Egyptian Journal of Chemistry

New Strategy to Enhance Transfer printing and Functional Finishing of Polyester fabric

Heba M. Khalil

Faculty of Applied Arts, Printing, Dyeing and Finishing Department, Helwan University, Cairo, Egypt

Abstract

This research work is aimed to upgrade the transfer printability, the UV-protection and antibacterial functionalities of polyester woven fabric via alkali-treatment followed by post-loading of functional agents namely PVP, Triclosan, Chitosan, metal oxide nano particles MO-NPs i.e. TiO_2, ZrO_2, ZnO-NPs individually. The modified fabric samples were subsequently transfer printed with certain disperse dyes. The effect of treatment sequence and type of the used additive on the printability and functionality of the polyester prints were investigated. The results revealed that the creation of hydrophilic active sites namely carboxyl and hydroxyl end groups at the fabric surface, as well as loading and fixation of the used functional agents onto the finish/fabric matrix brought about polyester prints with a darker depth of shades, excellent antibacterial activity, and higher UV-protecting functionality compared with the untreated one

Keywords: *Polyester fabric; Transfer printing; Nanomaterials; Functional finishing; Multifunctional finishes of polyester prints.*

1. Introduction

Polyester fabric is one of synthesized fabrics that showed several excellent properties namely, dimensional stability, wrinkle-resistance and blendability with other natural and/or man-made fabrics such as cotton, wool and viscose, However, polyester fabric is hydrophobic and exhibits numerous drawbacks such as, crystallinity, low moisture regain, pilling, generating of electrostatic charges and low chemical reactivity to and dyeability with ionic dyestuffs [1-3].

Many attempts have been carried out to modify the polyester surface properties such as alkaline hydrolysis [4-6] and enzyme treatment [7-9] to enhance the hydrophilicity and to create hydrophilic functional groups, i.e. hydroxyl and carboxyl groups [4-9]. Additionally, plasma [2, 9-11] and laser treatments [12, 13] have been utilized, as an eco-friendly dry tools, for surface and chemical modification of poly (ethylene terephthalate) fibers along with upgrading its dyeing properties [2, 10-13]. Moreover, many efforts have been made to develop surface modification and functionalization of polyester fabrics via aminolysis of polyester to create amino functional groups on the fiber surface [14, 15],

or by grafting of chitosan moieties onto the polyester surface thereby enhancing its hydrophilic character as well as dyeability with anionic dyes [16-18].

On the other hand, disperse dyes are considered to be the only suitable dyestuffs that used for dyeing polyester fibers, since they have the ability for sublimation under heating, followed by transferring in vaporized state from paper to fabric surface. Transfer printing technique is one of the most proper techniques for coloration of PET fabrics. Additionally, transfer printing is considered to be an eco-friendly process for several environmental advantages such as less water and energy consumption and less effluent generation [19].

The present study aims to enhance the multifunctional properties of polyester fabric namely antimicrobial and UV-protecting properties via pretreatment of polyester fabric with alkali in order to create hydroxyl and carboxyl polar groups onto the surface of the treated samples, followed by post-finishing with PVP, Triclosan, Chitosan or metal oxides MO-NPs namely TiO_2, ZrO_2, ZnO-NPs individually, Finally, the finished PET were transfer printed with disperse dyes to impart durable function

properties to printed PET fabrics. The imparted function/coloration properties of the printed fabric samples have been evaluated and reported.

2. Experimental

2.1. Materials

The plain weave white polyester fabric (PET, 220 g/m_2), ZrO_2-NPs (10% dispersion, Aldrich), ZnO-NPs (10-30 nm), Skyspring Nanomaterials Inc., USA), TiO_2-NPs (mixture of anatase and rutile, (10-30 nm), Skyspring Nanomaterials Inc., USA), Chitosan (degree of deacetylation > 82.9%, Sigma), PVP (Polyvinylpyrrolidone average mol. wt. 360.000, Sigma), Ruco®-BAC MED (nonionic antibacterial finishing agent-based on diphenyl alkane derivative of triclosan- Rudolf Chemie), Disperse® Red FB 60 and Disperse® Blue 2BL 56, Sinochem Ningbo, China), PEG-300 were used. Other chemicals such as acetic acid, sodium hydroxide, etc. were of laboratory reagent grade.

