

Characterizing a Novel Method for Blending Regenerated Cellulose Structures with Polyester Filaments

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ABSTRACT: The combination method of various manmade fibers with other fibers was developed to create special properties many years ago. Fibers can be mixed in a generation process, such as in solution or melt spinning, or in a fiber spinning process in the form of filaments, staple, sliver, yarn, and so on. Hybrid blended yarns are a common class of yarns in the textile industry, and the most are produced through cotton–polyester or viscose–polyester blending in the spinning process. The cellulose fibers blended in spun yarns should be at least 1 in. in length with appropriate surface properties. This causes limitations in the use of cheap materials. Cheap products owe their manufacturing to waste papers, wood trash, poor linters of cotton, spinning trash, and so on. In this study, a new method for combining regenerated cellulose structures with polyester filaments was examined; it is different from conventional hybrid polyester–viscose fiber production. In the first step, the viscose pulp was prepared and then coated on the polyester filaments in various forms. The properties, including the tensile strength, density, yarn count, moisture regain, static electricity, and dyeing, of the resulted hybrid fibers were evaluated with a variety of methods. The results show that almost all of the properties of the coated samples were improved, especially the moisture absorbance, static electricity, and dyeing properties. © 2012 Wiley Periodicals, Inc. *J. Appl. Polym. Sci.* 000: 000–000, 2012

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INTRODUCTION

Hybrid yarns either can be formed from a physically homogeneous multicomponent fiber blend or may have a core and sheath in which one of the blend components prevails. Mixed multiple yarns may also be produced by doubling, core spinning, or twisting to form deliberately selected single yarns.

Although blend yarns may be composed of several components, the most significant yarns are the two-component-blended yarns. In the cotton industry, blends of 33/67 cotton/polyester and rayon/polyester are used predominantly.¹

Polyester/rayon blended yarns exhibit a high strength and good elasticity. They show very good crease resistance and drape compared to pure linen fabrics.¹ Polyester blends with cellulosic fibers are used mainly in the production of shirting, dress goods, light suit fabrics, and coated fabrics. The cellulosic component is most often cotton and rayon staple and, less frequently, flax.²

Regenerated cellulose materials such as viscose and triacetate account for many cellulosic types of apparel because of their desirable hydrophilic, handling, and comfort properties, but there

are problems with their durability and strength features. On the other hand, various types of polyester yarns show appropriate strength, whereas they do not have desirable handling and comfort properties, especially their moisture absorbance ability.^{3–6}

The blending process of regenerated cellulose and polyester fibers, done to achieve better properties, is very expensive in the spinning process.^{3,4} However, during the 20th century, there have been many attempts to investigate the special properties of these blended yarns. Hamilton⁷ attempted to study high-bulk acrylic yarns and their effects on woven fabrics. Many studies on bulky yarns and blended yarns were done by Pillar⁸ and Wrang.⁹ Pajgrt and Reichstadter¹⁰ clarified the processing of polyester fibers, and Militky et al.¹¹ introduced new methods to produce modified polyester fibers. Hybrid textured yarns are common in textile products. The texturing of yarns by various methods has been applied to make hybrid yarns.¹² Semnani et al.¹³ used the hybrid yarns of cotton and highly shrinkable polyester to show wave-form wrinkling in woven fabrics after a heat-treatment process. In their study, various hybrid yarns were produced by different methods of twisting, commingling, and core spinning.

In this study, a suitable method was established to produce polyester–viscose blended yarns with high feasibility for the textile industry. First, viscose pulp was produced, and then, a layer of viscose was coated on the polyester fibers with the pad–dry method at different pressures. The results show usefulness of this method for improving the surface properties of polyester fibers, including the moisture regain, electricity, and dyeing. This research is a novel method for replacing previous methods of blending of cellulose and polyester and also for making high-quality products from cheap waste cellulosic materials such as papers and wood.

EXPERIMENTAL

Materials

Polyester textured filaments (100%, 250 dens) was prepared from a Polyacriliran Co. (Iran, Isfahan) Helizarin FWT 2003 binder (60 g/L) procured from BASF Co. (USA, North Carolina, Charlotte). All chemicals were analytic grade from Merck (Germany, Darmstadt).

