



Synthesis and Characterization of Smart Antibacterial Towels Based on Layered Silicates

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Abstract: New smart coating for towels was developed. Montmorillonite (MT) as clay layers was decorated with silver nanoparticles (AgNPs) of an average size of 32 nm. Developed MT-AgNPs composite were dispersed in commercial binder producing good dispersion coating system. Then the formed coating was coated on two different towels. The mass loadings of montmorillonite in the coating layer were varied and their effect was studied. Antibacterial properties of the untreated and treated towels were evaluated and the effect of coating layer on mechanical properties was investigated. The bacterial inhibition was significantly improved for developed towels achieved inhibition zone of 17 mm compared to zero mm for untreated ones. Also, the mechanical properties were improved.

Keywords: Towels, Antibacterial Properties, Clay Layers, Silver Nanoparticles, Two Dimensional Clay

1. Introduction

Textile materials have various forms and types which involved in various home applications such as furniture, clothes and towels due to their properties. Hence, based on their final application there is functional properties should be acquired in the textiles materials to achieve comfortability and safety to the consumers [1-2, 3, 4]. One of the most used textile in all homes and domestic places are towels which can be used in kitchen, bathrooms and other various applications. However, the towels should have enough pile height to perform their role in cleaning, absorption and release of water and humidity. However, the high pile height of towel is a rich environment to bacterial growth which threatens the human life of consumers [5-6]. So, the use of antibacterial agents is required and essential for kitchen towels to protect them from growth of bacteria and avoid their created diseases [7]. On the other hand, nanomaterials are involved in various textile application and treatments due to their outstanding properties [8-9, 10]. There are various nanomaterials have been used to inhibit bacterial growth such as silver and TiO₂ nanoparticles [11-12]. So that, in order to achieve safety in using kitchen towel antibacterial treatment is required to impart the towel with antibacterial property. As, silver nanoparticles are widely used as antibacterial agent [13].

However, to avoid their nanoparticles agglomeration, they should be decorated on inert substrate to enhance their performance as antibacterial agent [10]. On the other hand, montmorillonite (MT) is one of aluminosilicates which have various applications [14]. In this study, two towels with different pile height were developed as antibacterial towel. Silver nanoparticles were synthesized and decorated on MT surface. Then, dispersed in binder solution forming smart coating and then coated on towels surface. The antibacterial activity of treated and untreated towels was evaluated. Also, the mechanical and morphological properties were investigated for treated and untreated ones.

2. Experimental Section

2.1. Materials

Two different kitchen towels and commercial binder (B) were bought from Egyptian market. Montmorillonite K10 (MT) was bought from Sigma-Aldrich and silver nitrate was purchased from AppliChem GmbH-An ITW Company, Ottoweg. Dimethyl formamide (DMF) and acetone used in the preparation of coating layer were purchased from El Nasr Pharmaceutical Chemicals Co., Egypt.

2.2. Synthesis of MT Decorated Silver Nanoparticles (MT-AgNPs)

In a glass beaker PVP solution was prepared by dissolving 200 of PVP mg in 45 ml. This is followed by dissolving 30 mg of AgNO_3 (constant mass) in the previous solution. Afterwards, variable masses of MT were dispersed (5, 10, 15wt.%) based on the final weight of final B-MT composite in the previous solution. Then, the previous dispersion was exposed to ultrasonication at 50% output for 30 min to form MT-AgNPs as tabulated in Table 1. Also, AgNPs dispersion was prepared in absence of MMT.

2.3. Synthesis of B-MT-AgNPs Composites

Binder solution of 2 vol% concentration was prepared in acetone. Afterwards, different MT-AgNPs composites were dispersed in binder solution followed by ultrasonication at 50% output for 1hour to for well dispersed B-MMT-AgNPs nanocomposites as tabulated in Table 1. Also, B-MT-2-10 was prepared by dispersing 10wt.% of MT in binder solution based on final B-MMT composite.

2.4. Synthesis of Towel-B-MMT-AgNPs Composites

Table 1. Composition of coating layer.

Sample code	Binder (wt.%)	MT (wt.%)
T1	0	0
T2	0	0
T1-B-2	100	0
T2-B-2	100	0
T1-B-MT-2-10	90	10
T1-B-MT-AgNP-2-5	95	5
T1-B-MT-AgNP-2-10	90	10
T1-B-MT-AgNP-2-15	85	15
T2-B-MT-AgNP-2-5	95	5
T2-B-MT-AgNP-2-10	90	10
T2-B-MT-AgNP-2-15	85	15

Towel samples of 20 cm x 20 cm in dimension were immersed in the different coating dispersion prepared previously for 10 min. 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 T-B-MT-AgNP-2-10 whereas 2 refers to binder concentration in vol% and 10 refer to wt.% of MT based on B-MT composite.

