Surface Coating on Cellulose Fabrics with Nonionic Dyes - silica Hybrids

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Coatings obtained on cellulose fabrics with nonionic dyes – silica hybrids have been investigated. Composition of the impregnation bath and parameters having a major influence on coloring properties were studied in relationship with washing and light fastness. It was found that cotton can be coated with organic-inorganic nonionic dyes - silica hybrids exhibiting fair washing and light fastness. Properties of the coated materials can be controlled by variation of parameters affecting sol obtaining procedures or impregnation conditions. The presence of only one trialkoxysilane group per chromogen makes the formation of a highly crosslinked silica network to be difficult. The partial condensation of DR1-PTES (Disperse Red 1 dye covalently linked to 3-isocyanatopropyltriethoxysilane) to the stage of oligomeric structures, together with the existence of silanol and unhydrolyzed alkoxysilane groups can explain leaching behavior of the coatings obtained with this type of hybrid materials.

Keywords: nonionic dyes, silica hybrids, surface coating, cotton fabrics, sol-gel process

Silica coatings obtained by sol-gel processes have found applications in modifying surface of textile materials in order to obtain technical textiles with high mechanical and thermal stability. Furthermore, in the recent years the sol-gel approach was proposed to obtain functional moieties such as: super hydrophobic [1-3], biocide [4,5], UV-protective [6-8], conductive [9,10], flame-retardant [11,12], photochromic [13-15] or colored [16,17].

The sol-gel processes are studied also for coating different type of textile materials as alternative methods to conventional dyeing. Many of the studies presented until now are deal with the enhancement of the fastnesses of conventional dyeing by sol-gel after treatments [18]. Other authors studied application of different type of dyes frequently used in practical coloration together with silica sols for dyeing natural [19-21] or synthetic fibers [22].

Some of the recent concerns are focused to establish the most suitable components of silica sols in order to obtain improved wash and light fastness [23] of dyed fabrics and to study the influence of functional polysiloxanes on the color yield and color gamut of dyed fabrics [24].

There are well known concerns to find a practical solution for coloring textile blends with the same type of dyestuffs [25-27]. Obviously, cotton-polyester blends are the most important among the textile blends and as it is well established in practice, dyeing of such sort of textiles is made frequently with specific dyestuffs for each component. It is worth to be mentioned that there are some reported studies regarding the usage of a single class of dyestuffs, namely disperse dyes, for coloring textile blends [28-30]. Theoretically, this is the cheapest solution for such a purpose and all the processes comprise in a previous step chemical modification of the cotton fibers to made them compatible with disperse dyes, which in practice are not suitable for dyeing this type of fibers [31,32]. Since the application of disperse dyes on polyester fibers does not raise any problem it is important to study conditions of application of colored silica coatings on cotton fibers. The goal of the present study was to investigate the possibility of coloring cotton fabrics with disperse dyes embedded or chemically linked in hybrid silica networks, and to evaluate the performances of the obtained colored coatings from the point of view of practical coloration.

Experimental part

Materials and methods

The chemicals used were of laboratory reagent grade and were obtained from Merck (Germany) and Aldrich (USA). Hydrochloric acid (0.1 N), tetraethylorthosilicate (TEOS), phenyltriethoxysilane (PhTES), 1,4-diazabicyclo[2.2.2]octane (DABCO), ethanol, tetrahydrofuran (THF), sodium dodecylsulfate (SDS) were used in this study as they were received. Disperse Red 1 - C.I. 11110 (DR1) was obtained by diazotization-coupling reactions and purified by extraction with toluene in a Soxhlet extractor, followed by re-crystallization. Chemically modified Disperse Red 1 (DR1-PTES) was prepared by reaction of DR1 with 3-isocyanatopropyltriethoxysilane (NCOTEOS) in THF, in the presence of DABCO [33]. Textile material used was a 100% cotton fabric having a specific weight of 106 g/m^2, chemically whitened.

FTIR spectra were recorded on a Jasco FTIR 6300 spectrometer equipped with an ATR Specac Golden Gate (KRS5 lens), in the range 400-4000 cm^{-1} (30 scans at 4 cm^{-1} resolution). Spectra deconvolution was performed using Jasco Spectra Analysis Program.