Production of the Cellulosic Pulp

The preparation process of viscose involved several stages. In the steeping step, filter papers (100% cotton) were impregnated in an NaOH solution (18%) at a concentration of 3 wt % for about 90 min. In the aging step, soda cellulose was allowed to stand in contact with ambient air for 120 min at 25–30°C. The oxidation process occurred in the presence of air. During the shredding step, the solution was stirred by a magnetic stirrer, Staufen, Germany (IKA-COMBIMAG RED, Drehzahl-Electronic, and 900 rpm) to make it easier to process. In the xanthation step, excess soda cellulose was extracted, and pure CS₂, about 50 wt % of the papers, was added to the solution on the shaker. This stage continued for 150 min. At the end of the processing time, an orange honeylike crumb was achieved. Finally, the solution was left for 7–8 h to ripen.

Coating Process

The first step of the finishing process was the impregnation of the polyester fibers in a treatment bath containing HELIZARIN FWT binder for 20 s. Subsequently, the sample was passed through a two-roll laboratory padder (Mathis, Switzerland, Oberhasli) at pressure of 5 bar. This treatment gave a wet pickup of 70%. The binder-treated fibers were air-dried and impregnated in a treatment bath consisting of cellulosic pulp for 20 s. After that, they were padded at three different pressures of 1, 3, and 5 bar.

The prepared samples were put in a coagulation bath consisting of 10 g of sulfuric acid, 20 g of sodium sulfate, and 70 mL of distilled water for 2 min. The samples were air-dried at ambient temperature without any tension and then stabilized with a laboratory dryer (Warner Mathis AG, Niederhasli/Zürich) at 90°C for 2 min.

Evaluation Methods

The physical parameters of the coated polyester samples were measured to investigate their properties. For observation of the cross and longitudinal sections of the fibers by optical microscopy (Nikon microscope, USA, New York), polysilicon and the harder resin of polysilicon were mixed at a ratio of 24:1 and

were aged for 8 h in a special mold until they formed. Then, the fibers were transitioned from the mold, and a microtome instrument was used for sampling. The moisture regain of the samples was measured according to ASTM D 1576. Equation (1) was used to calculate the moisture regain (R):¹⁴

$$R = \frac{W_{\text{water}}}{W_{\text{dry fiber}}} \times 100 \quad (1)$$

where W_{water} is the amount of water absorbed by the dry fibers from the air under the standard conditions (ASTM D 1576) and $W_{\text{dry fibers}}$ is the weight of the dry fibers.

Density (d) was evaluated by a Mettler–Toledo densitometer (USA, Columbus, Ohio) according to eq. (2):

$$d = \frac{W_{\text{in air}}}{(W_{\text{in air}} - W_{\text{in distilled water}})} \quad (2)$$

where $W_{\text{in air}}$ and $W_{\text{in distilled water}}$ are the weights of fibers in the air and distilled water, respectively.

An static voltmeter R-404, Zurich, Switzerland was applied to measure the static electricity of the fibers. The length of the fibers used was 10 cm. The resistance was measured by eq. (3):

$$r = t \times 10^{11} \quad (3)$$

where r and t are the electrical resistance (ohm) and measurement time (s), respectively. The linear density (yarn count) was measured according to ASTM D 1577. The viscosity of the solution was measured before and after the ripening stages by a Brookfield viscometer (Middleboro, Massachusetts, USA) (0.5 rpm and 26.3°C). All samples were dyed by Youhao Disperse Blue E-2B (3% w) in the presence of a dispersing agent (1 mL) and at an (ratio of liquor to the weight of the sample in the dyeing bath) $L:R$ value of 60:1 to investigate the disperse dyeing of the coated polyester with cellulose pulp. In the dyeing process, samples were added to a dyeing bath at 40°C and dyed at 100°C for 60 min.

