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ORIGINAL ARTICLES

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

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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.

Key words: Polyester fabric, alkali hydrolysis, Cellulases, enzymatic hydrolysis, ZnO NPs, Sol-Gel, EDX, SEM, FT-IR, Antimicrobial, UPF.

Introduction

Loading of the nanoparticles onto the textile materials gained much scientific interest ***[****Bozzie et al 200-Kiwi et al 2010]*. Keeping in mind that COOH and OH groups are potential sites for binding of NPs, both, chemical and physical treatments proposed so far, rely mainly on the introduction of these groups to the textile materials surfaces. Several surface modification methods for synthetic fibers have been described, for example, the use of chemical finishers based on carboxyl containing polymers *[*Soane et al 2008***].*** Alkaline hydrolysis treatments are unspecific and result in strength and weight losses ***[****Shukla et al 1997 – Zeronian 1989]*. Ionized gas treatment of PET materials using plasma has also been investigated to introduce hydrophilic groups at the surface of the polymer *[*Negulescu et al 2000*]*. 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 *[Chan et al 1996]*.

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 *[Guebitz et al 2008 – Silva et al 2010]*. 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 *[Sarkar et al 2004]*. 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 [*Cavoco- Paulo et al 1996; Klahorst et at 1994; Ibrahim et al 1999*].

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 [*Koo, et al 1994*]. 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 [*Shalaby, et al 2007*].

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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.

Experimental Work:

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.

Enzyme:

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

Microorganisms:

Bacillus mycoides (*B.m*) (Gram positive bacterium), *Escherichia coli* (E.c) (Gram negative bacterium), and *Candida albicans* (*C.a*) (nonfilamentous fungus) were used for estimation of antimicrobial potency of control and treated 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.

Culture medium:

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

Methods:

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 *Moafi et al 2011*. Zinc acetate dihydrate was used as zinc oxide source. In a typical procedure 0.01 mol of zinc actate dihydrate was dissolved in 50 ml of methanol and heated at 50°C along with stirring for 30 minutes, 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 60minutes, making precursor solution B. In order to make ZnO nano – sol, solution B was added into solution A dropwise under constant stirring for 30 minutes and then mixture was heated at 50°C for further 30 minutes. Subsequently, after continuous stirring for 2hours and cooling at room temperature, a homogenous and transparent sol was obtained.

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 fabrics 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 minutes, 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 Cellulases:

The alkaline treatment of PET and PET/C Blend fabrics was carried out according to the method described by [*Shalaby et al 2007*] 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 minutes), 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 dessicator, 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.

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 pick up 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 minutes. In order to evaluate the ZnO NPs adhesion to the polyester fabrics, the treated fabrics were washed five times according to a standard method AATCC Test Method (61-1989).

Analysis:

Carboxylic content was determined according to the method described by [*Daul et al 1953*].

Antimicrobial Activity:

Antimicrobial activity of PET and PET/C blend fabrics loaded with ZnO NPS was quantified using the following method.

Disk diffusion method, in this method the antimicrobial potency by diffusion was quantified by measurement in millimeters of the width of the zone of growth inhibition around the sample according to AATCC standard test method [*Koneman et al 1997*].

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.

FT-IR:

The chemical structure was determined using the Fourier transformation infrared (FT-IR) spectrometer, model NEXUS 670, NICOLET USA. The measurements were carried in spectral range from 4000 to 500 cm^{-1}. Reflection percentage measurement technique was applied (R %) to all investigated samples.

UPF factor:

UPF factor was measured using UV- Shimadzu 3101 P C -Spectrophotometer. It is a double beam direct ratio measuring system. It consists of the photometer unit and a pc computer. UPF factor was determined

according to the method described in Australian / New Zealand standard AS / NZS 4399: 1996 [*Gambichler et al 2001*].

Results and Discussion

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 [*Lili et al 2010*], 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 has a higher specific activity towards 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 [*Rita et al 2008*].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.

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 towards cellulosic fibers, (Table1), so in order to 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) show that, increasing the oxygenated polar groups (OH and COOH) onto polyester fabrics able to enhances 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.

Table 1: Effect of the Cellulases Treatment on the Amount of Carboxylic Content and ZnO NPs Loaded on PET and PET/C Blend Fabrics.

