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Antibacterial activity of nano-silver non-woven fabric prepared by atmospheric pressure plasma deposition

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ABSTRACT

Antimicrobial non-woven polyethylene terephthalate (PET) fabric containing nano-silver of different concentrations has been prepared in a novel three step process. Nano-silver has been incorporated in between two layers of organosilicon thin film deposited by an atmospheric pressure plasma system. The top layer of 10 nm thickness was used as a barrier to prevent release of nanoparticles from the surface. The antimicrobial activity of the nano-silver fabrics was tested using *Staphylococcus aureus* and *Escherichia coli* by a dilution method. The effect of silver concentration on the lag phase, the specific cell growth rate, and the cell concentration has been studied and discussed based on bacterial growth curves.

1. Introduction

Non-woven fabrics with multifunctional performance, especially in health and hygiene field, receive increased attention. [1] The major drawback is potential growth of pathogenic microorganisms on non-woven fabrics, and for this reason the antibacterial fabrics are extensively studied. [2,3] With the ever increasing number of antibiotic-resistant strains of bacteria and silver's low toxicity, the use of restricted silver amounts as an antibiotic agent for antibacterial materials is a promising approach for practical applications. [4] Namely, silver ions exhibit broad spectrum biocide activity towards many pathogenic microorganisms, which are believed to be the source of its antibacterial activity in silver-containing products. Due to these properties silver nanoparticles (AgNPs) have potential in a new generation of medical materials. [4] Incorporation of AgNPs can be easily achieved by wet chemical processes [5], but the direct interaction of AgNPs with human cells leads to cytotoxicity and genotoxicity. [6] Considering toxicity concerns, it is of crucial to immobilize AgNPs onto the substrate material. In this way, the release of AgNPs from surface in real applications can be completely avoided and an advantage of controlled release of only silver ions achieved.

Herein we studied a novel method for the preparation of antibacterial polyethylene terephthalate (PET) non-woven fabrics by immobilizing AgNPs via double layer of plasma deposited organic films. The presented work investigates a way to control the concentration of the immobilized silver, and the effect of silver concentration on the antibacterial activity of the fabrics.

2. Experimental

Nano-silver non-woven polyethylene terephthalate (PET) fabrics were prepared using a three step procedure. At first, an organosilicon thin film was deposited on the surface of the PET fabrics using a plasma deposited system. [7,8] This 70 nm layer is used as a reservation layer for the silver immobilization and control of the silver nanoparticles adhesion to the PET fabrics. Then, the samples with plasma deposited layer were immersed into a suspension of AgNPs in ethanol and raised for drying. Silver nanoparticles (SSNANO, USA) of 20 nm size with a purity of 99.95% (trace metal basis) were used throughout the experiments as purchased. In the final step, a second layer of organosilicon film with a thickness of 10 nm was deposited. This layer was used as a barrier to prevent the release of AgNPs into the liquid medium. In this work, four different concentrations of the AgNPs dispersions (concentration of AgNPs in ethanol: 1 mg/ml, 2 mg/ml, 5 mg/ml, and 10 mg/ml) were prepared in order to easily control the amounts of incorporated silver onto the materials, which corresponded to 0.1 at%, 0.9 at%, 2.1 at% and 7 at%, respectively.

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The content of Ag on top PET surface was measured by a X-ray photoelectron spectroscopy (XPS) method. The morphology of AgNPs on the surface of the PET samples was studied by means of SEM techniques (JSM-6010 JEOL, Belgium).

Antibacterial activity of the treated fabrics was tested by using a macrodilution method against *Escherichia coli* (*E. Coli*) and *Staphylococcus aureus* (*S. aureus*). The samples were immersed in bacterial suspensions of culture (10^6 CFU/ml), and then were incubated at 37 °C for 24 h to analyze the number of colony forming units (CFU). Reduction of microorganisms *R* which indicates biostatic efficiency resulting from contact with the samples was determined by $R=(B-A)/B$, where *A* and *B* is CFU per milliliter for the medium with the treated fabrics and the control samples after incubation, respectively. The sample with only first layer deposition was used as a control. The kinetics of bacterial growth in tryptic soy broth (TSB) were studied through the optical density of cultured medium at $\lambda=600$ nm.

3. Results and discussions

Fig. 1 represents the SEM image of the raw samples and the samples prepared with four various AgNPs suspensions at two magnifications, i.e. × 1000 and × 10,000 on left and right respectively. The raw PET fabric consists of fibers with an average diameter of approximately 10 μm and a smooth surface as shown in Fig. 1(a). Fig. 1(b–e) on the left suggest the covering of the PET fabrics after the treatment. As labeled by the yellow arrows in the high magnification figures, AgNPs were uniformly incorporated on the PET surface.