The determination of the fabric tensile properties was carried out according to the ASTM D5035-90 strip method on an Instron 5564 instrument (Grove City, USA) with a gauge length of 0.15 m, a crosshead speed of 100 mm/min, and seven tests for each sample.

RESULT AND DISCUSSION

Production of Viscose Pulp

In this research, filter paper (100% cotton) was used as the cellulosic resource of viscose pulp because the other cellulosic materials may have contained some additive components. It was clear that removing the additive components was difficult, even in conditions of high pressure and temperature. Cellulosic trash and wastes can find application in this process if a primary refining set of works are processed;¹⁵ this could lead to the recycling of large amounts of cellulosic materials every year in the paper and textile industries.

We applied some different conditions in the cellulosic pulp preparation in comparison with the industrial process.

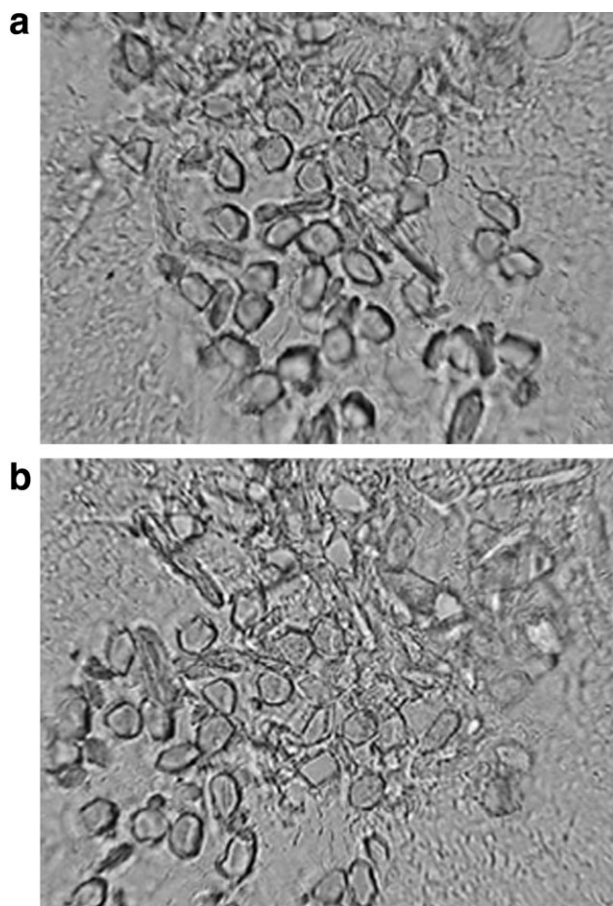


Figure 1. Cross section of the textured filament of polyester after it was coated with cellulosic pulp.

Cellulosic materials were not squeezed to remove exceeded alkaline solution in our experimental study because of disarrangement problems in the next stage. In the industrial process to manufacture viscose, an alkali cellulose mass is pressed to a wet weight equivalent of about 3.0 times the original pulp weight and then allowed to age. The quantity of CS_2 applied was greater than that in the regular preparation of viscose pulp, too.

The initial viscosity of the pulp was equal to 3500 cp at the beginning of the ripening stage and then started to decrease to approximately 3000 cp at the end of the ripening process. This matter could be justified by conversion of CS_2 groups to hydroxyl ones. As mentioned by others, two important processes can occur during ripening: redistribution and a loss of xanthate groups. The reversible xanthation reaction allows some of the xanthate groups to return to previous cellulosic hydroxyls and free CS_2 's. These free CS_2 's can then escape or react with other hydroxyls on other portions of the cellulose chain. In this way, the ordered or crystalline regions are gradually broken down, and a more complete solution is achieved.^{1,16}

