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Flame retardancy and UV protection of cotton based fabrics using nano ZnO and polycarboxylic acids

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ABSTRACT

This research mainly deals with a novel flame-retardant and UV-protection for cellulosic fabrics using ZnO nanoparticles. We present the preparation and application of ZnO nanoparticles. The size of the prepared nanoparticles was analysed using dynamic light scattering (DLS). The application of nano ZnO on cellulosic fabrics (cotton 100% and cotton/cotton polyester 65/35%) was achieved by using different polycarboxilic acids (succinic acid [SA] and 1,2,3,4-butane tetracarboxilic acids [BTCA]) with sodium hypophosphite (SHP) as catalyst through conventional pad-dry-cure method. The effect of concentration of SHP on the physical properties, flammability and UV-protection of cross-linked fabrics are investigated. The effect of concentration of zinc oxide nanoparticles and the effect of curing temperature were also investigated. The results revealed the importance of SHP in increasing the flame-redundancy of the treated cellulosic fabrics.

1. Introduction

The flammability of fabrics varies dramatically between fibres, ranging from a very high flammability of cellulosic fibres to the inherent flame-retardant (FR) nature of synthetic fibres. Generally speaking, fabrics made from untreated natural fibres, such as cotton, linen, and silk, will burn easily with a high flame velocity. In addition to fibres, the flame-spread rate of fabrics is also dependent on the fabric density and structure; lightweight and loose fabrics are more prone to catching fire quickly (Well & Levchik, 2004). Blended fabrics are considered to be less ignitable with slow flame spread as most synthetic fibres, such as nylon, acrylic, and polyester, resist ignition. However, once ignited, synthetic fabrics melt, and their hazard may increase because the high rate of burning, combined with the melting of the fabric, can result in even more serious burning. The fire hazard associated with blended fabrics may be greater than that of fabrics made of only synthetic or only cellulosic fibres. Reducing flammability of cellulosic fibres has then been one of the major challenges facing the textiles industry (Lam, Kan, & Yuen, 2011).

Cotton, one of the most important natural fibres (Adebajo, Frost, Kloprogge, & Kokot, 2006), is widely used as clothing materials due to its excellent characteristics including regeneration, biodegradation, softness, comfort, warmness, and hygroscopic properties. Cotton is the widely used textile fibre having a high flammability. Application of flame retardant products on cotton is an important textile issue (Wu & Yang, 2007) especially for protection of consumers in military and the airline industry (Schindler & Hauser, 2004). For a long time, phosphorous compounds including tetrakishydroxymethyl phosphonium chloride (THPC) and N-methylol dimethylphosphono propionamide (MDPA) with the trade names of “Pyrovatex CP” or “Pyrovatex CP New” have been the most useful approach to obtain durable flame-retardant finishes for cotton. They can react with the fibre or form cross-linked structures on the fibre (Cheng & Yang, 2009; Gaan & Sun, 2007a; Lecoeur, Vroman, Bourbigot, Lam, & Delobel, 2001; Schindler & Hauser, 2004; Yang & Wu, 2003; Wu & Yang, 2007, 2008a). These compounds influence the pyrolysis reaction, prevent the formation of levoglucosan and flammable volatiles, increase the formation of char and act as flame retardant for cellulose (Cheng & Yang, 2009; Gaan & Sun, 2009; Wu & Yang, 2008a). It is shown that the amount of phosphorus content on the treated cellulose is an important factor in flame retardant efficiency. In other words, a large amount of flame retardant led to more effectiveness in decreasing flammability of cellulose fibre (Siriviriyanun, O’Rear, & Yanumet, 2009).

Sodium hypophosphite (SHP) is a phosphorus-based salt and well-known catalyst for cross-linking cellulose with poly carboxylic acids (Yang, 2001; Wu & Yang, 2008a). Wu and Yang (2008b) studied the combination of Malic acid (MA) and SHP in flame retardant finishing of cotton fleece fabric. Yang

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and Wu investigated the flame retardant of cotton using a hydroxyalky-functional organophosphorus compound and BTCA, in the presence of SHP as a catalyst. They indicated that the polycarboxylic acid functions as a binder between the organophosphorus oligomer and cellulose and makes the organophosphorus compound flame retardant finish agent on cotton fabric.