Diffuse reflectance spectra were measured with a spectrophotometer UV-VIS-NIR Jasco V-570 equipped with an integrating sphere Jasco ILN-472 (150 mm) and using spectralon as a reference material.

The color yield (K/S) of the colored fabrics was calculated using Kubelka-Munk equation: $K/S = (1-R)^2/2R$, where K is the absorption coefficient of the substrate, S is the scattering coefficient, and R is the reflectance of the colored fabric at wavelength of maximum absorption.

The particle size distribution was obtained by dynamic light scattering (DLS) using a Malvern Nano ZS Zen3600

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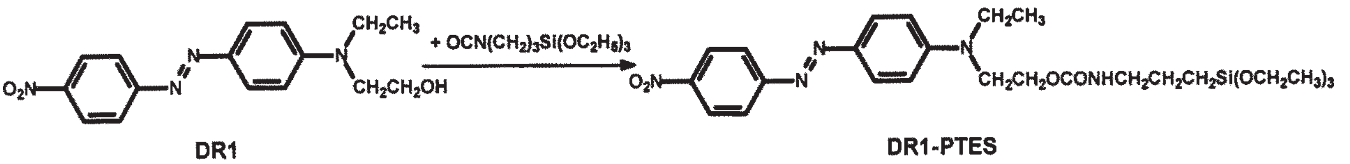

Scheme 1. Structure of nonionic dyes contained in hybrid materials

zeta sizer. A CAM 200 optical contact angle and surface tension goniometer (KSV Instruments) was used to assess wetting of the surfaces. Atomic force microscopy was performed in non-contact mode on a Park Systems XE 100 and scanning electron microscopy was made on a Quanta 200 microscope.

Light fading tests were performed with an ATLAS - XENOTEST 150S+ in accordance with ISO B05. To assess the stability of the fabrics dyed with different sol compositions, colored test-pieces were tested according to washing standards in place for determining the color change and transfer to the accompanying textiles during eight repeated washing cycles. For this purpose was followed a test like laundering household washing under conditions of ISO 105/C, using a solution of 1% by weight SDS, at a temperature of 40^{0}C, for 2 h, on a LINITEST type device. The test-pieces, consisting of a sample of the coated cotton fabric were placed between a cotton fabric on the one side, wool and a polyester fabric, on the other side, sewn on four sides. After washing, test-piece composite was rinsed with warm water and cold water and then left to dry in air, seams being disposed on three sides. After drying, test-pieces were evaluated comparatively with the original colored fabric textile and accompanying materials. The change in color of the specimen and the staining on the adjacent fabrics are assessed with the grey scale, according to EN ISO 105 A01, A02 and A03 / 1999. Color fastness to weathering is evaluated with the grey scale which includes five shades. The highest value is the best and the lowest is the worst. The procedure is based on the comparison of the contrast between the color of the sample before and after performing the test and the contrast on the scales. Light fastness is evaluated in a similar manner using a blue scale which includes eight grades.

Obtaining of the impregnation bath and pad-drying procedure

The impregnation bath was obtained mixing under vigorous stirring at room temperature ethanol, TEOS, a network modifying agent (PhTES), HCl solution, water and dyestuff and reactions were conducted in the usual manner of sol-gel processes. In a typical process 3.25 mL TEOS, 3.25 mL PhTES, 4.35 mL ethanol, 0.65 mL distilled water, 3.5 mL solution (2.2% by weight) DR1 or DR1-PTES in THF and 0.4 mL hydrochloric acid (0.1 N) were mixed and stirred at ambient temperature for 3 h to obtain a homogeneous solution, stable to ageing at least 6 months when it is stored at 4^{0}C.

A cotton fabric of about 2 g was impregnated with sol compositions prepared as previously described by four successive passes through a laboratory Ernst BENTZ horizontal pad mangle, at a constant rate of 0.5 m/min. and a pickup of 100%. Coated material was dried at room temperature for 2 h and then subjected to heat treatment at 120^{0}C for one hour in a thermo-fixation oven.

Results and discussions

During the experiments a major concern was focused to establish the composition of the sol that constitute the impregnation bath itself and that allowed us to obtain some uniform, elastic and covering layers having good adhesion properties for the cellulose material and exhibiting good washing fastness. An objective of the study was to compare coatings properties on cotton substrates, obtained using hybrids of class I (corresponding to the entrapped dye - DR1 - into the hybrid silica network) and hybrids of class II (corresponding to the chemically linked dye - DR1-PTES - into the hybrid silica network), structure of the dyestuffs being shown in scheme 1.

