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## Producing and Characterizing Hybrid Yarns Comprising Cellulose Acetate and Polyester

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### ABSTRACT

*Algae are an extremely diverse group of organisms that make up the lower phylogenetic echelons of the plant kingdom. Most of the algae are photosynthetic (like higher plants) or are closely related to organisms that are. Algae perform roughly 50% of the photosynthesis on this planet and thus are instrumental in supporting the biosphere. The first use of microalgae by humans dates back 2000 years to the Chinese, who used Nostoc to survive during famine. However, microalgal biotechnology only really began to develop in the middle of the last century. Nowadays, there are numerous commercial applications of microalgae. For example, (1) microalgae can be used to enhance the nutritional value of food and animal feed owing to their chemical composition, (2) they play a crucial role in aquaculture and (3) they can be incorporated into cosmetics. Moreover, they are cultivated as a source of highly valuable molecules. For example, polyunsaturated fatty acid oils are added to infant formulas and nutritional supplements and pigments are important as natural dyes. Stable isotope biochemicals help in structural determination and metabolic studies. Future research should focus on the improvement of production systems and the genetic modification of strains. Microalgal products would in that way become even more diversified and economically competitive. In this article some commercially available products derived from algae and a few product areas in which algae may make a significant contribution in the near future has been described.*

**Keywords:** Biodegradable polymers, Cellulose acetate, Coating, Hybrid yarns, Recycling.

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### INTRODUCTION

Uses of natural fibers progressively gain attention from numerous industrial areas, like environmental policies<sup>1</sup>, but at the end of their lifetime, these fibers finally end up in waste stations<sup>2</sup>. Amongst all natural fibers, cotton has the highest part of the market<sup>2</sup>. Presently the importance of cellulose as the major renewable resource is undeniable<sup>3</sup>. Cellulose acetate, an environmental friendly substance, is derived from cellulose by reacting purified cellulose from wood pulp with acetic acid and acetic anhydride in the presence of sulfuric acid<sup>4,5</sup>.

On the other hand, polyester fibers have taken a significant position in man-made fibers all over the world although they have some disadvantages. It was recommended that surface modifications can affect hand, thermal properties, permeability, and hydrophilicity of polyester fibers<sup>4-6</sup>.

Polyester blends with cellulosic fibers, to achieve better properties, are used mainly in the production of shirting, dress goods, light suit fabrics, and coated fabrics<sup>7</sup>. There are variety of research works to investigate different fiber mixtures, prepared by fiber blending, core and sheath, copolymerization and so on, as well as their properties and recycling techniques<sup>8-15</sup>. Qin and coworkers studied Hydrophilic hollow fiber membranes prepared from a solution containing cellulose acetate/poly(vinyl pyrrolidone)/N-methyl-2-pyrrolidone/water using a dry-jet wet spinning process<sup>9</sup>. Liu reported the study on the structures and morphologies of the chitosan and cellulose acetate blend hollow fibers<sup>10</sup>. Mixtures of microfibers and crimped bulking fibers producing a lofty resilient web were clarified by Hao<sup>11</sup>. There was a study on blends of crimped hollow polyester fiber and crimped lower-melting polyester binder fiber to bonded low density batts made therefrom<sup>12</sup>. William studied flame retardant fibers blends<sup>13</sup>. Buchanan et.al<sup>14</sup> produced binary blends of cellulose esters and aliphatic-aromatic copolyesters, cellulose esters and aliphatic polyesters as well as ternary blends of cellulose esters and/or aliphatic polyesters. Also, Samuel and Moulee<sup>15</sup> coated a layer of starch on polyester fibers to improve polyester hydrophilicity. However, there is some limitation in using cellulose fibers with polyester staple fibers in the expensive spinning process<sup>8</sup>.

