Carbohydrate Polymers 92 (2013) 353–359

Contents lists available at SciVerse ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Surface functionalization of viscose and polyester fabrics toward antibacterial and coloration properties

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ARTICLE INFO

Article history:
Received 2 August 2012
Received in revised form 20 August 2012
Accepted 27 August 2012
Available online 3 September 2012

Keywords:
Viscose
Polyester
SiO_2 nanoparticle
Physical properties
Antibacterial and coloration

ABSTRACT

Nanoparticles have been increasingly used to improve the properties of textile fabrics. Viscose and polyester fabrics are treated with SiO_2 nanoparticle by another technique than the conventional sol–gel method in presence of binder (acrylate based copolymer). The effect of the content of SiO_2 nanoparticle on the physical properties of the treated fabrics such as moisture regain, tensile strength and elongation % were investigated. Furthermore, the antibacterial activity and coloration properties of pretreated fabrics were evaluated. Characterizations of pretreated samples by infrared spectroscopy and scanning electron microscopy were also conducted. The results show that the physical and coloration properties of pretreated samples were improved. The treated viscose fabric showed outstanding antibacterial performance against both *Escherichia coli* (G−) and *Staphylococcus aureus* (G+). Excellent durability of the treatment to repeated home laundering toward antibacterial and coloration properties was obtained in presence of binder.

1. Introduction

Recently functionalization of polymer materials to achieve smart and intelligent properties is being the target idea of several research projects, and the high functional textile products and clothing is one from many application possibilities of these modified materials (Smole et al., 2006). Currently, functional finishes on textile fabrics are of critical importance to improve textile products with multifunctional properties such as antibacterial activity, UV protection, and wrinkle free properties (Abidi, Hequet, Tarimala, & Dai, 2007).

Nanotechnology promises an unprecedented era of innovation across multiple disciplines and diverse application (Laperre, 2002). The key to realizing nanotechnology's potential is still the ability to assemble and manufacture nano-scale devices and structures with dimensions smaller than 100 nm. At this scales, material properties, such as color, strength, conductivity and reactivity can differ substantially between the nano and macro scale due to the quantum effect (Wu, Wang, Wang, & Ge, 2008).

The incorporation of nanoscale particles into textile surface leads to a strong interfacial interaction and has a significant improvement in rigidity reinforcement (Hou, Wang, & Yu, 2009; Hou, Yu, & Chen, 2010).

Applications of monodisperse silica particles (SiO_2) are rapidly increasing, not only in the scientific field, but also in the commercial industrial fields. The alteration of materials' surface properties by nano size SiO_2 particles improves the mechanical properties and durability of materials and also influences material's functionality, activity or can enhance its stability (Mahltig, Audenaert, & Bottcher, 2005; Smole et al., 2006).

The sol–gel method seems to be more conventional for application of nano silica on textile materials, due to easy processing and acceptable treatment conditions (Gao, Zhu, & Gao, 2009; Li, Xiang, & Dai, 2008). In this method, hydrolysis and condensation reactions of the precursor material, tetraethoxysilane (TEOS) are carried out to form a nano-colloidal solution, and a network of nanoparticles will be formed on the substrate through the gradual evaporation of the solvent as shown in the reaction shown below:

$$Si(OC_2H_5) + H_2O \leftrightarrows Si(OH)_4 + 4C_2H_5OH \quad (1)$$

$$2Si(OH)_4 \rightarrow 2(Si{-}O{-}Si) + 4H_2O \quad (2)$$

Fabrication of superhydrophobic and antibacterial surface on cotton fabric by doped silica-based sols with nanoparticles of copper has been studied (Berendjch, Khajavi, & Yazdanshenas, 2011). The results indicated that all fabricated surfaces containing Cu nanoparticles showed the perfect antibacterial activity against both of gram-negative and gram-positive bacteria. The antibacterial cellulose fibers with acrylamide polymerization and Ag-loading SiO_2 nano antibacterial materials were successfully prepared. The nano-SiO_2 composite antibacterial materials were combined with cellulose fibers firmly by infiltrating into polyacrylamide layer

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http://dx.doi.org/10.1016/j.carbpol.2012.08.108

about 100 nm. The antibacterial cellulose fibers with antibacterial layer owned excellent antibacterial effect (Shuhua et al., 2011).

Modified silica sol coatings for highly hydrophobic cotton and polyester fabrics using two and one-step treatment procedures has been studied (Zhu, Gao, Guo, Charles, & Shen, 2011). The treatment imparted high levels of hydrophobicity to the fabrics. This one-step treatment produced superhydrophobic cotton fabric with a high water contact angle under optimal conditions. The treatment of both cotton and polyester causes very limited or negligible reduction in tensile strength, whiteness, and air permeability.

