Nylon Nanocomposite Fibers Infused with Silver Coated Carbon Nanotubes Inhibit Common Microbial Pathogens

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ABSTRACT

Surfaces with antimicrobial properties are of significant interest for the health, biomedical, food and personal hygiene industries. In this study, nylon nano-composite fibers infused with silver coated multi-walled carbon nanotubes (MWCNTs) were fabricated to enhance the mechanical, thermal and antimicrobial properties of the textile fibers. The antibacterial activity of the silver coated MWCNTs, commercial silver, neat nylon and plain MWCNTs was evaluated. Silver coated MWCNTs at 25µg/ml, demonstrated good antimicrobial activity against five common bacterial pathogens as tested by the Kirby-Bauer assay. The mean diameters of the zones of inhibition were 29mm, 29mm, 20mm, 22mm and 22mm, respectively, for *S. aureus*, *S. pyogenes*, *P. aeruginosa*, *E.coli* and *S. typhimurium*. By comparison, those obtained using the broad spectrum antibiotic amoxicillin-clavulinic acid were 43mm, 34mm, 28 mm, 19mm and 26mm respectively for *S. aureus*, *S. pyogenes*, *P. aeruginosa*, *E.coli* and *S. typhimurium*. The standard plate count assay also showed that silver coated MWCNTs (1mg/ml) inhibited the growth of most of the pathogens by 97 – 99 % as compared to controls. Our results suggest that nylon nanocomposite fibers infused with silver coated MWCNTs have significant antimicrobial activity.

Keywords: MWCNT, silver, nylon, antimicrobial

1. INTRODUCTION

Nanotechnology involves utilizing materials at atomic level to attain unique properties, which can be suitably manipulated for the desired applications. As most of the natural processes also take place at nanometer, nanotechnology can therefore, revolutionize the field of health and medicine. Nanotechnology is currently employed as a tool to explore the medical sciences in several ways like imaging, sensing, targeted drug delivery and gene delivery systems and artificial implants. For a long time silver has been known to have a disinfecting effect and has found applications in traditional medicines and culinary items. Several salts of silver and their derivatives are commercially employed as antimicrobial agents [1]. Thus, nanoparticles of silver have aptly been investigated for their antibacterial property [2–5]. Nanoparticles of silver also have been studied as a medium for antibiotic delivery [6], and to synthesize composites for use as disinfecting filters and coating materials. However, the bactericidal property of these nanoparticles depends on their stability in the growth medium, since this imparts greater retention time for bacterium–nanoparticle interaction. There lies a strong challenge in preparing nanoparticles of silver stable enough to significantly restrict bacterial growth.

In the present investigation we report the synthesis of highly stable nylon nano-composite fibers infused with silver coated multi-walled carbon nanotubes (MWCNTs) to enhance the mechanical, thermal and antimicrobial properties of the textile fibers. Studies were carried out on antibacterial activity of the silver coated MWCNTs, commercial silver, neat nylon and plain MWCNTs.

2. MATERIALS & METHODS

2.1 Synthesis of Nanomaterials

Silver coated MWCNT were synthesized by magnetically stirring 500 mg of Silver Acetate and 100 mg of MWCNT for 1hr. The uniform dispersed aqueous solution was reduced in ultrasonic irradiation environment in the presence of dimethylformamide solvent for about 3hr. The chemical effects of ultrasound arise from acoustic cavitations involving the formation, growth and collapse of bubbles in liquid. Bubbles generate localized hot spots having an effect of roughly 5000 K, 20Mpa and very high cooling rates of about 107Ks. Residues were then centrifuged and dried in vacuum under room temperature.

99:1 ratio mixture on Nylon-6 powder and Ag coated CNT was dry blended for deagglomera- tion. Process was carried out for 5-6 times each of 10 min duration.

Nylon-6 and CNT mixtures were further air dried in a dryer for 12 hr. The dried mixture was melted in a single screw extrusion machine and then extruded through an orifice. Extruded filaments were later stretched and stabilized by sequentially passing through a set of tension adjusters and a secondary heating and wound into spools in a filament winder.

2.2 Characterization of Nanofibers

The synthesized nanoparticles were analyzed using TEM (JEOL-2010 microscope). A small drop (20-30 μl) of each sample was placed on top of a formvar/carbon coated copper grid. The drop of sample was allowed to air dry. Once dry, the grid containing the sample was placed into the TEM and viewed. Pictures were taken at 50,000-125,000 magnifications. Samples were confirmed by EDS (Energy dispersive X-ray) analysis.