2.2. Methods

2.2.1. Alkali treatment

PET-fabric was immersed in an aqueous solution containing NaOH (25 g/L), roll squeezed to a wet-pick up of 85%, at speed of 30m/min, with a pressure of 2 bars to remove excess solution and steam fixed at 110ºC using a Korean weight reduction machine. The alkali treated fabric samples were then washed, neutralized with acetic acid, thoroughly rinsed with warm water, and dried and thermosetted at 200ºC for 30 sec.

2.2.2. Post treatment of alkali-treated PET fabric samples

The alkali-treated polyester fabric samples were post treated with PVP (0- 20% owf, 2ml/L acetic acid), Chitosan (0- 5% owf, 2% acetic acid), Triclosan (0-20% owf), ZrO_2- NPs (0- 20% owf), TiO_2-NPs (0-5% owf) and ZnO-NPs (0- 10% owf), and 2g/L PEG-300, L.R 1:10, at 50º C for 30 min, followed by drying at 100 ºC for 2 min.

2.2.3. Post-Transfer Printing

The finished polyester fabric samples were transfer printed using manual heat transfer press at 180 ºC for 90 seconds. The transfer printed samples were allowed to cool at room temperature before the removal of transfer printing paper. The sequence of polyester treatment is presented in Fig 1.

2.3. Test methods

The loss in weight of alkali-treated PET fabric was calculated according to the following equation: %WL= (W1-W2)/W1 X 100, where W1 and W2 are the weight of fabric before and after alkali treatment, respectively.

Depth of the obtained prints was measured using an automatic filter spectrophotometer and expressed as K/S values, $K/S = (1-R)^2/2R$, where R is the reflectance, K and S are the absorption and scattering coefficient, respectively [20, 21] .

The nitrogen content was determined according to Kjeldahl method.

Antibacterial activity assessment against (G+ve, *S. aureus*) and (G-ve, *E. Coli*) was evaluated qualitatively according to AATCC Test Method (147-1988), and expressed as zone of growth inhibition (ZI, mm) [22, 23].

UV-protection (UPF) was calculated according to the Australian/ New Zealand Standard (AS/NZS 4399-1996).

Scanning electron microscope (SEM) images for selected samples were obtained with Quanta SEM 250 FEG (Field Emission Gun) equipped with an energy – dispersive X-ray spectroscopy (EDX) with accelerating voltage – 30 KV FEI Co., Netherland for the surface composition analysis.
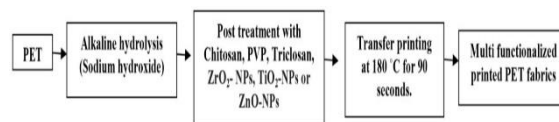

Fig. 1

3. Results and Discussion

3.1. Alkaline hydrolysis of PET-surface

Sodium hydroxide was used to modify polyester fabric-surface in order to increase its hydrophilicity via creating functional active groups such as -COO⁻ and –OH groups at the terminal of polyethylene terephthalate structure of the treated samples. The treated fabric sample showed a noticeable decrease in weight loss (13%) as a result of partial hydrolysis of ester-linkage in PET fabric as follow [24]:

PET- COO-PET + NaOH →
$$PET\text{-}COO^- Na^+ + HO\text{-}PET \quad (1)$$

3.2. Functional finishing using the nominated active materials

The impact of treatment sequences (Fig 1) and individually incorporation of active materials, in post-treatment step, on the functionality and printability of printed samples is demonstrated in

