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Large scaled strategy for natural/synthetic fabrics functionalization via immediate assembly of AgNPs

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ABSTRACT

Multi-functionalization of textile to protect against environmental factors and/or add fashionable characters is newly an enjoyable and interested field. One of the most challenges faces such process, is functionalization of natural and synthetic fabrics using the same technique/method. The current study focused on utilization of one applicable technique to functionalize both of natural and synthetic fabrics including linen, silk, nylon and PET. Silver nanoparticles (AgNPs) were in-situ deposited onto fabrics using sodium citrate as reducing agent. Fabrics macromolecules were stabilized the produced AgNPs which were inserted in fabric structure. Functions of the treated fabrics were tested against coloration and UV transmission radiation. The maximum and lowest Ag contents on fabrics were recorded for silk (12.05 g/kg) and nylon (2.65 g/kg), respectively. Except PET, fabrics macromolecules could be shared in the reduction process of Ag ions. Under electron microscope, crystalline – cupic AgNPs was seen on silk surface, while, agglomerated particles were formed on PET surface. Fabrics were acquired yellowish color with good fastness after AgNPs incorporation. UV transmission radiation through fabrics was reduced for all fabrics after treatment and PET showed highest UPF of 30.4. AgNPs-fabrics exhibited antimicrobial properties and followed the order of silk > linen > nylon > PET.

1. Introduction

Development in scientific technology and the progress in living standards directly strengthened the awareness of recent researches on functionalization of clothes for health and environmental protection, which have mainly influenced on social significance and economic benefits. Hence, numerous researches were recently interested in enhancing multi-functions for textile goods, such as antimicrobial action, coloration and UV protection [1–15].

Although silver nitrate is previously known in fabric functionalization [1], but due to skin irritation which is caused by nitrates, reduction of silver nitrate to act as nanosilver generator is preferable and becomes the recent conventional routs for textile multi-functionalization. Thus huge researches were focused on preparation of AgNPs using safely natural polymers [16] which were supposed to play the dual role of reducer and stabilizer for AgNPs including carboxymethyl cellulose [17], chitosan [18], starch [19], hyaluronan [20], alginate [21], pectin [22], acacia [6], xanthan [4] and schizophyllan [23]. Functionalization of natural fabrics such like cellulosic textiles with AgNPs were intensively studied by coating process [24,25] and in-situ incorporation [1,2,5,8,9].

Silk as natural fabric was coated by AgNPs for antibacterial property [26–29]. But, the direct incorporation of AgNPs into silk was carried out by using polyamide polymer [30], in the presence of multi-amino compound [28] or by forming polymeric film on silk under UV-irradiation effect [31]. Polyamide has numerous amino groups and three-dimensional structure which is beneficial in entrapping Ag ions into silk [30]. Color fastness of silk containing AgNPs was improved by using poly-dimethyl-siloxane in coating technique [32] and using of poly (acrylic acid) (PAA)/poly (dimethyl-diallyl-ammonium chloride) (PDDA) for in-situ growth technique of AgNPs [31].

For synthetic fabrics, Polyamide (PA) as an example is the third

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largest fabric consumed in the world, after polyester and cotton [33]. Manufacturing of antibacterial nylon was recently carried out by synthesizing and uploading of AgNPs using ultrasound-assisted reduction method [34] and electrospinning [35]. Chemical reduction method for ex-situ AgNPs before coating of nylon was taken place by using stannous chloride/cetyltrimethylammonium bromide system [36]. Moreover, Montazer et al. prepared antibacterial and conductive nylon fabrics by ex-situ and in-situ technique for AgNPs incorporation using ammonia complex [37,38].

Due to the outstanding characteristics for polyethylene terephthalate such as excellent mechanical strength and good chemical stability, non-woven terephthalate (PET) as synthetic fabrics, has been used in a wide range of applications [39,40]. In recent years, a lot of researches had been considered with achieving a more multifunctional performance of PET fabrics, especially in the health and hygienic field. For this purpose, PET fabric treated with antimicrobial agents has been extensively studied and results confirmed the capability of preventing the growth of pathogenic microorganisms, such as bacteria, fungi and algae [41]. Meanwhile, deposition of nano metallic silver on modified PET fabrics has been studied by using dipping process [42,43].

