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Chapter

Multi-Finishing of Polyester and Polyester Cotton Blend Fabrics Activated by Enzymatic Treatment and Loaded with Zinc Oxide Nanoparticles

Naser Gad Al-Balakocy, Khaled El-Badry and Talaat Mahmoud Hassan

Abstract

The present work discusses the possibility of applying enzymatic treatments for fabric surface activation that can facilitate the loading of zinc oxide nanoparticles (ZnO NPs) onto polyester (PET) and polyester cotton blend (PET/C) fabrics prepared by sol-gel method. Activated polyester fabrics loaded by ZnO NPs were investigated by the use of scanning electron microscopy (SEM), electron dispersion emission X-ray (EDX) and Fourier transformed infrared spectroscopy (FT-IR). The functionality of activated polyester fabrics loaded by ZnO NPs was evaluated by analyzing its antimicrobial activity and UV protection efficiency. Antimicrobial activity of activated polyester fabrics and loaded by ZnO NPs was tested against Gram-positive (*Bacillus mycoides*), Gram-negative (*Escherichia coli*), and nonfilamentous fungus (*Candida albicans*). The level of UV protection was verified by the UV protection factor (UPF) of polyester fabrics. Activated post-treated polyester fabrics exhibited outstanding antimicrobial and UV protection efficiency. The achieved antimicrobial function and UV protection on the polyester fabrics are durable with repeated laundering processes even after five washing cycles.

Keywords: polyester fabric, alkali hydrolysis, cellulases, enzymatic hydrolysis, ZnO NPs, sol-gel, EDX, SEM, FT-IR, antimicrobial, UPF

1. Introduction

Loading of the nanoparticles onto the textile materials gained much scientific interest [1, 2]. Taking into consideration that functional groups such as carboxyl and hydroxyl have the possibility for binding nanometal oxides, both physical and chemical modifications suggested to date depend primarily on the incorporation of these groups to the textile material surfaces. Several surface modification methods for synthetic fibers have been described, for example, the use of chemical finishers based on carboxyl containing polymers [3]. Alkaline hydrolysis treatments are unspecific and result in strength and weight losses [4, 5]. Ionized gas treatment of PET materials using plasma

has also been investigated to introduce hydrophilic groups at the surface of the polymer [6]. However, the application of this method is limited because it is complicated to use, and it can be difficult to control the extent of the material modification [7].

Alternatively, surface activation of PET fabrics can be achieved by biological treatment with enzymes that introduce polar groups to the polymer surface. A number of hydrolytic enzymes, such as lipases, cutinases, and esterases, have shown potential for surface functionalization of PET [8, 9]. Of the many enzymes suitable for textile applications, cellulases are one of the most important. Cellulases are used in biopolishing of cotton fabrics to improve their smoothness, softness, and wettability [10]. The extent of enzymatic treatment is governed by many factors such as accessibility of cellulosic substrate to cellulases enzymes, confirmation of the enzyme protein as well as enzyme activity, treatment conditions, i.e. enzyme dosage, pH, temperature, time, coexisting chemicals in the treatment bath, fabric's processing history, as well as mechanical action [11–13].

The biocatalytic method can be performed under mild reaction conditions for avoiding the use of large amounts of chemicals and energy for the finishing and dyeing processes. The enzymatic modifications are specific and can be limited to the fiber surface. Consequently, the bulk properties and mechanical stability of the fibers is not compromised and material savings and products of better quality or with new functionalities can be obtained where enzymatic treatment leads to an increase of free hydroxyl and carboxylic end groups changing the surface properties of the treated material [14]. This introduction of charged and functional groups directly leads to an increased hydrophilicity. Furthermore, the increased amount of hydroxyl and carboxylic groups facilitates the attachment of nanoparticles from sol-gel solutions [15].

This study discusses the possibility of applying enzymatic treatment for fabric surface activation that can facilitate the loading of ZnO NPs from solutions onto PET and PET/C blend fabrics and, thus, improve the laundering durability of their antimicrobial activity as well as the level of UPF factor. The addition of this technology to polyester finishers offers an environmentally friendly and mild alternative to the chemical and mechanical finishes currently being used in industry.

2. Experimental work

2.1 Materials

Polyester (PET) and polyester/cotton blend (PET/C 50/50) fabrics used throughout this study were in the form of filament woven fabric cloth made from filament yarns. They were kindly supplied by Misr polyester Co., Kafr EL-Dwar, Egypt. The fabrics were scoured at 80°C for 45 min. With solution containing 2 g/L nonionic detergent, washed with cooled water, squeezed, and finally air dried.

2.2 Enzyme

Acid cellulases used through this work: multifunctional acid cellulases enzyme formulations namely: Cellusoft ® L (Novo Nordisk).

