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# Conductive nylon fabric through in situ synthesis of nano-silver: Preparation and characterization

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ABSTRACT

A simple, green and low cost method based on Tollens' reagent is presented to synthesize a nano-conductive silver layer on nylon 6 fabric. The nylon fabric was first treated with potassium permanganate to oxidize fabric surface and thereby, increasing the number of assembled particles on the fabric surface. SEM images indicated distribution of silver nanoparticles on the fabric surface and formation of nanolayer on the fiber surface. EDX and XRD patterns confirmed assembling silver nanoparticles on the nylon fibers. The treated fabrics displayed a very low electrical resistivity i.e. 4.5 Ω/sq. Furthermore, the fabric color was indicated by a reflectance spectrophotometer in order to study the effects of the synthesized nanoparticles on the fabric color. It is also indicated that oxidation process has no significant influence on the mechanical properties of the fabric, and nano-treatment revenged the negative effect of oxidation of nylon fabric. Moreover, silver nanoparticles imparted reasonable antibacterial properties to the fabric against *Staphylococcus aureus*.



## 1. Introduction

Recent developments in textile have expanded their usage beyond traditional applications. In recent years, conductive textiles have attracted great attention due to the vast number of potential applications, these include textile construction, mining, electronics, automotive, sensing and detection, electro-energy and packaging sectors [1].

Thermoplastic fibers in textile fabric which generally have a surface resistivity of $10^{10}$ Ω/sq serve as very poor conductor of electrical charge and cannot be used in electronic applications [2,3]. Conductive textiles were traditionally produced through different methods including coating with metals or conductive films, incorporating conductive fillers, or insertion of metallic wires inside the yarns [4]. Textile materials with flexible structure can be used as a host for electronic component in applications needed to be secured where they are close to the human body [5]. However, electro-conductive yarns often suffer from low elasticity and non-durable electrical properties [6] and therefore, will face problem, during deforming when subjected to stress within body movements. This will often change their resistance or cause yarn breakage, and hence their reliability cannot be guaranteed [7].

One new domain, emerging from flexible electronics is electronic textile with integrated micro devices [8,9], however problems arise, as long wires inside the clothing cause rigidity. Moreover, another challenge arises during weaving when strips or yarns bend and strain leads to device failure, this is especially a problem in brittle inorganic layers [5,10]. One possible solution is the use of conductive polymers that can be strained up to 50% without changing the performance [11]. An ideal e-textile should "stretch and recover, drape and handle", and retain conventional textile behavior [12].

The technology involving conductive polymers has rapidly increased. Currently two types of conductive polymer (CP) are known including intrinsically conductive and extrinsically conductive polymers, while the latter shows lower sensitivity exceeds conductive polymers in long term stability to moisture or oxygen [13,14]. Conductive nanofiller/polymer composites have outstanding multifunctional properties [15], which mainly use a high ratio of conductive nanofillers.

In this paper, in-situ synthesis of nano-silver on nylon fabric has been introduced through a chemical reduction method in order to create a thin layer of silver nanoparticles on nylon fabric. This will produce an electro conductive fabric with considerable antibacterial properties. Functional groups were considered as active sites for nucleation of silver nanoparticles. The number of nanoparticles was increased through a simple pre-treatment of the nylon fabric. It is essential to have enough functional groups on the fiber surface to make the loaded nanoparticles much closer together to form a continuous and stable metallic layer on the fiber surface.

Chemical reduction method is the most frequently applied method for the preparation of Ag NPs in water or organic solvents [16]. Tollens' reagent has the ability to reduce silver (I) ions to silver (0) that can be used as a green approach in chemical reduction method [17]. Tollen's reagent has been used to synthesis silver nanoparticles without any stabilizer or capping agents and the prepared aqueous dispersion was stable for a long time [18].

Despite significant amount of research using Tollen's reagent on different type of fabrics in order to synthesize silver nanoparticles on

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the fibers, to the best of our knowledge, there is no published report on the synthesis of nano-silver on nylon fabric to produce electro conductive fabric. However, we had previously introduced electro conductive polyester fabric through similar method [19]. In order to obtain a multi-functional fabric with an extremely high improvement in adhesion of silver nanolayer, the nylon fabric has been chosen as the substrate. Nylon is an electron-rich and polar synthetic polymer (polyamide) usually made of adipoyl chloride and hexamethylene diamine monomers to form a linear molecular chain [20]. Further, most reactions take place in mild conditions in comparison to polyester. This eliminates high temperature approach results in continuous procedure beside a considerable decrease in the precursor consumption. The nylon fabric with multifunctional properties can be applied in various commercial usages due to good electrical conductivity, light weight, and corrosion resistance along with enhanced mechanical properties.

## 2. Experimental

### 2.1. Materials

Laboratory grade of chemical substances was used without further purification. Silver nitrate ($AgNO_3$), sodium permanganate (10%), sodium hydrosulfite ($Na_2S_2O_4$), sodium chloride (NaCl), ammonia, and sodium hydroxide (NaOH) were purchased from Merck Co. (Germany). The knitted nylon fabric with a weight of 90 g/m$^2$ was purchased from the local market in Tehran (Iran).