The application of hybrid silica particles with nanosilver (SiO_2/Ag) introduced into the polymer matrix and deposited on the textile surface was studied (Jasiorski et al., 2009). Microbiological tests were carried out on these textiles and confirmed their good antimicrobial activity. The role of silica spheres in SiO_2/Ag is as Ag metal carriers and effective matrix causing good dispersion of silver nanoparticles in polymer matrix.

Among all the textile fibers, cellulose fibers have the wide range of structures and properties. Viscose is another important cellulosic fiber mostly used in textile. Today there is a renaissance for viscose. Viscose is made from cellulose, a constituent of all land growing plant life. A variety of dissolving grade wood pulps is used as cellulose source to produce viscose rayon. Viscose is supposed to give an answer to the steadily increasing problems of: higher world market cotton prices; higher demand for fibers, including a chase for new fiber material sources and; a need for a broadening of the market for wood and pulp industry (Ghosh, 2011).

The current study aimed to develop antibacterial and functional surfaces on viscose and polyester fabrics using another technique than the conventional sol–gel method. In this technique, the commercial SiO_2 nanoparticle (21 nm) without modification or combination with other metal oxide was introduced into their surfaces in presence of acrylate based copolymer binder using the pad-dry-cure method. The influence of pretreatment on the physical properties such as moisture regain, tensile strength, elongation % as well as coloration properties was determined. The purpose is also to increase the durability of antibacterial and color of SiO_2 nanoparticle treated fabrics with repeated laundering, by improving the adhesion of SiO_2 nanoparticle to the surface of polyester and viscose fibers using acrylate based copolymer binder.

2. Experimental

2.1. Materials

Polyester and viscose fabrics were supplied by Misr El Mahalla Co., Egypt. The fabrics were soaped with (2 g/l) nonionic detergent solution (Hocstapal CV from Clariant, Egypt) with a liquor ratio 1:25, at 60 °C, for 45 min, then rinsed twice in cold tap water, and dried at room temperature. The nanoparticle used in this study was SiO_2, obtained from Sigma–Aldrich, Germany. Its average diameter was less than 21 nm, with a surface-area of more than 200 m^2/g and purity of more than 99.5%. C.I. Direct Red 80 and C.I. Disperse Red 60 were used as received from Ciba (Scheme 1). Meypro gum NP-16, a nonionic chemically modified guar endosperm derivative, kindly supplied by El Mahalla chemical AG, Switzerland, was used. Imperon Binder MTB (density ca. 1.03 g/cm^3 and viscosity 35–70 MPa s), self-crosslinking acrylate-based copolymer dispersion was supplied by Hoechst, Germany. Sera Gel B/EW (low Oder) was used as carrier supplied by Dye star, Egypt. All other chemicals and reagents used were laboratory grade.

2.2. Alkaline treatment of polyester

To improve the adhesion of SiO_2 nanoparticle to the smooth surface of polyester fiber, an alkaline pretreatment in water solution containing 5 g/l of KOH for 30 min at 98 °C with a liquor ratio 1:25 was performed. Subsequently, the samples were rinsed twice in cold tap water and then dried at room temperature.

2.3. Pretreatment of viscose and polyester fabric with SiO_2 nanoparticle

The fabrics (5 cm × 30 cm) were immersed in ethanol solutions of SiO_2 nanoparticle with a liquor ratio 1:10 and concentrations (5 and 10 g/l) for 1 h at room temperature. The fabrics were then padded at 90% pick up using a laboratory padding machine. One series of the padded samples was air dried and then cured at 140 °C for 10 min; another series was dried at 120 °C for 3 min followed by treatment with the binder diluted to 50% at a liquor ratio 1:10 then padded to 90% pick up, dried in air, cured at 150 °C for 3 min. The samples of the two series were then rinsed with tap water, and finally air-dried.

2.4. Dyeing procedures

The dyeing of control and treated viscose fabrics with C.I. Direct Red 80 was carried out by pasting 1% of dye, based on fabric weight, with cold water followed by adding boiling water with constant stirring to bring it into solution. Sodium chloride (10%) was then added to the liquor to reach (1:50), liquor ratio (LR) at 40–50 °C, then the dyeing bath temperature was raised to the boil over a period of (30–40) min. After that, the dyeing was continued for (45–60) min. On the other hand, the dyeing of untreated and SiO_2 nanoparticle treated polyester fabrics in absence of binder with C.I. Disperse Red 60 was carried out by pasting the dye with 1% acetic acid in hot water, followed by adding 2 g/l of carrier. The dye bath was gradually heated to 130 °C. The sample fabric was added to the bath and the dyeing continued for 60 min, at liquor ratio 1:50. The pretreated polyester samples in presence of binder were dyed as in the same manner without the use of carrier at 90 °C. The dyed samples were thoroughly washed in warm and cold water and then air-dried.