Coating Process

Nowadays, many types of viscose–polyester blends in the form of yarn and fabrics are produced in the textile industry because of their good properties. Polyester has some good properties,

including a strong resistant against stretching and shrinkage, chemicals, wrinkle, mildew, and abrasion¹ although it has some problems with dyeing and pilling. The most important characteristics of rayon fibers are their high absorbency, softness, and comfort.¹ Despite the good properties of viscose–polyester blends, the different chemical structures of polyester and viscose may lead to nonadhesive properties and, consequently, the disintegration of viscose pulp from polyester. Thanks to our research, it seems that the binder layer could be applied between the two components to provide better adherence and stick viscose on polyester. The used binder in this research was stabilized via temperature (at 90°C) and led to better abrasion resistance. In addition, the final yarns were not affected by the binder's properties because of its low coating concentration. According to results of cellulosic coating on the staple untextured and textured filaments, the textured polyester filaments were chosen for further experiments because they stuck well to the cellulosic pulp and these filaments showed a good dispersion of pulp. We only report the data for the coated textured polyester filaments.

Evaluation Methods

The application of optical microscopy showed that the coated viscose layer and also the pressure of the pad rollers did not affect the cross-sectional shape of the polyester [Figure (1)]. This may have occurred because of a little penetration of cellulosic pulp in the polyester, which could be proven by the small particles of viscose observed in the longitudinal section of the polyester (Figures 2–4). Figures 1–4 show the oval cross section

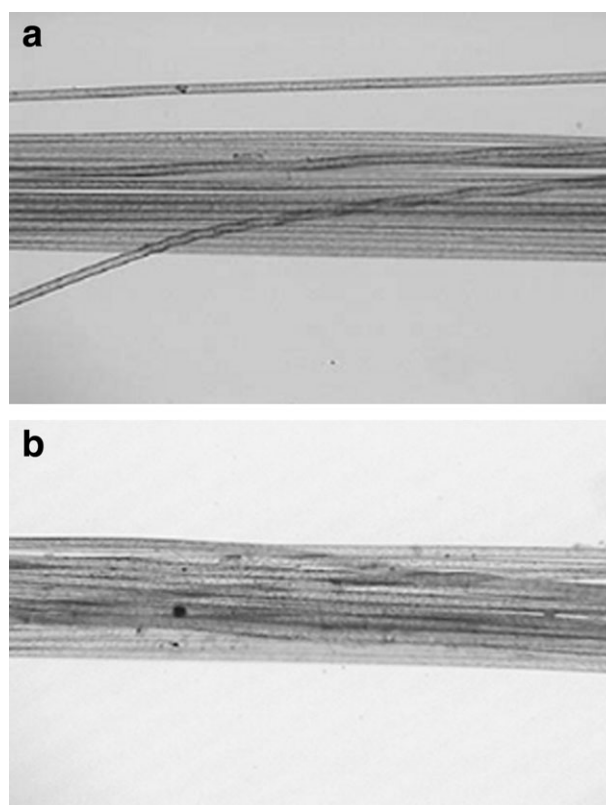


Figure 2. Longitudinal section of the untextured polyester filament after it was coated with cellulosic pulp.

