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Enhancing some functional properties of viscose fabric

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ABSTRACT

To enhance the functional properties of viscose fabrics, Tinosan® CEL (TC), Ag, and TiO_2 nano-particles were incorporated as functional additives in different easy care finishing formulations alone and in admixtures. Results indicated that padding viscose fabrics in finishing bath containing 10 g/l TC and 60 g/l dimethyloldihydroxyethylene urea (DMDHEU) enhances some performance as well as antibacterial properties of the treated fabrics. Moreover, incorporation of Ag or TiO_2 nano-particles in the DMDHEU or DMDHEU/TC finishing baths enhances the functional properties of the treated samples such as antibacterial properties, UV-blocking properties, and/or self cleaning performance. Incorporation of poly (N-vinyl-2-pyrrolidone) in the aforementioned finishing formulations enhances these functional properties along with durability to wash. On the other hand, incorporation of Silicon®-SLH softener in finishing baths along with TC affects the performance and antibacterial properties of the treated fabrics.

1. Introduction

Cellulosic textiles such as cotton and viscose are vulnerable to the microbial attack during use and storage due to their porous hydrophilic structure that retains water, oxygen and nutrients (Abo-Shosha, Hashem, El-Hosamy, & El-Nagar, 2007; Hou, Zhou, & Wang, 2009; Orhan, Kut, & Gunesoglu, 2009). Growing the microbes on textiles causes bad effects for the wearer as well as the textile itself. Such effects include unpleasant odor, stains and discoloration in the fabric, and a reduction in the fabric mechanical strength. For the wearer it causes skin irritation and leads to cross infections (Abo-Shosha et al., 2007; Orhan et al., 2009). The detrimental effects can be controlled by durable antimicrobial finishing of the textile using broad-spectrum biocides. Triclosan (2,4,4′-trichloro-2′-hydroxydiphenyl ether) is important as a textile antibacterial finish. It inhibits the microbial growth by blocking lipid biosynthesis (Gao & Cranston, 2009; Purwar & Joshi, 2004). During fabric use, the agent migrates to the surfaces of the treated textiles at a slow sustained rate to provide antimicrobial efficacy. To achieve a more durable finishing, Triclosan has been inserted into the hydrophobic cavity of β-cyclodextrins to form an inclusion complex which was then embedded in a polymer film or fiber, or encapsulated in microspheres which were subsequently attached to viscose (Purwar & Joshi, 2004). Antibacterial/easy care finishing of knitted cotton fabric is investigated by Abo-Shosha et al. (2007) by incorporation of a Triclosan in the easy care finishing formulation. Durable antibacterial finishing of cotton/polyester fabrics was performed by Ibrahim et al. using Triclosan (Ibrahim, Hashem, El-Sayed, El-Husseiny, & El-Enany, 2010). Besides, many heavy metals are toxic to microbes at very low concentrations either in the free state or in compounds (Purwar & Joshi, 2004). Textiles loaded with silver or titanium dioxide nano-particles exhibit antimicrobial properties (Ibrahim, Eid, Hashem, Refai, & El-Hossamy, 2010). Moreover, poly (N-vinyl-2-pyrrolidone) (PVP) is a synthetic, nontoxic, water-soluble polymer commonly used in a wide range of applications including several pharmaceutical applications. PVP polymers are film formers, protective colloid and suspending agents, dye-receptive agents, binders, stabilizers, detoxicants, and complexing agents (Barabas, 1990). PVP can be crosslinked by heating in air at 150 °C (Blecher, Lorenz, Lowd, Wood, & Wyman, 1980), radiation (Chapiro & Legris, 1986) and potassium persulfate (Can, Kirci, Kavlak, & Uner, 2003). Fahmy et al. crosslinked cotton fabrics with PVP thermally (Fahmy, Abo-Shosha, & Ibrahim, 2009).

On the other hand, the ultraviolet radiation (UVR) is a segment of the electromagnetic spectrum with a wavelength ranging from 100 to 400 nm. The UVR wavelength ranging from 290 to 320 nm is most responsible for the development of skin cancers (Chen, Wang, & Yeh, 2010; Ibrahim, Refaie, & Ahmed, 2010).

Keeping in mind this background, the present work is undertaken with the view to establish the proper conditions to impart easy care finished viscose fabric antibacterial and ultraviolet protection properties as well as self cleaning performance.

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2. Experimental

2.1. Materials

2.1.1. Fabrics

The fabric used throughout this work was 100% viscose fabric of weight 185 g/m^2 and thickness 0.55 mm.