Table 1. Incorporation of active materials namely PVP (20%), Triclosan (20%) or Chitosan (5%) into the finishing bath formulations resulted in a noticeable increase in %N, K/S, antibacterial activity, and UV-protection of transfer printed fabric samples. The increment in colour strength (K/S) the improvement in the UV-protection properties and antibacterial activity of polyester prints, is a result of the positive role of pretreatment of polyester fabric using sodium hydroxide thereby increasing the extent of loading and fixation of PVP, Triclosan, or Chitosan onto the modified PET fabric. It can be clearly noticed from the given data in Table 1 that the imparted functionalities of modified-printed PET fabric samples are governed by the type of loaded active materials and followed the decreasing order [24]:

- Regarding the antibacterial activities against G+ve (*S. aureus*), G-ve (*E. coli*) bacteria: Chitosan > Triclosan > PVP > none.

- Regarding UV-blocking properties: Triclosan > PVP > Chitosan > none.

- Regarding K/S, of transfer printed fabric samples with disperse dyes: Disperse® Red FB 60 > Disperse® Blue 2BL 56.

The results revealed that including chitosan as a bio-active cationic polymer in the post-treatment bath formulation demonstrated the highest antibacterial activity, which can be attributed to the interaction of protonated amino groups in chitosan with bacterial cell surface and the subsequent cell membrane disruption, increase in the permeability of the cell membrane thereby leading to inhibition the bacteria growth [25, 26].

On the other hand, the Triclosan loaded polyester prints showed a good antibacterial activity which may described to the ability of Triclosan to inhibit fatty acid biosynthesis that leads to prevent cell membrane building and reproduction [27, 28].

3.3. Functional finishing using MO-NPs

Table 2 demonstrates that the impact of the treatment sequence, post-treatment with the nominated MONPs namely ZrO_2-NPs (20%), ZnO-NPs (20%) or TiO_2-NPs (5%), as a functional agent on the coloration and fictionalization of modified polyester prints. It is clear that i) incorporation of the nominated MO-NPs onto/into PET fabric samples brings about a tangible increase in the %N, K/S, an improvement in UV-protection ability and antibacterial activity against tested G+ve and G-ve pathogenic bacteria, ii) the improvement in the coloration and the imparted functional properties of the polyester prints reflects the positive role of surface modification in enhancing the extent of loading and fixation of MO-NPs onto the modified fabric surface, and iii) the improvement in the antibacterial activity of the MO-NPs loaded polyester samples is due to their photocatalytic character that led to generation of highly active oxygen species such as •OH, O•⁻, H_2O_2, etc. as presented in equations [29-32]:

$$MO - NPs + H\nu \xrightarrow{\text{light exitation}} e^- + h^- \qquad (2)$$

MO-NPs –loaded substrate   negative electron   positive hole

$$H_2O \leftrightarrow (H^+ + {}^-OH) \rightarrow {}^\bullet OH + H^+ \qquad (3)$$

$$O_2 + e^- \rightarrow O_2^{\bullet -} \qquad (4)$$

$$O_2^{\bullet -} + e^- + 2H^+ \rightarrow H_2O_2 \qquad (5)$$

$$O_2^{\bullet -} + H^+ \rightarrow HO_2^\bullet \qquad (6)$$

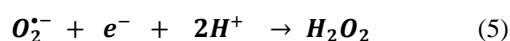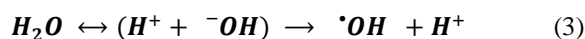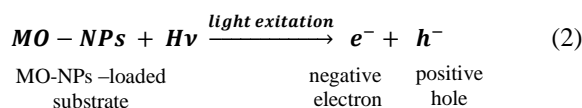$$H_2O_2 + e^- \rightarrow {}^\bullet OH + {}^-OH \qquad (7)$$

Table 1:Effect of treatment sequence and loading of active materials on coloration and functionalization of transfer printed PET fabric using different disperse colorants

