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Synthesis of effective multifunctional textile based on silica nanoparticles

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ABSTRACT

New and effective textile coating layer was developed. The new coating was prepared based on silica nanoparticles of an average particle size of 150 nm derived from rice husk. Then, silver nanoparticles of an average size of 14 nm were immobilized on silica nanoparticles surfaces and dispersed in binder and coated on textile surface. The mass ratio of silica nanoparticles was varied and studied. The textile properties of treated fabrics were improved. The UV protection factor of the treated textiles was significantly enhanced achieving more than 6 and 7 fold increase compared to textile binder treated and blank textile, respectively. The antibacterial properties of the treated fabrics were investigated and improved compared to untreated ones. The textile coated with coating containing silica nanoparticles-silver nanoparticles system achieved increase in clear inhibition zone compared to one containing silver nanoparticles only recording 30 mm clear zone. Also, the hydrophobic properties of the treated fabric surface were studied and excellent hydrophobic surface was obtained recording water contact angle of 145°.

1. Introduction

As the textile materials such as natural and synthetic fibers and their blends involved in various applications, so that, the properties of these textiles should be meet the required functions. To this end, several of textile properties have to be improved such as hydrophobicity [1], Ultraviolet (UV) protection [2,3], antibacterial [4], flame retardancy and mechanical properties [5–7]. The unique properties of nanoscale materials such as outstanding chemical, physical, electrical, electronic and mechanical properties attracted attentions in various applications including textile coating and finishing for imparting excellent properties [8–10]. It is important to mention that, silver nanoparticles (AgNPs) have been reported as effective antibacterial agent [11,12]. This is due to their ability to interact with cell wall surface producing changes in its properties and leak of its cell contents [13]. Furthermore, AgNPs damage the cell membrane due to their affinity to interact with cell bacterial sulfur and phosphorus containing proteins [14]. There is a research trend in the development of textile coating and medical cotton inducing antibacterial and hydrophobic properties to their surfaces [15–18]. This treatment process involves the coating of silver particles in both microscale [15] and nanoscale size [17], however, this process employed with various costive materials and successive steps. On the other hand, silica nanoparticles (SNP) and their composite have been used widely for textile treatment due to their good properties such as high surface area and easily processing in textile fiber surface [19,20,21]. Recently, SNP have been used for enhancing hydrophobic properties of textile surface [21].However, preparation of SNP from their precursors for industrial use still reflects relative high cost, so finding a cheaper source for SNP is appreciated. Interestingly, the high silica content in the rice husk which is a rice generation by product and their availability considered it as cost-effective source for silica production for advanced applications [7,22,23]. Rice husk silica nanoparticles (RH-SNP) have been used in various applications such as hydrogen storage and flame retardant materials [7,24]. In our recent studies, RH silica and RH-SNP have been used as flame retardant additives in polymer composite and textile coating [7,23]. Also, textile properties such as flame retardancy, mechanical, electrical and antibacterial properties have been investigated [9,25]. This is in conjunction to our research experience in organic and inorganic nanoparticles synthesis and applications [26,27]. AgNPs have been deposited on silica particles in sub micrometer scale prepared from their precursor's tetraethyl orthosilicate which prepared through

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prolonged time and complicated steps [28,29]. Interestingly, AgNPs used as antimicrobial agents can agglomerate when interact with bacterial medium results in loss of their effect. So immobilization of AgNPs on inert surface can avoid their agglomeration and maintain their dispersion and in turn enhance their effect. Synthesis of AgNPs immobilized on RH-SNP surface and using as an effective coating for textile surfaces for enhancing their antibacterial, UV-absorption, hydrophobicity and mechanical properties is a new and very interesting for investigation. In this study, RH-SNP of an average particle size of 150 nm were prepared and immobilized with silver nanoparticles (AgNPs). The developed composite was dispersed in binder solution and coated on cotton blend fabrics. Multifunctional properties of untreated and treated textile fabrics were investigated. The ability of treated fabrics to filter harmful UV rays (Ultraviolet Protection Factor: UPF) and inhibit bacterial growth were evaluated. The hydrophobicity and mechanical were also investigated.

2. Experimental section

2.1. Materials

Cotton/polyester blend of 65/35 respectively (C) was supplied by Al Mahalla Co., Algharbia, Egypt. Commercial binder of acrylic based type (B) used in the preparation was obtained from Egyptian market. Silver nitrate of high purity was purchased from AppliChem GmbH-An ITW Company, Ottoweg, Germany. Polyvinylpyrrolidone (PVP) was obtained from Sigma Aldrich, Germany. Toluene and dimethyl formamide (DMF) used in the preparation of coating layer was purchased from El Nasr Pharmaceutical Chemicals Co., Egypt. Rice husk was bought from egyptian market.

2.2. Synthesis of rice husk silica nanoparticles (RH-SNP)

Rice husk silica nanoparticles (RH-SNP) were prepared based on our previous report [7,23]. In brief synthesis: in alumina crucible rice husk was added and heated in a muffle furnace for 3 h at 700 °C with a heating rate of 20 °C/min. Then, the obtained silica was washed with deionized (DI) water and dried at 150 °C. After that, the silica particles were grinded using mortar for one hour and finally sieved to obtain RH-SNP.