2.3 Microorganisms

Gram-positive bacterium [*Bacillus mycoides* (*B.m*)], Gram-negative bacterium [*Escherichia coli* (*E.c*)], and nonfilamentous fungus [*Candida albicans* (*C.a*)] were selected for investigation of antimicrobial activity of parent and modified samples. Microorganisms were obtained from the culture collection of the Department of

Microbial Chemistry, Division of Genetic Engineering and Biotechnology, National Research Centre of Egypt.

2.4 Culture medium

Modified nutrient agar medium has been used and consists of the following components (g/L): peptone (10.0), beef extract (5.0), NaCl (5.0), and agar (20.0). The pH was adjusted to 6.8. The abovementioned medium was sterilized under pressure at 121°C for 20 min.

3. Methods

3.1 Preparation of ZnO NPs by sol-gel method

The typical procedure for synthesis of ZnO sol is based on the method described in the literature by [16]. Zinc acetate dihydrate was used as zinc oxide source. In a typical procedure, 0.01 mol of zinc acetate dihydrate was dissolved in 50 ml of methanol and heated at 50°C along with stirring for 30 min, thus making precursor solution A. Then, 0.02 mol of sodium hydroxide was dissolved in 50 ml of methanol and heated at 50°C for 60 min, making precursor solution B. In order to make ZnO nano-sol, solution B was added into solution a dropwise under constant stirring for 30 min and then mixture was heated at 50°C for further 30 min. Subsequently, after continuous stirring for 2 hours and cooling at room temperature, a homogenous and transparent sol was obtained.

3.2 Preparation of activated polyester fabrics

Two different methods were used to activate polyester fabrics:

A. Polyester fabrics treated by cellulases

The treatment of PET and PET/C blend fabrics with the cellulases was carried out using a high-temperature high-pressure laboratory dyeing machine. The required amounts of cellulases were placed in stainless-steel bowls (1 and 3%), the fabric samples were immersed in the solutions, its pH = 4.5 (with acetic acid), and the sealed bowls were rotated in a closed bath containing ethylene glycol at 45°C. The material:liquor ratio (M:L) was 1:15. The bath temperature increased at rate of 5°C/min. After 40 min, the enzymatic treatment was then terminated by raising the pH to 10 by using Na_2CO_3; the samples were removed from the bath, rinsed repeatedly with distilled hot and cold water, and then the treated fabric samples allowed to dry in the open air. The extent of biodegradation was estimated from the weight loss (WL) of the fabric samples based on the following equation:

$$WL\ (\%) = [W_1 - W_2/W_1] \times 100.$$

where W_1 and W_2 are the weights of the samples before and after enzymatic treatments.

B. Polyester fabrics treated by alkali before cellulase

The alkaline treatment of PET and PET/C blend fabrics was carried out according to the method described by [17] using a high-temperature, high-pressure

laboratory dyeing machine. Required amounts of alkali solutions were placed in stainless-steel bowls, fabric samples were immersed in the solutions (0.25 mol/L), and the sealed bowls were rotated in a closed bath containing ethylene glycol at 90°C. The liquor-to-fabrics ratio (M:L) was 1:50. The bath temperature increased at rate of 2°C/min. After the predetermined durations (60 min), the samples were removed from the bath, rinsed repeatedly with distilled water, neutralized with a solution of 1% hydrochloric acid, and rinsed. The samples were then dried at 100°C, cooled in a desiccator, and weighed. The weight loss is expressed as relative WL was calculated according to the equation:

$$WL\ (\%) = [W_1 - W_2/W_1] \times 100.$$

Where W_1 and W_2 are the weights of the samples before and after alkaline treatments, respectively.

The treatment of hydrolyzed polyester fabrics with cellulases was carried out according to the above mentioned method.

3.3 Preparation of polyester fabrics loaded by ZnO NPs

The activated PET and PET/C blend fabrics by cellulases and hydrolyzed fabrics before enzymatic treatment were immersed in the ZnO NPs dispersion, the samples were then squeezed to a pickup of 60% (wt/wt) of the solution, and dried in air at 22°C (laboratory temperature) for 24 hours, and finally cured in an oven at 150°C for 15 min. The modified polyester fabrics were rinsed five times to assess the adhesion of ZnO NPs to the fabrics by using the standard method AATCC test method (61-1989).

3.4 Analysis

Carboxylic content was calculated by using the analytical method described by Daul et al. [18].

3.5 Antimicrobial activity

Antimicrobial activity of PET and PET/C blend fabrics modified with ZnO NPS was measured using the technique below.

The antimicrobial efficacy by disk diffusion was calculated in this technique by measuring in millimeters the width of the growth inhibition area around the specimen according to the conventional test method of AATCC [19].

3.6 SEM and EDX

Surface structure and the morphology of all fabric samples characterized by a JEOL-Model JSM T20 scanning electron microscope (SEM) operating at 19 kV was used to obtain photomicrographs of fabrics surfaces.

3.7 FT-IR

The chemical composition was defined using the spectrometer Fourier transformation infrared (FT-IR), model NEXUS 670, NICOLET USA. Measurements ranged from 4000 to 500 cm^{-1} in spectral range. The method of measuring the percentage of reflection (R percent) was applied to all the specimens under investigation.