Disperse colorants	[a] Treatment conditions	[b] Additives	N%	K/S	UPF	Antibacterial activity ZI (mm)	
						G-ve	G+ve
Disperse® Red FB 60	Untreated	None	0.27	15.01	110	0.0	0.0
		PVP	0.69	19.94	149	2.0	3.0
		Triclosan	0.38	17.86	169.5	4.0	0.5
		Chitosan	0.28	17.78	111.4	5.0	6.0
	NaOH treatment	None	0.42	19.88	154	0.5	0.6
		PVP	0.77	20.60	168.5	6.5	0.5
		Triclosan	0.56	22.42	189	10.5	6.5
		Chitosan	0.50	21.76	164.5	18.0	15.0
Disperse® Blue 2BL 56	Untreated	None	0.35	4.08	110	0.0	0.0
		PVP	0.38	6.71	101.3	3.0	2.0
		Triclosan	0.35	6.62	123	4.0	4.0
		Chitosan	0.34	5.39	89.3	5.0	4.0
	NaOH treatment	None	0.51	4.83	96.2	0.4	0.6
		PVP	0.60	5.61	114.4	5.0	0.3
		Triclosan	0.58	10.90	135.4	10.0	5.6
		Chitosan	0.50	6.62	101.7	14.0	12.0

a) Alkali treatment: NaOH (25 g/L), wet-pick up of 85%, at speed of 30m/min, with a pressure of 2 bars to remove excess solution and steam fixed at 110ºC.
b) Post-treatment with active materials: PVP (0-20% owf, acetic acid 2 ml/L), Triclosan (0-20% owf) OR Chitosan (0- 5% owf), 2% acetic acid, L.R. 1:10, treatment at 50˚ C for 30 min, drying at 100 C for 2 min.
Post-Transfer Printing: press at 180 ˚C for 90 seconds.
N%: nitrogen content; K/S: colour strength, ZI: zone of inhibition, G+ve: (*S. aureus*); G-ve: (*E. coli*); UPF: UV-protection factor
Loss in weight of alkali-treated PET = 13 %, UPF of untreated PET (before transfer printing) = 28

which in turn inhibit the growth of the pathogenic bacteria [33], iv) the enhancement in the UV protection of the MO-NPs treated PET samples is due to the ability of the loaded nano-particles to enhance the UV-blocking properties of the printed PET samples [32].

Additionally, the data from Table 2 revealed that the functionalities of the finished PET prints are governed by the type of loaded MO-NPs and follows the decreasing order:

- Antibacterial properties: ZnO-NPs > ZrO$_2$-NPs > TiO$_2$-NPs > none.
- UV-protection properties: TiO$_2$-NPs > ZnO-NPs > ZrO$_2$-NPs > none.
- Color strength (K/S) values of transfer printed fabric samples with disperse dyes: Disperse® Red FB 60 > Disperse® Blue 2BL 56.

3.4. SEM images and EDX spectra

Fig. 2 (a&b) & (c&d) illustrate the SEM images and EDX spectra of the loaded PET fabric samples with active materials namely chitosan and PVP and transfer-printed with disperse dye respectively.

Fig. 2 (a&c) showed some depositions onto the surface of the printed PET which may be attributed to chitosan or PVP coats along with the used disperse dye. While, the EDX patterns detected carbon and oxygen elements on all the samples spectra, as well as nitrogen element due to the presence of chitosan or PVP along with disperse dye molecules Fig. 2 (b&d).

On the other hand, Fig 3 presents the SEM images & EDX spectra of finished polyester prints preloaded with MONPs. The SEM images (Fig. 3 a&c) showed well deposition for the used MONPs.

Table 2: Effect of treatment sequence and loading of MONPs on coloration and functionalization of transfer printed PET fabric using different disperse colorants

