

Fabrication of poly(lactic acid) incorporated chitosan nanocomposites for enhanced functional polyester fabric

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Abstract

This study dealt with the fabrication and analysis of poly(lactic acid) (PLA) mediated chitosan nanocomposite. Such a novel nanobiocomposite may get future applications in drug delivery, and nanofinishing of textile and polymer surfaces. Herein, this nanocomposite has been considered as an antibacterial finishing agent for a hydrophobic textile fabric like polyester. The prepared nanocomposite was characterized for zeta size and morphology, and subsequently applied on a woven polyester fabric through a cross linker. The treated polyester fabric was analyzed for textile functional characteristics as well as antibacterial activity. The spectral and optical properties demonstrated that the nanocomposite developed exhibited spherical morphologies with a mean nano particle size of ca. 88 nm. The treated fabric projected satisfactory antibacterial and fair fabric attributes. Hence, the nanofinished polyester fabric is a potential biocompatible candidate as medical and antibacterial textiles in addition to be used in antibacterial water filtration and materials packing.

Keywords: antibacterial, chitosan, cotton fabric, nanocomposite, PLA.

1. Introduction

Biodegradable polymers, like poly(lactic acid) (PLA), have much attentions in recent years because of their excellent biocompatibility and low toxicity even after degradation. PLA is finding application as drug carrier due to its good bioresorptivity and elimination on drug depletion^[1,2]. PLA is an example of bio-polyesters i.e., bio-based thermoplastic which in addition biodegradable are eco-compatible. Such bio-derived polymers reduce the carbon cycle by repaying plant-based carbon to the soil via biodegradation and alternatively reduce the environmental impact; hence, they reduce carbon dioxide emission during their life cycle. The PLA is extensively used in tissue engineering, bioscaffolds, drug delivery systems, membranes, cosmetic, biomedical implants and son on^[3].

Chitosan (CS) is an innate biodegradable polymer attained by alkaline *N*-deacetylation of chitin and it is the 2nd most available natural polymer after cellulose. It finds diverse applications in medical sector. Chitosan nanoparticles are preferred over powder or bulk because nanoparticles have potential of slow/controlled release of drug and other textile finishes^[4]. The chitosan based nanoparticles (NPs) have gained enormous attention because of their good environmental compatibility and prompt modifiability^[5,6]. It has broad spectrum antibacterial activity^[7]. Some studies have suggested that the degree of deacetylation and molecular mass of chitosan can be altered to obtain desirable characteristics. On the other hand, chitosan can also be employed to coat different NPs of other materials to enhance their effectiveness for the body and increase their bioavailability^[8,9]. In recent decades, chitosan based composite nanomaterials have been explored. Chitosan is versatile material that can be

used to prepare chitosan based different NPs like mediation chitosan with zinc oxide and other biopolymer for instance polylactic acid (PLA) to obtain different properties that can potentially be used in biomedical and drug delivery applications^[10].

Besides PLA, other candidate may be poly(glycolic acid) (PGA)^[11-13].

Textile materials have specific mechanical properties which make them a unique material for society. Nanoscience has recently introduced some nanofinishes for textile substrates. Textile finishes based on nanotechnology provides oil and water repellency, antibacterial activity and UV protection^[14,15]. The PLA nanofinishes are gaining importance in recent years because of fact that PLA is obtained from renewable resources and have ability to incorporate mechanical strength, antibacterial and ultraviolet protection to textiles^[16]. The PLA is one of the promising polymers in which stereochemical structure can easily be modified through the process of polymerization in order to form homo- and co-polymers. It is biocompatible and biodegradable. The biocompatibility of PLA is a useful property in biomedical application while biodegradability is adapted for packing purposes.

The aim of this study was to prepare the PLA-CS based NPs and their application on polyester fabric. The characterization of composite NPs was done by using the advanced analytical techniques like scanning electron microscopy, FTIR, zeta size and zeta potential whereas the treated polyester fabric was evaluated for its functional and textile performance properties.