The capability of the fabrics to prevent viable bacteria colonization was verified by plate counting technique (PCT). Fig. 2 shows typical colonization by *E. coli* and *S. aureus* on Mueller Hinton (MH) agar plates from the liquid medium cultured with samples containing different amount of AgNPs. All silver treated PET fabrics exhibited antibacterial activity against both bacteria, which clearly indicated that the growth of microorganisms in medium was affected by the presence of AgNPs on the fabrics. The numbers of survived colonies of *E. coli* and *S. aureus* on the agar plates decreased for the samples with higher silver concentration.

The bacterial reduction of *E. coli* and *S. aureus* is presented in Fig. 3. The trend indicates that the silver treated fabrics were more effective against *E. coli* than *S. aureus* as reported also elsewhere. [8] A great reduction of the bacterial growth was observed on the fabric samples prepared with 5 mg/ml of AgNPs dispersion. The reduction rates of *E. coli* and *S. aureus* achieved 100% and 99.7%, respectively. There was no cultivated and grown bacterium for the samples prepared with 10 mg/ml of AgNPs dispersion.

The growth of bacteria in liquid culture medium should normally follow an exponential. The growth profiles are displayed in Fig. 4 for *E. coli* and *S. aureus* in TSB medium. Typically, the bacterial growth curves in this work can be divided into three major phases, which provide a clue to understand the kinetic details of the growth or inhibition. [9] Three main microbial growth kinetic parameters can be estimated: the lag time (*Tlag*); the specific cell

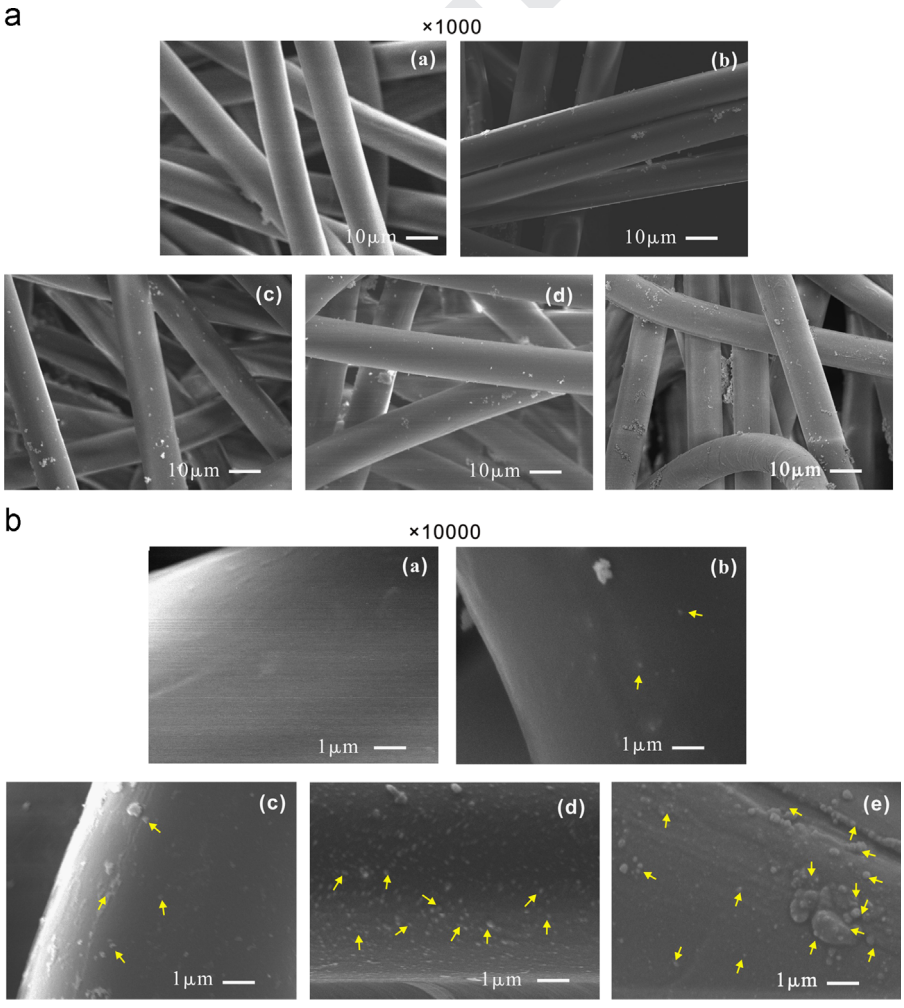

Fig. 1. SEM image of the control sample (a) and the samples treated with 1 mg/ml (b), 2 mg/ml (c), 5 mg/ml (d) and 10 mg/ml (e) of AgNPs dispersion. The arrows on the image with × 10,000 magnification indicate some AgNPs.

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