Disperse colorants	[a] Treatment conditions	[b] Additives	N%	K/S	UPF	Antibacterial activity ZI (mm)	
						G-ve	G+ve
Disperse® Red FB 60	Untreated	None	0.27	15.01	110	0.0	0.0
		ZrO₂	0.58	18.67	142	8.0	7.0
		ZnO	0.40	17.24	363	18.5	14.0
		TiO₂	0.35	7.53	815	6.0	5.0
	NaOH treatment	None	0.42	19.88	154	0.5	0.6
		ZrO₂	0.65	21.82	219.5	15.0	10.5
		ZnO	0.52	14.70	529	20.0	16.0
		TiO₂	0.48	9.11	1226	6.0	4.0
Disperse® Blue 2BL 56	Untreated	None	0.35	4.08	110	0.0	0.0
		ZrO₂	0.55	8.19	135	5.3	4.1
		ZnO	0.46	7.08	317	14.3	12.1
		TiO₂	0.33	3.26	800	4.2	3.0
	NaOH treatment	None	0.51	4.83	96.2	0.4	0.6
		ZrO₂	0.55	9.87	137.1	6.3	5.4
		ZnO	0.55	8.73	428	16.1	13.2
		TiO₂	0.50	4.95	1121	5.1	4.3

a) Alkali treatment: NaOH (25 g/L), wet-pick up of 85%, at speed of 30m/min, with a pressure of 2 bars to remove excess solution and steam fixed at 110ºC.

b) Post-treatment with MONPs: ZrO_2 NP's (0- 20%owf), ZnO NP's (0-20% owf OR TiO_2 NP's (0- 5% owf), 2g/L PEG-300, L.R. 1:10, treatment at 50˚ C for 30 min, drying at 100ºC for 2 min.

Post-Transfer Printing: press at 180 ˚C for 90 seconds.

N%: nitrogen content; K/S: colour strength, ZI: zone of inhibition, G+ve: (*S. aureus*); G-ve: (*E. coli*); UPF: UV-protection factor

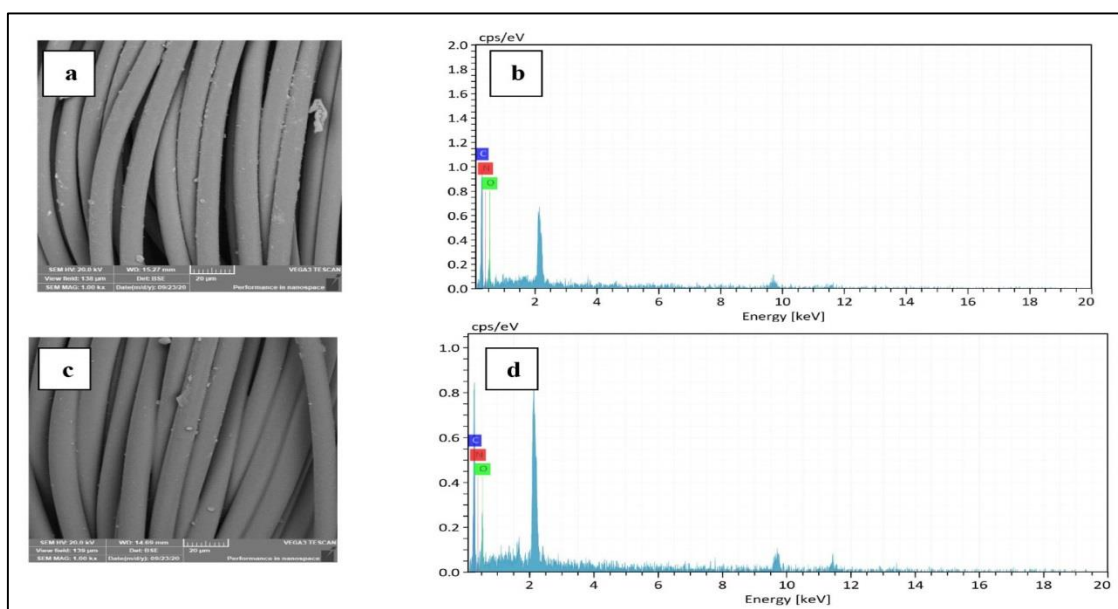Loss in weight of alkali-treated PET = 13 %, UPF of untreated PET (before transfer printing) = 28