This paper explores an efficient procedure to produce hybrid polyester-cellulose yarns with high possibility in textile manufacturing. This method not only shows new way to manufacture cellulose-polyester blended yarns, but also makes high quality products using waste cellulosic materials such as linters, papers, wood trashes. In our previous work<sup>8</sup>, application of cellulosic pulp in the form of regenerated viscose was successfully investigated. In this research, another form of regenerated cellulose which is acetate easier to be manufactured is studied. First of all cellulose acetate pulp was produced and then polyester fibers were coated by a layer of resulted pulp using pad-dry method. The process was varied by testing different polyester filaments, concentrations of binder and pressures of pad. It was concluded that cellulosic treatment of polyester filaments improved surface properties of polyester fibers such as moisture regain, electricity and dyeing. Therefore, with this research, we can reach two goals: using waste cellulosic materials as well as improving of polyester yarns surfaces in a new, inexpensive and available method.

## MATERIALS AND METHOD

### Materials

Polyester textured and intermingled filaments (100% and 250 dens) were prepared from POLYACRIL Company. HELIZARIN FWT 2003 binder, 60 gr/Lit, procured from BASF Company, USA. Other chemicals (sulfuric acid, acetic anhydride, acetic acid) were analytic grade from Merck, Germany.

### Procedure

In procurement step, 5 g filter papers (100% cotton) were impregnated in pure acetic acid (10 mL) about 12 hours at room temperature to become more reactive. After that, acetic acid (1.67 mL), acetic anhydride (41 mL), and then 0.25 mL sulfuric acid (96%) were added to prepared cellulose in the previous stage. The acetylation reaction was continued for an hour at 40°C.

For the finishing process, the polyester fibers were dipped in a treatment bath containing HELIZARIN FWT binder in three different concentrations of 60, 75 and 90 g/L. After that, the samples were pressed with a laboratory padder (Mathis, Switzerland) at a nip pressure of 5 bar. Subsequently, the binder-treated fibers were impregnated in a treatment bath consisting of regenerated cellulosic pulp and then again padded at three different pressures of 1, 3, and 5 bar. The prepared segments were put in a coagulation bath consisting of 12.5 mL acetic acid (50%) and 67 g

sodium acetate for 2 min. The wet samples were kept at ambient temperature without any tension to dry and then at 100°C, in a laboratory dryer (Warner Mathis AG, Niederhasli/Zürich) for 10 min.

### Evaluation

The physical parameters of the coated polyester samples were measured to investigate their properties. For observation of cross section as well as longitudinal section of fibers by optical microscopy (Nikon Microscope), microtome instrument was used for sampling<sup>8</sup>. The moisture regain of the samples was measured according to ASTM D 1576, equation (1)<sup>8</sup>.

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

Where,  $W_{\text{absorbed water}}$  and  $W_{\text{dry fiber}}$  are the weight of water absorbed by the dry fibers from the air under the standard conditions and the weight of the dry fibers, respectively. By weighting samples after special intervals, when there is no change in the weight of dried sample, it can be reported as  $W_{\text{dry fiber}}$ .

Density (d) was evaluated following equation (2) (Mettler-Toledo densitometer (USA)).

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

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

A static voltmeter R-404, Switzerland, was applied to measure the static electricity of the fibers. The resistance was measured by equation (3):

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

Where,  $r$  is electrical resistance (Ohm) and  $t$  is measurement time (s).

The Linear density (yarn count) was measured according to ASTM D1577<sup>8</sup>. For the comparison of luster properties of the coated fibers with the uncoated one, MINGLOSS 101N instrument was applied, which detects specular reflection of samples and reports it in gloss unit. Unpolarized white light was concentrated by a condenser lens onto a field aperture, which was located in the focal plane of the source lens. The reflected beam at the surface was later collected by the receptor lens. The intensity of the beam was then measured through a photodetector. The angle of incidence for the gloss measurement was 60°. The gloss of the initial filaments was compared with two randomly selected coated ones. All samples were put in a dyeing bath containing YouhaoDisperse Blue E-2B (3% w), a dispersing agent (1 mL) with L:R 60:1 at 40°C and dyed at 100°C for 60 min to investigate disperse dyeing of the coated polyester with cellulose pulp.

To measure the absorbance of the dye solution after the dyeing process, Gretagmacbeth COLOREYE 7000A spectrophotometer was used. Equation 4, Beer-Lambert law is used to measure dye absorption:

$$A = \log \frac{1}{T} = \varepsilon cl \quad (4)$$

Where  $A$  is the absorbance,  $T$  is the transparency,  $\varepsilon$  is the molar absorptivity,  $c$  is concentration and  $l$  is path length.