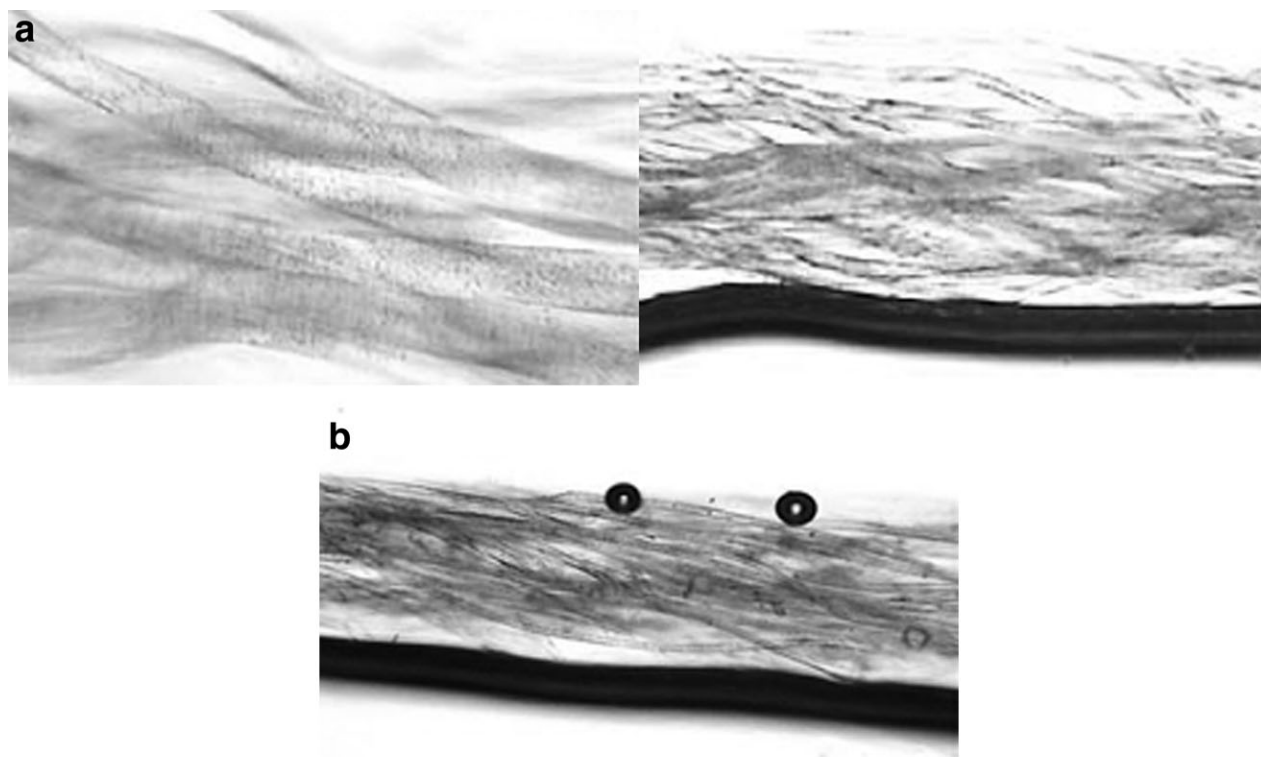


Figure 3. Longitudinal section of the textured polyester filament after it was coated with cellulosic pulp.

and longitudinal section of polyester after coating via cellulosic pulp.

Table I presents the amount of moisture regain of the fibers after coating. According to the data that are shown in Table I the coated yarns had suitable moisture absorbance.

We observed that the water adsorption properties of yarns increased with decreasing pressure of the padding process. In other words, the yarns padded at the lowest pressure had the most water absorption; this indicated more viscose on the yarn at this pressure. After that, the yarn padded at a pressure of 3 bar and then one at the pressure of 5 bar were arranged. Thus, the amount of extracted viscose was greater at higher pressures, compared to those at lower pressures. The water adsorption properties of the resulting yarns were much greater than those of the 100% viscose yarns.

Cellulose has three hydroxyl groups per unit glucose so they can create hydrogen bonds from water molecules. Polyester fibers are hydrophobic and do not have absorbent groups of water, but by this method, the water absorbance properties of the final coated polyester yarns by cellulose was improved. This may have been because of the irregular penetration of viscose to polyester and the creation of a porous surface according to the Wenzel equation.^{17,18}

The Wenzel equation indicates that with increasing surface roughness, the apparent contact angle (θ) decreased for hydrophilic materials ($\theta < 90^\circ$) and increased for hydrophobic materials ($\theta > 90^\circ$). Obviously, this is a very important issue in the preparation of hydrophilic and hydrophobic coatings. Euvananont et al.¹⁹ reported that for a P25 Degussa screen-printed

