Materials Chemistry and Physics 180 (2016) 364–372

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

Facile synthesis of novel nanocomposite as antibacterial and flame retardant material for textile fabrics

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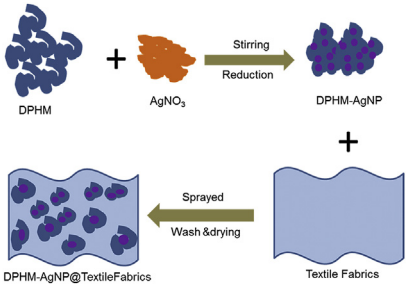
HIGHLIGHTS

- Novel and effective nanocomposite materials were developed.
- The silver nanoparticles sizes were tuned in the nanocomposites.
- The flame retardancy of treated textiles was improved.
- The antibacterial activity of treated textiles was significantly enhanced.
- Effect of nanocomposite coating on textile fabrics was investigated.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form
23 April 2016
Accepted 5 June 2016
Available online 11 June 2016

Keywords:
Composite materials
Nanostructures
Mechanical testing
Thermogravimetric analysis (TGA)

ABSTRACT

Novel nanocomposite materials have been developed using facile one pot method. The nanocomposites were developed based on silver nanoparticles and diphosphate malonate as organic phosphates. The mass ratios of both silver nanoparticles and organic phosphate in the nanocomposites were varied and optimized. The silver nanoparticle sizes were tuned and the average size was in the range 17–102 nm. Different textile fabrics were treated with the developed nanocomposites for improving their antibacterial and fire retardancy properties. The flame retardancy of the treated textiles was improved significantly and optimized. The rate of burning of the treated textiles was recorded as zero mm/min achieved high class flame retardant textiles compared to 125.6 and 336 mm/min for untreated cotton blend and polyester textiles, respectively. The antibacterial activity against *Staphylococcus aureus* bacteria and mechanical properties of the treated and untreated fabrics was evaluated. The clear bacterial inhibition zone reached to 4.48 mm compared to zero mm for blank textiles.

1. Introduction

Due to the wide application of synthetic and natural textile fibers in various fields such as furnishing, medical and apparel, the research to improve their properties attracted much attention [1,2]. The synthetic polyester and their blends with cotton fibers constitute the majority of the textile products in the market due to their excellent properties and their demand in a variety of applications [3,4]. However, due to the polymeric origin of these textile fabrics such as cellulose and synthetic polyester they have low thermal stability and highly flammable [5]. So there are attempts to enhance their thermal and flame retardancy properties [6]. Different classes of flame retardant materials have been used in the treatment of textiles fabrics to reduce their fire hazard such as

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http://dx.doi.org/10.1016/j.matchemphys.2016.06.019
0254-0584/

halogenated materials, nitrogen and phosphorus based compounds [7–9]. On the other hand, the easily growth and adherence of microorganisms on the surface of textile fabrics threaten the human life of consumers [10–13].Therefore, the treatment of textile fabrics surface with antibacterial agent is mandatory especially for textile fabrics used in medical and hospital applications. Recently, the trend to introduce dual specific functions to textile fabrics to impart flame retardancy and antibacterial behavior has attracted many researchers [14,15]. Interestingly, silver nanoparticles have been recognized as antibacterial agent for various substrates [16]. It is important to note that, the organophours compounds were used widely as flame retardant additive for different textile fabrics [9,17]. Also, various nanoparticles and their composite have been studied to improve antibacterial and flame retardant properties of fabrics such as TiO_2, ZnO and Ag nanoparticles [1,18–20]. In our recent studies, the flame retardancy and electrical conductivity of cotton-polyester blend textile fabrics were studied [3]. This is in addition to the study of the use of organophours compounds as effective back coating flame retardant to different textile fabrics [17]. This is along with our experience in various nanoparticles and nanocomposites synthesis and applications [21–25]. In this report, synthesis and treatment of novel nanocomposite as effective flame retardant and antibacterial agent to polyester and cotton-polyester blend textiles have studied. The nanocomposites prepared were composed from organophosphate; diphosphate malonate compound (DPHM) and silver nanoparticles (DPHM-AgNP). The mass ratio of DPHM and silver salt has varied and silver nanoparticle sizes were evaluated. The flame retardant and antibacterial properties of the treated textile fabrics were studied and optimized. The effect of the treatment of the nanocomposites on textile fibers in terms of mechanical properties was also studied. In addition, the thermal stability of treated and untreated fabrics was evaluated.