Fig 2. SEM and EDX spectra of transfer printed modified PET samples finished with Chitosan (a,b) and PVP (c,d)
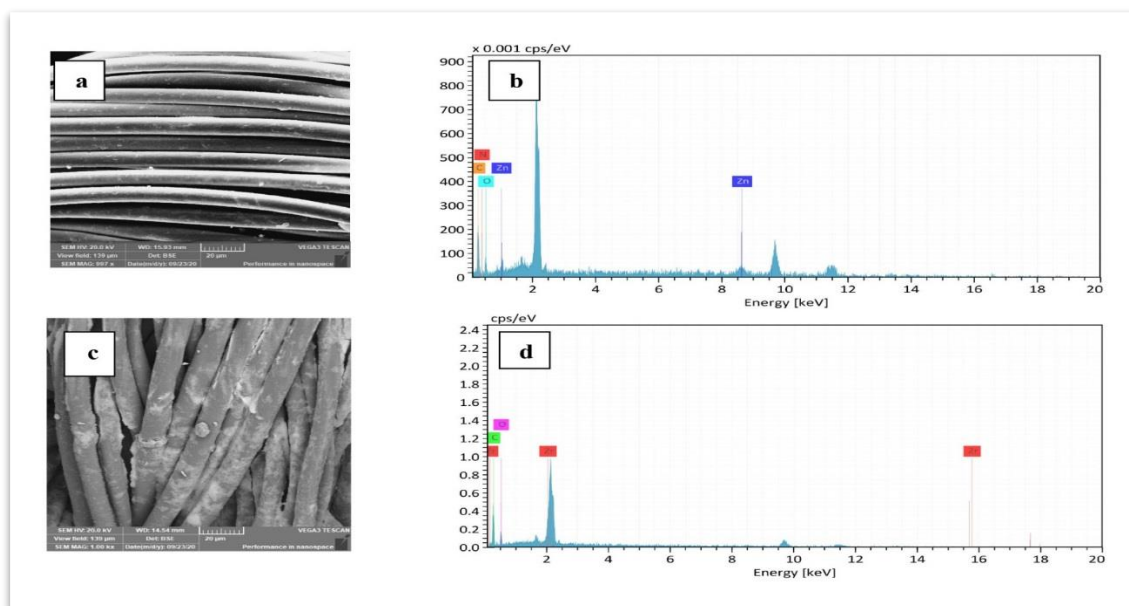
Fig 3. SEM and EDX spectra of transfer printed modified PET samples finished with ZnO-NPs (a, b) and ZrO$_2$-NPs (c, d)

4. Conclusion

- Functionalized transfer printed polyester fabric samples were obtained by pre-treatment of the PET-fabric with NaOH (25 g/L), using wet-pick up of 85%, at speed of 30m/min, then post-treatment with PVP (20%), Triclosan (20%), Chitosan (5%), ZrO$_2$-NPs (20%), ZnO-NPs (20%) or TiO$_2$-NPs (5%) as a functional agents and finally transfer printed at 180 ˚C for 90 seconds. However, the distribution, homogeneity, and thickness of the deposition are governed by the type of the used MONPs. Additionally, the EDX spectra of alkali-treated PET prints and pre-loaded with ZnONPs and ZrO$_2$NPs individually were given in (Fig. 3 b&d) respectively. The EDX spectra confirmed the existence of -Zn, - Zr elements on PET prints along with nitrogen element attributed to the used disperse dye. The given spectra confirmed loading and fixation of ZnO-NPs (Fig. 3 b), and ZrO$_2$-NPs (Fig. 3d) respectively onto the modified PET prints.
- The improvement in coloration and functional properties are governed by the type of the used active materials
- The enhancement in UPF values of the obtained transfer prints follows the descending order:

- Triclosan > PVP > Chitosan > none
- TiO$_2$-NPs > ZnO-NPs > ZrO$_2$-NPs > none.

- Antibacterial activity against G+ve (*S. aureus*) and G-ve (*E. coli*) bacteria follows the decreasing order:

- Chitosan > Triclosan > PVP > none
- ZnO-NPs > ZrO$_2$-NPs > TiO$_2$-NPs > none

5. Conflicts of interest

There are no conflicts to declare.