2.5. Characterization

The SEM images were obtained using a scanning electron microscope (Quanta FEG-250, with operating at a voltage of 30 kV). Transmission electron microscope (TEM) images were carried out using JEOL (JEM-1400 TEM). UV-Vis spectra were measured using a UV-Vis Spectrophotometer - Shimadzu UV 3101PC in the wavelength range 200-800 nm in absorbance mode. The tensile strength, bursting and elongation were tested using tensile testing machine model H1-5KT/S. The antibacterial activity of samples against *staphylococcus aureus* bacteria was investigated using the AATCC test method 147-2004[15].

3. Results and Discussion

3.1. Characterization of Developed Coating Layer Coated on Towels

MT-AgNPs were prepared using facile method by aid of ultrasonication in the presence of PVP. The AgNPs were prepared and reduced from Ag salt using the aid of ultrasonication and PVP. Whereas, the role of PVP and ultrasonication in synthesis of AgNPs was reported previously [16-17, 18]. The confirmation of synthesis of AgNPs and their decoration on MT surface was supported by UV-Vis spectroscopy as indicated in Figure 1. The absorption band detected at 463 nm was corresponds to the surface plasmon resonance (SPR) of AgNPs prepared [19]. However, the decorated ones on MT surface confirmed by the absorption band located at 463 nm which assigned to SPR of AgNPs at MT surface [10-19].

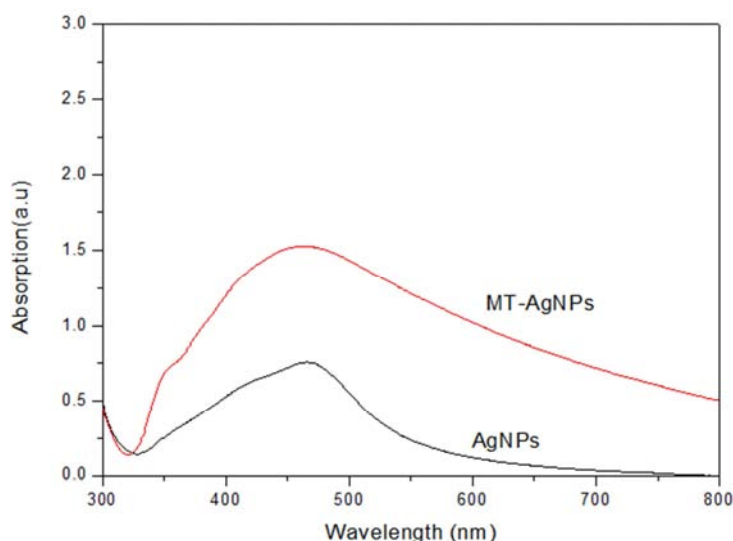


Figure 1. UV-Vis spectra of AgNPs and AgNPs decorated on MT surface MT-AgNPs.

The noticed broadness in the absorption band of MT-AgNPs compared to AgNPs was attributed to decoration of AgNPs on MT surface [10-19]. Furthermore, confirmation and morphology of AgNPs and their decorated ones MT-AgNPs were investigated using microscopic images. Figure 2a reflects TEM images of AgNPs which indicated their spherical shape and the average particle size was 8 nm.

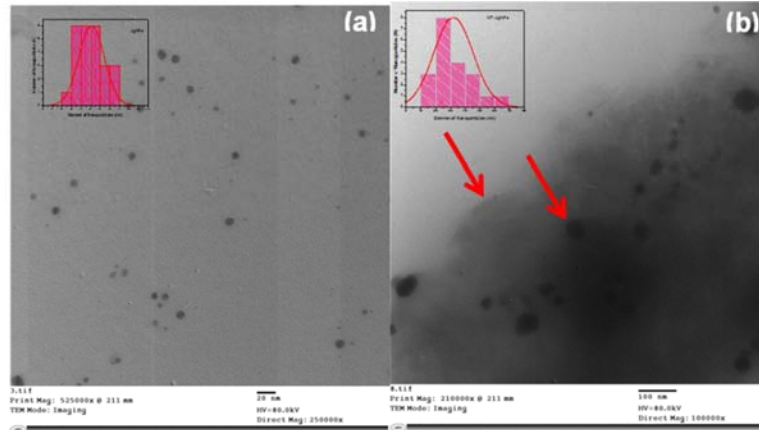


Figure 2. TEM images of AgNPs (a) and AgNPs decorated on MT surface MT-AgNPs(b).