2. Materials and Methods

2.1 Materials

Chitosan, with >90% purity and degree of deacetylation of 90% and viscosity 200-800 cps, was procured from Bio Basic Inc., Canada and acetic acid (congealing temperature ≥ 15.6 °C, limit of nonvolatile residue ≤ 1.0 mg and heavy metal ≤ 5 ppm) from Acros Organics. Polylactic acid (melting point 150-160 °C and density $1.21-1.43$ g·cm⁻³) and sodium hydroxide (molecular mass 39.997109 g/mol) from Sigma-Aldrich. Sodium tripolyphosphate (STPP, Mol. mass 367.86 amu) was purchased from BioM Lab, USA. Nutrient agar was procured from Merck and nutrient broth from Lab. M. Ltd., UK. Knittex RCT[®] (modified dihydroxy ethylene urea) and Knittex MO[®] (magnesium chloride based) were kindly donated by the local office of Huntsman. The properties of polyester fabric are shown in Table 1.

2.2 Fabrication of nanocomposite

PLA/CS NPs were synthesized by ionic gelation method. Briefly, CS was dissolved in 0.5% acetic acid. Different concentrations of PLA from 1-3% were dissolved in chloroform, which was then added into the 1-2% CS solution with different volumes. 1% STPP solution was then added after ultrasonication for 30 min at 30°C. Blank PLA/CS NPs were gradually formed under vigorous stirring condition. After that the sample was centrifuged at 6500 rpm at 4°C for 30 min and resultant pellets were freeze-dried to obtain the required composite NPs. The design of experiments (DOE) of preparation of PLA incorporated CS NPs is shown in Table 2.

2.3 Size determination of nanocomposite

The average diameter of PLA/CS NPs was measured using dynamic light scattering technique using a Zetasizer Nano (Malvern ZEM-3600, Malvern instruments Ltd., UK) at 25°C.

Table 1. Properties of used polyester fabric.

Property	Values	Standard method
Fabric construction	Plain weave (1×1)	AATCC-20
Surface density, g/m ²	97	ASTM D-3776
Ends/inch	130	ASTM D-3775
Picks/inch	70	ASTM D-3775
Warp count	32	ASTM D-1059
Weft count	32	ASTM D-1059
Tensile strength (warp), KgF	34	ASTM D-5034
Tensile strength (weft), KgF	32	ASTM D-5034
CIE whiteness	70°CIE	AATCC-110
Bending length (warp), cm	0.71	ASTM D-1388

Table 2. DOE for PLA incorporated chitosan nanoparticles preparation.

Chitosan (%w/v)	TPP	PLA
	(Sodium tri polyphosphate) (%)	(Poly lactic acid) (%)
1.0	1.0	1
1.5	1.5	2
2.0	2.0	3

2.4 Fabric impregnation of nanocomposites

The PLA/CS nanocomposite (as 1 to 3% w/v) was ultrasonicated for 10 min at room temperature to get uniform aqueous suspension. A low temperature cross-linking agent of Knittex RCT[®] was used as 80 g/L and a catalyst Knittex MO[®] as 20 g/L to bind the nanocomposite to the polyester fabric. To this suspension, the fabric specimens (at a fabric to liquor ratio of 0.05) were padded in two dips and nips at 100% wet pick up. The specimens were dried at 110°C for 1 min and cured at 150°C for 3 min.

2.5 Characterization of nanocomposites treated fabrics

The prepared nanocomposite particles were spherical in shape with the mean size of 88 nm measured as number distribution (Figure 1). The surface morphology of the nanocomposite applied polyester fabric samples were examined under an FEI Quanta 250 scanning electron microscope (SEM) at an accelerating voltage of 20 kV. The fabric impregnation of NPs on fabric was examined using Attenuated Total Reflectance-Fourier transform infrared spectroscopy (ATR-FTIR, Bruker Tensor 27).