Cheng and Yang (2009) studied flammability of cotton fleece using the phosphorus-containing maleic acid oligomers (PMAO) with SHP as the catalyst. They found that PMAO can be bound to cotton fleece by esterifying with cotton cellulose in the presence of SHP and reduces the fabric flammability (Cheng & Yang, 2009). However using carboxylic acid as crosslinking agent with SHP causes discolouration of white cotton fabrics during the curing process (Schramm & Rinderer, 1999). Therefore, it is necessary to prevent yellowing.

With advent of nanotechnology, a semiconductor nanoparticle has attracted much attention due to their novel optical, electrical and mechanical properties. Among various semiconductor nanoparticles, nanosized zinc oxide (ZnO) particles are the most frequently studied because of their interest in fundamental study and also their applied aspects such as in solar energy conversion, varistors, luminescence, photo-catalysis, electrostatic dissipative coating, transparent UV protection films and chemical sensors (Abd El-Hady, 2012).

Certainly, the selection of catalyst plays a significant role in influencing the bonding of the flame retardant agents to cotton. Researchers showed that nano-zinc oxide (nano-ZnO) coated on cotton fabrics could impart functional properties such as better strength properties, air permeability and UV-absorption property (Yadav et al., 2006). Zinc oxide (ZnO) as catalyst could even help to enhance the flame-retardant action (Well & Levchik, 2004). Hence, the first goal of this article is to investigate the action of sodium hypophosphite as a flame retardant finishing agent in the presence of butane tetracarboxylic acid, succinic acid and nano-ZnO, to cotton and cotton/polyester blend fabrics. The finishing system proposed is applied to textile materials by conventional pad-dry-cure finishing techniques at two different curing temperatures. The second goal of this study to optimize the proper condition for the resistance of bleached cotton and cotton/polyester blend fabrics against creasing and UV blocking testes.

2. Experimental

2.1. Materials

Mill bleached 100% cotton fabric (230 g/m^2) and cotton/polyester blend fabric 65/35 (152 g/m^2) were kindly supplied by Misr Company for spinning and weaving Mehalla El-Kobra, Egypt.

2.2. Chemicals

1,2,3,4-Butane tetracarboxylic acid, succinic acid and sodium hypophosphite were supplied by Merck chemical company (Germany). Isopropanol, zinc acetate, lithium hydroxide, sodium carbonate were of laboratory grade chemicals.

2.3. Preparation of nano-ZnO

The preparation procedure employed has been described in (Farouk et al., 2009) and is a variation of a preparation described by Spanhel and Anderson (1991). A two neck round bottom distillation flask was used to suspend 2.8 g of (ZnAc $2H_2O$) in 100 ml of isopropanol by reflux heating for 3 h. 0.75 g lithium hydroxide was dissolved in 100 ml isopropanol at room temperature by magnetic stirring. The ZnAc suspension was cooled to 0 °C before the lithium hydroxide solution was added drop wise under vigorous stirring. The mixture was treated in an ultrasonic bath (SONOREX TK 52H) at room temperature for about 2 h.

2.4. Coating of fabrics with poly carboxylic acids (crosslinking of fabrics)

Various aqueous solutions of butantetracarboxylic acid and succinic acid (6%, w/v) with different concentrations of sodium hypophosphite (4% and 6%, w/v) were prepared. Bleached cotton and cotton/polyester blend fabrics were padded in the previously prepared solutions in two dip and nip and then squeezed to a wet pick-up of 100%. Padded fabrics were dried at 80 °C for 5 min and then cured at two different temperatures (160 °C and 180 °C) for 3 min. Treated fabrics were rinsed with hot water then with cold water and finally dried at room temperature.

2.5. Coating of cotton and cotton/polyester fabrics with nano-ZnO

Fabrics were coated with nano particles of zinc oxide using pad-dry-cure method. Two suspended solutions of nano-ZnO were firstly prepared by dissolving two different concentration of nano-ZnO prepared previously in isopropanol (0.25 and 0.5 w/v%) and allowed sonication for 10 min. Bleached fabrics and dried fabrics at 80 °C for 5 min treated with SA or BTCA were immersed in suspended solutions of nano-ZnO for 10 min. The fabrics were padded in two dip and nip and then squeezed to a wet pick-up of 100%. Padded fabrics were dried at 80 °C for 10 min and then cured at 130 °C for 3 min. Cured fabrics were ultrasonically washed for 10 min in order to remove zinc oxide nanoparticles having no bonding reaction with fabrics.