On the other hand, the coating layer for towels was prepared by dispersion of the prepared composites MT-AgNPs composites in binder solutions and indicated in Table 1. The ultrasonication was implemented to produce high dispersion of MT-AgNPs on binder solution giving rise well dispersed coating dispersion. The coating layer was coated on the towels and the morphology of the untreated and treated towel was studied using SEM. Figure 3a represent the morphology of blank towel fibers which reflect smooth

surface, however, Figure 3b shows the SEM image of T_1 -B-MT-AgNP-2-15 which reflect the roughness surface and morphology of fibers due their treatment by coating layer of B-MT-AgNP-2-15 as clarified by arrows. Figure 3c-d of high magnification SEM images of T_1 -B-MT-AgNP-2-15 clearly reflect the dispersion of MT-AgNPs on fiber surface and decoration of AgNPs on MT on dispersed form as indicated by arrows and inset (Figure 3d).

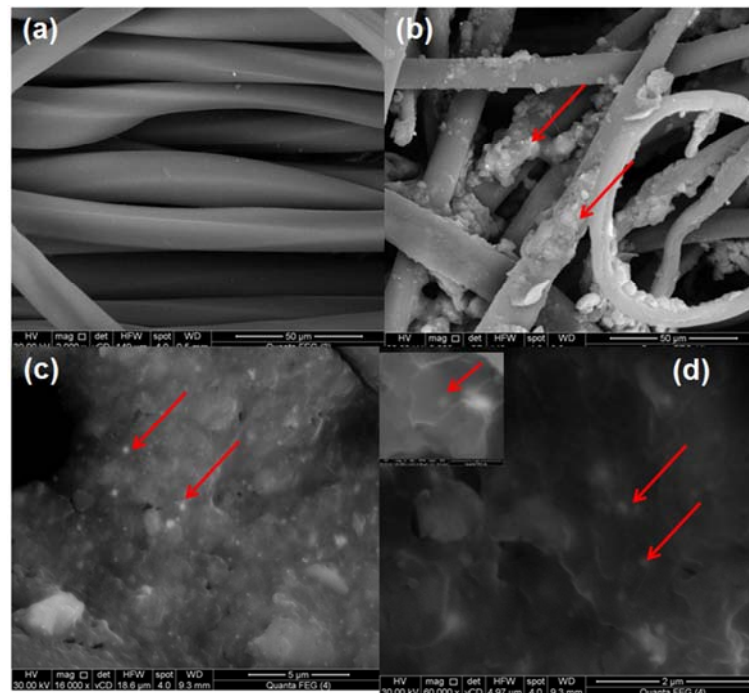


Figure 3. SEM images of blank T_1 towel (a), T_1 -B-MT-AgNP-2-15 (b), T_1 -B-MT-AgNP-2-15 at high magnification (c), and T_1 -B-MT-AgNP-2-15 at high magnification clarifying MT-AgNPs dispersion (d).

3.2. Mechanical and Antibacterial Properties

The effect of coating layer treated on surface of different towels was tested using mechanical properties. As, the T_1 of low pile height was tested by tensile strength and elongation tests, however, bursting strength was used for T_2 of high pile height. Tensile strength and elongation of untreated and treated T_1 was tabulated in Table 2. The tensile strength of untreated and binder treated T_1 was similar in values without noticeable change. However, when MT was inserted in coating layer the tensile strength was reduced to 296 N (Table 2). Moreover, the elongation has similar trend of improvement achieved 39.5%. When MT-AgNPs dispersed in coating layer, the tensile strength and elongation was enhanced achieved 310 N and 52%, respectively in T_1 -B-MT-AgNP-2-5. However, in T_1 -B-MT-AgNP-2-10 the tensile strength was reduced to 263 N, but elongation was almost similar (Table 2). Further increase of MT in the coating layer of T_1 -B-MT-AgNP-2-15 achieved improvement in tensile strength and elongation achieved 328 N and 59%, respectively. On the other hand, the bursting strength of untreated and treated T_2 was tabulated in Table 3. The bursting strength of blank and T_2 -B-2 have almost similar with little reduction in case of binder treated (Table 3), when, MT was involved in coating layer the bursting strength was improved to 347 N. In case of T_2 -B-MT-AgNP-2-5 and T_2 -B-MT-AgNP-2-10 the bursting strength was enhanced achieved 390 and 420 N respectively. However, the bursting strength was reduced in T_2 -B-MT-AgNP-2-15 (Table 3) when MT mass further increased in coating layer.

Table 2. Mechanical properties of untreated and treated towel samples (towel one).

Sample code	Tensile strength (N)	Elongation (%)
T_1	330 ± 20	19 ± 2
T_1 -B-2	356 ± 23	42 ± 2
T_1 -B-MT-2-10	296 ± 6	39.5 ± 1.8
T_1 -B-MT-AgNP-2-5	310 ± 35	52 ± 1.7
T_1 -B-MT-AgNP-2-10	263 ± 18	50 ± 3.7
T_1 -B-MT-AgNP-2-15	328 ± 30	59 ± 1.4

Table 3. Mechanical properties of untreated and treated towel samples (towel two).