2.1.2. Chemicals

Poly (N-vinyl-2-pyrrolidone) (PVP) of molecular weights 10,000 Da (Sigma–Aldrich) and titanium tetraisopropoxide (Merck) were used. Triclosan in the form of a commercial product namely Tinosan® CEL (TC), a mixture of 2,4,4′-trichloro-2′-hydroxydiphenylether and polymeric encapsulating material, was used as an antibacterial agent and kindly supplied by Ciba, Switzerland. Arkofix® NG, aqueous solution of dimethyloldihydroxyethylene urea (DMDHEU), kindly supplied by Clariant, Egypt. The commercial textile softeners (TSs) namely: Basosoft® SWK (weakly cationic mixture of a fatty acid condensation product and polyethylene wax, supplied by BASF), Leomin® NI-ET (nonionic, hydrophilic, and supplied by Clariant) and Silicon®-SLH (micro emulsion silicon softener) (SME), supplied by Texchem Egypt CO., LTD, were used. Egyptol®, non-ionic wetting agent, supplied by the Egyptian Company for Starch and Yeast and Detergents, Egypt, was used. Sodium hydroxide, trisodium citrate, silver nitrate, acetic acid, sodium carbonate, boric acid, hydrochloric acid, sulfuric acid, ammonium chloride, magnesium chloride, zinc sulfate, copper sulfate, potassium sulfate, Methylene Blue, as a basic dye, were of laboratory grade chemicals.

2.2. Methods

2.2.1. Titanium dioxide sol–gel preparation

Titanium dioxide nano-particles (TiO_2-NPs) were prepared as previously reported using titanium tetraisopropoxide precursor with 2-propanol and nitric acid (Bozzi, Yuranova, & Kiwi, 2005).

2.2.2. Silver nano-particles preparation

Silver nano-particles (Ag-NPs) were prepared using trisodium-citrate as a reductant as reported elsewhere (Sileikaite, Prosycevas, Puiso, Juraitis, & Guobiene, 2006).

2.3. Fabric treatments

2.3.1. Easy care finishing in presence of Tinosan® CEL

Viscose fabric strips (30 cm × 30 cm) were padded twice, at wet pick-up 85%, in different finishing formulations containing DMDHEU/NPs, DMDHEU/NPs/PVP, DMDHEU/TC, DMDHEU/TC/NPs, DMDHEU/TC/NPs/PVP or DMDHEU/TC/TSs (using ammonium chloride, magnesium chloride or zinc sulfate as a catalysts). The padded fabrics were dried at 85 °C for 5 min followed by curing in Wenner Mathis AGCH-8155 oven at specific temperature and intervals of time. The finished fabrics were then washed under occasional stirring (at 50 °C for 10 min), thoroughly rinsed and finally dried for testing.

2.4. Testing and analysis

- Nitrogen content (%N) was determined according to Kjeldhal method (Vogel, 1975).
- Wrinkle Recovery Angle (WRA) was determined according to ASTM method D-1296-98.
- Tensile strength (TS) was tested in the warp direction according to ASTM procedure D-2256-98.
- Wettability (W) was carried out according to AATCC Test Method 39-1980.
- Whiteness index (WI) was evaluated by using Color-Eye® 3100 spectrophotometer supplied by SDL Inter, England, according to the Standard Test Method ASTM E313.
- Surface roughness (SR) was measured according to JIS 94 Standard, by Surface Roughness Measuring Instrument, SE 1700α.
- The color strength of the of the dyed samples, expressed as *K*/*S* value, was measured on Optimacth 3100 and the values were automatically calculated from reflectance data by use of Kubelka–Munk equation (Judd & Wyszecks, 1975).

$$K/S = \frac{(1-R)^2}{2R}$$

where R is the reflectance of the dyed fabric at the wavelength of maximum absorption and K/S is the ratio of the absorption coefficient (K) to the scattering coefficient (S).