2.6 Textile performance properties

Binding length of fabric samples was measured as per standard protocol of ASTM D-1388 on a cantilever, crease recovery angle (CRA) as per standard protocol of ISO 2313 and tensile strength as per standard protocol of ASTM D-5034. The bacterial strains of *Escherichia coli* and *Staphylococcus aureus* were employed to estimate the antibacterial activity of treated samples as per documented earlier^[17].

3. Results and Discussions

The morphology of the control fabric sample and after implication of PLA-CS NPs was detected under SEM. The SEM images revealed the fact that the control fabric has smooth surface (Figure 2a); while, the treated one indicated the impregnation of particles on fabric surface (Figure 2b).

The FTIR results (Figure 3a) show that the peak at 1701 cm⁻¹ indicated the presence of C=O, another peak in the range 1016 to 1239 cm⁻¹ corresponds to C-O-C band stretching; hence confirm the ester linkage in polyester fabric. Whereas, the treated fabric showed the peaks at 1407 cm⁻¹ regarding to C-NH₂ amine band (Figure 3b). The peak at 1071-1016 cm⁻¹ is the indication of C-O band stretching. While the peaks appearance at 1710 cm⁻¹ is assign to the C=O.

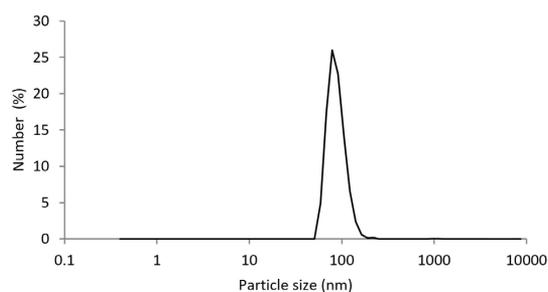


Figure 1. Particle size distributions of PLA-CS nanocomposite.

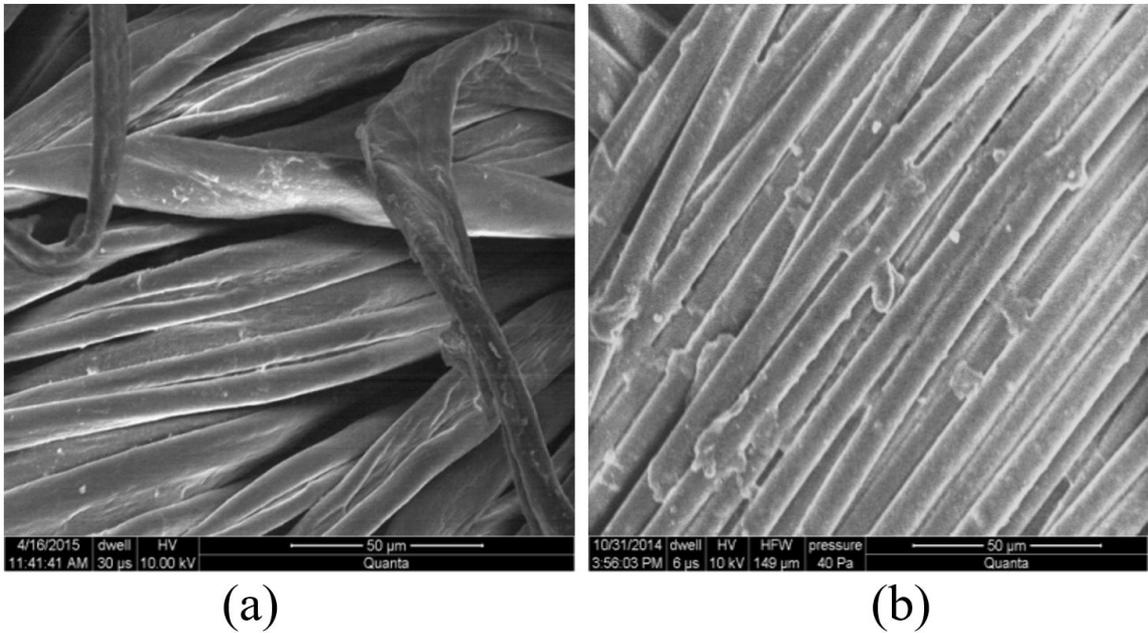


Figure 2. SEM images of (a) untreated and (b) PLA-CS nanocomposite treated polyester fabrics.