Compositions formed of TEOS and network modifying agents in different ratios, water, ethanol, dyestuffs and acid catalysts were used as impregnation baths. Starting from these few general characteristics, several mixtures were prepared and used to obtain silica coatings having good wash and light fastness on cellulose fibers. Cotton fabric samples were dipped into the impregnation bath and passed through a two-roller laboratory-padding mangle. The padded fabrics were then dried to evaporate water and residual solvents from the inorganic network. In addition to the hydrolysis process, polycondensation occurs leading to a polysiloxane network, while during thermal treatment silanol groups can also react with alcoholic groups of cellulose. Succession of reactions during sol-gel process before and after the impregnation of textile materials has been shown in other previous works [34] and explains at least in part the adhesion of coatings to cellulose and other properties of the coated textile materials.

Film building materials were prepared under acidic conditions from mixtures of organically modified silicon alkoxides and tetraethoxysilane. We found that when the volume of the organic substituent in the hybrid network was increased, such in the case of phenyl ring, the amount of leached dye decreased during the washing tests, comparatively with alkyl modified silica coatings [31]. On the other hand, when PhTES was used as a network modifying agent, we obtained coatings having improved light and washing fastness. An explanation of this behavior could be a higher degree of compatibility achieved between phenyl groups in the silica networks and highly conjugated dyestuffs molecules. During the experiments it was observed that disperse dyes DR1 and DR1-PTES are homogeneous incorporated and distributed in film building materials, when the amount of phenyl groups in the inorganic network increases, probably because hydrophobic nature of pore surface increases and the hydrophobic dyes can be easily adsorbed on them and accomodate with the new formed environments. This was the main reason for the selection of PhTES and TEOS as network forming agents. Under these circumstances the leaching stability of disperse dyes used for the experiments depends only on the conditions under which the silica matrix was formed and on the chemical structure of the disperse dyes.

Light fastness of the dyeing was also largely influenced by the dyestuff content and composition of the impregnation bath, as it can be seen from table 1. Thus, the lowest value of the light fastness was recorded when coatings were obtained with sols containing only TEOS. Investigations regarding the effect of adding PhTES to the

Table 1
FASTNESS OF COATINGS OBTAINED WITH HYBRID MATERIALS

Silanes molar ratio and dyestuff content (w/v, %) in the padding liquors			Light-fastness (grade)	Washing fastness (grade)				Rubbing fastness (grade)	
TEOS	Modifying agent (mole)	Dye (%)		Color change	Color staining on			Dry	Wet
					cotton	polyamide	wool		
3	PhTES (1)	DR1 (0.2)	2-3	3	4-5	4-5	4-5	3	2-3
1	PhTES (1)	DR1 (0.2)	3-4	2-3	4	4	4-5	3	2-3
1	PhTES (1)	DR1 (0.4)	4 Y	3-4	3	3-4	5	2-3	2
1	PhTES (1)	DR1 (0.6)	4 Y	3-4	2-3	3-4	4-5	2	1-2
1	PhTES (1)	DR1 (0.8)	4 Y	3-4	2	3	3-4	1-2	1-2
1	PhTES (1)	DR1 (1)	4-5 Y	3-4	2	3	3-4	1	1
3	MeTES (1)	DR1 (0.4)	3	2-3	3-4	4	4	2	2
1	MeTES (1)	DR1 (0.4)	3	2-3	4-5	4	4	2	1-2
-	MeTES (1)	DR1 (0.2)	3-4	1-2	4-5	3-4	4	1-2	1
1	OTES (1)	DR1 (0.2)	3	2	4-5	3-4	3-4	2	1-2
1	OTES (1)	DR1 (0.4)	3-4	2	4-5	2-3	2-3	1-2	1
1	PhTES (1)	DR1-PTES (0.5)	4-5	3-4	4-5	4	4	3	2-3

silica sol, as network modifying agent, shows that the light fastness increased with its content in the impregnating sol. The improvement of light fastness could result because dyestuff molecules are well separated each other due to the homogeneous embedding or even better to covalent bonding onto the silica network, in the case of hybrids of class II. It is obviously that the dyestuffs will be more protected from eventually formed photodecomposition products. Likewise, interactions between dyestuff molecules and organic vicinities of the host matrix could lead to an efficient energy dissipation of the excited states to the organic surroundings of hybrid silica network. The existence of such interactions between dyes and the host matrix was demonstrated in several studies regarding colors variation obtained with dyestuffs entrapped in different organically modified silica matrices [35] and could explain some of our results. The same behavior was recorded when the dyestuff content in the impregnation bath was increased, as with increasing the number of passes through the impregnation baths. In the last case, the reason for this behavior is an increase of the color strength obtained due to a higher content of dyestuff on the fiber.