6. Formatting of funding sources

There is no significant financial support for this work.

References

[1] A.J. East, 3 - Polyester fibres, in: J.E. McIntyre (Ed.), Synthetic Fibres, Woodhead Publishing2005, pp. 95-166.

[2] C.W. Kan, C.W.M. Yuen, Static properties and moisture content properties of polyester fabrics modified by plasma treatment and chemical finishing, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 266(1) (2008) 127-132.

[3] N. Ibrahim, E. El-Zairy, M. El-Zairy, H. Khalil, Enhancing disperse printing and ultraviolet protecting of polyester-containing fabrics via pretreatment with chitosan/polyethylene glycol/dimethylol dihydroxyethylene urea,

_____

Journal of Industrial Textiles 42(3) (2013) 269-282.

[4] M. Kanik, A.H. Bayari, Effect of weight reduction process on printing properties of polyester fabrics, Coloration Technology 119(5) (2003) 264-268.

[5] N. Ibrahim, Effect of alkali on selected properties of PET-fabrics, Am Dyest Rep 79(9) (1990) 87-93.

[6] N. Ibrahim, B. Eid, M. Youssef, H. Ameen, A. Salah, Surface modification and smart functionalization of polyester-containing fabrics, Journal of Industrial Textiles 42(4) (2013) 353-375.

[7] M. Alisch-Mark, A. Herrmann, W. Zimmermann, Increase of the Hydrophilicity of Polyethylene Terephthalate Fibres by Hydrolases from Thermomonospora fusca and Fusarium solani f. sp. pisi, Biotechnology Letters 28(10) (2006) 681-685.

[8] A. Hebeish, N.A. Ibrahim, The impact of frontier sciences on textile industry, Colourage Annual 54(4) (2007) 41-55 .

[9] G.M. Guebitz, A. Cavaco-Paulo, Enzymes go big: surface hydrolysis and functionalisation of synthetic polymers, Trends in biotechnology 26(1) (2008) 32-38.

[10] A. Raffaele-Addamo, E. Selli, R. Barni, C. Riccardi, F. Orsini, G. Poletti, L. Meda, M.R. Massafra, B. Marcandalli, Cold plasma-induced modification of the dyeing properties of poly (ethylene terephthalate) fibers, Applied Surface Science 252(6) (2006) 2265-2275.

[11] N.A. Ibrahim, B.M. Eid, M.A. Youssef, S.A. El-Sayed, A.M. Salah, Functionalization of cellulose-containing fabrics by plasma and subsequent metal salt treatments, Carbohydrate Polymers 90(2) (2012) 908-914.

[12] C. Kan, Interaction of laser on some textile properties of poly (ethylene terephthalate), Nuclear Instruments & Methods In Physics Research Section B-Beam Interactions With Materials And Atoms 267(20) (2009) 3491-3491.

[13] W. Wong, K. Chan, K.W. Yeung, K.S. Lau, Chemical modification of poly (ethylene terephthalate) induced by laser treatment, Textile Research Journal 71(2) (2001) 117-120.

[14] M. Bide, M. Tao Zhong, J. Ukponmwan, M. Phaneuf, W. Quist, F. LoGerfo, Bifunctional

Surface Modification of Polyester, AATCC Review 3(11) (2003).

[15] M. Ellison, L. Fisher, K. Alger, S. Zeronian, Physical properties of polyester fibers degraded by aminolysis and by alkalin hydrolysis, Journal of Applied Polymer Science 27(1) (1982) 247-257.

[16] S.-i. Eom, Using Chitosan as an Antistatic Finish for Polyester Fabric, AATCC Review 1(3) (2001).

[17] A. Walawska, B. Filipowska, E. Rybicki, Dyeing polyester and cotton-polyester fabrics by means of direct dyestuffs after chitosan treatment, Fibres and Textiles in Eastern Europe 11(2) (2003) 71-74.