2.3. Synthesis of silver nanoparticles immobilized on rice husk silica nanoparticles (RH-SNP-AgNPs)

In a beaker containing 45 ml of DMF 300 mg of PVP was dissolved, then 60 mg of $AgNO_3$ was dissolved (fixed concentration). Then, disperse variable masses (10, 20, 30, 40, 50) of RH-SNP based on the final weight of B-RH-SNP composite in the previous solution. The previous solution was exposed to ultrasonication at 50% output for 15, 30 and 60 min to form RH-SNP-AgNPs composites. Also, B-AgNPs solution was prepared by mixing previous solution with binder solution directly (binder dissolved in toluene).

2.4. Synthesis of B-RH-SNP-AgNPs nanocomposites

In a beaker containing 50 ml of toluene dissolve 5 vol% of binder (B). Afterwards, mix the RH-SNP-AgNPs dispersion prepared in 2.3 step to the previous solution, followed by ultrasonication at 50% output for 1 h to for well dispersed B-RH-SNP-AgNPs nanocomposites as indicated in Table 1. Also, B-RH-SNP was prepared by dispersing RH-SNP in binder solution.

2.5. Preparation of textile- B-RH-SNP-AgNP composites

Textile samples of 20 cm × 20 cm in dimension were immersed in the different coating dispersion prepared previously for 10 min.

Table 1
Composition of coating layer (RH-SNPs-AgNPs).

Sample Code	Binder (wt.%)	RH-SNP (wt.%)
C	0	0
a C-B-2[a]	100	0
b C-B-5[b]	100	0
C-B-RH-SNP-5-10	90	10
C-B-RH-SNP-AgNP-5-10-30	90	10
C-B-RH-SNP-AgNP-5-20-30	80	20
C-B-RH-SNP-AgNP-5-30-15	70	30
C-B-RH-SNP-AgNP-5-30-30	70	30
C-B-RH-SNP-AgNP-5-30-60	70	30
C-B-RH-SNP-AgNP-5-40-15	60	40
C-B-RH-SNP-AgNP-5-40-30	60	40
C-B-RH-SNP-AgNP-5-40-60	60	40
C-B-RH-SNP-AgNP-5-50-30	50	50

Where a and b refers to concentration of binder by vol. % 2 and 5 vol % respectively.

Then, removed and squeeze out, this step repeated several times. Afterwards, the samples were dried in air followed by curing in oven at 130 °C for 5 min. Final samples coded as C-B-*RH*-SNP-AgNP-5-10-30 whereas 5 refers to binder concentration in vol% and 10 refer to wt.% of RH-SNP based on B-RH-SNP composite and finally 30 refer to first sonication time in min.

2.6. Characterization

Transmission electron microscope (TEM) images were taken using JEOL (JEM-1400 TEM). The scanning electron microscope (SEM) images were obtained using a scanning electron microscope (Quanta FEG-250, with operating at a voltage of 20 kV). UV–vis spectra were measured using a UV–vis Spectrophotometer – Shimadzu UV 3101PC in the wavelength range 190–400 nm in transmittance mode and 200–800 nm in absorbance mode. The tensile strength (maximum Force) and elongation were tested using tensile testing machine model H1-5KT/S using standard test method EN ISO 13934-1:1999 [30] and results were the average of three replicate samples and young modulus were calculated. The antibacterial activity of samples against staphylococcus aureus bacteria was investigated using the AATCC standard test method 147-2004[31]. The average clear inhibition zone W in mm was evaluated based on this equation W = (T-D)/2 where T is the total diameter of both test specimen and clear zone in mm and D is width of the test specimen only in mm. The hydrophobicity of the treated textile surfaces was evaluated by measuring the water contact angle (WCA) based on the standards [32,33].

3. Results and discussion

3.1. Characterization of silver nanoparticles immobilized on rice husk silica nanoparticles RH-SNP-AgNPs

RH-SNP of an average particle size of 150 nm and purity of 95% was prepared. Interestingly, RH-SNP-AgNPs were prepared from RH-SNP and silver nitrate salt using PVP as reducing and capping agent in a facile one step method. The effect of mass ratio of RH-SNP studied and optimized which was in the range 10–50 wt.%. The synthesis and immobilization of AgNPs on RH-SNP surface were characterized and confirmed using microscopic and spectroscopic techniques.

Fig. 1A represents the UV–vis spectra of RH-SNP-AgNPs which confirm the formation of AgNPs as indicated by the absorption band located at 465 nm which corresponding to the surface plasmon resonance (SPR) of AgNPs at RH-SNP [34]. Furthermore, the formation of AgNPs itself using PVP and ultrasonication (just in absence of RH-SNP) was also prepared and assured by the UV–vis spectra by the formation of absorption band of SPR which situated at 425 nm.