Several types of sols having a PhTES content varied from 25 to 50% (molar) and a DR1 content of about 0.6% (by weight) in the padding liquors were initially studied and wash fastness of colored materials were compared. During the experiments it was observed that an increasing of the PhTES content, lead to a layer having good adhesion for cellulose and as a consequence washing fastness increased, as it is shown in table 1. This trend is even more pronounced when using DR1-PTES instead of DR1 in the composition of the padding liquors.

By coating cellulose textile materials with sols having an equal content of TEOS and PhTES and varying the amount of water, were obtained uniform coatings, but fastness to washing and intensities of the obtained colors decreased when TEOS : water molar ratio increased from 1:2 to 1:10.6. An explanation could be in direct relationship with the coatings surfaces obtained on the cellulose fibers. As it was previously mentioned by other authors [36], large quantities of water in the sol composition lead to films cracks and cannot ensure the integrity of the coatings to successive washing cycles and therefore lower fastness properties are obtained.

In both cases the silica hybrids formed at the surface of the textile material can interact with the surface OH groups of the cellulose macromolecules leading to the formation of a coating having embedded or covalently linked dyestuff molecules. Adsorption of silanes on the surface of cellulose fibers, followed by heat treatment at 120°C can induce chemical bonding by Si-O-C coupling, as it was showed by other authors [37, 38]. The permanent bonding of the silanes to the cellulose surface is ensured by the self-condensation of silanol groups that generate a siloxane network which shields the surface from hydrolysis of the Si-O-C moieties. This bond exhibited poorer stability to hydrolysis than C-O-C or Si-O-Si bonds, mainly in alkaline conditions. It is obviously that when the coating become more hydrophobic due to the network modifying agents, its stability to washing will be more effective.

Unfortunately, rubbing fastness is relatively poor due to mechanical damage of the hybrid silica coatings. It is very probable that dyestuffs molecules situated in the proximity of the silica surface will be easily removed by rubbing, thus affecting the color of the coatings. The same phenomenon is also seen in the case of coatings containing covalently linked DR1-PTES dyestuff. This confirms removal of the dyestuffs from the coating surface along with parts of silica polymer network during the wet and dry rubbing tests.

The characteristic bands of cellulose and DR1-PTES silica coatings revealed that in spite of the similar absorption bands of the Si-O-C, C-O-C and Si-O-Si bonds, for the coated cellulosic materials some differences are recorded in the FTIR spectra. Much broader shape of some bands is obtained due to overlapping of the bands corresponding to the components of the hybrid coatings and textile substrate. After normalization, the absorption peaks assigned to Si-O stretching vibration show increased intensity while the relative intensity of the 945 cm^{-1} band assigned to Si-OH stretching vibration decreased, which in our opinion is definitely related to the formation of Si-O-Si and Si-O-C bonds during thermo-fixation. Other aspects that can be mentioned are related to the 1105 and 1158 cm^{-1} peak broadening after coating due to the Si-O-C, C-O-C and Si-O-Si overlapped bands. The formation of substituted oligomeric cyclic siloxanes was evidenced after spectral deconvolution which revealed the existence of a characteristic band situated at 1130 cm^{-1} similarly to that identified in the FTIR spectrum of DR1-PTES coating, as shown in figure 1.