3.8 UPF factor

The ultraviolet protection factor (UPF) was estimated using the spectrophotometer UV-Shimadzu 3101 P C. It is a scheme of double beam direct measurement proportion. It comprises of the unit of the photometer and a P C. The UPF factor was determined by the technique outlined in AS/NZS 4399, Australian/New Zealand: 1996 [20].

4. Results and discussion

4.1 Polyester fabrics treated by cellulases

It is clear from **Table 1** that the PET fabrics had the lowest hydrolysis rate with 1.5% weight loss [21], while enzymatic treatment brings about a noticeable decrease in loss the weight of PET/C blend fabrics, 2.1 and 3.0% respectively, by increasing cellulases concentration from 1.0 to 3%. Cellulases have a higher specific activity toward cotton fibers than polyester; this explains the high weight loss with PET/C fabric. A higher specific activity correlates with higher weight loss % with PET/C fabric. This is a direct consequence of a partial enzymatic hydrolysis of the cellulosic fibers especially on the fabric surface and amorphous regions, yielding soluble products such as short-chain oligomers and glucose [22].This finding accompanied by an increase in the carboxylic content, and the extent of the ZnO NPs increase by increasing the amount of carboxyling groups. The atomic weight % of ZnO value is higher, the greater the loss in weight, regardless of the used polyester fabrics.

4.2 Polyester fabrics treated by alkali before cellulases

PET fabrics had the lowest degradation rate with less than 2.0% weight loss. This is a direct consequence of the chemical and physical structure of polyester fabrics and specific activity of the celluloses toward cellulosic fibers, (**Table 1**), so in order to

Fabrics	Weight loss %	Carboxylic content (meq/100 gr. Fabric)	Zn content (atomic %) estimated by EDX[*]
PET	0.0	3.30	0.0
PET+E	1.5	6.50	0.0
PET+E + ZnO			1.19
PET+H + E	3.4	10.8	0.0
PET+H + E + ZnO			1.53
PET/C	0.0	8.10	0.0
PET/C + E	4.2	13.3	0.0
PET/C + E + ZnO			1.33
PET/C + H + E	6.6	16.4	0.0
PET/C + H + E + ZnO			1.71

Enzymatic treatment conditions: (Cellulases): 3%, pH = 4.5, Time, 40 min, Temperature, 45°C, M:L, 1:15. Alkali treatment conditions: (NaOH), 0.25 mol/L, Time, 60 min, Temperature, 90°C, M:L, 1:50. Sol–gel treatment conditions: (ZnO), 0.4×10^{-1} mol/l; Curing Temperature, 150°C; Curing Time, 15 min. E, cellulases; H, alkali hydrolyzed.
[*]*According to AATCC test method (61-1989).*
[**]*According to Australia (AS)/New Zealand (NAS) Standard No. 4399 (1996).*

Table 1.
Effect of the cellulases treatment on the amount of carboxylic content and ZnO NPs loaded on PET and PET/C blend fabrics.

enhancement the bond ability of ZnO NPs loaded onto polyester fabrics, the surface textile modifications induced by cellulases treatment of PET and PET/C blend fabrics was enhanced by doing partial weight loss 3.4% with PET and 6.6% with PET/C using alkali hydrolysis before cellulases treatment. **Table 1** shows that increasing the oxygenated polar groups (OH and COOH) onto polyester fabrics able to enhance its ability to bind ZnO NPs in stable way on their surfaces where the atomic weight % of Zn loaded onto PET and PET/C were 1.53 and 1.71, respectively. This funding can be attributed to the action of NaOH on the surface of the polyester and short fibers by partial hydrolysis, which help the cellulases to be more effective, then the Zn ONPs is attached to the modified textile surfaces by exchange with the carboxylic groups.

4.3 Formation of ZnO NPs on polyester fabrics

The dispersion solution prepared as mentioned before was applied directly to the pre-activated PET and PET/C blend fabrics, and ZnO NPs is fixed during the thermal treatment. The preparation of ZnO NPs in the nanometer range can be effectively conducted through the hydrolysis and condensation of zinc alkoxide in aqueous media. The chemical reactions that occur during this synthesis are explained as follow:

$$M\,(OR)_n + H_2O \rightarrow M(OH)\,(OR)_{n-1} + ROH \qquad (1)$$

$$M\,(OH)\,(OR)_{n-1} + M\,(OR)_n \rightarrow (RO)_{n-1}MOM\,(OR)_{n-1} + ROH \qquad (2)$$

$$2\,M\,(OH)\,(OR)_{n-1} \rightarrow (RO)_{n-1}MOM\,(OR)_{n-1} + H_2O \qquad (3)$$

Interaction of alkoxides with water yields precipitates of hydroxides, hydrates, and oxides. The precipitate particles usually range in size from 0.01 to 1 μm. So we can easily produce nanoparticles. Metal alkoxides undergo hydrolysis very easily; the hydroxyl metal alkoxide product can react by a further condensation reaction to form polymerizable species.

