seen by the naked eyes. They may be known as microorganisms like bacteria, fungi, algae, and viruses, etc. These bacteria are sub classified into different groups namely gram positive (Staphylococcus aureus), gram negative (Escherichia coli), spore bearing or non-spore bearing types. Apart from that some are pathogenic and cause cross infection bacteria whereas some microbes like fungi, molds or mildews are shown slower growth rate due to its complex nature [42].

Various studies have already been done on zinc oxide nanoparticles as antibacterial substance by many researchers. The ability of the antibacterial agent to inhibit bacterial growth was first tested using a disc diffusion method [43]. ZnO nanoparticles treated fabric shows higher antibacterial activity when compared with ZnO bulk treated fabrics whereas the untreated fabrics showed no antibacterial activity. It has also found that the ZnO nanoparticles constitute an effective antimicrobial agent against pathogenic microorganisms [44]. A zinc oxide nanoparticle is used as an antibacterial substance against E. coli and S. aureus and exhibits the highest toxicity against microorganisms. It has also been demonstrated from SEM and TEM images that zinc oxide nanoparticles first damage the bacterial cell wall, then penetrate, and finally accumulate in the cell membrane [45].

In this study, two different methods have been used to apply the ZnO nanoparticles named spin coating and paddry- method. Spin coating is known as a procedure used to deposit uniform skinny films to flat substrates. In this coating system, very few amount of coating material is applied on the center of the substrate, which is either spinning at low speed or not spinning at all. The substrate is then rotated at high speed in order to spread the coating material by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner.

Pad-Dry-Cure or Exhaust-Dry-Cure is a finishing process applied to textiles to impart different finish treatments, such as waterproofing, softening, antibacterial or anti-odor finishes. A water-based solution bath contains finishing chemicals through which the textile materials pass. The textile is then dried and cured using heat and pressure. This is known as the parent process for various finishing treatments. Then antibacterial analysis of the treated and untreated samples was carried out by disc diffusion method [46]. To determine the effective ness of the finishing process and coating, the diameter of the zone of inhibition produced by the coated samples has been measured and compared with each other.

From this study, it concludes that double Jersey fabric showed highest protection against bacteria than single jersey and woven fabric. Moreover, pad-dry-cure method gave good antibacterial protection than spin finish. There is more scope to test others structures of fabric like silk, polyester etc. for finding out the best antibacterial coated cloth. Although, spin coating takes less time and saves chemical solution uptake than pad-dry-cure. But setting up a spin coater for antibacterial finish is a costlier matter than pad-dry-cure method [47]. Moreover, antibacterial activity of ZnO particles were greater on gram-positive than gram-negative bacteria. Therefore, antibacterial treatment resists the S. aureus bacteria better than that of E. coli bacteria. The antimicrobial properties of these fabrics will allow additional protection to them from bio deterioration during storage, transportation and consumption of goods and provide new opportunities to use in medical application.

Development of UV protection and antimicrobial fabrics

The use of nano materials in modern textiles lies in areas where innovative principles will be combined into long-lasting, multifunctional textile structures without compromising the intrinsic textile properties such as aesthetics, breathability, flexibility, etc [48]. Coating fabrics with nanoparticles is important because they improve durability by penetrating the fabric surface due to their small size and high surface to volume ratio [49]. Incorporating nanomaterials into a textile can affect a host of properties, including shrinkage, strength, antimicrobial qualities, and ultraviolet (UV) protection. 1, 2, 5, 6

The adhesion strength of nano-particles to the fabric they cover depends on the morphological structure and the stabilization of the covered materials in the washing system. Zinc oxide (ZnO) is a chemical agent used in defense clothing because of its unique chemical and physical characteristics, biocompatibility, environmental friendliness, nontoxicity, and low cost. ZnO can also provide textiles with excellent UV blocking ability owing to its high intrinsic optical band gap energy (3.3 eV), which lies in the UV range [50-52]. To our knowledge, the dielectric constant of a solvent influences the kinetics of nucleation and the growth of crystallites during their formation. Therefore, the preparation of ZnO in different solvent media with different dielectric constants can produce ZnO with varied morphological structures. Accordingly, the present study is mainly designed to prepare the distinctive morphology of nano-ZnO and investigate the effects on the antimicrobial and UV-protection capacities of particular fabrics (cotton, polyester, and 50/50% cotton/polyester). Three different morphological ZnO nanoparticles have been synthesized in three different media: water, methanol, and ethylene glycol. The UV protective properties of the ZnO-treated textiles are measured by their UV protection factor (UPF).