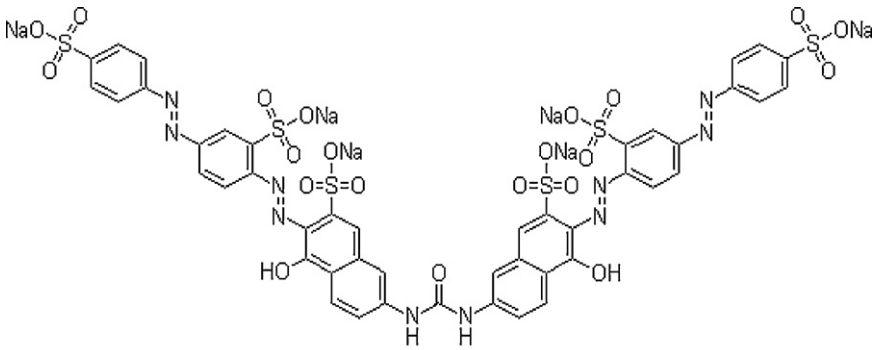
2.5. Printing method

The printing pastes for polyester were prepared using the following recipe: C.I. Disperse Red 60, 30 g; Meybro gum, 60; urea, 75 g; citric acid, 10 g and 825 g; water. Printing was carried out using the flat screen technique. Printed samples were then dried at 100 °C for 3 min. The SiO_2 nanoparticle treated polyester fabrics in absence of binder fixed by superheated steam at 180 °C for 10 min while the other samples pretreated in presence of binder were fixed at 110 °C for 10 min. Printed samples were rinsed with cold water and then hot water at 60 °C for 15 min, followed by soaping with an anionic detergent (Hocstapal CV, 2 g/l), rinsed well and finally dried at 85 °C for 5 min.

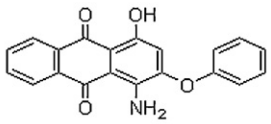
2.6. Measurements and analysis

2.6.1. Tensile strength and elongation %

The tensile strength and elongation of fabric before and after treatment were evaluated using a Instron Tensile Tester (USA) according to ASTM D 76 Standard Specification for Textile Testing Machines. The average was taken for 10 samples (5 cm × 20 cm).



C.I. Direct red 80



C.I. Disperse red 60

Scheme 1. Chemical structures of direct and disperse dyes.

2.6.2. Moisture regain

Measurements of moisture regain of the fabrics were performed using the standard ASTM method 2654-76 (West, 1981). Moisture regain of the samples was calculated according to the following equation:

$$\text{Moisture regain} \quad \% = \frac{W_1 - W_2}{W_2} \times 100$$

where W_1 is the weight of sample (g) after saturation in the standard humidity atmosphere; W_2 is the constant weight (g) of dry sample.

2.6.3. Antibacterial test

The antibacterial properties were quantitatively evaluated by Bacterial colony count according to the AATCC test method 100-1999. Two non-spore forming bacteria were used, one Gram-positive *Staphylococcus aureus* (AATCC 2665) and one Gram-negative *Escherichia coli* (AATCC 2666). The colonies of the bacterium on the agar plate were counted and the reduction rate of bacteria by the treated fabrics is calculated using the following equation.

$$\text{Reduction rate} \quad (R) \quad \% = \frac{B - A}{B} \times 10$$

where R is the % reduction, B is the number of the bacterial colonies of the untreated fabric and A is the number of bacterial colonies after 18 h in contact with treated fabric. The durability of antibacterial test of SiO_2 nanoparticle treated fabrics with repeated laundering was stimulated. The specimens were immersed into an aqueous solution containing 5 g/l nonionic deterges and 2 g/l sodium carbonate liquor ratio of 1:50 at 45 °C. The test was run for 15 min. The sample was then removed, rinsed twice in 100 ml of water with stirring and hand squeezing.

2.6.4. Infrared spectroscopy

Infrared spectra were recorded on FT-IR Nicolet 5 DX Spectrophotometer. The samples were examined as 1.5% K Br pellets.

2.6.5. Scanning electron microscopy

The surface morphology of the treated fabrics was examined using scanning electron microscopy (SEM; Model JSM-5600LV, produced by Jeol, Tokyo, Japan).

2.6.6. Color intensity (K/S)

Spectral reflection measurements of the dyed fabrics were carried out using a recording filter spectrophotometer. The color intensity expressed as K/S values of the dyed samples were determined by applying the Kubleka–Munk equation at λ_{max} 520 nm (Judd & Wyszecki, 1975).

$$\frac{K}{S} = \frac{(1-R)^2}{2R} - \frac{(1-R_0)^2}{2R_0}$$

where R is the decimal fraction of the reflectance of the dyed substrate; R_0 is the decimal fraction of the reflectance of the undyed substrate; S is the scattering coefficient; K is the absorption coefficient.