4.4 Characterization of polyester fabrics loaded with ZnO NPs

The verification of ZnO NPs on the surface of PET fabrics was confirmed by EDX analysis. EDX spectra of the PET fabrics loaded with ZnO NPs after five washing cycles are shown in **Figure 1**. It is noteworthy to conclude on the basis of these spectra that, the precipitated substance consists mainly of Zn and O_2. This demonstrates that ZnO is still available on the surface of the polyester fabrics (**Table 1**) even after five washing cycles (25 home washings). EDX measurements also reveal higher Zn content on hydrolyzed and treated polyester fabrics by cellulases more than treated fabrics by cellulases only (Zn atomic weight % was 1.19 increased to 1.33 in case of PET fabric, on the other hand 1.33 up to 1.71 with PET/C fabric). This means that ZnO NPs have sufficient adhesion toward the activated PET fabrics either by cellulases or by alkali treatment followed by cellulases.

4.5 Surface topography

4.5.1 Scan electron microscope (SEM)

In order to investigate the morphology of the modified polyester fabrics and loaded by ZnO NPs, SEM images of samples were recorded in **Figure 1**. **Figure 1** shows the
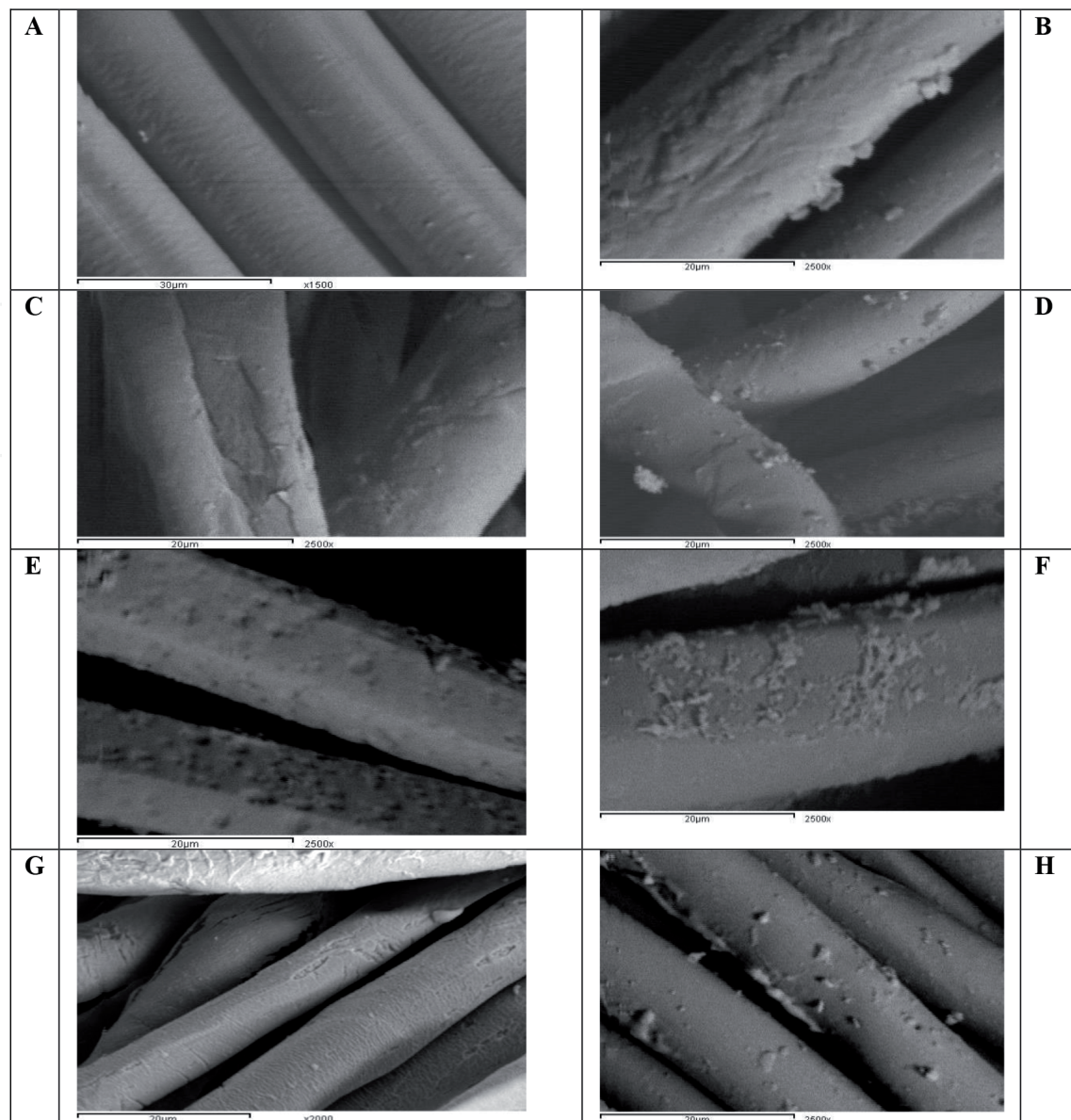
Figure 1.
SEM micrographs of activated PET and PET/C blend fabrics and loaded with ZnO NPs (1000×). (A) PET+E; (B) PET+ E + ZnO; (C) PET/C + E; (D) PET/C + E + ZnO; (E) PET+H + E; (F) PET+H+ E + ZnO; (G) PET/C + H + E; (H) PET/C + H + E + ZnO. *After five washing cycles according to AATCC test method (61-1989). E, cellulases; H, alkali hydrolyzed.*