### 2.2. Methods

Oxidation of nylon fabric was carried out with $KMnO_4$ to enhance the carbonyl groups on the fiber surface by dipping 1 g nylon into 3% (w/w) $KMnO_4$ and 10 g/L NaCl for 20 min in an ultrasonic bath. 5% (w/w) sodium hydrosulfite at pH 4 was also added to remove the precipitate manganese from the nylon fabric. Ultimately, the treated fabric was dipped into 100 mL aqueous solution of $AgNO_3$ (0.059 M) and 20 mL NaOH solution (0.01 M) at 90 °C resulting $Ag_2O$ brown powder. Then, 30 mL ammonia was added causing the brown color to be disappeared after 2 min due to the formation of silver-amine complex ion $[Ag(NH_3)^2]^+$. The complex was exhausted for 1.5 h and the fabric color changed to goldish-gray.

### 2.3. Test methods

#### 2.3.1. Surface resistivity measurements

Surface resistivity measurements were performed on 3 cm × 6 cm treated and untreated samples employing a surface resistivity meter namely Precision Impedance Analyzers (6500 B series, Wayne Kerr Electronics, UK) at 100 Hz and 1 V.

The electrical surface resistivity was measured in 'ohm/square' according to the American Association of Textile Chemists and Colorists (AATCC) test method 76-2006. In order to measure electrical surface resistance, the electrode assembly was based on two flat copper electrodes (30 mm × 20 mm), separated by a distance of d = 20 mm. A voltage source was connected to the electrodes through a multimeter. The measurement involved placing the electrode assembly over the fabric specimen (30 mm × 60 mm) with a weight of 5 kg; finally, the electrical surface resistivity was calculated using Eq. (1) [21]:

$$\text{Electrical surface resistivity} = \text{Resistance} \times \text{Width of electrodes}/\text{Distance between electrodes}. \quad (1)$$

#### 2.3.2. Antibacterial test

The antibacterial test was carried out based on a qualitative method namely agar diffusion method (AATCC 147). The antimicrobial activities of the fabrics were tested using the zone of inhibition method. *Staphylococcus aureus* Gram-positive bacteria was cultured on a plate containing Muller–Hinton agar as culture medium from Merck (Germany). The 25 mm diameter circular fabrics were placed on the plate. The samples were incubated for 24 h in an oven at 37 °C. Subsequently, the samples were studied visually and the zone of inhibition against specified microorganisms was measured [22].

#### 2.3.3. Mechanical properties of fabrics

The tensile properties of the raw and treated nylon fabric (sample 1) were assessed using tensile instrument (Instron 5566 H1730). This was repeated 5 times in order to get reliable results. Moreover, in order to study the influence of pre-treatment on the fabric strength, another sample (sample 2) was treated only with Tollens' reagent without prior treatment.

#### 2.3.4. Color coordinates

The three coordinates (L*, a*, and b*) of CIELAB color system as a common method for color measurement of textile were obtained using a Color eye XTH spectrophotometer (Standard Illuminate D65/10°). L* indicates the lightness and a* and b* show the redness–greenness and yellowness–blueness values, respectively. The color difference between two various fabrics determined by ΔE as calculated using Eq. (2) [23].

$$\Delta E = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{0.5} \quad (2)$$

#### 2.3.5. UV–vis reflectance spectrum

UV–vis reflectance spectra of different samples were obtained using a Varian Cary 500 spectrophotometer by irradiation of the wavelength between 200 to 800 nm.

## 3. Results and discussion

### 3.1. Preparation of nylon/silver nanocomposite

Initially, nylon fabric was pre-treated with potassium permanganate, which oxidizes the polyamide chains and thereby increases the number of loaded nanoparticles on the fabric surface. The permanganate ($MnO_4^-$) has the ability to oxidize inorganic or organic compounds under neutral, acidic and alkaline conditions in aqueous or non-aqueous media. However, acidic conditions are more desirable than alkaline conditions used for bleaching [24–26].

Wet processing of textiles can be accelerated through ultrasonic due to the cavitation that is the growth and explosion of microscopic bubbles [27–29]. This sudden explosive collapse of the bubbles generates hot spots that are able to break a chemical bond. The polyamide chain oxidation was assisted by an ultrasound bath due to ability of shortening the processing time and the energy consumption.

Generally, three main reactions are imparted in oxidation of polyamide chains leading to the formation of imides and carbonyl groups (r 1–r 3) [30]. These functional groups will serve as active sites for silver nanoparticles nucleation.

The formation of N-acylamide (imides) is presented in r 1

$$R-CO-NH-CH_2-R' \rightarrow R-CO-NH-CO-R'. \quad (r\ 1)$$

In addition, formation of N-formamide as a result of $C_1$, $C_2$ scission is showed in r 2:

$$R-CO-NH-CH_2-R' \rightarrow R-CO-NH-CHO. \quad (r\ 2)$$