- Ultraviolet-protection factor (UPF) values were calculated according to the Australian/New Zealand standard (AS/NZS 4399-1996) with a UV-Shimadzu 3101 PC spectrophotometer. According to the Australian classification scheme, fabrics can be rated as providing good protection, very good protection, and excellent protection if their UPF values are 15–24, 25–39, and greater than 40, respectively.
- Scanning electron microscope (SEM) images of the treated and untreated fabric samples were obtained Using SEM Model Quanta 250 FEG (Field Emission Gun) attached with EDX Unit (Energy Dispersive X-ray Analyses), with accelerating voltage 30 kV, magnification 14× up to 1,000,000 and resolution for Gun.1n), FEI company, Netherlands.
- The morphology and particles size of Ag-NP's and TiO_2-NP's were obtained by transmission electron microscope (TEM) using a JEOL, JEM 2100 F electron microscope at 200 kV.
- Antimicrobial activity of control and finished viscose fabrics were tested, expressed in the inhibition zone (IZ) per millimeters, according to the disc diffusion method, AATCC Test Method 147-2004. The antibacterial activities of the untreated blank as well as finished fabrics were tested against the following bacteria:
  (1) Gram-positive bacteria: *Staphylococcus aureus (SA)*.
  (2) Gram-negative bacteria: *Escherichia coli (EC)*.
- Durability to wash was assessed by subjecting the fabric to 1, 15 and 25 laundering cycles. Each laundering cycle consists of washing (10 min at 50 °C using 2 g/l nonionic surfactant followed by rinsing and air drying at ambient conditions.
- The self-cleaning action of the TiO_2-loaded substrates was assessed as described elsewhere (Ibrahim, Refaie, et al., 2010).

3. Results and discussion

Tinosan® CEL (TC), silver or titanium dioxide nano-particles and some textile softeners were utilized, individually or in combinations, to functionalize viscose fabric. Factors affecting the performance and functional properties of viscose fabric were investigated. Results obtained along with appropriate discussion follow.

3.1. Imparting functional properties to viscose fabric

3.1.1. Tinosan® CEL

3.1.1.1. Tinosan® CEL concentration. Fig. 1 shows the antibacterial activities of viscose fabric samples treated with different concentrations of Tinosan® CEL in presence of 60 g/l of DMDHEU. It is obvious that increasing the Tinosan® CEL concentration from 0 to 15 g/l, brings about an increase in the inhibition zone, against

Table 1
Effect of DMDHEU concentration on the performance and antibacterial properties of the treated viscose fabric samples.

DMDHEU (g/l)	% N	WRA (w + f)°	TS (kg)	W (S)	WI	Inhibition zone (mm)	
						EC	SA
Untreated	0	184	60.1	1.1	56.9	0	0
60	0.3428	218	52.4	1.5	55.7	13	15
80	0.4216	247	50.1	1.6	55.3	14	15
100	0.5197	269	47.2	1.7	55.1	14	16

[TC], 9 g/l; [NH_4Cl], 10% (based on DMDHEU concentration); wetting agent, 2 g/l; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min.

either *S. aureus* or *E. coli*. Furthermore, the results depict that the treated fabrics have higher inhibition zones for *S. aureus* than that for *E. coli* which may be attributed to the differences between these species in their cell wall structure, amenability to disruption of the metabolic process and/or in response for inactivation to death (Ibrahim, Khalifa, El-Hossamy, & Tawfik, 2010).

3.1.1.2. DMDHEU concentration. Table 1 shows the performance properties of viscose fabrics treated with different concentrations of DMDHEU in presence of 9 g/l Tinosan® CEL. It is clear that increasing DMDHEU concentration, from 0 to 100 g/l, brings about an enhancement in the nitrogen content and resiliency along with a reduction in tensile strength, wettability and whiteness indices of the treated fabrics as a direct consequence of increasing the extent of crosslinking. On the other hand, the antibacterial activities of the treated samples, against *S. aureus* and *E. coli*, are enhanced upon increasing the DMDHEU concentration up to 60 g/l as a direct consequence of increasing the extent of Tinosan® CEL fixation. Beyond 60 g/l and up to 100 g/l these activities are marginally increased (Fahmy, 1994; Ibrahim, Bayazeed, Refai, & Hebeish, 1986).

3.1.2. Combined Tinosan® CEL and nano-particles

3.1.2.1. Silver nano-particles (Ag-NPs). To enhance the antibacterial properties of viscose fabric samples, Ag-NPs were introduced as bio-active additives in different finishing formulations containing DMDHEU, as a crosslinker, in presence of ammonium chloride as catalyst. Table 2 signifies that, for a given set of finishing conditions: (i) using DMDHEU/Ag-NPs or DMDHEU/TC/Ag-NPs finishing baths enhance the antibacterial properties of the treated fabrics reflecting the ability of Ag-NPs to damage the bacterial membrane and hence the cell death; formation of Ag-ions, in the presence of moisture, that bind to the bacterial DNA causing their inactivation according to Eq. (1):