2.6.7. Washing fastness

Washing fastness tests were carried out according to BS1006: CO_2 Test 2 with a soap solution (5 g/l, liquor ratio = 50:1) for 45 min at 48–50 °C (Achwall, 1985).

3. Results and discussion

3.1. Tensile strength, elongation % and moisture regain %

Table 1 summarizes the results of physical properties of the viscose and polyester fabrics, including tensile strength, elongation and moisture regain, for treated and untreated fabrics in presence and absence of binder. The data in Table 1 shows that the physical properties of the viscose and polyester fabrics were adversely affected by the pretreatment with SiO_2 nanoparticle. The results indicate that the untreated fabrics possessed a tenacity of approximately 0.515 and 2.47 and elongation values of 21.8% and 34.01% for viscose and polyester, respectively. The treatment causes an increase of tensile strength ranging from 20% to 30% in viscose fabrics and from 2% to 12% in polyester fabrics. Moreover the presence of binder increased the tenacity in fabrics with respect to

Table 1
Tensile strength, elongation % and moisture regain % of treated and untreated fabrics.[a]

Samples	Tensile strength (kgf/mm^2)	Change in tensile strength (%)	Elongation (%)	Change in elongation (%)	Moisture regain (%)	Moisture regain (%) after 10 washes
Untreated viscose	0.515	–	21.8		12.3	12.3
Treated viscose 5 g/l SiO_2	0.620	20.3	26.27	20.5	14.8	13.8
Treated viscose 5 g/l SiO_2 + binder[b]	0.66	28.1	18.7	−14.2	11.2	11.1
Treated viscose 10 g/l SiO_2	0.65	26.2	19.2	−11.9	14.9	13.5
Treated viscose 10 g/l SiO_2 + binder	0.67	30.09	20.6	−5.5	12.5	12.4
Untreated polyester	2.47	–	34.01	–	0.4	0.4
Treated polyester 5 g/l SiO_2	2.53	2.4	27.5	−19.1	1.1	0.8
Treated polyester 5 g/lSiO_2 + binder	2.678	8.4	28.9	−15.02	0.88	0.87
Treated polyester 10 g/l SiO_2	2.636	6.7	26.8	−21.1	0.91	0.8
Treated polyester 10 g/l SiO_2 + binder	2.764	11.9	26.1	−23.2	0.79	0.75

Pretreatment conditions: (5 and 10 g/l) SiO_2 nanoparticle, pick up 90%, fixed at 140 °C for 10 min.
[a] Average of 10 measurements.
[b] (5 and 10 g/l) SiO_2 nanoparticle, pick up 90%, at 120 °C for 3 min, binder (50%) pick up 90%, at 150 °C, for 3 min.

the samples pretreated in its absence. This may be attributed to the crystallinity arises from the acrylate-based copolymer binder which crosslinks the copolymer molecules with each other or with the end group of fabrics during curing. It was also shown that the pretreatment causes a significant loss in elongation properties in the majority of samples. The treated fabrics showed approximately 5–23% loss in their elongation. It is clear that a relative increase in the moisture regain was generally observed for the treated polyester fabrics with respect to the untreated in presence and absence of binding agent. On the other hand, the treatment exhibited a little marginal increase in the moisture regain of treated viscose fabrics. The increase of moisture regain for the treated fabrics could be attributed to the opening of the fiber structure with the aid of SiO_2 nanoparticle, which allowed more water vapor molecules to penetrate the fiber structure. Based on the literature, it is worthy to mention that the presence of silica nanoparticles on the surface of the fabrics using the sol–gel method increases the water repellency of textile fabrics and its hydrophobicity which in term decreases the wettability (Zhu et al., 2011). In contrast, our data demonstrated a little marginal increment of moisture regain of textile fabrics. This observation was understandable. In the sol–gel method, the precursor material, the hydrophobic agent (TEOS) is hydrolyzed to silicic acid then, condensation reactions led to the formation of Si—O—Si bounds. After drying and curing, the solvent was evaporated and the agglomeration of silica nanoparticles with mean size of 80 nm fabricated silicon nanostructures on fabrics. However, due to its covering effect on fabrics with higher air trapping capability, a water droplet could not easily penetrate into the fabric as in pristine fabric which in turn would increase the hydrophobicity (Berendjch et al., 2011). On the other hand, another technique than the conventional sol–gel method has been conducted in this work using SiO_2 nanoparticle without modification with particle size of 21 nm as the precursor material which lead to the formation of ordinary SiO_2 nanostructured surface with lower air trapping capability. This may be explained the little marginal increase of moisture regain on the treated fabrics.

It is important to mention that the presence of acrylate-based copolymer binder retain the moisture regain for treated fabrics after 10 washes. Therefore, we can conclude that the effects of the treatment with SiO_2 nanoparticle in presence of binder for the enhancement of physical properties of treated fabrics are significant.