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, 40minutes, Temperature, 45°C, M: L, 1:15. Alkali Treatment Conditions: [NaOH], 0.25 mol/L, Time, 60 minutes, Temperature, 90°C, M: L, 1: 50. Sol-gel Treatment Conditions: [ZnO], $0.4x10^{-1}$ mol/l; Curing Temperature, 150˚C; Curing Time, 15 min. *According to AATCC Test Method (61-1989). **According to Australia (AS) / New Zealand (NAS) Standard No. 4399 (1996). E=Cellulases, H= Alkali hydrolyzed

Formation of ZnO NPs on Polyester Fabrics:

The dispersion solution prepared as mention before was applied directly 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:

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

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

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

Interaction of alkoxides with water yields precipitates of hydroxides, hydrates, and oxides. The percopitate 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.

Characterization of polyester Fabrics Loaded with ZnO NPs:

The presence 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. On the basis of these spectra, it is noteworthy to conclude that the deposited material consisted of Zn and oxygen. This shows that even after five washing cycles (25 home washings), ZnO is still present on the PET fabrics surface Table (1). 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 incase 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 towards the activated PET fabrics either by cellulases or by alkali treatment followed by cellulases.

Surface Topography:

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 (Fig. 1). Fig.1 shows the images of the activated and treated fabrics followed by five washing cycles. Figures 1A and 1C 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 Fabric Surfaces (Figures 1E and 1G). The treated polyester fabrics by sol-gel (Figures 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.

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 (Figure1). This is reflected on the amount of ZnO NPs percentage on the fiber's surface (Table 1). The above mentioned changes which 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.

FT-IR:

Evidently, both enzymatic and alkali hydrolysis before activation induced a significant change in the chemical composition of the polyester fabrics surfaces. The FTIR spectrum (Figures 3 and 4) of untreated 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.