## RESULTS AND DISCUSSION

### Cellulose acetate pulp production and coating on polyester

Manufactured cellulosic materials surely are contained some additives; so, it seems more reliable to use filter paper (100% cotton) as the 100% cellulosic resource to produce cellulose acetate pulp. Cellulose linters, trashes and wastes retained from fabrics or other cellulosic materials can be used in this process by an initial purifying process<sup>16</sup>. Therefore, a large amount of cellulosic materials in the paper and textile industries may be recycled every year.

At first, filter papers were added to the dilute acetic acid solution at room temperature to make the cellulose more reactive for better acetylation. In the acetylation stage, sulfuric acid was poured to the bath as a catalyzer to speed up the acetylation of hydroxyl groups. It was found by trial and error that the catalyzer should not be added simultaneously with other materials because it prevents cellulose to be wet well with acetic anhydride and acetic acid. In order to control temperature during the acetylation reaction that was violently endothermic, the reaction vessel was kept in a mixture of water and ice for an hour and materials were poured slowly. One vessel was kept at room temperature (about 30°C) and another one at 40°C. To ensure that complete acetylation was achieved, the resulted solution of cellulose acetate was solved in chloroform. As a result, cellulose pulp was acetylated at 40°C was soluble in chloroform demonstrating that hydroxyl groups were desirably changed to acetate groups. After coating process, disintegration of cellulosic pulp coated on the polyester may happen due to different chemical structures of polyester and cellulosic pulp, and subsequently non-adhesive properties. So, it seems that application of the binder layer between two components can provide better adherence between cellulose and polyester. It is noteworthy that binder cannot affect the properties of resulted yarns due to its low concentration. Combination of strong resistant of polyester with softness and high absorbency of cellulosic fibers in the form of cellulose–polyester blends have a lot of application in the textile industry<sup>8</sup>.

### Surface and physical properties

*Fig. 1, 2 and 3* show oval cross and longitudinal section of polyester filaments after coating by cellulosic pulp, respectively. Application of optical microscopy displayed that the cellulose acetate layer and also the applied pressure in the coating process have no effect on the cross sectional shape of polyester.

Moisture regain of resulted fibers after coating was presented at *Table 1* for different polyester filaments. According to the results, the coated yarns had suitable moisture absorbance.

It is clear that for all samples, either for textured or for intermingled, the moisture regain is significantly more than that for polyester filaments alone (~ 0.4-0.5 %).