3.2. Antibacterial property

The modification of fibers by pretreatment with SiO_2 nanoparticle gave viscose fibers certain antibacterial efficiency against *E. coli* and *S. aureus* bacteria (Table 2). The criterion for passing the test or evaluating them was the percentage of bacteria growth reduction. Approximately, the total numbers of bacteria for samples were 22,800 CFU/ml (for *E. coli* bacteria) and 17,440 CFU/ml (for *S. aureus* bacteria) at zero contact time. It is clear that there are significant differences in antibacterial effects between the untreated viscose fabric, viscose fabric treated only with SiO_2 nanoparticle, and the viscose fabric treated with SiO_2 nanoparticle in presence of binder. It can be seen that the amounts reduced considerably (more than 95% for *E. coli* and 82% for *S. aureus* bacteria) for treated viscose samples in absence of binder but increased for control samples (untreated fabrics). It may be attributed to the antibacterial activity of SiO_2 nanoparticle. It is also clear that the durability for the inhibition of the bacterial growth has been greatly decreased after 10 laundering cycles. On the contrary, the presence of acrylate-based copolymer binder increases the percent reduction of bacteria, for both *E. coli* and *S. aureus*, reach maximum reduction up to 100% against *E. coli* and *S. aureus* when the concentration of SiO_2 was 10 g/l. It was also seen that the presence of binder indicates that not only an excellent inhibitory effect of the treated viscose fabric but also a durable antibacterial activity after 10 laundering cycles. This observation may be attributed to trapping of SiO_2 nanoparticle on the surface of fabrics under the influence of the binder.

3.3. Morphological observation

Treated and untreated viscose and polyester fabrics were imaged in order to evaluate the morphology and distribution of the coatings with SiO_2 nanoparticle in presence and absence of binder using SEM (Fig. 1). The surface of the untreated viscose fabrics clearly shows grooves and cracks (Fig. 1a). In contrast, such characteristics completely disappeared on the surface of the treated viscose fabric in absence of binder and apparently showed higher roughness and agglomerated clusters of silica nanoparticles than the untreated one (Fig. 1b). It was shown that the presence of acrylate-based copolymer binder disaggregate and disintegrate the agglomerated particles of SiO_2, therefore a homogeneous SiO_2 coatings would be formed on the surface of viscose sample (Fig. 1c). These uniform coatings may be attributed to the chelating of SiO_2 nanoparticles with acrylate-based binder which in turn disaggregates the nanoparticles on the surface of fabrics. On the other hand, a typical untreated polyester fabric (Fig. 1d) shows a smooth surface with few defects. A change in the surface morphology is easily observable for SiO_2 nanoparticles treated polyester fabrics (Fig. 1e), if compared with the uncoated control sample. The image of treated polyester fabrics shows the increase of fiber coverage with of SiO_2 nanoparticles. Here too, homogeneous SiO_2 coatings would be formed on the surface of polyester fabric in presence of binder (Fig. 1f).

Table 2
Percent reduction of bacteria on SiO_2 nanoparticle treated viscose and polyester fabrics.

Samples	Reduction of bacterial count (%)					
	Escherichia coli (G−)			*Staphylococcus aureus* (G+)		
	1 Washing cycle	5 Washing cycle	10 Washing cycle	1 Washing cycle	5 Washing cycle	10 Washing cycle
Untreated viscose	0	0	0	0	0	0
Treated viscose without binder[a]	95	50	30	82	53	33
Treated viscose (5 g/l SiO_2) + binder[b]	98	98	98	96	95	95
Treated viscose (10 g/l SiO_2) + binder	100	100	100	100	100	100
Untreated polyester	100	100	100	100	100	100
Treated polyester (10 g/l SiO_2) + binder	100	100	100	100	100	100

[a] *Pretreatment conditions*: 10 g/l SiO_2 nanoparticle pick up 90%, fixed at 140 °C for 10 min.
[b] (5 and 10 g/l) SiO_2 nanoparticle, pick up 90%, at 120 °C for 3 min, binder (50%) pick up 90%, at 150 °C, for 3 min.

