Synthesis, Characterization and Coating of the Zinc Oxide Nanoparticles on Cotton Fabric by Mechanical Thermo-Fixation Techniques to Impart Antimicrobial Activity

Imana Shahrin Tania, Mohammad Ali

Abstract—The present study reports the synthesis, characterization and application of nano-sized zinc-oxide (ZnO) particles on a cotton fabric surface. The aim of the investigations is to impart the antimicrobial activity on textile cloth. Nanoparticle is synthesized by wet chemical method from zinc sulphate and sodium hydroxide. SEM (scanning electron micrograph) images are taken to demonstrate the surface morphology of nanoparticles. XRD analysis is done to determine the crystal size of the nanoparticle. With the conformation of nanoformation, the cotton woven fabric is treated with ZnO nanoparticle by mechanical thermo-fixation (pad-dry-cure) technique. To increase the wash durability of nano treated fabric, an acrylic binder is used as a fixing agent. The treated fabric shows up to 90% bacterial reduction for S. aureus (Staphylococcus aureus) and 87% for E. coli (Escherichia coli) which is appreciable for bacteria protective clothing.

Keywords—Nanoparticle, zinc oxide, cotton fabric, antibacterial activity, binder.

I. INTRODUCTION

NANO-science and use of nanoparticles are considered to be the key technology for the recent time. It is a growing interdisciplinary technology and seen as a new industrial revolution. According to the National Nanotechnology Initiative (NNI), nanotechnology is defined as utilization of structure with at least one dimension of nanometer size for the construction of materials, devices or systems with novel or significantly improved properties due to their nano-size [1]. The chemical and physical properties of a material changes from the bulk to the nanometer scale. So, nanoparticles are more reactive because of the high ratio of the surface area to its volume. Use of nano technology is increasing day by day due to its huge economic potential. The textile sector is also advancing by taking the benefits of nanoparticles. Moreover, increasing customer demand for durable and functional apparel manufactured in a sustainable manner has created an opportunity for nanomaterials to be integrated into textile substrates [2].

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Various nanoparticles like silver, ZnO, TiO₂, SiO₂ are used by the researchers to impart functional property and to meet the demand of the modern market. Those nanoparticles are mainly used as coating on a fabric surface by gun spray, padding and in-situ. However, the durability of those nanoparticles is not satisfactory. Furthermore, ZnO is highly attractive material because of its unique properties, such as optical transparency, electric conductivity, piezoelectricity, near-UV emission and antimicrobial activity [3]-[6].

In the current study, ZnO nanoparticle is applied on cotton by mechanical thermo fixation method along with an acrylic binder. This binder makes a cross linking reaction with the fiber and nanoparticles which increases the strength of bonding of nanoparticles. So, the antimicrobial activity and the durability of nanoparticles on nano treated fabric will improve.

II. EXPERIMENTAL SECTION

Materials

Fabric of 100% cotton containing plain weave is collected from local industry, named the SIM group (Vulta, Rupganj, Narayanganj, Bangladesh) with 80 ends per inch (EPI) and 75 picks per inch (PPI) while GSM is 151 (grams per square meter). The raw cotton fabric is then scoured and bleached [7] before nanocoating to impart absorbency and permanent whiteness. The synthesis chemical zinc sulphate heptahydrate (ZnSO₄·7H₂O, 99% purity) is purchased from Merck Life Science Private Ltd, Mumbai, India. Ethanol and sodium hydroxide are purchased from Sigma Aldrich, Germany. Acrylic binder, Pretreatment chemical: wetting agent, sequestering agent, detergent, caustic soda, and hydrogen peroxide are collected from Orient Chemical Industries Co., Ltd.

Synthesis of ZnO Nanoparticles

The experimental setup of ZnO nanoparticle synthesis is shown in Fig. 1. Wet chemical process is applied to synthesized ZnO nanoparticle by following the method used by [8] with some modification. An aqueous solution of 0.2 M zinc sulfate (ZnSO₄) is made from zinc sulfate heptahydrate (ZnSO₄·7H₂O) in de-ionized water. Then 25 ml of 0.2 M NaOH (pH = 13.8) solution is prepared separately with purified water. The reaction is performed by slowly dropping
of NaOH into ZnSO₄ solution. The bath is placed on a magnetic stirrer for 30 minutes and kept for 4 hours at 60 °C temperature. The nanoparticles are obtained by centrifuging and drying at 60 °C after washing.