According to literatures, manufacturing of multifunctional textiles were involved the usage of various reducing and capping agents for initial preparation and deposition of AgNPs on fabric surface. These studied procedures could be disadvantaged by chemical and energy consumption, which were dramatically affected on the waste water and it also proceeded in multi-steps for controlling size and shape of NPs [44]. However, in-situ manufacturing of multi-functional cellulosic fibers by consuming fiber building blocks itself to play the dual role of reducer and stabilizer for AgNPs in alkaline media could be expressed as eco-friendly, energy and time saving processes [2,45]. This technique was not effective in case of using wool according to its sensitivity for high alkalinity. Hence, citrate medium was further used for multifunctional wool fabrics by in-situ incorporation of AgNPs [5]. Additionally, most of in-situ AgNPs synthesis methodologies which were designed to be applicable for multi-functionalization of natural fabrics are not suitable for application on synthetic fabrics. As frequently, activation of natural fabrics building chain using alkali or hydrogen peroxide may cause fabric deterioration in case of synthetic fabrics. For example, finishing of PET with sodium hydroxide, results in chain cleavage as progressive reactions of polymeric chain with hydroxide ion resulted in polymer hydrolyzing to monomer units and alternately removed terephthalate anions and ethylene glycol [46].

Therefore, the current work is considered with designing one large scaled technique, relied on in-situ synthesis of AgNPs using natural (linen and silk) and synthetic (nylon and PET) fabrics in citrate medium for multi-functionalization. Sodium citrate was used as reducer for Ag ions. Comparative study was established between the multi-functions acquired by fabrics under consideration. Metal contents on treated fabrics were measured by using atomic absorption spectroscopy (AAS). Colorimetric data, mechanical properties and color fastness were all evaluated for fabrics as functions of treatment. Treated fabrics were further characterized by scanning electron microscope (SEM) and energy dispersive X-ray (EDX). UV protection property was tested by passing UV transmission radiation through fabrics and the UV protection factor (UPF) was calculated.

2. Experimental

2.1. Materials and chemicals

Silver nitrate (99.5%, from Panreac, Barcelona – Spain), Trisodium citrate (99% from Sigma-Aldrich – Germany) and sodium hydroxide (99%, from s.d. fine Chemical Limited, Mumbai – India) were used as received without further treatments.

Scoured and bleached 100% Linen fabrics (212 g/m^2) were supplied from SDL Textile innovator – USA. Scoured and bleached 100% Silk fabrics (65 g/m^2), 100% Nylon fabrics (159 g/m^2) and 100% Polyester fabrics (149 g/m^2) were all supplied from El-Mahalla Company for Spinning and Weaving, El-Mahalla El-Kubra – Egypt.

For impurities removal, fabrics were washed using 2 g/L nonionic detergent (Hospital CV – Clariant) with 1/50 material to liquor ratio at 50 °C for 30 min. Washing process was performed at 50 °C for all fabrics except linen at 90 °C. In case of PET, 2 g/L Na_2CO_3 was added to washing liquor. Fabrics were rinsed thoroughly with tap water at RT and then air dried at RT.

2.2. Procedure

Fabric specimens with dimension of 20 × 25 cm^2 were immersed in 200 mg/L silver nitrate solution using liquor ratio of 1/50 and then heated till boiling with stirring. To each 100 mL silver nitrate solution, 10 mL from 3% tri-sodium citrate as reducing agent was added drop wisely; keeping the reaction proceeded for 30 min. Afterwards, the fabrics were taken out, squeezed and rinsed two times by tap water. The fabrics were then dried at room temperature prior to analyses and characterizations.

2.3. Measurements

2.3.1. Silver contents

Silver in treated fabrics were firstly extracted from fabrics as follows; A 0.15–0.20 g of treated dried fabrics was submerged in 20 ml of 15 wt % nitric acid for 2 h at 80 ± 3 °C. Ag concentrations in the extracted solutions were analysed with high-resolution continuum source flame atomic absorption spectrometer (HR-CS AAS, ContrAA 300, Analytic jena AG, Technology quality innovation, Jena, Germany) which is conducted to continuum source. The extracted silver from fabrics was calculated using Eq (1). A standard solution of silver nitrate (1000 mg/L) was used to prepare calibration solutions in the range of 0–10 mg/L. The extracted solutions were diluted to be in the calibration range.

$$Ag_{fabric} = \frac{C}{W(1 - MC/100)} \times 0.02 \qquad (1)$$

Where, Ag $_{fabric}$ = Ag content on fabrics (g/kg); M_s = Ag concentration (mg/L) in extracted solution; 0.02 = Volume of extracted solution (L); W = weight of treated fabrics (g); MC = moisture content in treated fabrics (%).

2.3.2. Color measurements

The color coordinates of CIE lab (L, a*, b*) for both of untreated and treated fabrics were measured using a spectrophotometer with light source of pulsed xenon lamps (KONICA MINOLTA CM 3610d, Japan), using 10° observer with illuminant of D65, d/2 viewing geometry and 8 mm measurement area. L is lightness factor from black to white (0–100), a* is a reddish/greenish factor and b* is yellowness/bluish factor [47]. The corresponding absorbance spectra and color strength (K/S) were both measured in the wavelength range of 360–740 nm. All samples were measured at three different areas, considering both sides of fabrics and the mean values were recorded.

2.3.3. Fastness properties

Color fastness properties were tested for all fabrics samples after Ag treatment according to ISO standard methods. The typical tests