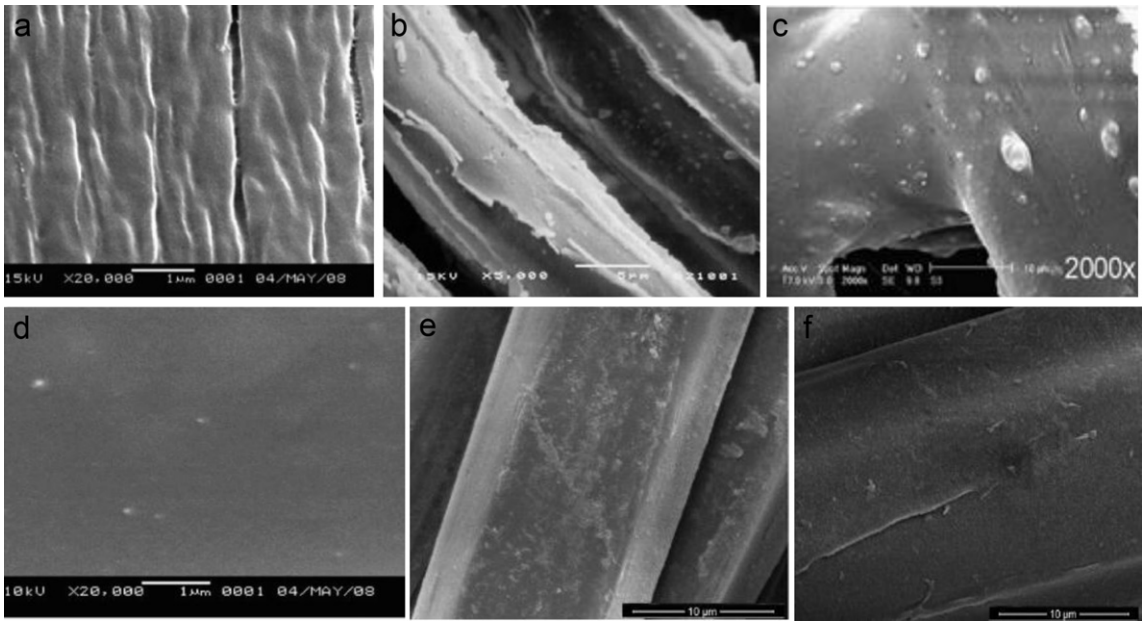


Fig. 1. SEM micrographs of untreated and treated viscose and polyester fabrics.

3.4. Effect of pretreatment on the color yield of viscose and polyester fabrics

The viable modification of viscose and polyester fibers after SiO_2 nanoparticle and binder pretreatment has prompted us to explore the dyeability and printability of the modified fibers with conventional direct and disperse dyes, respectively. The earlier alkaline pretreatment of polyester increase the adhesion of SiO_2 nanoparticle to the surface of polyester macromolecules, because of the absence of active groups in the polyester. The pretreatment in an alkaline solution containing 5 g/l KOH is permitted (Hakeim, El-Gabry, & Okeil, 2008). Color yield as expressed as *K*/*S* for the colored viscose and polyester fabrics treated with SiO_2 nanoparticle in presence and absence of binder is given in Figs. 2 and 3, respectively. The results clearly demonstrate that pretreatment using SiO_2 nanoparticle enhances the color strength of dyed viscose and polyester fabrics. The enhancement in color strength could have arisen from the coordination of SiO_2 with dye and fibers and/or the thin film from silica nanoparticles formed on the surface of fabrics which imparted low reflectance index and increased color yield. It is obviously clear that the dyed samples exhibit *K*/*S* of higher value in presence of binder than in its absence regardless the type of fabric. This observation may be attributed to trapping of SiO_2 nanoparticle on the surface of fabrics under the influence of the binder, consequently the number of fixed nanoparticles which are the chelating sites for the dyes increases. The binder contains up to 60% reactive groups (based on the weight of the binder) in the copolymer which crosslinks the copolymer molecules with each other or with the end group of fabrics during curing. The self-cross linking binder react with the active end groups of viscose (—OH) or the generated group of polyester after its alkaline hydrolysis during curing forming films which trap the SiO_2 molecules producing

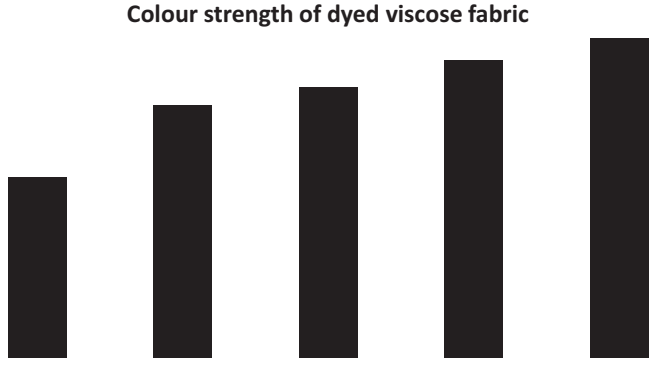


Fig. 2. Color yield (*K*/*S*) of pretreated dyed viscose fabrics using C.I. Direct Red 80 at various conditions.