images of the activated and treated fabrics followed by five washing cycles. **Figure 1A** and **C** show that the surfaces of treated PET and PET/C blend fabrics with cellulases are clean and smooth. After treatment by alkali before cellulases, a few pits were appeared on the surfaces of PET and PET/C, the latter have gained a roughness on fabric surfaces (**Figure 1E** and **G**). The treated polyester fabrics by sol-gel (**Figure 1B**, **D**, **F** and **H**) are covered by a thinner uniform surface layer; a continuous deposited material is shown clearly. Based on the images seen in **Figure 1**, the following can be concluded:

1. The surfaces of treated PET and PET/C fabrics by enzyme are clean and smooth (**Figure 2**). A partial hydrolysis by cellulases imparted the fabrics a smooth surface with improved resiliency and soft handle. This is due to the amount of weight reduction along with elimination of hairiness on the fabric surface, thereby minimizing stiffness and thickness as well as imparting a smooth surface.

2. PET and PET/C fabrics hydrolyzed with alkaline solutions before treatment with enzyme are characterized with pits and grooves. The treatment with ZnO

leads to blocking of these defects and formation of thin layer of active substrate on the fiber surface (**Figure 1**).

3. The treatment of the fabrics with ZnO leads to the formation of some deposits on the surface of treated fabrics. The shape and the size of such deposits vary according to the fabrics used during the enzymatic treatment.