[18] N. Ibrahim, E. El-Zairy, M. El-Zairy, H. Khalil, Enhancement of Printing and UV-Blocking Properties of Polyester and Polyester/Wool Fabrics by Aminolysis, AATCC Review 11(4) (2011).

[19] N.A. Ibrahim, E.M. El-Zairy, M.R. El-Zairy, H.M. Khalil, Improving transfer printing and ultraviolet-blocking properties of polyester-based textiles using MCT-β-CD, chitosan and ethylenediamine, Coloration Technology 126(6) (2010) 330-336.

[20] N.A. Ibrahim, M.H. Abo-Shosha, E.A. Allam, E.M. El-Zairy, New thickening agents based on tamarind seed gum and karaya gum polysaccharides, Carbohydrate Polymers 81(2) (2010) 402-408.

[21] D. Judd, G. Wyszeck, Color in Business, Science, and Industry, THIRD EDITION ed., Wiley-Interscience; 3rd edition1975.

[22] N.A. Ibrahim, A.A. Aly, M. Gouda, Enhancing the Antibacterial Properties of Cotton Fabric, Journal of Industrial Textiles 37(3) (2008) 203-212.

[23] S. Sharaf, M.E. El-Naggar, Wound dressing properties of cationized cotton fabric treated with carrageenan/cyclodextrin hydrogel loaded with honey bee propolis extract, International Journal of Biological Macromolecules 133 (2019) 583-591.

[24] N.A. Ibrahim, B.M. Eid, H.M. Khalil, A.A. Almetwally, A new approach for durable multifunctional coating of PET fabric, Applied Surface Science 448 (2018) 95-103.

[25] N.A. Ibrahim, B.M. Eid, E.A. El-Aziz, T.M.A. Elmaaty, S.M. Ramadan, Loading of chitosan – Nano metal oxide hybrids onto cotton/polyester

_____

fabrics to impart permanent and effective multifunctions, Inter. J. Biol. Macromol. 105(Part 1) (2017) 769-776.

[26] A.A. Nada, A.T. El Aref, S.S. Sharaf, The synthesis and characterization of zinc-containing electrospun chitosan/gelatin derivatives with antibacterial properties, International Journal of Biological Macromolecules 133 (2019) 538-544.

[27] N.A. Ibrahim, B.M. Eid, H.M. Khalil, Cellulosic/wool pigment prints with remarkable antibacterial functionalities, Carbohydrate Polymers 115 (2015) 559-567.

[28] N.A. Ibrahim, W.A. Abdalla, E.M.R. El-Zairy, H.M. Khalil, Utilization of monochloro-triazine β-cyclodextrin for enhancing printability and functionality of wool, Carbohydrate Polymers 92(2) (2013) 1520-1529.

[29] H. Gaminian, M. Montazer, Enhanced self-cleaning properties on polyester fabric under visible light through single-step synthesis of cuprous oxide doped nano-TiO2, Photochemistry and Photobiology 91(5) (2015) 1078-1087.

[30] S. Nourbakhsh, M. Montazer, Z. Khandaghabadi, Zinc oxide nano particles coating on polyester fabric functionalized through alkali treatment, Journal of Industrial Textiles 47(6) (2018) 1006-1023.

[31] N.A. Ibrahim, A. Amr, B.M. Eid, Z.E. Mohamed, H.M. Fahmy, Poly(acrylic acid)/poly(ethylene glycol) adduct for attaining multifunctional cellulosic fabrics, Carbohydrate Polymers 89(2) (2012) 648-660.

[32] C. Yuen, S. Ku, Y. Li, Y. Cheng, C.W. Kan, P. Choi, Improvement of wrinkle-resistant treatment by nanotechnology, The Journal of The Textile Institute 100(2) (2009) 173-180.

[33] M. Montazer, S. Seifollahzadeh, Pretreatment of wool/polyester blended fabrics to enhance titanium dioxide nanoparticle adsorption and self-cleaning properties, Coloration Technology 127(5) (2011) 322-327.

_____