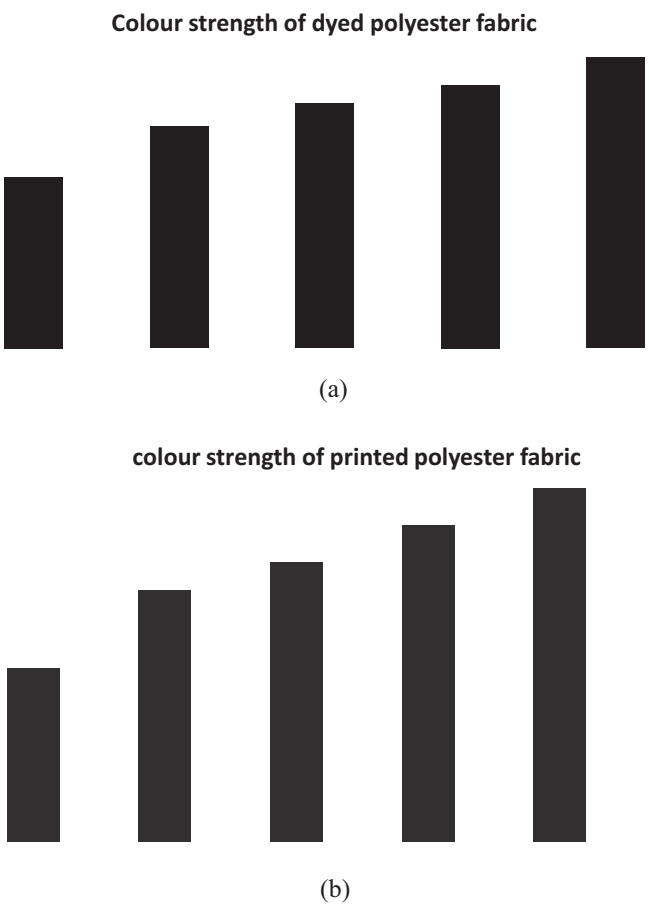


Fig. 3. Color yield (K/S) of pretreated dyed and printed polyester fabrics, using C.I. Disperse Red 60 at various conditions.

high durability of SiO_2-treated fabrics that increase the color fixation. It was further demonstrated that the K/S of the pretreated fabrics hase a noticiable increase with increaing SiO_2 nanoparticles in presence and absence of binder. Moreover, the presence of binder accelerate the dyeing properties of SiO_2 nanoparticles pretreated polyester with disperse dye by decreasing the temperature of dyeing from 130 °C to 90 °C without the use of carrier as well as increasing the color yield,compared with the control sample. This approach is a greener way for effective dyeing of SiO_2 nanoparticles pretreated polyester with disperses dye in presence of binder.

Fig. 3b illustrates the effect of pretreatment on the color strength of printed polyester fabrics using C.I. Direct red 80 in presence and absence of binder. The reults reveal that the pretreatement of polyester with SiO_2 nanoparticles has a profound impact on the printing properties of treated polyester. It is clear that the color strength of printed polyester fabrics follow the same trend of the dyed fabrics. It was also clear that the pretreatment with SiO_2 nanoparticles in presence of binder decrease the temperature of steaming (from 180 °C to 110 °C) needed to reach maximum color strength for disperse dye. In other words, the fixation rate is accelerated by the pretreatment in presence of binder, which can be explained in a strong trapping between SiO_2 and fibers. Due to the enhanced attraction, the disperse dyes reach the dye sites in the fibers faster, and subsequently the physical bonding rate is also accelerated. Thus, all the data presented in Fig. 3a and b for dyeing and printing of polyester fabrics, respectively, demonstrate the superiority of pretreatment of polyester fibers in presence of acrylate-based copolymer binder to impart maximum color strength of colored samples. Besides, the saving of energy and auxiliaries has been achieved in this manner.

Table 3
Washing fastness of untreated and treated viscose and polyester fabrics in presence and absence of binder fabrics then with binder.

Washing fastness	SC	SW	Alt.
Untreated viscose	4	3	3
Treated viscose 5 g/l SiO_2	4–5	3–4	4
Treated viscose 10 g/l SiO_2	4–5	3–4	4
Treated viscose (5 g/l SiO_2) + binder	4–5	4–5	4–5
Treated viscose (10 g/l SiO_2) + binder	4–5	4–5	4–5
Untreated polyester fabric			
Dyeing	3–4	3–4	3–4
Printing	3	4	3–4
Treated polyester (5 g/l SiO_2)			
Dyeing	3	4	3–4
Printing	4–5	4	4
Treated polyester (10 g/l SiO_2)			
Dyeing	4–5	4	4
Printing	4–5	4	4
Treated polyester (5 g/l SiO_2) + binder			
Dyeing	4–5	4	5
Printing	4–5	4–5	5
Treated polyester (10 g/l SiO_2) + binder			
Dyeing	4–5	4–5	5
Printing	4–5	4–5	5

SC: staining on cotton; SW: staining on wool and Alt.: change of color.