4.5.2 EDX

The surface topography of PET and PET/C blend fabrics was investigated using EDX technique (**Figure 2**). Treatment of polyester fabrics with ZnO NPs activated with cellulases only or after alkali hydrolysis is also accompanied with the formation of precipitates (**Figure 1**). This is reflected on the amount of ZnO NPs percentage on the fiber's surface (**Table 1**). The above mentioned changes that took place on the surface topography of polyester fabrics loaded with ZnO NPs are a direct indication that ZnO NPs are directly attached to the fabrics surfaces.
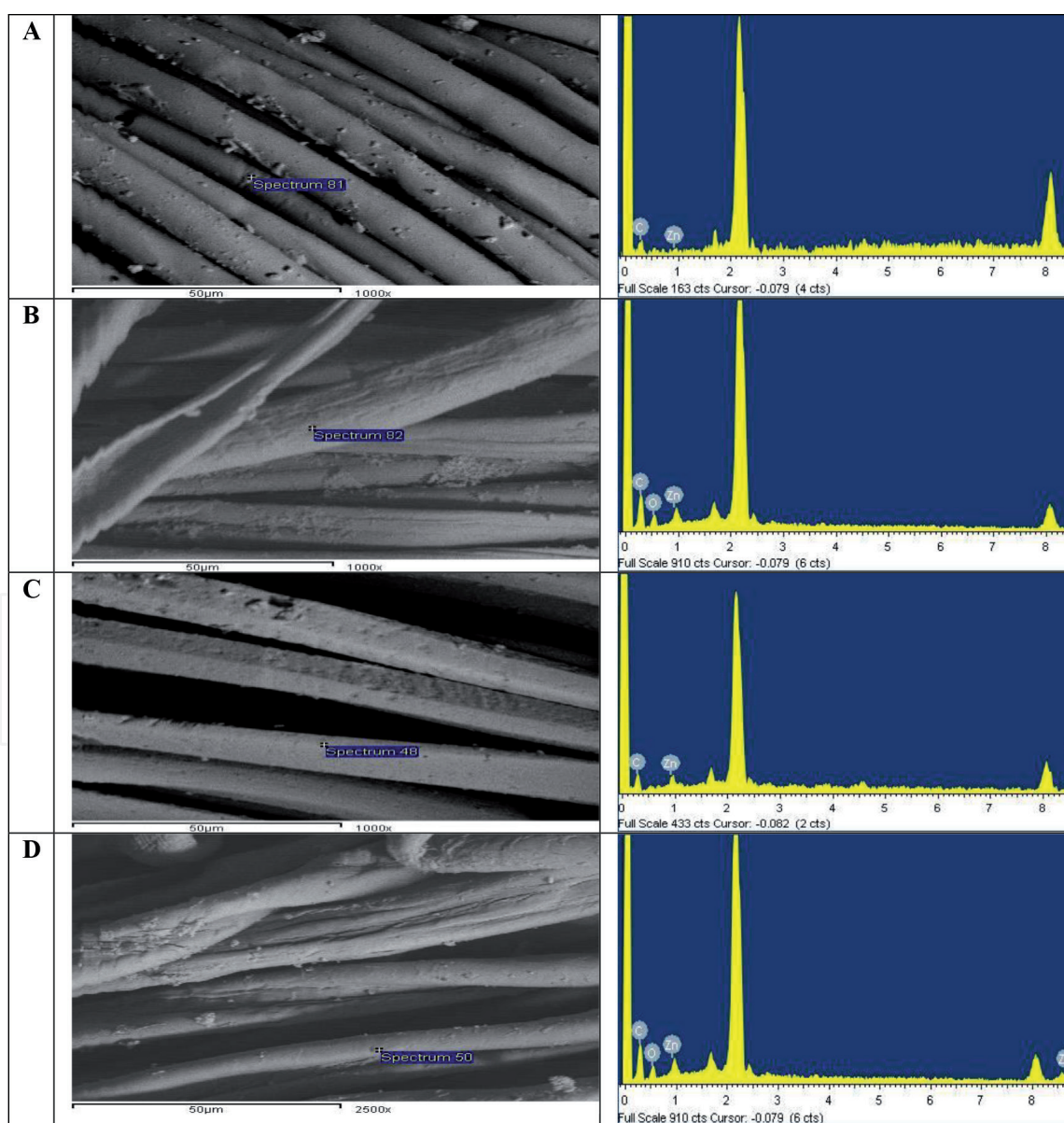
Figure 2.
EDX micrographs of activated PET and PET/C blend fabrics and loaded with ZnO NPs (1000×). (A) PET+ E + ZnO; (B) PET/C + E + ZnO; (C) PET+H+ E + ZnO; (D) PET/C + H + E + ZnO. *After five washing cycles according to AATCC test method (61-1989). E, cellulases; H, alkali hydrolyzed.*
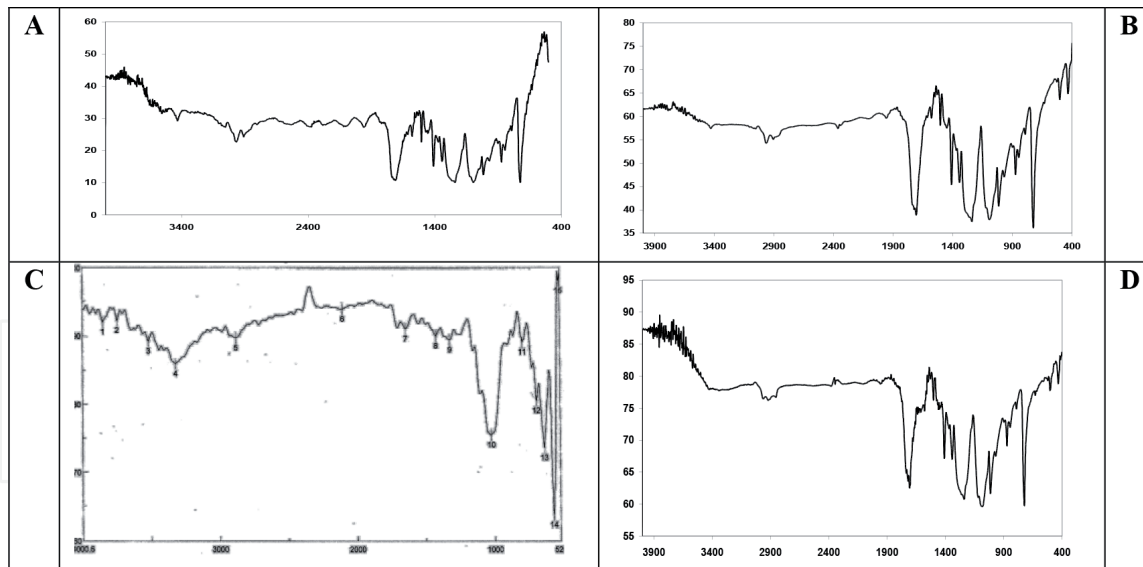
Figure 3.
FT-IR spectra of activated PET fabrics and loaded with ZnO NPs (1000×). (A) PET+ E; (B)
PET/C + E + ZnO; (C) PET+H+ E; (D) PET/C + H + E + ZnO. After five washing cycles according to AATCC
test method (61-1989). E, cellulases; H, alkali hydrolyzed.*
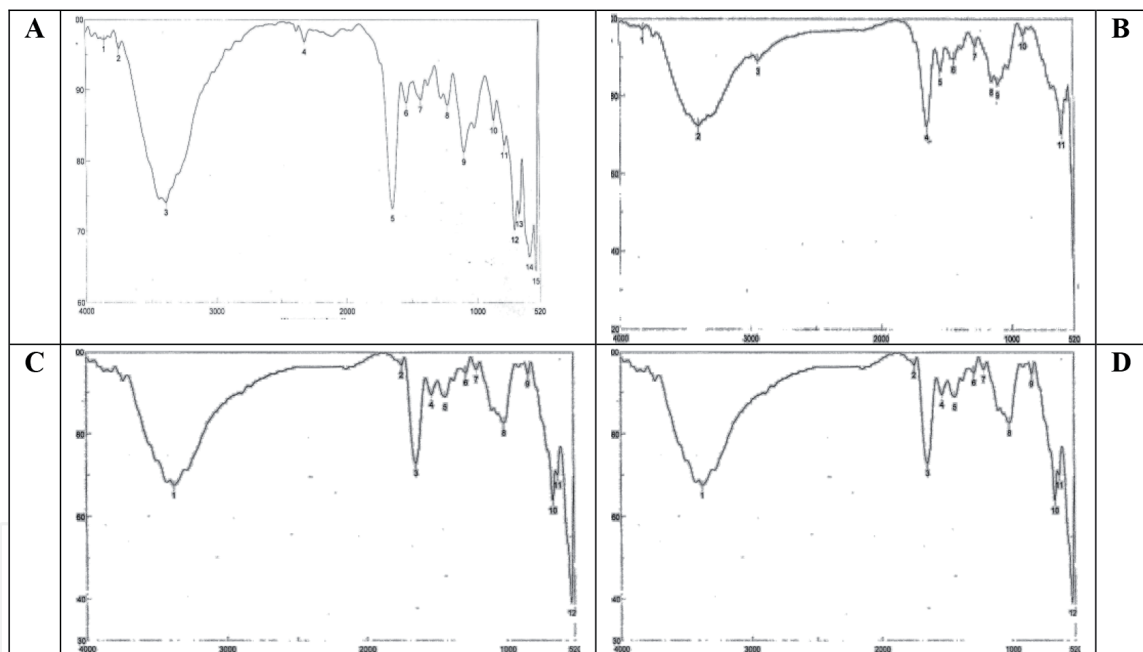
Figure 4.
FT-IR spectra of PET/C fabrics activated and loaded with ZnO NPs.(A) PET/C+ E; (B)
PET/C + E + ZnO;(C) PET/C + H+ E;(D) PET/C + H + E + ZnO.* After five washing cycles according to
AATCC test method (61-1989) E, cellulases; H, alkali hydrolyzed.*