Moreover, we studied the antimicrobial action of the nanoparticles on fabrics against Gram-negative bacteria (Escherichia coli), Gram-positive bacteria (Staphylococcus aureus), and diploid fungus (Candida albicans). The improvement in the physical properties of the fabrics treated with different morphological ZnO nanoparticles opens up the possibility of protecting the human body from disease and solar radiation, and has uses in other technological applications.

A simple method has been utilized to arrange nano-ZnO particles with a diverse morphological structure and coating them on cotton, cotton/polyester, and polyester fabrics to grant useful properties. Nanoparticles were analyzed by XRD, SEM, and FTIR. The existence of nanoparticles on the fabric surface was tested by SEM and showed a significant change in the UV-absorbing activity of ZnO-treated fabrics. The UPF values of coated fabrics were much higher than 50, revealing excellent protection against UV radiation. The cotton fabric treated with ZnO nanorods exhibited the highest UPF value of 247.2.

No significant difference was found between the tensile strength and elongation values of the treated and untreated samples. The antimicrobial activity of the treated textiles was measured qualitatively by agar diffusion methods and quantitatively by a percentage reduction test. The bactericidal activities of samples were tested with E. coli, S. aureus, and C. albicans. The treated fabrics exhibited notable antimicrobial action against these microorganisms. The cotton fabric treated with 26nm non-spherical ZnO particles exhibit the highest antimicrobial efficiency values of 91.4%, 86.8%, and 84.7% for S. aureus, E. coli, and C. albicans, respectively. All the treated fabrics exhibit high antimicrobial and excellent UPF values, even after five washing cycles [53]. These coated antimicrobial textiles are potentially useful in a wide variety of biomedical applications. The results obtained suggest the possibility of using the ZnO-coated fabrics in defense clothing to protect the body against solar radiation and Microorganisms and for use in other technological applications.

Functionalized polyester fabric

Zinc oxide has been studied as antimicrobial agents because of their photocatalytic activity under UV light [54-57]. Zinc oxide particles resist against microorganisms [58,59]. The inorganic oxides of CaO, MgO, and ZnO have antibacterial activity, which is attributed to the generation of reactive oxygen species on the surface of these oxides [60]. The antimicrobial mechanism of chemical agents is attributed to binding of the surface of the agent with a microorganism and the consequent metabolism of the agents inside the microorganism. Researchers have reported the antimicrobial activity of metal ions [61,62]. Many researchers have also attempted to correlate the biological activity of inorganic antibacterial agents with the size of the constituent particles [63,64]. In recent years, metal nano particles are used for microelectronics, photo catalysis, magnetic devices, and powder metallurgy [65-67]. Nano particles coating of textiles is considered because of UV blocking, antimicrobial and self-cleaning properties. It may affect the other fabric properties like dyeing, strength, bending length, air permeability, and friction. ZnO nanoparticles were used to improve antistatic properties of polyacrylonitrile. Jesionowski synthesized zinc oxide and deposited it on PES nonwoven. Prasad synthesized and characterized the ZnO nanoparticles using solid-state reaction [68]. The ZnO nanoparticles applied onto cotton fabrics using acrylic binder. The UV-blocking property of these fabrics was evaluated in addition to their friction and mechanical properties. AbdElhady synthesized chitosan/ZnO nanoparticles using different concentrations of ZnO at different temperatures and applied it to cotton fabric for antibacterial and UV protection results [69]. Zinc oxide–soluble starch nanocomposites (nano-ZnO) synthesized using water as a solvent and soluble starch as a stabilizer was impregnated onto cotton fabrics to impart antibacterial and UV-protection functions [70]. Researchers also investigated antibacterial properties of textiles treated with zinc oxide nanoparticles [71-75].

Glass fiber–unsaturated polyester composites with different contents of ZnO were prepared by Peng et al. [76]. Their resistance after exposure to UV irradiation was evaluated. A sufficient content of ZnO in unsaturated polyester could significantly increase the resistance to simulation by exposure of the composites to Sun [40]. In the present study, zinc oxide colloidal solution was used for polyester fabric to enhance self-cleaning and antibacterial effect of polyester fabric. Polyester fibers have hydrophobic properties, which need alkaline treatment to achieve hydrophilicity.