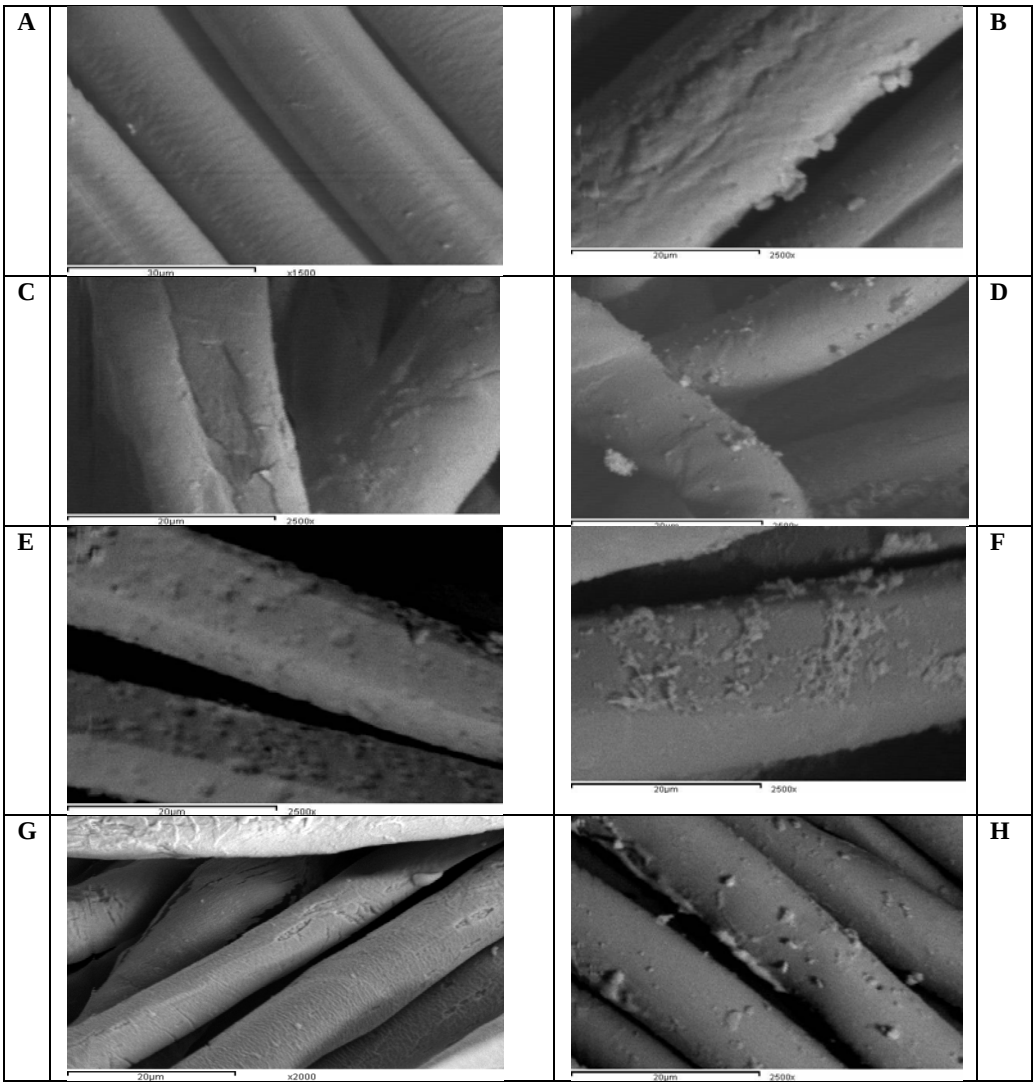

Fig. 1: SEM Micrographs of Activated PET and PET/C Blend Fabrics and Loaded with ZnO NPs* (1000x). (A) PET+E; (B) PET+ E +ZnO; (C) PET/C +E; (D) PET/C +E +ZnO; (E) PET+H+E; (F) PET+H+ E + ZnO; (G) PET/C +H+E; (H) PET/C+H +E +ZnO. *After Five Washing Cycles According to AATCC Test Method (61-1989). E=Cellulases, H= Alkali hydrolyzed

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 cm^{-1} 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 2009*]. During this study we found that only activated surfaces were able to fix ZnO NPs from dispersion solutions.

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 Gram-positive *B. mycoides*, Gram-negative, *E. coli* and non-filamentous fungus *C. albicans*. The activity by diffusion is quantified by the measurement in millimeters of the width of the zone of inhibition around the sample. Table (2) indicates the antimicrobial activity of PET and PET/C blend fabrics loaded with ZnO NPs after activation with different methods. It is seen from the data listed is this Table (2) that, all polyester fabrics showed, after 5 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 proves the feasibility of the enzymatic activation of PET and PET/C blend fabrics on its antimicrobial finishing with ZnO NPs.