$$O_{2(aq)} + 4H_3O^+ + 4Ag_{(s)} \rightarrow 4Ag^+{}_{(aq)} + 6H_2O \quad (1)$$

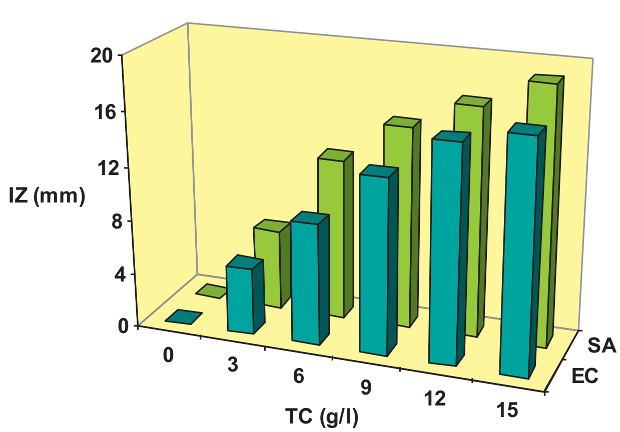


Fig. 1. Effect of Tinosan® CEL concentration on the antibacterial properties of treated viscose fabric. Conditions: [DMDHEU], 60 g/l; [NH_4Cl], 6 g/l; wetting agent, 2 g/l; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min.

and/or producing of oxygen radicals that oxidize the molecular structure of bacteria according to Eq. (2) (Hoskins, Karanfil, & Serkiz, 2002):

$$H_2O + (1/2)O_2 \xrightarrow{Ag^+} H_2O_2 \rightarrow H_2O + (O) \quad (2)$$

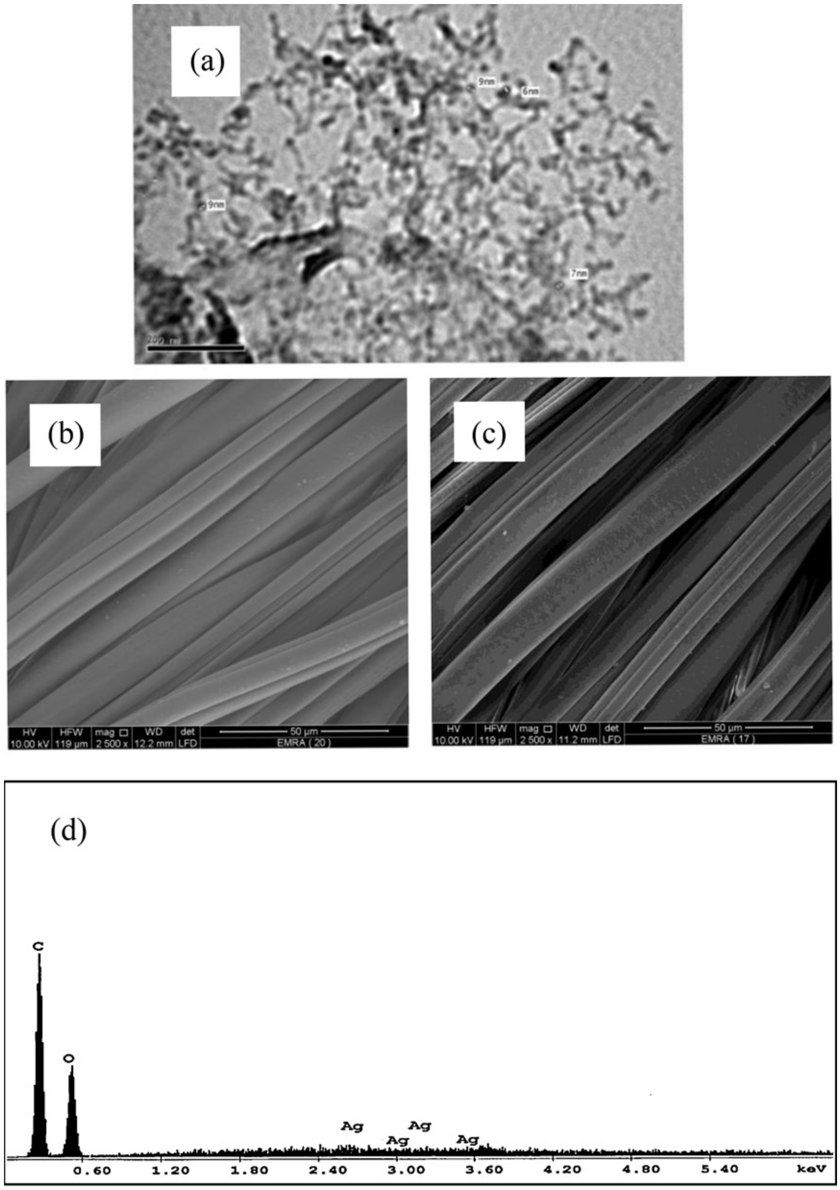
(ii) using the DMDHEU/Ag-NPs/PVP finishing bath indeed enhances the extents of the antibacterial properties of the treated fabrics. This enhancement may be attributed to the fixation of the PVP polymer chains onto/within the finish/fabric matrix (Fahmy et al., 2009) which have strong affinity for the silver ions and metallic silver due to the N and O atoms of the polar amide group of PVP (Carotenuto, Pepe, & Nicolais, 2000) and/or forms coordination bonds between PVP and the formed silver metal ions as represented in Eq. (1) (Zhang, Zhao, & Hu, 1996), (iii) using the DMDHEU/Ag-NPs/TC/PVP finishing bath results in a reduction in the imparted antibacterial properties of the treated fabrics, most probably due to arising of competitive reactions between PVP and TC to be fixed onto the finish/fabric matrices, increasing the finishing bath viscosity and/or formation a PVP/TC/Ag-NPs film on the cured fabric surfaces that can be swept away by washing, (iv) the inactivation efficiency of *E. coli* (G −Ve bacteria) was lower than that of *S. aureus* (G +Ve bacteria), regardless of the finishing regime, and (v) the antibacterial activities of the viscose fabrics treated with DMDHEU/Ag-NPs finishing bath decrease rapidly after 15 washing cycles, while adding PVP to the DMDHEU/Ag-NPs finishing bath enhances the retention of the antibacterial properties even after 15 washing cycles. On the other hand, Fig. 2(a) shows the TEM image of Ag-NPs where these particles are less than 10 nm in size. Fig. 2(b) and (c) shows the SEM of untreated and Ag-NPs loaded viscose fabric images respectively. Fig. 2(d) shows the EDX of Ag-NPs loaded viscose fabric confirming the presence of Ag-NPs onto the treated fabric with Ag-content of 0.34% (w/w).