3.5. Infrared spectra

All the previous good results in presence of binder are attributed to trapping of SiO_2 nanoparticle on the surface of fabrics under the influence of the binder. In this regard the infrared spectra of treated polyester fabric are focused on the peak intensities and broadening of bands of SiO_2 nanoparticles. The spectrum of treated polyester in presence and absence of binder are summarized in Fig. 4. The characteristic bands almost at 1085, 800 and 460 cm^{-1} are correspond to the stretching, bending and out of plane of Si—O bonds, respectively. The position and the shape of the main Si—O vibrational band at 1085 cm^{-1} shows a stoichiometric silicon dioxide structure. It is clear that the intensity and broadening of peaks increase obviously (see Sample A) in presence of acrylate-based binder. It is also clear that the peak at 2357 cm^{-1} for Si—C stretching is strengthened very much and become stronger in presence of binder. These observations confirm the trapping of SiO_2 on the surface of fiber in presence of binder.

3.6. Washing fastness

The durability of direct and disperse dyes on viscose and polyester fabrics pretreated with SiO_2 nanoparticle in presence and absence of acrylate-based binder was evaluated in terms of fastness toward washing using the gray scale according to AATCC Test Method 61 as shown in Table 3 with fastness rating 5, 4, 3, 2, and 1 on the gray scale, respectively. The assessement shown in Table 3 adressed that the washing fastness of the pretreated dyed and/or printed viscose and polyester fabrics with SiO_2 nanoparticle in presence and absence of binder is better than those untreated fabrics. The results show that washing fastnesses of the two dyes on viscose and polyester for the pretreated samples under investigation are good to excellent with rating 3–4 and 5 and the best washing fastness rating was obtained on pretreated polyester fabrics in presence of binder,irrespective of the amount of SiO_2 nanoparticle. This may be attributed to the earlier alkaline pretreatement of polyester fabric which enhanced the durability toward washing in presence of binder.

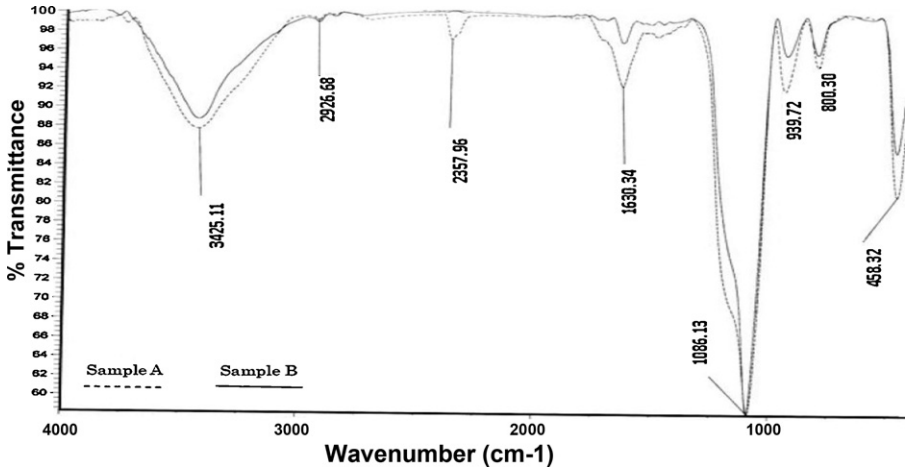


Fig. 4. FTIR spectra of treated polyester fabrics in presence of binder (Sample A) and in its absence (Sample B).

4. Conclusions

The treatment of the viscose and polyester fabrics with SiO_2 nanoparticle in presence of binder imparted high level of surface functionalization to the fabrics. Another technique than the conventional sol–gel method has been conducted in this works using SiO_2 as the precursor material which lead to the formation of ordinary SiO_2 nanostructured surface with lower air trapping capability on the treated fabrics. The effects of the treatment with SiO_2 nanoparticle in presence of binder for the enhancement of physical properties of treated fabrics are significant. The presence of acrylate-based copolymer binder increases the percent reduction of bacteria on pretreated viscose, for both *E. coli* and *S. aureus* as well as a durable antibacterial activity after 10 laundering cycles has been achieved. The results reveal that the pretreatement of polyester with SiO_2 nanoparticles has a profound impact on the dyeing and printing properties of treated polyester. The presence of binder accelerate the dyeing properties of SiO_2 nanoparticles pretreated polyester with disperse dye by decreasing the temperature of dyeing from 130 °C to 90 °C without the use of carrier as well as increasing the color yield,compared with the control sample. This approach also decrease the temperature of steaming of printed polyester fabrics (from 180 °C to 110 °C) needed to reach maximum color strength for disperse dye. Moreover, the washing fastnesses for the colored samples of viscose and polyester are good to excellent with rating 3–4 and 5.

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