The synthesized nanoparticles were analyzed using X- Ray Diffraction (XRD) to study the crystallinity and coating of Ag nanoparticles on MWCNTs. The samples were measured from 10° to 80° on the equatorial direction. Spherical Ag nanoparticles are highly crystalline in nature. The XRD measurements were carried out with a Rigaku-D/MAX-2200.

The Ag coated MWCNT and MWCNT nylon-6 fibers were also tested for their tensile properties. Test was carried out for ~ 80 µm dia. samples.

The synthesized nanoparticles for checked for their thermal stability, % crystallinity and recrystallization temperatures were also characterized for the synthesized nanoparticles.

2.3 Antibacterial Characterization

The antibacterial activity of Ag coated MWCNT was tested by Kirby Bauer Disk Diffusion Method and by the broth dilution assay. Bacterial strains tested include *Staphylococcus aureus, Streptococcus pyogenes, Pseudomonas aeruginosa, Escheria coli* and *Salmonella. typhimurium*

3. RESULTS & DISCUSSION

3.1 Transmissiom Electron Microscope (TEM)

TEM Studies were carried out to understand the extent of Ag coating on MWCNTs. TEM micrograph revealed that silver coated CNT nanoparticle had a size of ~10nm with nanotubes ~30nm (Fig. 1).

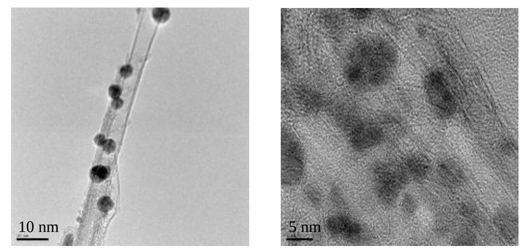

Fig. 1 TEM micrograph of Silver coated CNT nanoparticle

3.2 X- Ray Diffraction (XRD) of samples

The technique was used to study the crystallinity and coating of Ag nanoparticles on MWCNTs. Spherical Ag nanoparticles were highly crystalline in nature (Fig. 2).

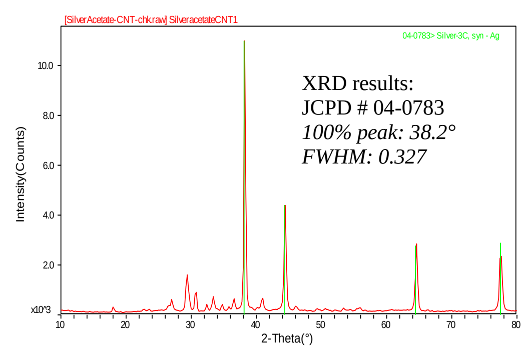

Fig. 2 XRD of Silver coated CNT nanoparticle

3.3 Tensile Testing of Nanofibers

The Ag coated MWCNT and MWCNT nylon-6 fibers were tested for their tensile properties. Test was carried out for ~ 80 µm dia. Samples (Fig. 3). The failure stress of Ag/MWCNT nanofibers is about 66 % higher than the neat nylon fibers.

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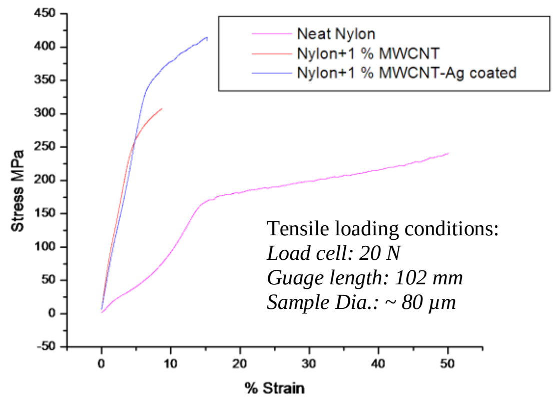
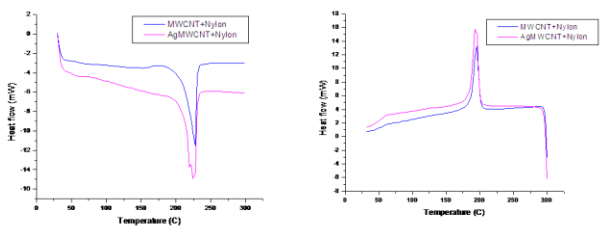


Fig. 3 Tensile strength and elongation (%) for the neat nylon-6, MWCNT infused nylon and Ag coated MWCNT infused nylon-6 fibers.

3.4 Thermal Characterization

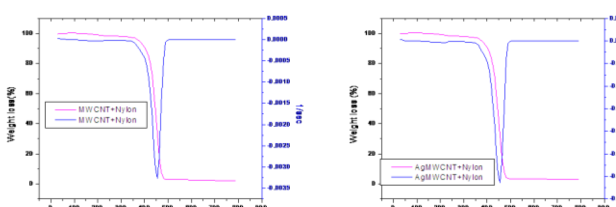
The Thermal stability, % crystallinity and recrystallization temperatures were characterized for nanophase filaments (Fig. 4a, b).