3. Testes and analysis

3.1. Characterization of nano-ZnO

The size of the nano-ZnO was measured by dynamic light scattering (DLS), using Zetasizer, Nano-S, produced by Malvern.

3.2. Scanning electron microscopy

SEM was studied using a scanning electron probe microanalyzer (JXA-840A) Japan. The specimens in the form of fabrics were mounted on the specimen stabs and coated with thin film of gold by the sputtering method. The micrographs were taken at magnification of 2000× using (KV) accelerating voltage.

3.3. Fabric whiteness and yellowness

Whiteness and yellowness index were evaluated with a Color-Eye 3100 Spectrophotometer from SDL Inter.

3.4. Surface roughness

Surface roughness was monitored according to JIS 94 standard, using surface roughness measuring instrument, SE 1700α made in Japan.

3.5. Crease recovery angle

Standard method was used to measure wrinkle recovery angles WRA (AATCC test method 66-1984).

3.6. UV protection factor

UV–vis spectrum was recorded on Perkin Elmer Lambda 3B UV-Vis spectrometer. Ultraviolet protection factor (UPF) was measured using UV Shimadzu 3101 PC-Spectrophotometer.

3.7. Vertical flammability

The vertical flammability of cotton fabrics was measured according to BS3119 standard Method and chair length of samples obtained.

3.8. Char yield

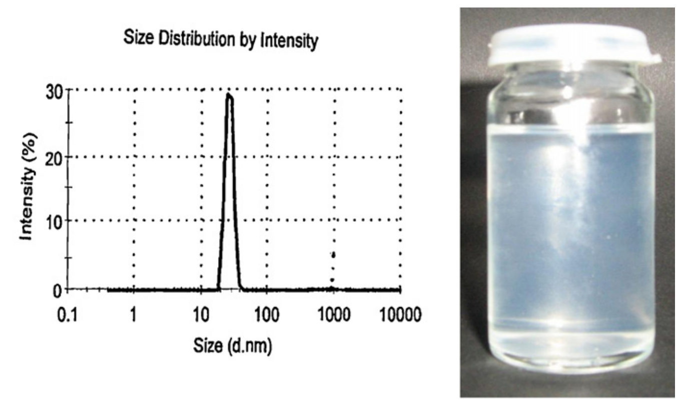
The measuring of char yield is an appropriate factor for study the influence of flame retardance (Chen, Wang, Hu, & Qu, 2005; Gaan & Sun, 2007b). In this order, the weight of each sample before and after burning was measured and char yield was calculated according to following equation:

$$\text{Char yield} = \frac{W_2}{W_1} \times 100$$

where W_1, W_2 are weight of sample before and after burning, respectively.

4. Results and discussion

The synthesis of nano-ZnO basically described by Spanhel and Anderson (1991) lead to the formation of colloidal ZnO particles with a homogenous distribution and an average particle size of 30 nm as shown in Fig. 1a. The ZnO sols show no significant precipitation for weeks. The picture shown in Fig. 1b shows a corresponding sol after more than 24 h indicating the stability of the prepared solution and the absence of any precipitation.



(a) Average particle diameter=30 nm (b) ZnO nanoparticle

Fig. 1. (a) DLS measurements of ZnO nanoparticle and (b) image of ZnO nanoparticle taken 24 h after synthesis.

4.1. Physical properties of treated cotton and cotton/polyester fabrics

4.1.1. Effect of temperature

Physical properties of the treated samples are summarized in Tables 1 and 2. Table 1 shows that, at curing temperature 160 °C, CRA values of the finished fabrics with constant concentrations of SA and BTCA are gradually increased at first, but with adding different concentrations of SHP (4 wt% and 6 wt%) it followed by increasing in values of CRA with increasing concentrations of SHP (regardless type of substrate used). This increase in CRA is attributed to the effect of crosslinking agent on cotton and cotton/polyester fabrics. CRA give higher value in case of using BTCA than using of SA. This could be explain by the fact that BTCA has one more carboxylic acid group which bond to the adjacent carbons in their molecular backbones and both are able to estrify cellulose by first forming a reactive 5-membered cyclic anhydride intermediate (Yang, Wang, & Kang, 1997). On the other hand although SA is a bifunctional carboxylic acid, it is unable to form the second anhydride intermediate for further esterification to form crosslinkage between cellulose molecules once its first carboxylic group esterifies (Yang et al., 1997).