4.5.3 FT-IR

Evidently, both enzymatic and alkali hydrolysis before activation led to a
substantial shift in the chemical structure of the surfaces of polyester fabrics. The
FTIR spectrum (**Figures 3** and **4**) of parent polyester fabric shows absorptions at
1649–1712, 3408–3388, and 2317 cm^{-1}, which are typical to those of C=O, OH,
and CH stretching, respectively. New bands at 640 and 660 cm^{-1}, respectively, are
observed in the spectrum PET and PET/C blend fabrics activated with cellulases
and alkali hydrolyzed before activation, which can correspond to Zn-O of the new
bonds PET + ZnO and PET/C blend + ZnO. The presence of this band can support

the ionic character of the new band formed due the addition of ZnO NPs to enzymatic and alkali hydrolyzed fabrics.

The FT-IR spectrum of activated PET and PET/C blend fabrics with enzyme and/or alkali hydrolysis and loaded by ZnO NPs (**Figures 3** and **4**) shows that new characteristic peaks are appeared and located at around 665 and 770 cm^{-1}, as well as 794 cm^{-1}, respectively. These peaks are corresponding to Zn-O bond. The similar finding was reported by Hong et al. [23]. During this study, we found that only activated surfaces were able to fix ZnO NPs from dispersion solutions.

4.5.4 Antimicrobial activity

The antimicrobial activity of PET and PET/C blend fabrics activated with cellulases on one hand, and with alkali hydrolysis followed by enzyme, on the other hand, and loaded with ZnO NPs, was investigated against *B. mycoides* (Grampositive), *E. coli* (Gram-negative), and *C. albicans* (nonfilamentous fungus). The activity by diffusion is quantified by the measurement in millimeters of the width of the zone of inhibition around the sample. The antimicrobial efficacy of PET and PET/C fabrics modified with ZnO NPs after activation using distinct techniques is shown in **Table 2**. It is seen from the data listed in this **Table 2** that, all polyester fabrics showed, after five washing cycles, high antimicrobial activity against the previously mentioned three microorganisms. In fact, the inhibition zones for all tested polyester fabrics samples are significant, whereas no dedication is found for all untreated fabrics. The role of activation of polyester fabrics with cellulases after alkali hydrolysis before loading with Zn ONPs on the antimicrobial activity seems to be more significant as the samples were laundered repeatedly in Launder-Ometer. This demonstrates the validity of the enzymatic activation of PET and PET/C blend fabrics on its antimicrobial finishing with ZnO NPs.