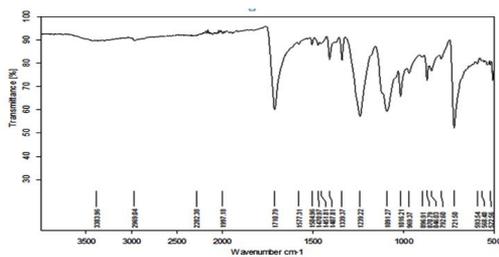


Fig. 3a

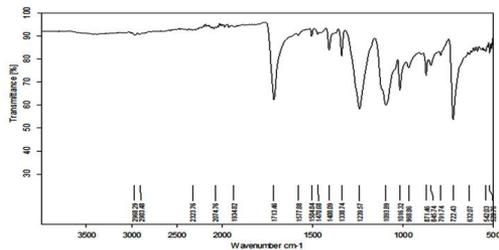


Fig. 3b

Figure 3. FTIR spectra of (a) untreated and (b) PLA-CS nanocomposite treated polyester fabrics.

The bending length of polyester sample after treatment with PLA/CS NPs showed an overall increment. Figure 4a shows that in the case of control sample, warp and weft bending lengths were lower while after treatment there observed a significant increase in warp and weft bending lengths. The warp bending length was higher than weft due to presence of size material. The overall increment was due to the presence of chitosan which enhance the stiffness of fabric and increase stiffness of fabric^[18].

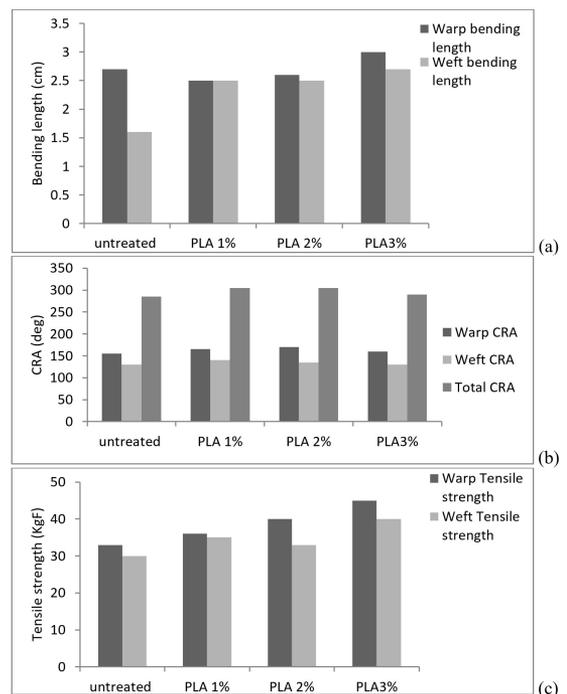


Figure 4. Effect of PLA-CS nanocomposite on (a) bending length, (b) CRA and (c) tensile strength of polyester fabric.

The minimal increase in CRA values, provide improved easy care properties. Figure 4b shows an increase in CRA as compare to untreated sample the reason behind that the PLA-CS nanocomposite fills the amorphous regions and causes to improve the CRA^[19].