\[ \text{full width at half maximum intensity} \]

\[ \cos \theta \]

\[ \lambda = 1.54060 \text{ Å}, \ 0.9 \times \lambda = 1.38654, \ \theta = 2\theta/2, \ d = \text{approximate size} \]

\[ \text{crystalline shape and size is also obtained by X- Ray diffraction analysis.} \]

\[ \text{The SEM images show the particles with nearly spherical shape with various diameters.} \]

\[ \times 1000 \]

\[ \times 1000 \]

\[ \text{Fabric interior and the groove present on cotton surface.} \]

\[ \text{the cross linking of nanoparticles with the fibril structure of the fabric.} \]

\[ \text{after synthesis, the ZnO nanoparticles are applied on cotton fabric by pad, dry and cure method.} \]

\[ \text{The synthesized nanoparticles are characterized by SEM and X-ray diffraction analysis.} \]

\[ \text{The peaks of XRD pattern are obtained at } 2\theta = 31.6^\circ, 34.3^\circ, 36.1^\circ, 47.43^\circ, 56.52^\circ, 62.77^\circ, 67.9^\circ, 72.1^\circ, \text{ and } 76.98^\circ \text{ which indicate the obvious formation of ZnO nanoparticle.} \]

\[ \text{Surface Morphology of ZnO Nano Coated Fabric} \]

\[ \text{To compare the treated fabric surface with untreated fabric, the morphological changes are observed by SEM.} \]

\[ \text{The antimicrobial activity after one-hour contact time against gram positive and gram negative bacteria whereas, the treated fabric shows significant reduction after washing.} \]

\[ \text{The result indicates small amount of bacterial reduction (R %) decreases after washing. The rate of reduction is not too high for five and 10 washing cycle. Thus, the wash durability of nanoparticles is remarkable for ZnO nano coated fabric.} \]
V. CONCLUSIONS

ZnO nanoparticles are prepared and applied on cotton fabric by pad, dry and cure method. Nanoparticles in powder form and nano coated fabric are characterized by SEM. The approximate size range obtained from XRD pattern analysis is around 35 nm. Due to the nano ZnO coating, antimicrobial activity is imparted on cotton fabric which is an important biological property of cotton. So, the bacterial growth of cotton fiber decreases. Moreover, the treated fabric shows sufficient bacterial reduction after nanocoating. Treated fabric exhibits 90% bacterial reduction (R %) for *S. aureus* and 87% for *E. coli*. The wash durability of treated fabric is also satisfactory. The treated fabric retains remarkable bacterial reduction after 15 washes. Therefore, the ZnO nano coated fabric is useful as a medical textile for bacterial protective cloth.
Fig. 5 Surface morphology of nano ZnO coated cotton fabric obtained by SEM in ×1000 magnification: (a) untreated and (b) treated fabric

<table>
<thead>
<tr>
<th>Sample</th>
<th>Staphylococcus aureus (CFU) after 0 Contact Time</th>
<th>Staphylococcus aureus (CFU) after 1.0 hour Contact Time</th>
<th>Bacterial Reduction % (R%) after 1.0 hour</th>
<th>Escherichia coli (CFU) after 0 Contact Time</th>
<th>Escherichia coli (CFU) after 1.0 hour Contact Time</th>
<th>Bacterial Reduction % (R%) after 1.0 hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>2.44×10⁸</td>
<td>2.44×10⁷</td>
<td>0</td>
<td>2.44×10⁸</td>
<td>2.44×10⁷</td>
<td>0</td>
</tr>
<tr>
<td>Nano coated</td>
<td></td>
<td></td>
<td></td>
<td>2.44×10⁸</td>
<td>2.44×10⁷</td>
<td></td>
</tr>
<tr>
<td>Unwashed</td>
<td>2.44×10⁸</td>
<td>2.2×10⁶</td>
<td>90</td>
<td>2.44×10⁸</td>
<td>3.5×10⁶</td>
<td>85</td>
</tr>
<tr>
<td>5 wash</td>
<td>2.44×10⁸</td>
<td>4.2×10⁶</td>
<td>83</td>
<td>2.44×10⁸</td>
<td>4.7×10⁶</td>
<td>80</td>
</tr>
<tr>
<td>10 Wash</td>
<td>2.44×10⁸</td>
<td>4.7×10⁶</td>
<td>80</td>
<td>2.44×10⁸</td>
<td>6.5×10⁶</td>
<td>73</td>
</tr>
<tr>
<td>15 Wash</td>
<td>2.44×10⁸</td>
<td>7.1×10⁶</td>
<td>70</td>
<td>2.44×10⁸</td>
<td>9.0×10⁶</td>
<td>63</td>
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