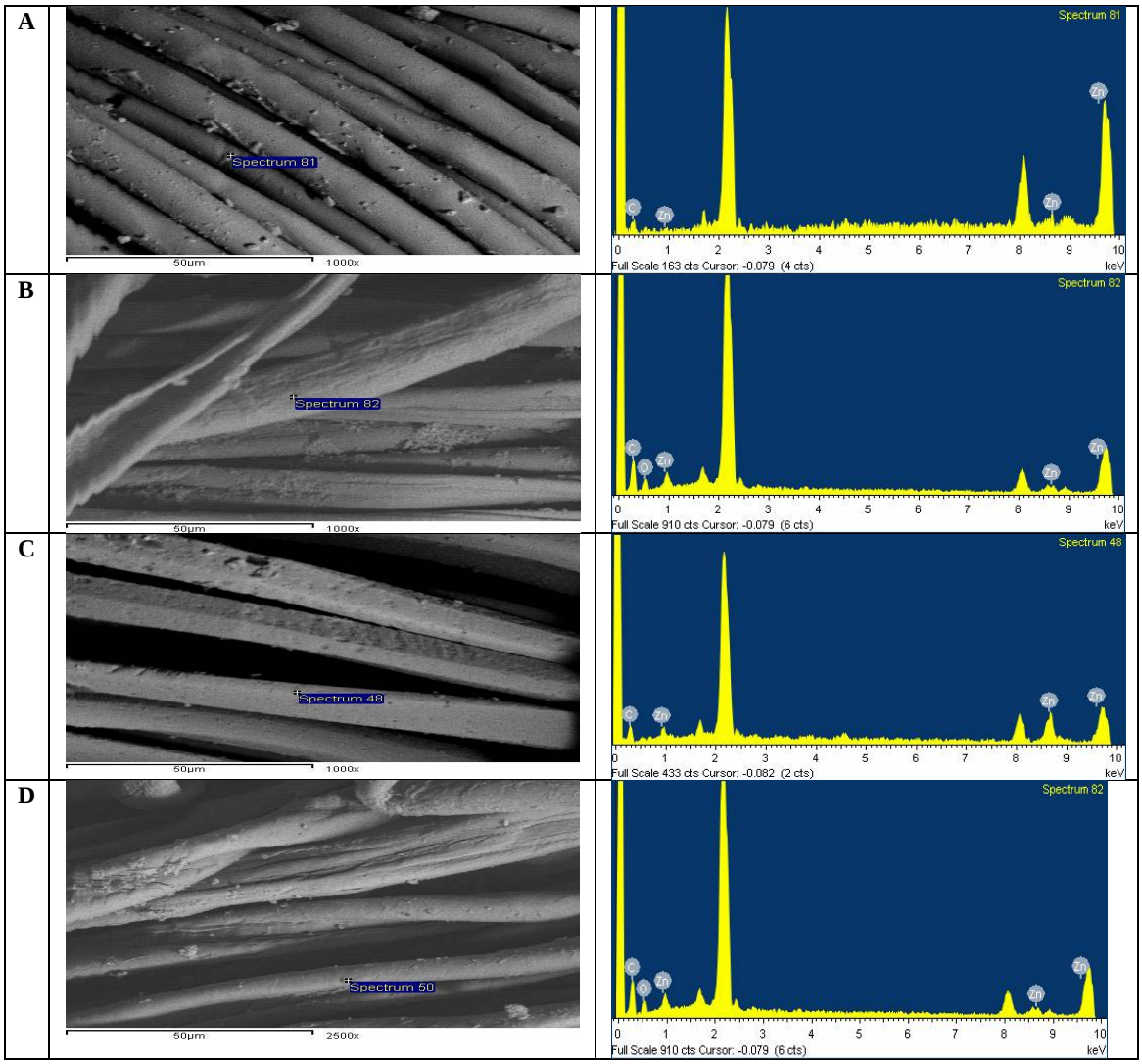

Fig. 2: EDX Micrographs of Activated PET and PET/C Blend Fabrics and Loaded with ZnO NPs*(1000x). (A) PET+ E +ZnO; (B) PET/C +E +ZnO; (C) PET+H+ E +ZnO; (D) PET/C+H +E + ZnO . *After Five Washing Cycles According to AATCC Test Method (61-1989). E=Cellulases, H= Alkali hydrolyzed

Table 2: Effect of Activation of PET and PET/C Blend Fabrics on its Antimicrobial Activity.

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, 40minutes, Temperature, 45°C, M: L, 1:15. Alkali Treatment Conditions: [NaOH], 0.25 mol/L, Time, 60 minutes, Temperature, 90°C, M: L, 1: 50. Sol-gel Treatment Conditions: [ZnO], $0.4x10^{-1}$ mol/l; Curing Temperature, 150˚C; Curing Time, 15 min.*According to AATCC Test Method (61-1989). *According to Australia (AS) / New Zealand (NAS) Standard No. 4399 (1996). E=Cellulases, H= Alkali hydrolyzed