A



Heating Curve   Cooling Curve

B



MWCNT curves   Ag-MWCNT curves

Fig. 4 (a) DSC curves for MWCNT and Ag-MWCNT nylon fibers (b) TGA curves for MWCNT and Ag-MWCNT nylon fibers

3.5 Antibacterial Activity of Nanoparticles

The antibacterial activity of the silver coated MWCNTs, commercial silver, neat nylon and plain MWCNTs was evaluated by the Kirby-Bauer disc diffusion assay and the standard plate count assay. Silver coated MWCNTs at a final concentration of 25µg/ml in distilled water (AgCNT1) or ethanol (AgCNT2), demonstrated good antimicrobial activity against five common bacterial pathogens as tested by the Kirby-Bauer assay (Fig 5). The mean diameters of the zones of inhibition were 29±3 mm, 29±5 mm, 20±3 mm, 22±2 mm and 22±5 mm, respectively, for *S. aureus, S. pyogenes, P. aeruginosa, E.coli* and *S. typhimurium*. By comparison, those obtained using the broad spectrum antibiotic amoxicillin-clavulinic acid (30 µg) were 43±1 mm, 34±1 mm, 28±8 mm, 19±1 mm and 26±2 mm respectively for the same microorganisms (Fig. 6).

A   B

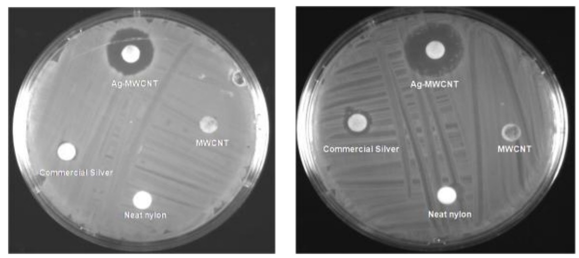


Fig. 5 Kirby-Bauer disc diffusion assay for (a) *Salmonella typhimurium* and (b) *Staphylococcus aureus*

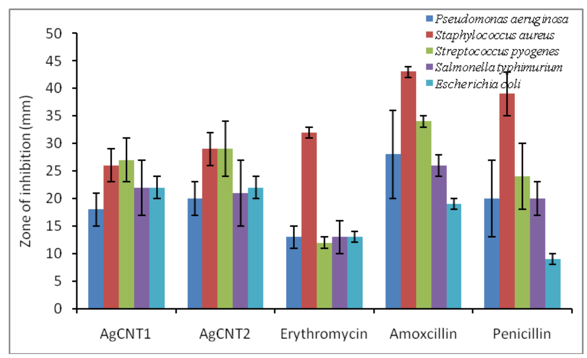


Fig 6. The antibacterial activity of the silver coated MWCNTs, at a final concentration of 25µg/ml in distilled water (AgCNT1) or ethanol (AgCNT2), as evaluated by the Kirby-Bauer disc diffusion assay.

Bacterial growth inhibition as studied by the broth dilution assay revealed that silver coated CNT inhibited bacterial growth upto 99.9%. Nylon impregnated with silver coated CNT also showed upto 96% inhibition of bacterial growth, however, it did not show any effect on *Streptococcus pyogenes* (Fig. 7). Further investigation is required to determine the precise effect of silver coated CNT on bacterial surfaces.

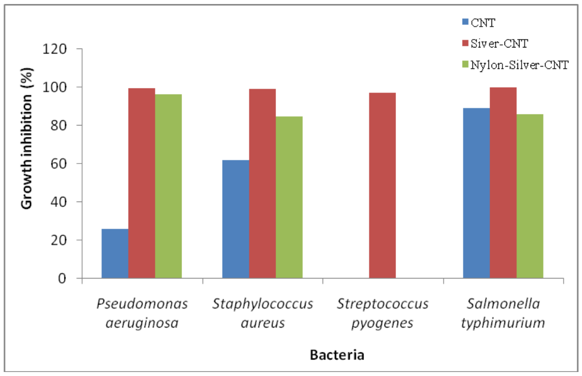


Fig. 7 Growth inhibition of four bacterial isolates by the broth dilution assay

Our results showed that Ag nanoparticles were almost uniformly coated on MWCNT. Young's Modulus of Ag-MWCNT nylon fibers increased by ~ 490% than neat nylon sample. Thermal stability and % crystallinity increased. Ag-MWCNT nylon fibers exhibited remarkable antimicrobial behavior.

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