Results of Table 1 also show that the treated samples with BTCA give higher values of roughness and yellowness than the samples treated with SA (regardless type of substrate used), while samples treated with SA give higher whiteness index than samples treated with BTCA. This could be associated with differences between SA and BTCA with respect to the number of carboxylic groups.

Furthermore an increase in the curing temperature from 160 °C to 180 °C (Table 2), lead to slight increase in CRA values, yellowness index, roughness and decrement in whiteness index of samples treated by BTCA and SA acids. This is because the higher curing temperature acts in favour of formation of ester crosslinking between cellulose chains and polycarboxylic acids (BTCA and SA) (Nazari, Montazer, Rashidi, Yazdanshenas, & Anary-Abbasinejad, 2009).

The above results disclose that cotton fabric give higher value of roughness, yellowness and whiteness index than cotton/polyester fabric. On the other hand cotton fabric gives lower CRA than cotton/polyester fabric for the same condition of treatments. This is most probably due to the polyester component in the blend fabric.

4.1.2. Effect of concentration of nano-ZnO

Table 3 shows the effect of concentration of nano ZnO on physical properties of crosslinked and non crosslinked cotton

Table 1
Effect of curing temperature (160 °C) on physical properties of treated cotton and cotton/polyester fabrics.

Substrate		Roughness	Whiteness index	Yellowness index	CRA (W + F)°
Untreated	Cotton	17.56	73.30	2.78	180°
	CO/PET	15.83	68.23	1.75	210°
Treated with 6% SA	Cotton	18.29	63.99	6.15	198°
	CO/PET	16.13	61.79	2.76	217°
Treated with 6% SA, 4% SHP	Cotton	19.5	71.56	3.53	200°
	CO/PET	17.28	69.72	1.53	228°
Treated with 6% SA, 6% SHP	Cotton	19.97	70.92	3.60	222°
	CO/PET	17.95	69.33	1.46	232°
Treated with 6% BT	Cotton	19.42	64.01	6.06	207°
	CO/PET	16.32	59.14	4.90	223°
Treated with 6% BT, 4% SHP	Cotton	20.05	68.61	4.37	236°
	CO/PET	17.76	63.62	3.20	245°
Treated with 6% BT, 6% SHP	Cotton	21.26	69.26	4.19	248°
	CO/PET	18.17	66.62	2.09	255°

Table 2
Effect of curing temperature (180 °C) on physical properties of treated cotton and cotton/polyester fabrics.

Substrate		Roughness	Whiteness index	Yellowness index	CRA (W + F)°
Untreated bleached	Cotton	17.56	73.30	2.78	180°
	CO/PET	15.83	68.23	1.75	210°
Treated with 6% SA	Cotton	18.43	54.67	7.31	199°
	CO/PET	17.58	63.20	3.38	219°
Treated with 6% SA, 4% SHP	Cotton	19.60	65.07	5.10	209°
	CO/PET	18.44	68.27	1.75	229°
Treated with 6% SA, 6% SHP	Cotton	20.30	66.79	4.82	226°
	CO/PET	19.22	69.11	2.34	238°
Treated with 6% BT	Cotton	18.60	63.57	4.49	212°
	CO/PET	16.57	61.60	3.44	228°
Treated with 6% BT, 4% SHP	Cotton	14.99	68.13	4.40	240°
	CO/PET	20.20	66.02	2.43	248°
Treated with 6% BT, 6% SHP	Cotton	16.95	65.34	5.34	250°
	CO/PET	13.00	68.08	1.69	256°

and cotton/polyester fabrics. Table 3 disclose that increasing the concentration of nano ZnO from 0.25% to 0.5% (wt/v), for non-crosslinked fabrics, lead to slight increase in roughness values and slight decrease in whiteness index. This is observed irrespective of the substrate used. This may be due to the deposition of nanoparticles of ZnO on the treated cotton and cotton/polyester fabrics. On the other hand when the fabrics crosslinked by polycarboxylic acids (BTCA and SA) then treated with nano ZnO, all physical properties under studied are altered. In detail, increasing the concentration of nano-ZnO from 0.25% to 0.5% for the same concentration of poly carboxylic acid and catalyst used is accompanied by increasing in roughness values (regardless type of fabric used), this could be related to more deposition of nano ZnO particles on the surface and/or higher crosslinking.

Table 3 also shows small decrease in CRA values and yellowness index (increase in whiteness index) of the fabrics treated with constant concentration of BTCA, SA and SHP. This reduction could be attributed to the agglomeration of nano particles of ZnO on the surface of the fabrics and or inhibiting the action of the crosslinking.