3.1.2.2. Titanium dioxide nano-particles (TiO_2-NPs). To functionalize viscose fabrics, TiO_2-NPs were introduced as additives in different finishing formulations listed in Table 3. Table 3 depicts that the treated fabrics indeed acquire additional antibacterial activities as a result of introducing of the TiO_2-NPs in the DMDHEU/TiO_2-NPs and DMDHEU/TC/TiO_2-NPs finishing baths.

Table 2
The antibacterial properties of viscose fabric samples treated with Ag-NPs and/or Tinosan® CEL containing finishing formulations.

Treatment bath	Inhibition zone (mm)	
	EC	SA
DMDHEU/Ag-NPs	9 (0)	11 (0)
DMDHEU/Ag-NPs/PVP	12 (5)	13 (7)
DMDHEU/TC	13 (8)	15 (10)
DMDHEU/TC/Ag-NPs	15 (8)	16 (9)
DMDHEU/TC/Ag-NPs/PVP	10 (4)	12 (5)

[TC], 9 g/l; [DMDHEU], 60 g/l; [NH_4Cl], 6 g/l; [PVP], 4%; [Ag-NPs], 20 g/l of the stock solution; wetting agent, 2 g/l; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min. Values in parentheses indicate retained antibacterial properties after 15 laundering cycles.