At 783 cm^{-1} has also been identified the band corresponding to Si-O-Si symmetric stretching vibration of ring structures. These bands are absent in the FTIR spectra of the cellulosic substrate and result from Si-O cage like structure of oligomeric silsesquioxanes formed during sol-gel process [39-43]. Oligomeric structures are responsible for the relatively low washing fastness recorded in the case of DR1-PTES silica coated material and sol-gel process

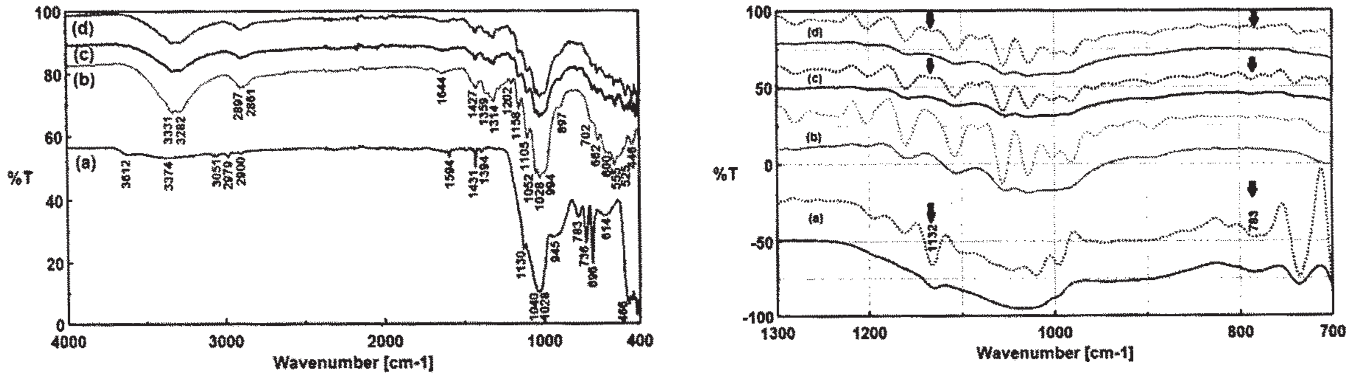

Fig. 1. FTIR-ATR spectra (a) and deconvoluted spectra (b) of (a) DR1-PTES silica coating, (b) cotton fibers, (c) DR1 silica and (d) DR1-PTES silica coated cotton

must be conducted so as to diminish the possibility of forming such compounds.

Size of the hybrid nanoparticles in the impregnation sols

The particle size distribution in the impregnation baths according to DLS measurements is shown in figure 2, and reveals that for silica modified with phenyl groups (colorless sol) the average particle size was about 2 nm. For colored hybrids it was found that aggregation was favored when the dyestuff was present in the composition. Thus, in the case of the hybrids of class I, DR1 molecules are entrapped in the silica network and consequently we obtained predominant aggregates having an average particle size of about 531 nm. An explanation could be the association between DR1 free molecules and phenyl groups from the organic modified silica sol that lead to aggregates having a relatively large size. When we used DR1-PTES we obtained hybrids of class II and probably because dyestuff is chemically grafted onto the silica network, smaller aggregates are obtained, having an average particle size of only 297 nm. It is important to note that in the last case, the degree of freedom of the molecules is limited because the dyestuff is tightly linked on the silica network in a constrained environment. In this case, dyestuff molecules and phenyl groups from the network modifier are randomly distributed onto the inorganic surface, associations between dyestuffs molecules are hindered and thus particles and aggregates formed during sol-gel processes are smaller.

Morphology, roughness and hydrophobic character of the coating materials

The SEM images of uncoated, DR1 and DR1-PTES coated cotton fibers presented in figure 3 show small differences regarding the surface uniformity. Cotton fibers presented a relatively smooth surface affected only by fibrils bundles. Silica coatings obtained on the cotton surface cover uniform the fibers, independently of the dyestuff contained in the hybrid coatings. The surface roughness is very close to that of uncovered material which proves uniformity of the hybrid coatings as a result of the numerous small particles adsorbed on the fabric surface. From the SEM images are clearly seen some areas in which are observable bridges of silica between cotton fibers.