4.2. Flammability of cotton and cotton/polyester treated fabrics

4.2.1. Effect of curing temperature on flammability of cotton and cotton/polyester fabrics treated by polycarboxylic acids

Table 4 shows the effect of curing temperature on chair length and chair yield of finished cotton and cotton/polyester fabrics with BTCA and SA acids. Results of Table 4 depict that the performed treatments were decreased the flammability of the treated samples. In other words, at the same curing temperature 160 °C and same concentration of acid used, it is followed by insignificant decrease in chair length and insignificant increase in chair yield. But in the presence of SHP, 4–6% as a catalyst leads to higher decreasing in chair length and increasing in chair yield. These results confirmed the impact of phosphorous deposited form SHP.

Evidently, both SA and BTCA acids are effective in reducing flammability of treated fabrics in the presence of SHP; but BTCA is more effective than SA acid in reducing flammability.

Char length of samples was measured in the vertical flammability test and reported in Table 4. It is seen Table 4 that increasing the curing temperature from 160 °C to 180 °C of the treated cotton and cotton/polyester fabrics are followed by marginal enhancing in chair length and chair yield. Also differences in the burning behaviour and char length in vertical flame test for untreated sample compared to the treated fabrics were shown in Fig. 2 (a–c). The results showed that, the performed treatment was decreased the flammability of the samples. It can be concluded that increasing of nano ZnO, BTCA and SHP concentrations leads to decrease the fabric flammability (see the results of samples b and c) (Table 5).

It is interesting to note also that the charred surface of the SHP treated samples was very uniform indicating that the phosphorus compound uniformly covered the fabric surface.

4.3. UV protection factors of cotton and cotton/polyester treated fabrics

To consider the durability of the treatments laundry test were carried out. All samples were exposed to two washing cycles (40 °C, 20 min, washing agent 1 g/l) before the UV transmission was investigated. The corresponding data for selected cellulosic fabrics are summarized in Table 6 indicating changes in the absorption characteristics of the treated samples which expressed as UPF value compared to the untreated fabrics. Because of the aromatic backbone,

Table 3
Effect of concentration of zinc oxide nanoparticles on physical properties of crosslinked cotton and cotton/polyester treated fabrics.

Substrate		Roughness	Whiteness index	Yellowness index	CRA (W + F)°
Untreated	Cotton	17.56	73.30	2.78	180°
	CO/PET	15.83	68.23	1.75	210°
Treated with 0.25%(W/V) ZnO	Cotton	18.06	67.58	5.10	202°
	CO/PET	16.38	65.76	3.11	220°
Treated with 0.25%(W/V) ZnO, 6% SA, 6% SHP	Cotton	18.62	71.21	3.61	226°
	CO/PET	17.02	68.67	1.73	236°
Treated with 0.25%(W/V) ZnO 6% BT, 6% SHP	Cotton	20.08	69.16	4.27	247°
	CO/PET	18.23	71.05	3.66	255°
Treated with 0. 5%(W/V) ZnO	Cotton	18.70	66.17	5.35	207°
	CO/PET	16.71	68.67	2.03	223°
Treated with 0.5%(W/V) ZnO, 6% SA, 6% SHP	Cotton	19.03	72.06	3.41	225°
	CO/PET	17.42	67.76	1.89	235°
Treated with 0.5%(W/V) ZnO, 6% BT, 6% SHP	Cotton	20.42	70.53	3.77	245°
	CO/PET	19.38	68.79	1.55	253°