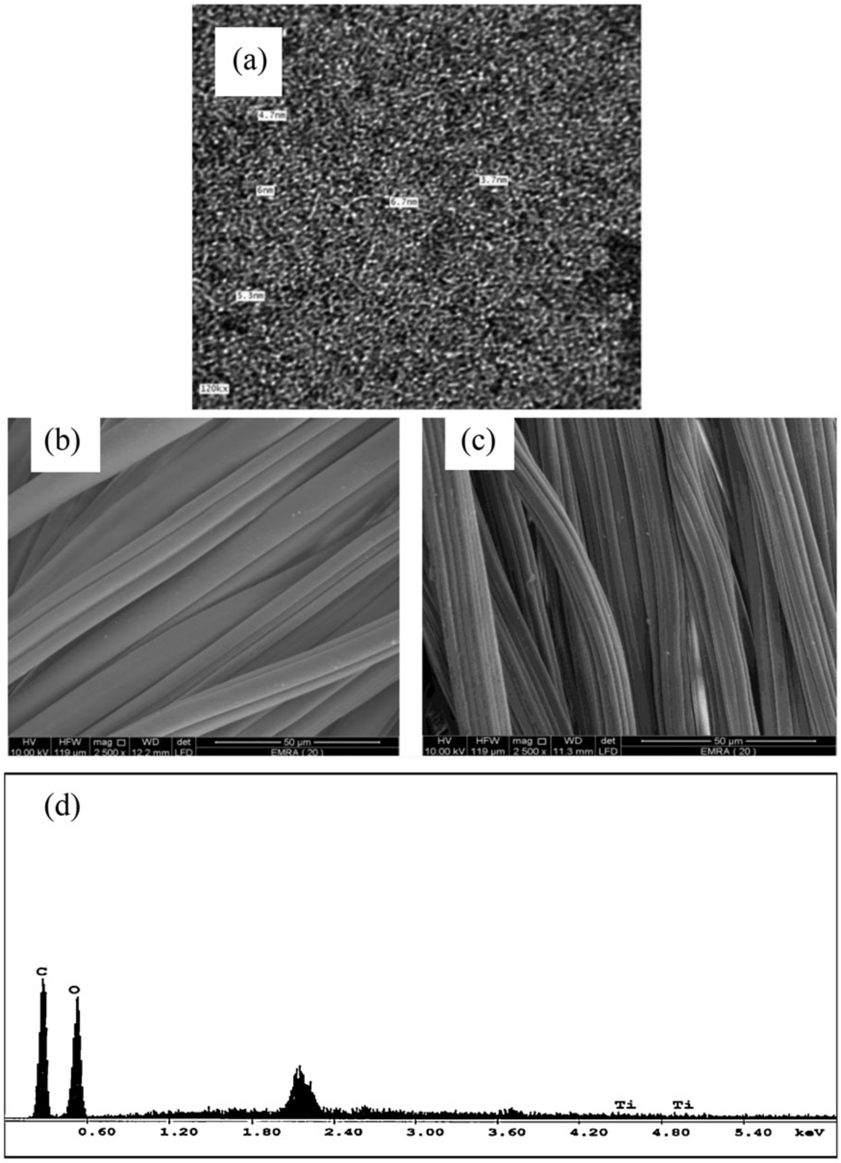
Element	Wt %	At %	K-Ratio	Z	A	F
C K	57.47	64.44	0.3316	1.0064	0.5731	1.0004
O K	42.19	35.51	0.0738	0.9923	0.1763	1.0000
AgL	0.34	0.04	0.0034	0.7657	1.3145	1.0000
Total	100.00	100.00				

Fig. 2. (a) TEM image of Ag-NPs, (b) SEM of untreated viscose fabric, (c) SEM of Ag-NPs loaded viscose fabric, and (d) EDX image of Ag-NPs loaded viscose fabric.

Table 3
The functional properties of viscose fabric samples treated with TiO_2-NPs and/or Tinosan® CEL containing finishing formulations.

Treatment bath	*K/S*		UPF	Inhibition zone (mm)	
	Exposure time (h)			EC	SA
	0	10			
Untreated	1.4	0.69	7 (7)	0	0
DMDHEU/TiO_2-NPs	1.27	0.18	18 (14)	12 (2)	13 (5)
DMDHEU/TC/TiO_2-NPs	2.25	0.13	26 (16)	16 (10)	18 (11)

[TC], 9 g/l; [DMDHEU], 60 g/l; [NH_4Cl], 6 g/l; [TiO_2-NPs], 20 g/l of the stock solution; wetting agent, 2 g/l; dye conc.: 3% owf; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min. Values in parentheses indicate retained functional properties after 15 laundering cycles.



Element	Wt %	At %	K-Ratio	Z	A	F
C K	48.14	55.40	0.2535	1.0077	0.5222	1.0006
O K	51.49	44.49	0.1040	0.9936	0.2033	1.0000
TiK	0.38	0.11	0.0034	0.8513	1.0584	1.0000
Total	100.00	100.00				

Fig. 3. (a) TEM image of TiO_2-NPs, (b) SEM of untreated viscose fabric, (c) SEM of TiO_2-NPs loaded viscose fabric, and (d) EDX image of TiO_2-NPs loaded viscose fabric.