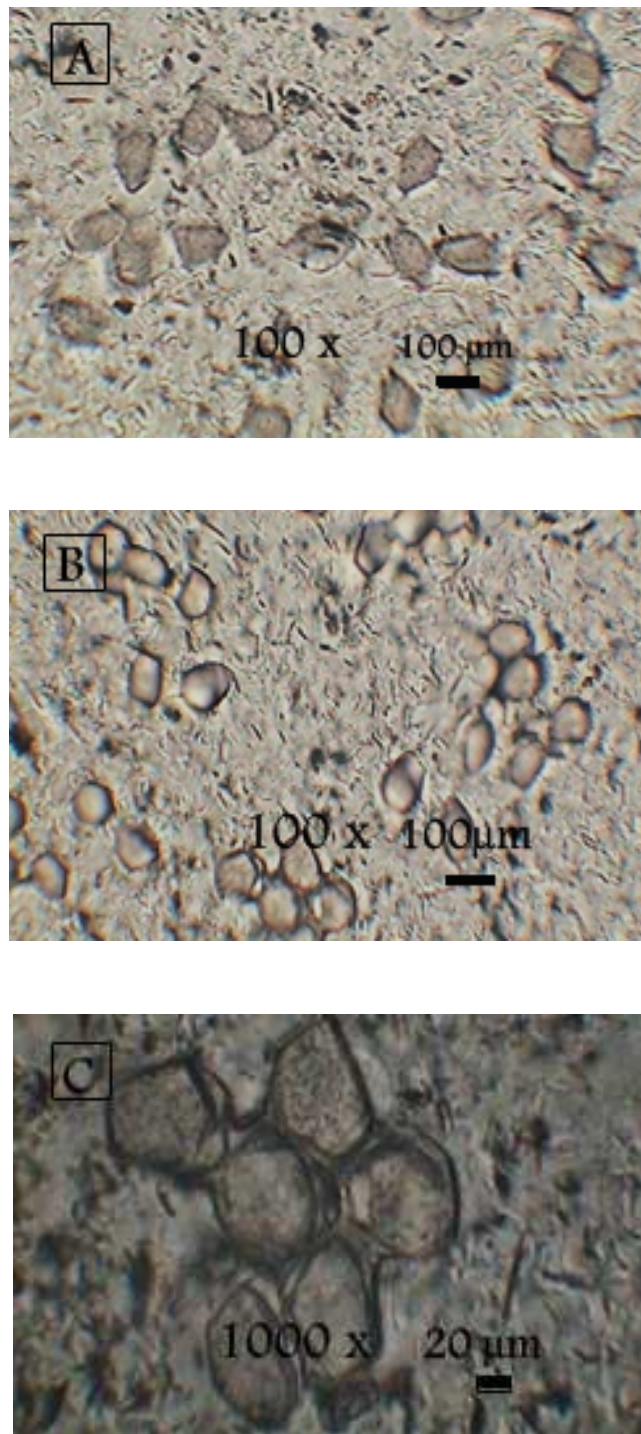


Fig. 1. Cross section of polyester filaments, (A) before and (B-C) after coating with cellulose acetate pulp.

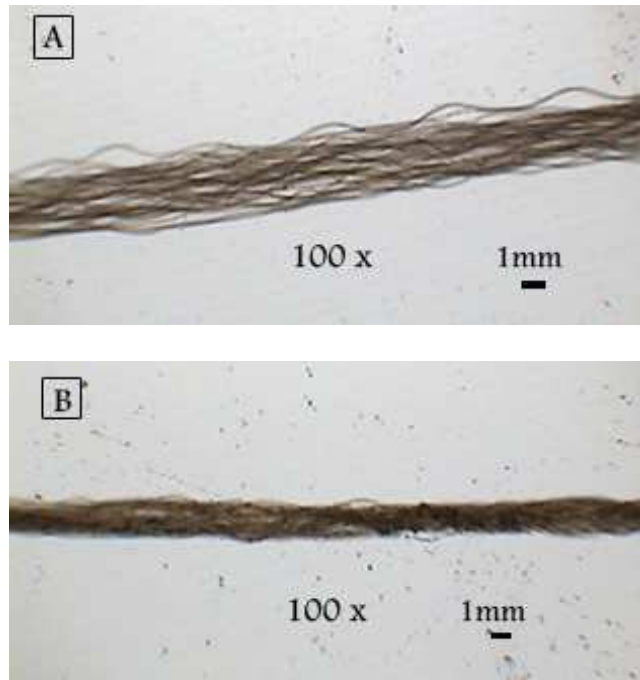


Fig. 2. Longitudinal section of intermingled polyester filaments, (A) before and (B) after coating with cellulose acetate pulp.