The same result was obtained from the SEM images on the silica matrices obtained after performing a thermo oxidative treatment at 900^{0}C on the coated fabrics. It can be seen that the obtained residue reproduces the structure of the cotton fabrics and is formed of silica shell which constitute the inorganic part of the hybrid coatings. In the SEM micrographs could not be distinguished bridges between discrete silica shells or damaged areas of the silica coatings. This is a solid proof of the continuity and

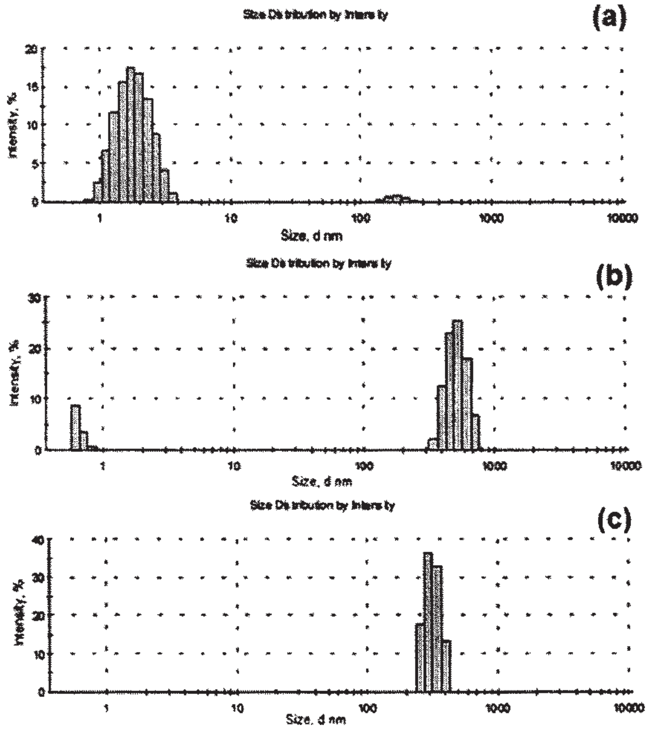

Fig. 2. The hydrodynamic size of (a) colorless silica, (b) DR1-silica and (c) DR1-PTES-silica sol nanoparticles

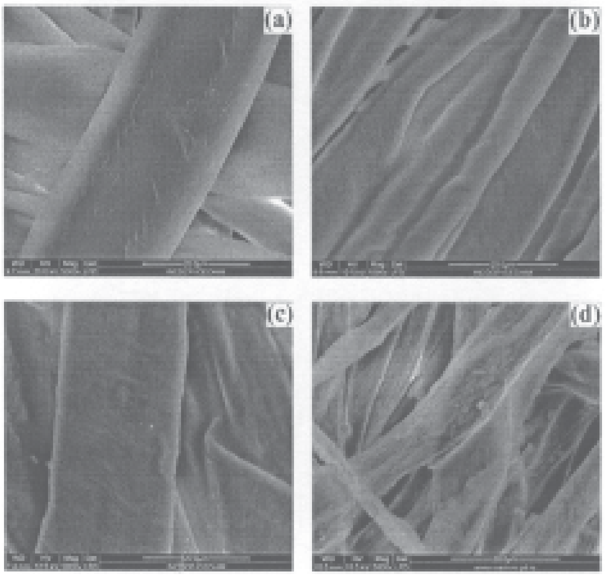

Fig. 3. SEM images of (a) uncoated cotton fibers, (b) DR1 and (c) DR1-PTES silica coated cotton fibers, (d) residue at 900^{0}C obtained after thermo oxidative decomposition of DR1 - silica coated cotton fabric

integrity of the silica films obtained on the cotton fibers. The SEM images show that cotton fibers are completely covered by silica coatings.

The AFM images shown in figure 4, revealed that the uncoated, DR1 and DR1-PTES modified silica coated cotton surfaces showed a root-mean-square (RMS) roughness value of 28, 34, and 30 nm, respectively. Moreover the slightly increasing in surface roughness recorded for the DR1 modified silica coating as compared to DR1-PTES and uncoated cotton also explain the higher contact angle obtained in the first case.

It was observed a significant variation in the water contact angle as a function of network modifying agents and dyestuff molecules present at the surface of textile materials. Thus, the surface characteristics can be changed from hydrophilic to more hydrophobic by varying type and quantity of network modifying agents. But, as it is well known for hydrophobic coatings, relatively smooth surfaces cannot provide contact angles of water that exceed 120^0. From the analysis of the obtained contact angles and from their evolution in time we can conclude that a low content of network modifying agent in the coating composition lead to relatively low values of contact angle of about 90^0 which decrease in time, as it was observed when PhTES content is 25%. This is probably due to an uneven distribution of the phenyl groups at the silica surface. When the quantity of PhTES was increased to 50%, the measured contact angle become higher, nearly 110^0 and it is maintained relatively constant in time. It was also found that in the case of DR1-PTES coatings the contact angle is lowered at about 88^0 when the content of PhTES in the composition is about 50% (mole). This is probably due to the length of propyl spacer provided by NCOTEOS bifunctional anchoring agent used for the synthesis of DR1-PTES. On the other side, this behaviour can be also supported by the hydrogen bonds formed due to the presence of urethane groups from DR1-PTES molecules present at the surface of coating materials.