Such additional antibacterial activities may be arises from the generation of extremely reactive species, e.g. superoxide ions, hydroxyl radicals, etc. that attacking the bacterial cell membrane, losing of its essential functions and destroying it (Ibrahim, Refaie, et al., 2010). Table 3 shows also that incorporation of TiO_2-NPs in the aforementioned finishing baths enhances the UV protection properties, expressed as UPF values, of the treated fabrics. Such enhancement reflects the ability of the TiO_2-NPs loaded viscose fabrics surfaces to scatter as well as absorb the harmful UV radiation (Ibrahim, Refaie, et al., 2010). Moreover, the self cleaning activity of the TiO_2-NPs loaded viscose fabrics was appeared obviously in the discoloration of the Methylene Blue after their exposure for the sunlight for 10 h. The discoloration of the dyed fabrics suggests that the TiO_2-NPs loaded fabric samples have a photocatalytic power, compared with untreated ones, resulting from the generation of high oxidative radicals on the TiO_2-NPs loaded fabric surface, e.g. $HO^•$, $HO_2^•$ that causes a photocatalytic degradation for the basic dye due to the visible light irradiation (Qi, Wang, & Xin, 2011). Obviously, Table 3 shows also that among the aforementioned TiO_2-NPs treated samples, the samples treated with DMDHEU/TC/TiO_2-NPs finishing bath have durable function properties even after 15 washing cycles. On the other hand, Fig. 3(a) shows the TEM image of TiO_2-NPs where these particles are less than 10 nm in size. Fig. 3(b) and (c) show the SEM of untreated and TiO_2-NPs loaded viscose fabric images respectively. Fig. 3(d) shows the EDX of TiO_2-NPs loaded viscose fabric confirming the presence of TiO_2-NPs onto the treated fabric with Ti-content of 0.38% (w/w).

3.1.3. Combined Tinosan® CEL and some textile softeners

3.1.3.1. Softener type. At this step of the work, both the easy care and soft finishing of viscose fabrics were combined and the antibacterial activities of the treated fabrics are monitored in Fig. 4. It is clear from Fig. 4 that incorporation of Leomin® NI or Basosoft® SWK softeners in finishing bathes containing Tinosan® CEL reduces the

Table 4
Effect of finishing bath ingredients on the performance properties of treated viscose fabric samples.

Finishing bath ingredients	% N	WRA (w + f)°	TS (kg)	W (S)	WI	SR	Inhibition zone (mm)	
							EC	SA
Untreated	0	187	60.1	1.1	56.9	22.3	0	0
TC[a]	0	183	58.4	1.3	55.1	22.7	12 (2) (0)	14 (3) (0)
TC/SME[b]	0.0424	227	55.3	26.1	55.7	21.1	14 (4) (0)	16 (7) (0)
DMDHEU/$ZnSO_4$/TC/SME[c]	0.3227	259	49.4	29.5	53.4	21.9	22 (20) (16)	24 (22) (17)

Values in parentheses indicate retained antibacterial properties after 15 and 25 laundering cycles respectively.
[a] Test fabric padded in aqueous solution containing 9 g/l Tinosan® CEL; pH, 5; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min.
[b] Test fabric padded in aqueous solution containing 9 g/l Tinosan® CEL and 20 g/l SME. pH, 5; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min.
[c] Test fabric padded in aqueous solution containing 9 g/l Tinosan® CEL, 20 g/l SME, 60 g/l DMDHEU and 6 g/l $ZnSO_4$. Wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min.

antibacterial properties, against *S. aureus* and *E. coli*, of the treated samples, compared to the control sample, with different extents whereas Silicon® SLH (SME) enhances that properties reflecting the differences between these hand modifiers in chemical composition, functionality, ionic nature, location and extent of surface modification, film forming properties, compatibility with other ingredients, mode of interaction, durability to wash as well as thermal stability (Hashem & Ibrahim, 2002). Meanwhile, the enhancement in the antibacterial properties achieved by SME may be attributed to the more fixation of the Tinosan® CEL encapsulated by that softener on the fabric surface.