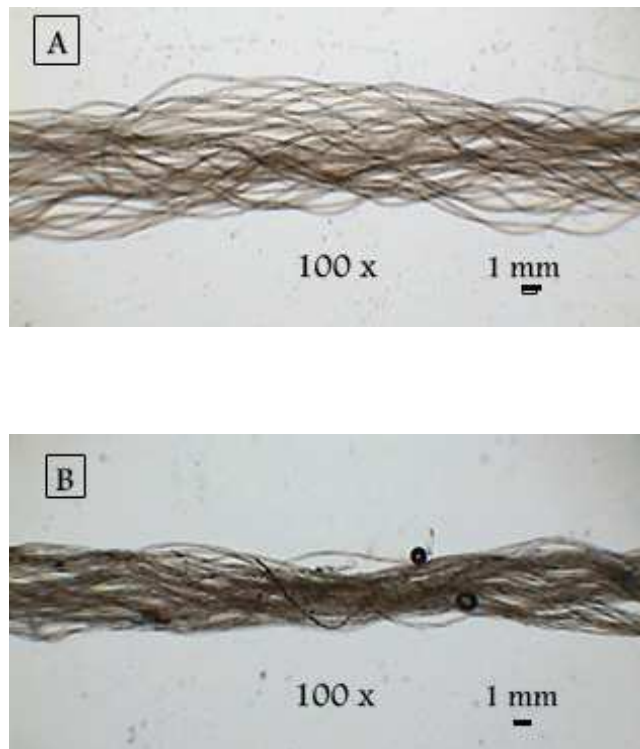


Fig. 3. Longitudinal section of textured polyester filaments, (A) before and (B) after coating with cellulose acetate pulp.

As the pressure of pad process decreased from 5 to 1 bar, a negligible increase could be observed in the moisture regain because the higher pressure of pad rollers leads to more remove of pulp from the surface and less pick-up of cellulosic pulp on the surface, although this trend cannot be observed regularly for all samples maybe because of unevenness of padding. There is no trend by variation of binder concentration on the water absorbance properties. However, cellulose can create hydrogen bonds of water molecules due to its hydroxyl groups, while polyester fibers don't have any absorbent group of water <sup>8</sup>.

**Table 1.** Moisture regain (%) of the textured and intermingled polyester filaments after coating by cellulose acetate pulp in different pressures and binder concentrations

		Binder concentration (g/L)	Pressure of coating (bar)					
			textured			intermingled		
			5	3	1	5	3	1
Weight (g)	After adsorption of standard moisture	60	0.0632	0.0597	0.0581	0.0596	0.0343	0.0296
		75	0.0583	0.0450	0.0559	0.0393	0.0153	0.0369
		90	0.0640	0.0603	0.0655	0.0330	0.0354	0.0365
	After heating for 60 min	60	0.0587	0.0552	0.0534	0.0543	0.0320	0.0273
		75	0.0543	0.0414	0.0520	0.0357	0.0139	0.0335
		90	0.0534	0.0564	0.0596	0.0309	0.0332	0.0337
Moisture regain		60	7.12	7.54	8.09	8.89	6.71	7.77
		75	6.86	8.01	6.98	9.16	9.15	9.21
		90	8.44	6.47	9.00	6.36	6.21	7.67

Improvement of hydrophilicity of polyester fibers by creating functional groups on the surface via chemical etching of surface such as aminolysis and alkaline hydrolysis was reported previously<sup>17-19</sup>. Also, it was mentioned that by increase of cotton fibers in the polyester-cotton blended yarns, the moisture regain could be increased as well <sup>20</sup>. So, increasing in water adsorption of fibers decreased the electrical resistance and subsequently static electricity of the coated filaments.

Since many years ago, conductive textiles have attained extra importance for variety of application such as security against static electricity charge, electromagnetic interference (EMI) shielding and for heating elements. While native textiles show electrical conduction of more than  $10^{14}$  Ohms, this can declined for antistatically finished textiles to less than  $10^{10}$  Ohms and for conductive textiles (heating applications) to less than  $10^3$  Ohms <sup>21</sup>. According to *Table 2*, required times for movement of electrical current from uncoated textured and intermingled polyester filaments were 24 and 21 seconds, respectively. So, to follow equation (3), expressed in experimental section, initial resistance of textured polyester filament was  $24 \times 10^{11}$  and initial resistance of intermingled polyester filament was  $21 \times 10^{11}$  Ohm, while coated fibers indicated lower resistance. As for binder



concentration of 60 g/ L, the resistance for coated textured and intermingled filaments at pad pressure of 5 bar decreased to  $23 \times 10^{11}$  and  $19 \times 10^{11}$  Ohm, respectively, followed by those at pressure of 3 bar and then pressure of 1 bar ( $20 \times 10^{11}$  and  $17 \times 10^{11}$ , respectively).