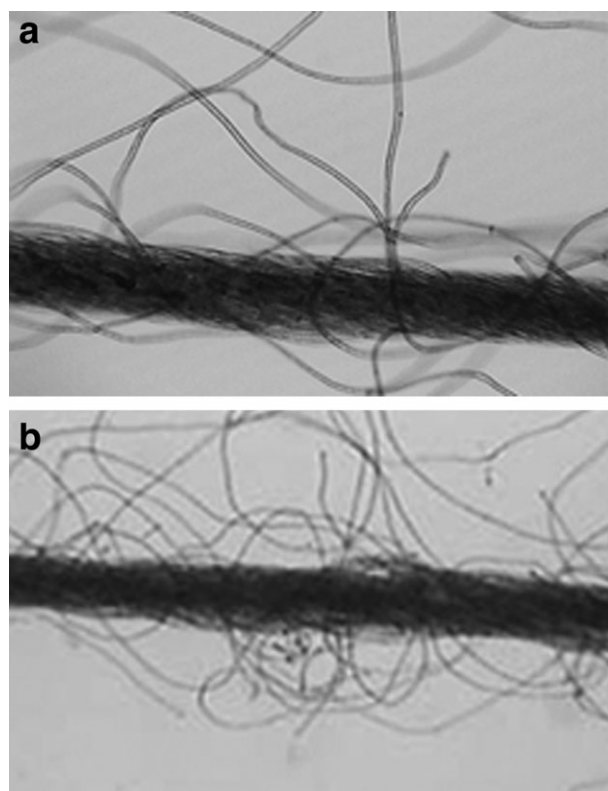


Figure 4. Longitudinal section of the staple yarn of polyester after it was coated with cellulosic pulp.

Table I. Moisture Regain (%) of the Polyester Filaments after They Were Coated by Cellulosic Pulp at Different Pressures

		Sample number	Uncoated	Pressure of the coating (bar)		
				5	3	1
Weight (g)	After adsorption of standard moisture	1	0.0051	0.0280	0.0270	0.0270
		2	0.0060	0.0240	0.0300	0.0360
		3	0.0053	0.0260	0.0290	0.0350
	After heating in the oven for 60 min	1	0.0048	0.0230	0.0210	0.0220
		2	0.0056	0.0194	0.0230	0.0270
		3	0.0052	0.0200	0.0220	0.0260
Moisture regain		1	5.8	21.7	28.5	22.7
		2	6.6	24.3	30.4	33.9
		3	1.92	30.0	22.7	34.6
Average moisture regain			4.77	25.3	27.2	30.4

TiO₂ film, its superhydrophilic properties may have been caused by its porous structure, and this was believed to have been related to the density of the surface hydroxyl of the TiO₂ films as well. The surface hydroxyls could combine with water molecules to form hydrogen bonds, and this resulted in good wettability.¹⁹

An image processing technique was applied to investigate the roughness parameters of the coated samples in comparison with those of the uncoated sample according to previous works.^{20,21} Image processing was complemented in the high level process by the simulation and identification of image components. The images in RGB format were converted to grayscale images, and then, the edges of the objects in the images were recognized by a Sobel filter. In the second level of processing, the images were converted to the binary format, and then, they were reversed for easier detection of the cross section of each fiber. After we marked the fibers from each other with a labeling procedure for the binary object, different properties were measured by MatLab image processing toolbox (USA, Massachusetts, Natick). To estimate the surface area $[A(x)]$ in the discrete space, eq. (4) was used:

$$A(x) = \sum_{i,j} g(x_i, y_j) \quad (4)$$

where $g(x_i, y_i)$ is a white element of the object in the binary images.

To measure the perimeter of the cross section in a discrete space (P), eq. (5) was used:

$$P = \sum_k \sqrt{(x_k - x_{k-1})^2 + (y_k - y_{k-1})^2} \quad (5)$$

where the spots (x_k, x_{k-1}) and (y_k, y_{k-1}) are successive points on the close borders of every cross section.

The length of the edges is a standard parameter for the measurement of the perimeter, and the number of these was recorded as the perimeter of the cross section.

Solidity was identified by the use of the dilation and erosion processes with eq. (6):

$$Solidity = \frac{S_i}{S_c} \times 100 \quad (6)$$

where S_i is the surface area of the cross section and S_c is the surface area of the surrounding convex shape.