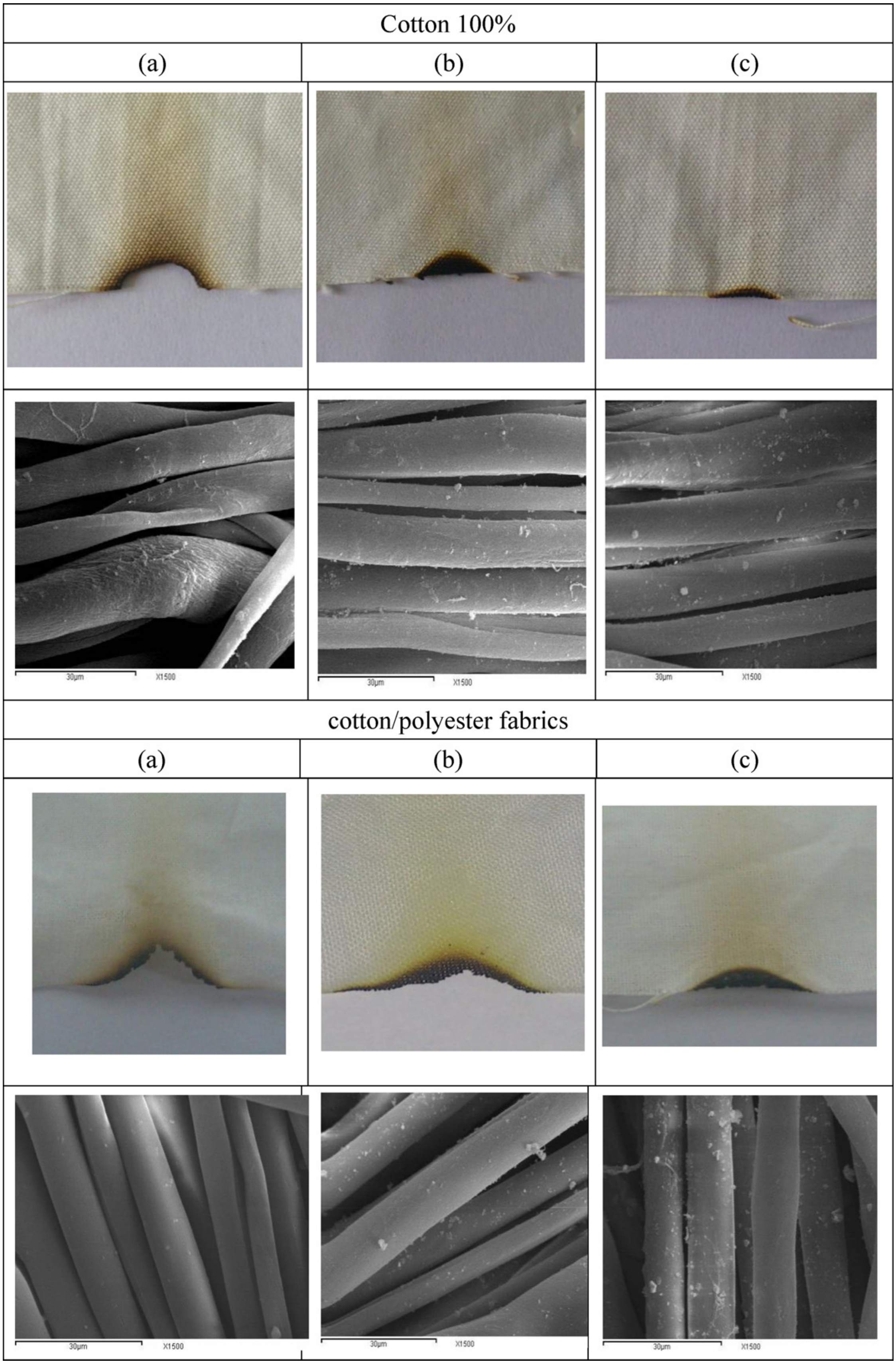


Fig. 2. Images of vertical flame testing as well as SEM micrographs of the uncoated and coated cotton and cotton/polyester fabrics (a) blank cotton and cotton/polyester fabrics, (b) fabrics treated with 0.25%(W/V) ZnO 6% BT, 6% SHP and (c) fabrics treated with 0.5%(W/V) ZnO 6% BT, 6% SHP.

Table 4
Effect of curing temperature on flammability after 2 washing cycles of treated cotton and cotton/polyester fabrics treated with polycarboxylic acids.

Substrate		Flammability			
		160 °C		180 °C	
		Chair length (cm)	Chair yield (%)	Chair length (cm)	Chair yield (%)
Untreated bleached	Cotton	2	78.44	2	79
	CO/PET	2.5	70	2.5	71
Treated with 6% SA	Cotton	1.80	78.48	1.80	79.3
	CO/PET	2.3	70	2.3	71
Treated with 6% SA, 4% SHP	Cotton	0.90	82	0.74	83
	CO/PET	1.56	74	1.30	75
Treated with 6% SA, 6% SHP	Cotton	0.77	85	0.43	85
	CO/PET	1.15	78	0.99	79
Treated with 6% BT	Cotton	1.67	80	1.67	80
	CO/PET	2.35	71	2.31	72
Treated with 6% BT, 4% SHP	Cotton	0.8	86	0.75	87
	CO/PET	1.10	77	1.18	77
Treated with 6% BT, 6% SHP	Cotton	0.60	90	0.44	91
	CO/PET	0.77	80	0.85	80

Table 5
Effect of concentrations of zinc oxide nanoparticles on fammability of treated cotton and cotton/polyester fabrics by polycarboxylic acids.