**Table 2.** Static electricity resistance (Ohm) of the polyester filaments after coating by cellulose acetate pulp in different pressures

	Binder concentration (g/L)	Pressure of coating (bar)					
		Textured filaments			Intermingled filaments		
		5	3	1	5	3	1
Time (s)	60	23	22	20	19	17	17
Average resistance		$23 \times 10^{11}$	$22 \times 10^{11}$	$20 \times 10^{11}$	$19 \times 10^{11}$	$17 \times 10^{11}$	$17 \times 10^{11}$

Therefore, static electricity slightly decreased by lowering of pressure of coating, resulted in more cellulose acetate and subsequently more OH groups on the coated fiber. A static electricity charge causes textiles to attract dust and particles, or flash when they are used, especially during uncoil processes<sup>21</sup>.

Fibers' density has irregularly changed based on results of *Table 3*. Samples' density was really close to each other and as the same as the initial polyester. In fact there was no difference between treated and untreated polyester samples statically (measured by SPSS). Although the mass of coated samples increased, the volume of them rose due to porosity too and caused the same density. Having yarn with a density not very large is favored usually.

**Table 3.** Density ( $\text{g/cm}^3$ ) of the textured and intermingled polyester filaments after coating by cellulose acetate pulp in different pressures and binder concentrations

	Binder concentration (g/L)	Pressure of coating (bar)		
		5	3	1
	60	1.220	1.224	1.289
texture	75	1.381	1.419	1.350
	90	1.280	1.298	1.312
	Uncoated	1.333		
	60	1.273	1.259	1.111
intermingle	75	1.290	1.667	1.267
	90	1.259	1.286	1.241



	Uncoated	1.333
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Another interesting result was a significant increase in the linear densities of resulted fibers by decreasing of the pressure of pad rollers from 5 to 1 bar. The linear density of both textured and intermingled coated filaments was significantly, about 30-40 %, more than that of uncoated one. In the other words, the fiber coated by the pressure of 1 bar had the most linear density, followed by the pressure of 3 bar and then 5 bar, *Table 4*.

**Table 4.** Linear density and tenacity of the polyester filaments after coating by cellulose acetate pulp in different pressures and binder concentrations

	Polyester type	Binder concentration (g/L)	Pressure of coating (bar)		
			5	3	1
Linear density (den)	Textured	60	202.9	212.55	224.6
		75	198	199	209
		90	200.7	203	206
		Uncoated	152		
	Intermingled	60	132.77	133	135
		75	127	129.6	132
		90	126.90	127.59	128.89
		Uncoated	101.88		
Tenacity (cN/den)	Textured	60	2.1100±0.09	2.2020±0.07	2.2210±0.06
		75	2.1673±0.08	1.9490±0.04	2.2570±0.03
		90	2.2200±0.06	2.1683±0.07	2.2122±0.05
		Uncoated	2.7141±0.13		
	Intermingled	60	1.9552±0.09	2.0667±0.12	1.9563±0.17
		75	1.9300±0.09	1.0490±1.48	2.1367±0.04
		90	2.1030±0.10	2.0045±0.11	2.1073±0.09
		Uncoated	2.5457±0.10		

Again, for the specific concentration of binder, it is due to more pulp on the coated filaments on the lower pressures that in the unit length showed more weight and density. Surprisingly, the results showed decrease of linear density by the rise of binder concentration, but it was not significant according to SPSS statistical software. So, optimum concentration of binders can be 60 g/L. The presence of cellulose acetate on the polyester filaments did not have a significant effect on the fabric tenacity in comparison with the untreated sample and no decreasing or increasing trend was observed in different pressures and binder concentrations, *Table 4*. Therefore, it can be concluded that coating of cellulosic pulp on polyester did not show any opposing influence on the tensile properties so important for manufacturing request. The effect of cellulosic treatment to increase dye adsorption from the dyeing bath was significant, resulting in darker color of coated polyester filaments in comparison with the uncoated one, *Fig. 4*. Because the lower absorbance indicates the lower concentration in the bath after dyeing process (*Table 5*), so that more dyes has been absorbed by the coated samples, equation (4).

As far as luster properties are concerned, the results indicated the loss of gloss for the cellulosic coated samples, *Table 6*. Gloss is an optical property, which is based on the interaction of light with physical characteristics of a surface.