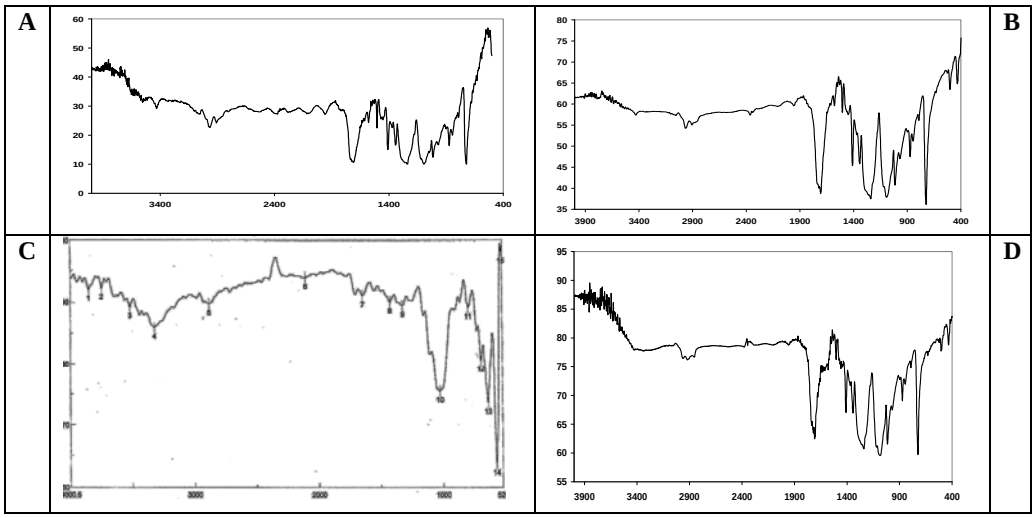

Fig. 3: FT-IR Spectra of Activated PET Fabrics and Loaded with ZnO NPs* (1000x). (A) PET+ E; (B) PET/C +E +ZnO; (C) PET+H+ E; (D) PET/C+H +E +ZnO.*After Five Washing Cycles According to AATCC Test Method (61-1989). E=Cellulases, H= Alkali hydrolyzed

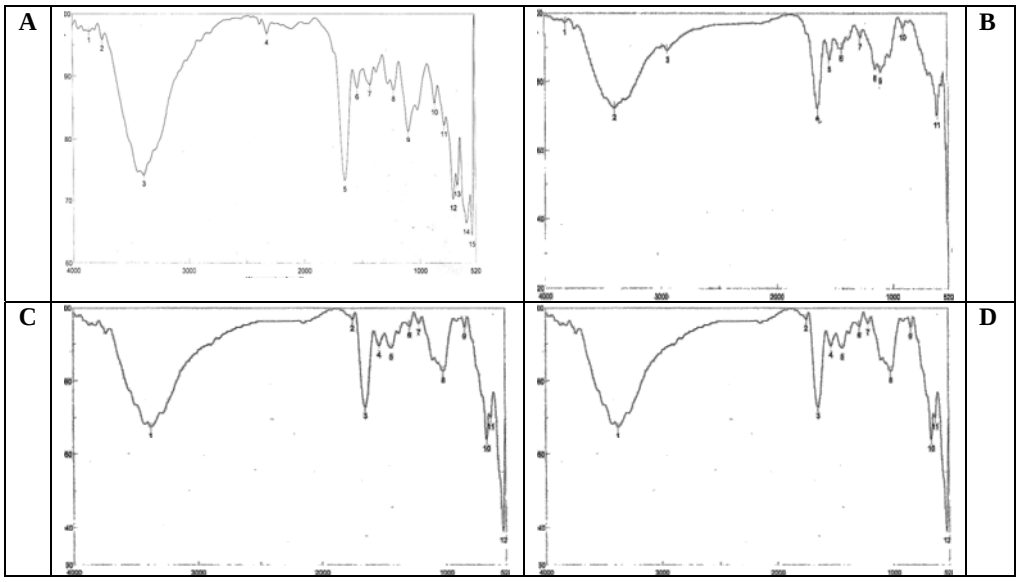

Fig. 4: FT-IR Spectra of PET/C Fabrics Activated and Loaded With ZnO NPs*.(A) PET/C+ E; (B) PET/C +E +ZnO;(C) PET/C+H+ E;(D) PET/C+H +E +ZnO.*After Five Washing Cycles According to AATCC Test Method (61-1989) E=Cellulases, H= Alkali hydrolyzed

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 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.

Table 3: Effect of Activation of PET and PET/C Blend Fabrics on its UPF Values.

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, 40minutes, Temperature, 45°C, M: L, 1:15. Alkali Treatment Conditions: [NaOH], 0.25 mol/L, Time, 60 minutes, Temperature, 90°C, M: L, 1: 50. Sol-gel Treatment Conditions: [ZnO], $0.4x10^{-1}$ mol/l; Curing Temperature, 150˚C; Curing Time, 15 min.*According to AATCC Test Method (61-1989). **According to Australia (AS) / New Zealand (NAS) Standard No. 4399 (1996). E=Cellulases, H= Alkali hydrolyzed

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 unactivated fabrics. Activated polyester fabrics exhibited outstanding antimicrobial activity and UV protection efficiency even after five washing cycles, indicating the excellent laundering durability. In general, the received data in the present work indicate the possibility of applying biological surface activation method to bind the ZnO NPs to polyester fabrics. 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

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