The last factor that we contemplated was the average roughness, as evaluated by eq. (7). The roughness average (S_a) is a dispersion parameter defined as the mean of the absolute values of the surface departure above and below the mean plane within the sampling area:²⁰

$$S_a = \frac{1}{MN} \sum_{k=0}^{M-1} \sum_{t=0}^{N-1} |Z(x_k, y_t) - \bar{Z}| \quad (7)$$

where $Z(x_k, y_t)$ is intensity of each pixel of the longitudinal axis of the image, \bar{Z} is the mean value of $Z(x_k, y_t)$, and MN is the number of spots in the picture. The results of image processing are illustrated in Table II. As for the solidity and the average roughness, the average roughness for the coated samples increased, and solidity showed the opposite trend. It can be realized from Table II that the area changes were in a limit range for the coated yarns at a pressure of 5 bar, but this range was more extensive for the coated one at a pressure of 1 bar.

Table II. Results of the Geometrical Parameters of the Fiber Cross Section by Image Processing

	Uncoated	Pressure of the coating (bar)		
		1	3	5
Area mean (pixel ²)	641.2	943.2	846.5	753.1
perimeter(pixel)	153.7	196.7	173.3	161.4
Roughness average (pixel)	101	110	106	105
Solidity(dimensionless)	0.9889	0.914	0.9361	0.9475

Table III. Static Electricity Resistance (Ohm) of the Polyester Filaments after They Were Coated by Cellulosic Pulp at Different Pressures

	Sample number	Uncoated	Pressure of the coating (bar)		
			5	3	1
Time (s)	1	72	61	61	57
	2	71	62	63	55
	3	73	65	61	60
Average resistance		71×10^{11}	62.6×10^{11}	61.6×10^{11}	57.3×10^{11}

Table IV. Density of the Polyester Filaments after They Were Coated by Cellulosic Pulp at Different Pressures

	Sample number		Pressure of the coating (bar)			Uncoated
			5	3	1	
Weight (g)	1	In air	0.027	0.027	0.024	0.005
		In water	0.003	0.003	0.002	0.001
	2	In air	0.035	0.029	0.026	0.004
		In water	0.006	0.005	0.006	0.001
	3	In air	0.036	0.03	0.028	0.006
		In water	0.008	0.006	0.008	0.002
Volume (mL)	1		0.024	0.024	0.022	0.004
	2		0.029	0.024	0.02	0.002
	3		0.028	0.024	0.02	0.004
Density (g/mL)	1		1.125	1.125	1.091	1.25
	2		1.206	1.208	1.3	1.5
	3		1.285	1.25	1.4	1.333
Average of density			1.205	1.194	1.263	1.276

Table V. Linear Density of the Polyester Filaments after They Were Coated by Cellulosic Pulp at Different Pressures

	Sample number	Uncoated	Pressure of the coating (bar)		
			5	3	1
Linear density (tex)	1	31	53	60	60
	2	28	57	64	77
	3	24	62	66	80
Linear density (den)	1	279	479	540	360
	2	252	520	579	693
	3	216	559	600	720
Average linear density (tex)		27.6	57.3	63.3	72.3
Average linear density (den)		249	519.3	539	591

The increasing S_a indicated a greater roughness in the coated fibers at lower pressures; this led to more water absorption. On the other hand, the more coated pulp was at the lower pressures, the less solidity there was, and consequently, ore variation in the surface area could be recognized.

In addition, the static electricity of fibers decreased because of increasing water adsorption of fibers; this decreased the electrical resistance. Applications of conductive textiles have gained more and more importance, for example, for protection against static electricity charge, electromagnetic interference shielding, and heating elements. The scale of electrical conduction covers a broad range, from the surface resistivity of native textiles at more than $10^{14} \Omega$ down to antistatic finished textiles ($R < 10^{10} \Omega$) and conductive textiles (surface resistivity $< 10^3 \Omega$).²² The necessary time for the transition of electrical flow of the polyester filaments was 71 s. So according to eq. (3) the initial resistance of polyester was $71 \times 10^{11} \Omega$, whereas the coated fibers indicated lower resistance. As shown in Table III the coating pressure of 1 bar resulted in more cellulose or more OH groups on the coated fibers and, consequently, caused the static electricity to decrease. A static electricity charge on the textiles led to the unwanted attraction of dust and dirt particles to the