It is actually the ability of a surface to reflect light into the specular direction.

Some delusterant agents such as  $\text{TiO}_2$  are used in the production of manmade polyester fibers in order to more preferable dull fibers in textile industries.

Therefore, there was probably no necessity to use delusterant agent by coating of polyester filaments with regenerated cellulosic pulp.

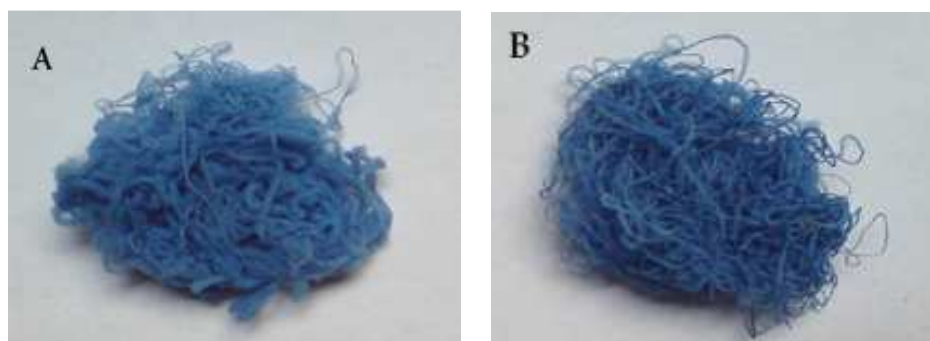


Fig. 4. Pictures of dyed (a) uncoated and (b) cellulose acetate coated polyester filaments

**Table 5.** Absorbance of dyeing bath after disperse dyeing for 60 min

Polyester type	Coating	Absorbance
Textured	Uncoated	0.3
	Coated	0.2

**Table 6.** Gloss of the polyester filaments before and after coating with binder (60 g/L) and cellulose acetate pulp at pressure of 1 bar

Polyester type	Coating	Gloss
Textured	Uncoated	3.9
	Coated	3.3
Intermingled	Uncoated	3.7
	Coated	3.1

## CONCLUSION

The idea to make valuable fibrous products from waste compounds has been planned by many industries. Polyester yarns have better physical properties than the cellulose acetate, but cellulose acetates are very good at their appearance, colors, drapability and softness, relatively fast drying as well as dyability. Also, Cellulose acetate is an environmental friendly substance for making products since it is a non-toxic and available at low cost.

To continue our previous research work to apply new methods for blending regenerated cellulose structure with polyester filaments, in this paper a layer of cellulose acetate was coated on the surface of polyester filaments to improve moisture absorbance, anti-static properties, color and handle. Therefore, the cellulosic part of waste materials in different industries such as textile, paper and wood can be used as an alternative renewable biomass for the production of valuable products via this process.

Results indicated that cellulose acetate coating of polyester filaments did not changed the cross section of polyester filaments. Water absorption increased and accordingly, static electricity decreased in final yarns when more cellulosic pulp was coated on the polyester fibers at lower pressure of padding from the pressure of 5 bar to the 1 bar because the higher pressure of pad rollers leads to more remove of pulp from the surface and less pick-up of cellulosic pulp on the surface. Density of yield fibers was the same as that of uncoated polyester because although the mass of coated samples increased, the volume of them rose due to porosity too and caused the same density. An increasing trend was indicated in linear density or yarn counts via additional weight of cellulose acetate in the unit of length. The linear density of both textured and intermingled coated filaments was significantly, about 30-40 %, more than that of uncoated one. Furthermore, coated samples revealed better dyeing properties, compared to initial ones at the same condition of dyeing via more hydrophilic functional groups on the surface. Also, good strength of products may be due to their polyester core.

As far as luster properties are concerned, the results indicated the loss of gloss for the cellulosic coated samples. Therefore, there is probably no necessity to use delusterant agent, in the melt spinning process, for polyester filaments that will be coated by regenerated cellulosic pulp.

Therefore, with this research, two goals simultaneously could be achieved: regenerating waste cellulosic materials as well as improving of polyester yarns surfaces by a new, inexpensive and available method.

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