2. Experimental section

2.1. Materials

Polyester (PS) and cotton-polyester blend (CB, 80:20 respectively) fabrics were supplied by Helwan Co., Cairo, Egypt. Diethyl malonate was purchased from PKD By: Oxford Laboratory, Mumbai, India and phosphoric acid was obtained from Sigma Aldrich Co., USA. Silver nitrate was supplied by AppliChem GmbH-An ITW Company, Ottoweg, Germany. Deionized water (DI) was used for synthesis of nanocomposites.

2.2. Synthesis of diphosphate malonate (DPHM)

The synthesis of diphosphate malonate was performed based on previous report [26]. For synthesis; in a dried flask mix 1 mol of diethyl malonate with 2 mol of phosphoric acid. Then refluxed at 130 °C for 2 h to obtain clear viscous solution of DPHM.

2.3. Synthesis of diphosphate malonate-silver nanoparticles composites (DPHM-AgNP)

In a beaker containing 150 ml of DI water dissolve different mass of DPHM individually (5,10, 20 g) then magnetic stirring for 30 min. Afterwards, dissolve different mass of silver nitrate (0.5,1,1.5 g) in the previous solutions, followed by stirring for 15, then add 20 μL of sodium borohydride solution of 0.02 M. This followed by magnetic stirring for 24 h to obtain DPHM-AgNP nanocomposites.

2.4. Treatment of textile fabric with DPHM-AgNP

The polyester (PS) and cotton-polyester blend (CB) fabrics samples were cut in 20 × 20 cm and DPHM-AgNP solution was sprayed on the surface of the textile samples completely. Then dried and this step was repeated three times. Finally, rinsed in DI water for wash and then dried. The samples coded as CB5-0.5 and PS5-0.5 where 5 refer to mass of DPHM and 0.5 refer to mass of $AgNO_3$ in gram, respectively.

2.5. Characterization

TEM images were obtained using JEOL (JEM-1400 TEM). The SEM images were taken using a scanning electron microscope (Quanta FEG-250, at operating voltage 30 kV). FT-IR spectra were recorded using a Nicolet 380 spectrophotometer (Thermo Scientific) in the spectral range 4000–400 cm^{-1}. UV–Vis spectra were recorded using a UV-Vis Spectrophotometer - Shimadzu UV 3101 PC in the wavelength range of 200–800 nm in absorbance mode. Thermogravimeteric analysis was conducted using TGA 50 (TA Shimudzu, Inc.) over temperature range from room temperature to 600 °C under nitrogen. The mechanical properties measurements were performed by tensile testing machine model H1-5 kT/S. The flammability properties of the untreated and different treated textile fabrics were evaluated using a Fire Testing Technology UL94 flame chamber according to modified ISO 3795 [3,17,27]. The flame retardancy evaluated in terms of rate of burning B in mm/min which was calculated based on the following equation $B = s/t \times 60$ where s: is the burnt distance in mm t: is the time consumed for the burned distance in seconds.

The antibacterial activity was recorded using the AATCC test method 147-2004 [28]. The antibacterial against *Staphylococcus aureus* bacteria was examined by measuring the average clear inhibition zone using the following equation $W = (T-D)/2$ where W is the width of the clear zone of inhibition in mm, T is the total diameter of test specimen and clear zone in mm and D is the diameter of the test specimen in mm.

3. Results and discussion

3.1. Structural and morphological characterization of DPHM-AgNP nanocomposite

Firstly, the DPHM were prepared based on the literature [26]. The structure of DPHM was elucidated using IR spectroscopy. The

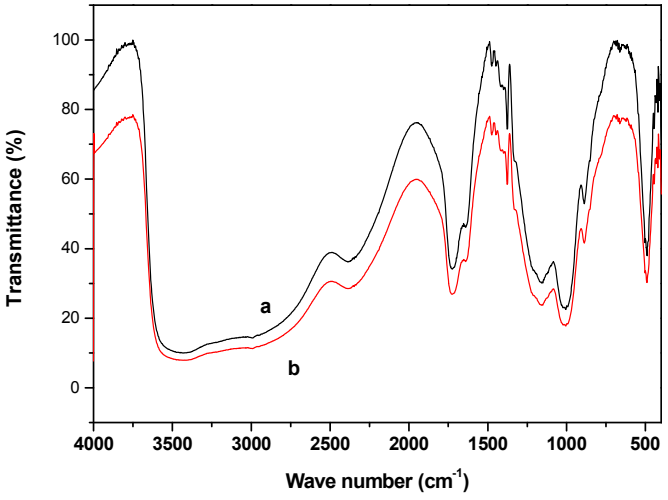

Fig. 1. FTIR spectra of diphosphate malonate (a) DPHM and (b) DPHM-AgNP nanocomposite.