Table VI. Absorbance of the Dyeing Bath after Disperse Dyeing for 60 min

Polyester type	Coating	Absorbance
Textured	Uncoated	0.35
	Coated	0.18

Table VII. Tenacity of the Polyester Filaments after They Were Coated by Cellulosic Pulp at Different Pressures

Coating	Pressure of coating (bar)	Tenacity loss (%) ^a
Uncoated	—	0
Coated with cellulosic pulp	1	-2.2
	3	-1.5
	5	-3.1

^aMinus shows the tenacity loss compared to untreated sample.

textile surface. This matter is more critical with regard to flashes and sparks in synthetic fibers during the uncoiling processes. To prevent or at least reduce these effects, it is common to incorporate organic antistatic agents.²²

Table IV confirms the fiber density irregularity. According to SPSS statistical software (Armonk, New York), in contrast to what we expected, there was no significant difference between the densities of the treated and untreated polyester samples. This was attributed to the simultaneous increases in both the mass and volume of the treated samples [eq. (2)]. In other words, it was possible that an increase in the amount of cellulosic pulp, as well as the probable porosity that they made, caused their volume to rise and, subsequently, cause the same density. Yarns with low densities are usually favorable.

Linear density is an important characteristic that should be determined for every yarn. The linear density can affect many characteristics of yarn and their resulting fabrics and the dyeing and finishing process.

There was moderate growth in the linear density or yarn count of the resulting fibers with decreasing pressure of the pad rollers. In fact, fibers coated at a pressure of 1 bar had the highest linear density, followed by those coated at 3 bar and then 5 bar (Table V). The higher linear density of the coated polyester samples in comparison with that of the uncoated sample proved the existence of cellulosic pulp coated on the filaments.

The coated filaments with cellulosic pulp showed darker color in comparison with the uncoated one in the same conditions of disperse dyeing (Table VI). According to the data gathered in Table VI the absorbance of the dyeing bath after the dyeing of the uncoated samples was much greater than that of the coated ones. According to the Beer–Lambert eq. [eq. (8)], a low absorbance (A) accompanies a low concentration and finally leads to greater dye absorbance in the samples:

$$A = \log \frac{1}{T} = \epsilon cl \quad (8)$$

where T is the transparency, ϵ is the molar absorptivity, c is the concentration, and l is the path length.

In the measurement of the tensile properties of the coated samples, Table VII did not show any significant decrease in fabric tenacity in comparison with the untreated sample. For coated samples, there was little decrease in the tensile properties from 1 to 5 bar. Therefore, we concluded that the coating of cellulosic pulp on polyester did not have any adverse effects on the tensile properties, which are so important for industrial application.

CONCLUSIONS

Although polyester yarns have better physical properties than viscose yarns, such as strength, resistance to wrinkling, durability, and chemical stability, viscose yarns are very good in handling, appearance, and moisture absorbance. Also, the dyeing of cellulosic fibers is easier than polyesters. Along with these properties, there are problems in the combination of viscose/polyes-

ter because they are different in processing and cost. The idea of converting waste compounds to valuable products has been considered by many industries for many years.

In this study, an effort was made to apply a novel method for blending regenerated cellulose structures with polyester filaments as a coating layer of viscose on the polyester filament to improve the moisture absorbance, appearance, and handling.

It seems that cellulosic materials, such as waste papers or cellulose fibers, could be used as the cellulose source to make the cellulose pulp. The results indicate that there was no change in the cross section of the polyester filaments before and after coating. Also, the polyester core of the resulting hybrid yarns gave them a good strength. Although the fibers' tenacity decreased slightly in comparison with that of the initial fibers, it was not significant. The water absorption increased in final yarns, and the static electricity dropped as more viscose pulp was coated onto the polyester fibers. Although the density of the yielded fibers was the same as that of initial polyester, there was an increase in the linear density or yarn counts due to the viscose layer coated on the fibers. Furthermore, the coated samples revealed better dyeing properties compared to the uncoated ones under the same conditions of dyeing.

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