Researchers worked on alkaline treatment of polyester fibers such as hydrolysis of PET treated with nano TiO2 and optimization of hot alkali treatment of polyester [77-82]. In the present work, polyester fabric was treated with sodium hydroxide, then was coated with ZnO nano particles and also treated with sodium hydroxide and ZnO nano particles at the same time to compare different treatments of ZnO nano particles on polyester fabric with alkali.

In this research, polyester fabric was treated with sodium hydroxide, then was coated with ZnO nano particles, and also polyester fabric was treated with sodium hydroxide and ZnO nano particles at the same time. Alkaline hydrolysis of polyester fabric before treating ZnO nano particles and also in the presence of nano particles showed different amounts of zinc oxide nano particles in fabrics, therefore different properties [83]. The properties such as bending length, water adsorption, antibacterial effect, and self-cleaning were investigated. The results of these properties demonstrated that increasing of zinc oxide nano particles concentration increased these properties. The antibacterial performance of pre-alkaline polyester fabric also showed higher bacteria reduction as compared with treatment in the presence of alkali. Self-cleaning effect of ZnO nano particles on polyester fabric was more significant when pre-alkaline treatment was used. Pre-alkaline-treated polyester fabric revealed higher water drop adsorption time and slightly increase in bending length. Results of atomic absorption spectroscopy confirmed that pre alkaline-treated fabric had more zinc oxide nano particles. The SEM of alkaline treated polyester fabric showed surface hydrolysis of polyester and scares on the fiber surface, and FTIR spectroscopy indicated chemical bonding. Self-cleaning and antibacterial effects of ZnO nano particles can be important in textile industries. Textile industries also need to reduce the processing time of finishing. This study reveals that although one step of chemical finishing is desirable for textile industries, two steps of alkaline and zinc oxide nano particles treatment on polyester fabric is significant.

Conclusion

The topographical analysis of untreated, treated, and washed fabrics of different structures (knit and woven) were studied and compared. The results showed that the finished fabric demonstrated significant antibacterial activity against S. aureus and E. coli. As per result, it was also found that double jersey (rib) fabric showed highest amount of bacterial protection & pad-dry-cure method showed better result against bacterial attack than spin coating method. Moreover, gram negative bacteria (E. coli) showed more strength against antibacterial treated unwashed and washed fabrics than gram positive bacteria (S. aureus). The bending length, water adsorption time, bactericidal properties, atomic absorption spectroscopy, and self-cleaning effect were measured according to the standard methods. Scanning electron microscopy and Fourier transform infrared spectroscopy analysis were used for the study of surface morphology and surface chemical bonding. The results demonstrated that increasing of zinc oxide nano particles concentration increased bending length, water adsorption time, antibacterial and self-cleaning effect. Comparing with pre-alkaline and simultaneous alkali treatment showed that pre-alkaline-treated fabric had more zinc oxide nano particles, therefore more self-cleaning and bactericidal effect. The scanning electron microscopy of alkaline-treated polyester fabric showed surface hydrolysis and nano-particles on the surface of polyester, and Fourier transform infrared spectroscopy spectroscopy indicated chemical bonding. Acquired powders showed different morphologies (rod, star, and spherical structures), which were affected by the nature of the solvent in the reaction. The different zinc oxide powders have varied optical band gaps. Scanning electron microscopy examinations confirmed the arrangement of nano-zinc oxide on the surfaces of the materials. The zinc oxide-covering procedure was carried out on cotton, polyester, and 50/50 wt% polyester/cotton blended fabrics using a simple dip and curing system. The cotton fabric treated with nano rod zinc oxide exhibited the highest ultraviolet protection factor with a value of 247.2. The antimicrobial properties of untreated and treated fabrics with nano-zinc oxide were measured against Gram-negative bacteria (Escherichia coli), Gram-positive bacteria (Staphylococcus aureus), and diploid fungus (Candida albicans). The results showed the antimicrobial action relies on the morphological structure and the particle size of zinc oxide and that it increases with a reduced particle size. The cotton fabric treated with 26 nm nonspherical zinc oxide particles showed the highest antimicrobial efficiency with values of 91.4%, 86.8%, and 84.7% for Staphylococcus aureus, Escherichia coli, and Candida albicans, respectively. The mechanical properties of treated fabrics were studied. The results confirm that nano-zinc oxide is highly useful for improving the performance of defense textile products because of its biocompatibility, environmental friendliness, and nontoxicity.

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