Sample code	Bursting strength (N)
T_2	367 ± 27
T_2 -B-2	339 ± 13
T_2 -B-MT-2-10	347 ± 28
T_2 -B-MT-AgNP-2-5	390 ± 22.5
T_2 -B-MT-AgNP-2-10	420 ± 33
T_2 -B-MT-AgNP-2-15	336 ± 11

On the other hand, the antibacterial properties of the new developed towels have been evaluated against staphylococcus aureus bacteria. The two types of towels (T_1 and T_2) have no effect on bacterial inhibition and recorded zero inhibition zones (Table 4 and Figure 4). However, when binder was treated on towels in T_1 -B-2 and T_2 -B-2 they show antibacterial properties as indicated in Table 4. When, MT was incorporated in binder coating the inhibition zone was

improved to 6.8 and 7.6 mm for T_1 -B-MT-2-10 and T_2 -B-MT-2-10, respectively. Interestingly, when AgNPs was involved in the coating layer the bacterial inhibition zone of the new towels was further improved recording 8 and 10 mm for T_1 -B-MT-AgNP-2-5 and T_2 -B-MT-AgNP-2-5, respectively. This improvement in inhibition of bacterial growth was followed when MT loading increased compared to constant AgNPs and achieving significant enhancement recording 14 and 17 mm for T_1 -B-MT-AgNP-2-15 and T_2 -B-MT-AgNP-2-15, respectively (Table 4 and Figure 4). This enhancement in inhibition zone was due to the fact that the increased loadings of MT in coating layer compared to constant AgNPs attributed to better dispersion of decorated AgNPs on MT surface which provide more stability for AgNPs and avoid their agglomeration when interacted with bacterial medium [10].

Table 4. Antibacterial zone of untreated and treated towel samples.

Sample code	Width of clear inhibition (zone mm)
T_1	0
T_2	0
T_1 -B-2	5
T_2 -B-2	6.8
T_1 -B-MT-2-10	6.5
T_1 -B-MT-AgNP-2-5	8
T_1 -B-MT-AgNP-2-10	11
T_1 -B-MT-AgNP-2-15	14
T_2 -B-MT-2-10	7.6
T_2 -B-MT-AgNP-2-5	10
T_2 -B-MT-AgNP-2-10	13.5
T_2 -B-MT-AgNP-2-15	17

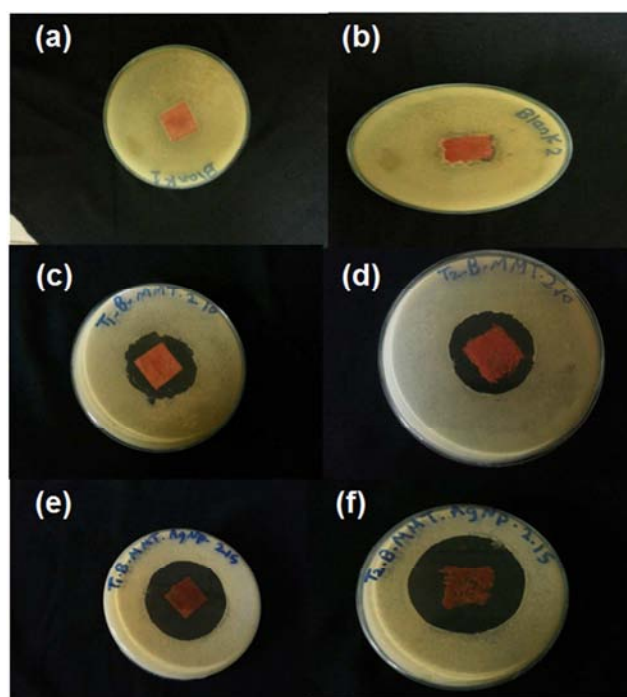


Figure 4. Digital photos of bacterial inhibition zone of T_1 (a), T_2 (b), T_1 -B-MT-2-10 (c), T_2 -B-MT-2-10 (d), T_1 -B-MT-AgNP-2-15 (e) and T_2 -B-MT-AgNP-2-15 (f).

4. Conclusion

Effective antibacterial coating for towels has been developed. The developed coating layer was based on cost-effective clay layers montmorillonite which decorated with silver nanoparticles. The effect of dispersion of silver nanoparticles on montmorillonite surface was studied by variation of montmorillonite loadings. The new developed towels show significant bacterial growth inhibition achieving inhibition zone of 17 mm compared to zero and 8 mm for untreated and binder treated towel, respectively. The smart coating not only improved antibacterial properties but also enhance mechanical properties

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