Substrate		Flammability	
		Chair length (cm)	Chair yield (%)
Untreated	Cotton	2	78.44
	CO/PET	2.5	70
Treated with 0.25%(W/V) ZnO	Cotton	1.0	75
	CO/PET	1.4	73
Treated with 0.25%(W/V) ZnO, 6% SA, 6% SHP	Cotton	0.22	93
	CO/PET	0.35	85
Treated with 0.25%(W/V) ZnO 6% BT, 6% SHP	Cotton	0.05	97
	CO/PET	0.31	88
Treated with 0. 5%(W/V) ZnO	Cotton	0.95	75
	CO/PET	1.3	73
Treated with 0.5%(W/V) ZnO, 6% SA, 6% SHP	Cotton	0.25	94
	CO/PET	0.30	85
Treated with 0.5%(W/V) ZnO, 6% BT, 6% SHP	Cotton	0.02	98
	CO/PET	0.30	88

Table 6
Effect of concentrations of zinc oxide nanoparticles on UV protection of treated cotton fabrics by polycarboxylic acids.

Substrate		UPF value	UV protection	
Untreated	Cotton	21	20	Good
	CO/PET	18	15	Good
Treated with 0.25%(W/V) ZnO	Cotton	35	35	Very good
	CO/PET	31	30	Very good
Treated with 0.25%(W/V) ZnO, 6% SA, 6% SHP	Cotton	37	35	Very good
	CO/PET	35	35	Very good
Treated with 0.25%(W/V) ZnO 6% BT, 6% SHP	Cotton	45	45	Excellent
	CO/PET	38	35	Very good
Treated with 0. 5%(W/V) ZnO	Cotton	40	40	Excellent
	CO/PET	36	35	Very good
Treated with 0.5%(W/V) ZnO, 6% SA, 6% SHP	Cotton	55	50+	Excellent
	CO/PET	51	50+	Excellent
Treated with 0.5%(W/V) ZnO, 6% BT, 6% SHP	Cotton	60	50+	Excellent
	CO/PET	57	50+	Excellent

untreated polyester fibre should absorb certain amounts of UV radiation. Nevertheless, from the tables it can be seen that blended with cotton the grey fabric yields only good UV protection as well as untreated cotton fabric. Results presented in Table 6, show the increase of UV protection ability with the polycarboxilic acids treatment on the both treated fabrics–cotton and cotton/polyester. All cotton fabrics give off excellent UV protection, as well as the most of cotton/polyester fabrics. Treatment with BTCA result in higher UV protection for the both treated fabrics.

4.4. SEM investigation

SEM investigates the changes in the topography of the treated fabrics compared with the untreated one. The corresponding SEM micrographs are shown in Fig. 2. It is clearly seen that the surface of the untreated fabrics is comparably rough, but the surface of the treated fabrics appears much smoother, because the coatings obviously lead to a flattening of the fibre surface but by increasing the concentration of the nanoparticles within the coating layer, some agglomerations on the fabric surface in case of cotton and cotton polyester blend were seen as shown in Fig. 2(c).

5. Conclusion

SA and BTCA are environment-friendly compounds used for the finishing of cellulosic fabrics. In this research, the effect of two different carboxylic acid agents (SA and BTCA) together with SHP as catalyst and nano ZnO as a novel flame retardant for cotton and cotton/polyester fabrics was investigated. Some analysis including char length, char yield, UV protection, SEM and DLS in addition to the physical properties of the cross linked cotton and cotton/polyester treated fabrics were studied in order to evaluate flame retardant property of treated samples. Nano ZnO is an effective compound in increasing the char formation. Also, the presence of phosphorus deposited on the SHP treated samples is the most effective parameter in the char forming and decreasing the flammability of the treated fabrics. The effect of increasing the curing temperature and the concentration of nano ZnO were also studied. Totally, the performed treatment helps to form more non-flammable char residue and increases char formation after heating in addition to the improvement of the UV-protection property. The increased char formation of fabric is measured after 2 washing cycles.

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