Figure 4c shows that after the application with PLA-CS nanocomposite, the tensile strength of the treated fabric

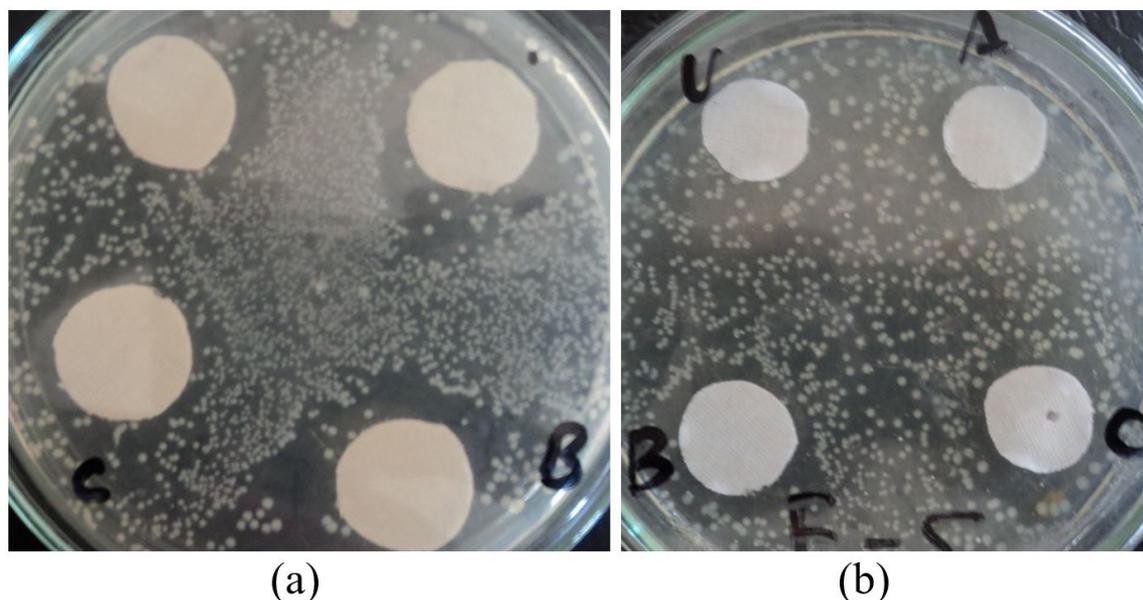


Figure 5. Antibacterial activity of PLA-CS nanocomposite treated fabric against (a) *S. aureus* and (b) *E. coli*, and (c) respective quantitative antibacterial activities.

improved on increasing the nanocomposite contents (1-3% w/v). The overall increment as compare to control fabric is due to the binding of PLA nanocomposite between fiber and yarn^[18].

Chitosan is being used worldwide because of its antimicrobial propertie. The zone of inhibition could not be expected if the antibacterial agent were firmly attached to the fabric surface (e.g. covalently) which could prevent the diffusion into the nutrient agar. Nevertheless, if the antibacterial agent could diffuse into the nutrient agar, a zone of inhibition became evident and its size indicated the potency of the antibacterial agent. The antibacterial action of polyester fabric after implication of finish was checked and Figure 5a, b shows that there is clear zone of inhibition against the tested strains of *S. aureus* and *E. coli*. The zone of inhibition was higher against *E. coli*. The results show that the antibacterial activity was higher in case of 1 and 3% (w/v) PLA-CS nanocomposite because the higher concentration of antibacterial agent (i.e., chitosan and PLA) adsorb on the cell wall of bacteria and ultimately cause the destruction of cell membrane and death of bacteria.

4. Conclusions

The presented study under took finishing of 100% polyester fabrics with some combinations of chitosan and polylactic acid (PLA) to impart functional attribtes in treated fabrics. The impregnation of PLA incorporated chitosan nanocomposite on the polyester fabric was authenticated by, SEM and FTIR spectroscopy. The particle size was confirmed by using zeta sizer. All combinations of PLA-CS showed inhibition against bacterial strains, viz. *E. coli* and *S. aureus* but zone of inhibition increased by increasing nanobiocomposite. On combining PLA with chitosan, the crease recovery properties of treated polyester fabric improved

in addition to the antibacterial activity. The CRA of treated polyester fabrics was almost comparable to control sample.

5. Acknowledgements

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