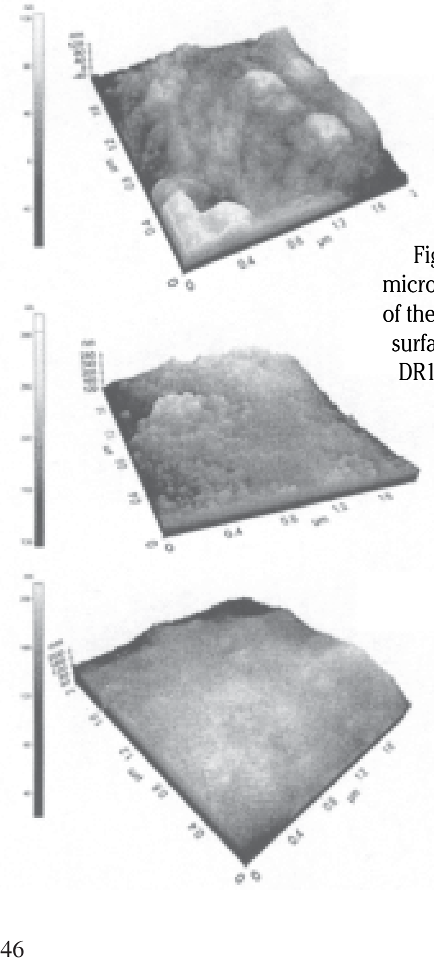

Fig. 4. Atomic force microscopy (AFM) images of the (a) uncoated cotton surface, (b) DR1 and (c) DR1-PTES hybrid silica films

Leaching behaviour of the colored coatings

Analyzing residues obtained after calcination in air, at 900^0C, of cotton coated fabrics successively washed at 40^0C it was observed that leaching is significantly reduced for fibers coated with hybrids of class II comparatively to coatings obtained with hybrids of class I. In the case of hybrids of class II, this behaviour was a result of immobilization of dyes within silica network by chemical bonding, and thus the fastness properties were significantly improved, as it can be observed in figure 5.

Furthermore, from the residues, practically we evaluate the quantity of silica remained on the fibre after each washing cycle. Results show for DR1-PTES a degree of leaching of nearly two and a half lower than for DR1 after performing eight washing cycles. This behavior supports the idea of forming of a more compact network in the case of DR1-PTES, ensuring better protection to hydrolysis.

Analysis of the recorded data resulted from diffuse reflectance spectroscopy shows differences after performing several washing cycles for fabrics coated with the two types of hybrids. Thus, it was observed that major differences are recorded in both cases mainly after the first washing test and especially for coatings obtained using hybrids of class I.

Results confirm the existence of two leaching pathways during washing cycles, which are characteristic to fabrics coated with hybrids of class I. The first one consists of leaching DR1 molecules at the surface of the hybrid coating which can be easily removed by washing and the second one imply removing parts of the inorganic network containing DR1 entrapped in the pores. In the case of hybrids of class II, leaching could be due to the presence of DR1-PTES chemically linked at the surface of the inorganic network and can be removed by washing only with parts of the hosting network.

The degree of leaching can be calculated from the most significant minimum of the reflectance spectrum, method similar to that presented elsewhere [44-47]. The degree of leaching by washing calculated from diffuse reflectance measurements follow the same trend as was determined from residues at 900^0C, as can be observed in figure 5. From the measurements of K/S parameter, dependence against dyestuffs concentration in the padding liquors (situated in the range 0.1-0.6% by weight) and considering the amount of silica coating deposited on the fiber, determined by weighting the samples before and after the impregnation and the subsequent thermal treatment, were established relationships that best approximates the leaching behaviour. It is important to note that K/S values recorded for all coated samples are very high for this type of dyestuffs which in the case of conventional dyeing doesn't manifest affinity for cotton fabrics. Differences recorded between the two methods used to calculate leached material confirm the existence of the two pathways for leaching.