4.5.5 Ultraviolet protection properties

The effect of activation of PET and PET/C blend fabrics either with cellulases or by alkali hydrolysis before enzymatic treatment and before loading with ZnO NPs on UV protection efficiency was investigated. The rate of UV protection was

Fabrics	Inhibition zone diameter (mm) in case of loaded polyester fabrics with ZnO NPs[*]		
	B.m	*E.c*	*C.a*
PET	−ve	−ve	−ve
PET+E + ZnO	18	20	18
PET+H + E+ ZnO	21	22	20
PET/C	−ve	−ve	−ve
PETC+E + ZnO	18	20	19
PET/C + H + E + ZnO	20	22	21

Enzymatic treatment conditions: (Cellulases), 3%, pH = 4.5, Time, 40 min, Temperature, 45°C, M:L, 1:15. Alkali treatment conditions: (NaOH), 0.25 mol/L, Time, 60 min, Temperature, 90°C, M:L, 1:50. Sol-gel treatment conditions: (ZnO), 0.4×10^{-1} mol/l; Curing temperature, 150°C; Curing time, 15 min. E, cellulases; H, alkali hydrolyzed.
[*]*According to AATCC test method (61-1989).*
[**]*According to Australia (AS)/New Zealand (NAS) Standard No. 4399 (1996).*

Table 2.
Effect of activation of PET and PET/C blend fabrics on its antimicrobial activity.

Fabrics	UPF values after no of washing cycles			
	1[*]		5[*]	
	UPF value	UPF[**] rating	UPF value	UPF[**] rating
PET	19.0	Good	9.6	Poor
PET+E	17.3	Good	11.3	Poor
PET+E + ZnO	28.2	V. Good	18.2	Good
PET+H + E	16.8	Good	15.2	Poor
PET+H + E + ZnO	31.2	V. Good	27.4	V. Good
PET/C	18.5	Good	12.8	Poor
PETC+E	20.1	Good	14.2	Poor
PET/C + E + ZnO	51.1	Excellent	35.4	V. Good
PET/C + H + E	19.2	Good	14.7	Poor
PET/C + H + E + ZnO	68.4	Excellent	55.2	Excellent

Enzymatic treatment conditions: (Cellulases), 3%, pH = 4.5, Time, 40 min, Temperature, 45°C, M:L, 1:15.
Alkali treatment conditions: (NaOH), 0.25 mol/L, Time, 60 min, Temperature, 90°C, M:L, 1:50. Sol-gel treatment
conditions: (ZnO), 0.4×10⁻¹ mol/l; Curing temperature, 150°C; Curing time, 15 min. E, cellulases; H, alkali
hydrolyzed.
[*]According to AATCC test method (61-1989).
[**]According to Australia (AS)/New Zealand (NAS) Standard No. 4399 (1996).

Table 3.
Effect of activation of PET and PET/C blend fabrics on its UPF values.

quantified and expressed via UPF values that are given in **Table 3**. It was found that the UPF factors for untreated PET, PET/C blend fabrics are equal to 9.6 and 12.8, respectively. Activation with cellulases followed by the ZnO NPs deposition onto the above mentioned polyester fabrics led to a significant increase in UPF factor to the level corresponding to UPF rating of 25+, which assigns the very good UV protection, after five washing cycles. These results imply good laundering durability of polyester fabrics and excellent laundering durability of polyester fabrics activated with enzyme and loaded with ZnO NPs. It was found that PET and PET/C blended fabrics activated with alkali hydrolysis before enzymatic treatment and loaded with ZnO NPs showed better UV protection efficiency compared to enzymatic treated ones 50+, which assigns the excellent UV protection. The UV protection efficiency of these fabrics is higher even after five washing cycles, indicating the excellent laundering durability.

5. Conclusions

The present study illustrates a simple method for improving the binding ability of ZnO NPs to PET and PET/C blend fabrics. This method is based on applying the biological activation method by cellulases before loading polyester fabrics with ZnO NPs by sol-gel method. These loaded fabrics were characterized by SEM, EDX, and FT-IR spectroscopy, which confirmed that ZnO NPs is chemically bonded to PET fabrics. The effect of surface activation method on antimicrobial activity and UV protection efficiency of polyester fabrics was evaluated. It was found that PET and PET/C fabrics activated with enzyme before its treatment with ZnO NPs showed better antimicrobial and UV protection properties compared to parent fabrics. Activated polyester fabrics even after five washing cycles showed excellent antimicrobial activity and UV protection effectiveness, revealing the excellent durability

of laundering. In general, the results obtained in this study show the possibility of implementing the technique of biological surface activation to attach the ZnO NPs to polyester fabrics. The addition of this technology to polyester finishers offers an environmental friendly and mild alternative to the chemical and mechanical finishes currently being used in industry

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