3.1.3.2. Finishing bath ingredients. Table 4 shows the effect of the finishing bath ingredients on the performance as well as antibacterial properties of the treated viscose fabrics. It is clear that incorporation of SME in the finishing baths containing TC or DMDHEU/$ZnSO_4$/TC brings about an enhancement in the nitrogen content, resiliency, softness and antibacterial activities along with the reduction in tensile strength, whiteness and wettability of the treated fabrics. The enhancement in such properties may be due to: (i) deposition of a softener film onto and/or within the viscose structure thereby softening the fibers and thus decreasing interfiber and interyarn friction, and (ii) formation of interfiber and interyarn bonds (Hashem & Ibrahim, 2002). Furthermore, the relatively higher antibacterial properties of the treated samples on using the zinc sulfate as catalyst may be attributed to the deposition of the antibacterial zinc compounds (Gaffar, 1996; Nakashima, Sakagami, Ito, & Matsuo, 2001) onto/into the fabric structure. Meanwhile, beside the advantage of SME softener in encapsulation of Tinosan® CEL, it imparts the fabric surface with hydrophobic characters that form unsuitable environment for the bacterial growth, thereby enhances the antibacterial properties of the treated samples. Table 4 also shows the durability of antibacterial properties of the aforementioned treated fabrics after 1, 15 and 25 washing cycles. It is clear that the antibacterial activities of finished viscose samples decrease until the complete disappearance after 15 washing cycles in case of finishing baths A and B and after 25 washing cycles in case of finishing bath C. Moreover, the disappearance of the antibacterial activities of viscose samples treated with the finishing baths A and B after 15 washing cycles indicate that Tinosan® CEL is not firmly bound to the cellulose structure as it has no reactive groups capable to attach chemically the fabric structure (Abo-Shosha et al., 2007; Ibrahim, Hashem, et al., 2010). Meanwhile, the antibacterial activities of the viscose sample finished through treatment C show gradual little drops after 25 washing cycles reflecting the role of the crosslinker in fixation the encapsulated Tinosan® CEL onto the fabrics matrices (Abo-Shosha et al., 2007; Ibrahim, Hashem, et al., 2010).

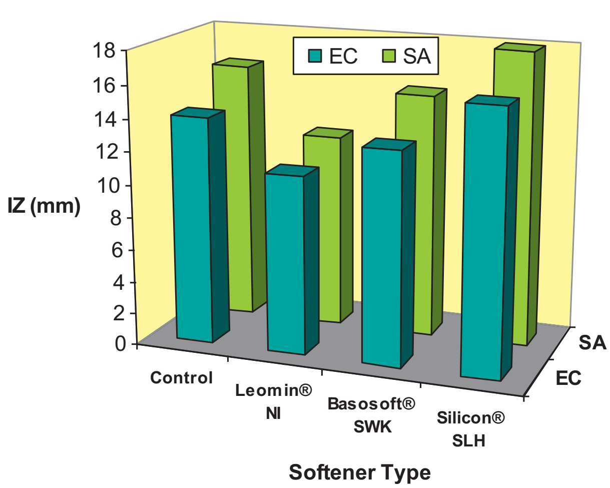


Fig. 4. Effect of softener type on the antibacterial activities of treated viscose fabrics. Conditions: [TC], 9 g/l; [softener], 20 g/l; [DMDHEU], 60 g/l; [NH_4Cl], 6 g/l; wet pick up, 100%; drying, 85 °C/5 min; curing, 160 °C/3 min. Control sample, without softener.

4. Conclusions

To enhance the functional properties of viscose fabrics, Tinosan® CEL, Ag or TiO_2 nano-particles alone or their admixtures were incorporated as additives in different easy care finishing formulations. Results indicated that:

(i) padding viscose fabrics in finishing bath containing 10 g/l Tinosan® CEL and 60 g/l DMDHEU followed by drying at 85 °C for 5 min and curing at 130 °C for 3 min, enhances the nitrogen content, resiliency and antibacterial activities along with the reduction of tensile strength, wettability and whiteness indices of the treated fabrics,
(ii) incorporation of Ag- or TiO_2-NPs in the DMDHEU containing finishing baths, in absence of PVP, imparts functional properties for treated viscose fabrics along with a rapid decrease in that properties after 15 washing cycles,
(iii) incorporation of PVP in the aforementioned finishing formulations enhances that functional properties along with considerable durability in that properties after 15 washing cycles,
(iv) the inactivation efficiency of *E. coli* (G −Ve bacteria) was lower than that of *S. aureus* (G +Ve bacteria), regardless of the finishing regime,
(v) incorporation of SME softener in the finishing baths containing TC or DMDHEU/$ZnSO_4$/TC brings about an enhancement in the nitrogen content, resiliency, softness and antibacterial activities along with the reduction in tensile strength, whiteness and wettability of the treated fabrics, and

(vi) among the TC, TC/SME and DMDHEU/$ZnSO_4$/TC/SME finishing formulations, the latter is the only durable finish for 25 washing cycles.

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