However, the diffusional mechanism could be encountered even for the hybrids of class II because of the existence of cyclic oligomers formed during DR1-PTES hydrolysis-condensation. As it was presented in other papers the formation of cagelike oligomeric structures is kinetically favored over chain extension during co-hydrolysis of tetralkoxysilanes and trialkoxysilanes containing organic groups [48]. Thus, during the washing tests, besides Si-O-C hydrolysis, SDS micelles can extract DR1 physically

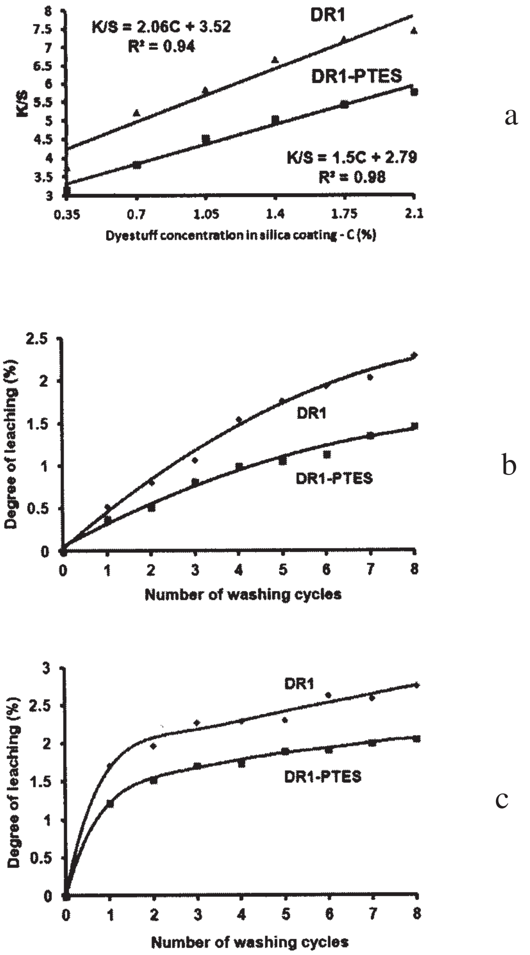

Fig. 5. The K/S parameter variation vs. dyestuffs concentration in the silica coatings (a) and the degree of leaching by washing at 40^{0}C estimated from (b) residue at 900^{0}C, (c) diffuse reflectance spectra

entrapped into the pores or located at the silica surface and also DR1-PTES derived oligomeric structures, due to the hydrophobic nature of the nonionic dyestuffs.

The profiles of the leaching curves show for coatings containing DR1 that more than a half of the leached dye was lost during the first washing cycle. This is an important finding that confirm the presence of DR1 at the surface of the silica coating. Paradoxically, for DR1-PTES the leaching after the first washing cycle was almost the same with that of DR1 and can be sustained only by the existence of oligomers. Because DR1-PTES is chemically linked to the silica matrix, after three succesive washing cycles the K/S parameter became almost constant, which mean that the dyestuff cannot be leached from the fabric anymore after the removal of the oligomeric structures.

Conclusions

Cellulose textile materials can be colored in sol-gel systems in a single phase, with nonionic chromogens that are not specific for this type of textile fibers. Properties of the colored materials can be controlled by variation of parameters affecting sol obtaining procedure or impregnation conditions. The sol with a TEOS : PhTES = 1:1 molar ratio containing nonionic dyestuffs allowed obtaining colored cellulose fabrics having fair light and good washing fastness.

Colored coatings are sufficiently intense and uniform, while after eight washing cycles leaching of the hybrid material and dyestuffs from the fabrics is acceptable and can be estimated from diffuse reflectance spectra and residues at 900^{0}C. The presence of only one trialkoxysilane group per chromogen makes the formation of a highly crosslinked silica network to be difficult. Apparently, the partial condensation of the functional DR1-PTES to the stage of oligomeric structures due to steric effects together with the existence of residual silanol and alkoxysilane groups can explain leaching behavior of the coatings obtained with hybrids of class II.

The results of the study offers a method for coloring cotton fibers with disperse dyes and open the possibility of finding a viable solution for coloring polyester-cotton blends, in a single stage with nonionic dyestuffs by sol-gel method.

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