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Improvement in physical properties of paper fabric using multi-wall carbon nanotubes

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Abstract Using carbon nanotubes (CNTs) in textile industry has attracted much attention due to its special properties. Also paper fibers and fabrics are the most important raw materials of textile. In this manuscript, paper yarns were weaved and treated with multi-wall CNTs (MWCNTs) in order to improve the physical properties of paper fabrics. In this regard, different percents of MWCNTs were coated on fabrics and some physical properties were investigated. Based on the results, paper fabrics treated with MWCNTs show excellent UV protection. The treated samples have more crease recovery. Also bending test and abrasion resistance analyses show improvements in treated fabrics. The adsorption test of samples shows an increase in water adsorption due to MWCNTs role of adsorbent. The results show a little decrease in strength that seems natural because of acidic pH of the used cross-link agent. In general, in addition to economic benefits of using paper fabrics, treating them with MWCNTs can also improve their physical properties.

Keywords MWCNTs · Paper yarn · Physical properties

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Introduction

Using environmentally friendly fibers such as cotton, linen and in general cellulosic fibers is an important subject which has attracted much attention these days because of their benefits such as lightweight and low static electricity [1]. Many parameters can affect the life span of these fabrics including their intrinsic characteristics such as materials, diameter, strength, and extrinsic characteristics like spinning method and speed of spinning [2]. Paper yarns are one of these fibers that have recently been widely utilized. However, paper yarns have some disadvantages such as being wrinkled easily, low stretching properties, and low softness [1]. Also most paper yarns do not have enough strength [3], so, as they are made from cellulose, it is attractive to finish them in order to improve their physical properties.

Cellulose is a plentiful biopolymer in the world. In addition to its wide use in papermaking and textiles, cellulose is a very important renewable source for development of many industries due to its special properties. Based on polar surface of cellulose fibers and its hydrophilic groups, the inorganic phases can be grown outward of cellulose that can make it possible to produce a composite with novel properties [4–8]. One of the remarkable materials for improving paper yarn properties is carbon nanotubes (CNTs).

CNTs are allotropes of carbon which can be assorted to four groups according to their wall number: single-wall CNTs, double-wall CNTs, triple-wall CNTs and multi-wall CNTs (MWCNTs) [9].

CNTs have particular properties such as excellent adsorption [10], high flexibility, low mass density [11, 12], electrical conductivity, high strength, elastic modulus, electromagnetic interference shield [13], thermal properties

Table 1 General specification of fabric

Fabric type	Density (yarn/cm)		Weight (g/m^2)	Yarn count (Ne)
	Warp	Weft		
Paper yarn fabric, cellulose 100 %	10	35	350	8

[14] and if they disperse in polymers, they play an important role in the composite properties especially mechanical strength [15–18].

CNTs have great ratio of surface to area which make them so appropriate for various applications such as super capacitors [19]; however, they cause agglomeration of the nanoparticles [20].

Majority of the studies on methods of preparing textile containing CNTs have concentrated on compounding fiber spinning and dipping–drying [21–30].

As there is no tendency between cellulose and inorganic particles, cross-link agents are suitable for fixation of nanoparticles on cellulosic fibers [14]. One of these cross-link agents is succinic acid that has been used as cross-link agent in previous works and the reported results were good for coating nanomaterials on cotton fabric [31, 32].

In this paper, physical properties of paper fabric (weaved paper yarns) coated with different percents of MWCNTs were investigated and its effects on paper fabric have been discussed.

Materials and methods

Materials

Paper yarns from Paperphine Co., MWCNTs from NANOSAV (SAV30102) with outer diameter between 10 and 20 nm and wall length of 10 μm and purity of 92 %, succinic acid from Merck, and sodium hypophosphate from Fluka were prepared. The specifications of paper fabric are presented in Table 1.

Methods and characterization

The first step was preparing the yarns, so the paper yarns were washed with distilled water at 80 °C in order to remove any impurities. Then 6 % w/w succinic acid and 4 % w/w sodium hypophosphate were bath mixed in magnetic field for 20 min (preparing cross-link agent). Then the washed paper yarns were immersed in cross-link dispersion for an hour and after that, they were dried in oven for 3 min at 85 °C and 2 min at 160 °C. During this process, MWCNTs (with different percent) were sonicated for 30 min at 50 °C for the preparation of the precursor dispersion of nanomaterials. Then the paper fabrics were immersed in the bath of MWCNTs for an hour at 75 °C. Finally, for fixation of nanomaterials, the paper yarns were kept in an oven at 100 °C for an hour.

Table 2 Specification of samples

Sample code	A	B	C	D	E	F
Used MWCNT (on weight of fabric) %	0.10	0.30	0.50	1.00	1.50	0.00

The strengths of treated and untreated paper yarn were applied by ISO5079-Breaking strength.

The main work began with weaving the untreated paper yarns into fabrics. Panama weaving was done (Table 1). The fabrics were divided into five groups and each group was treated (as above) with a special percent of MWCNTs (Table 2). The strength test of fabric was done with same device as mentioned above. The crease recovery properties of samples were measured using the AATCC 66-2003 test. Water drop absorption times of the fabrics were measured according to AATCC 79-2000. Abrasion test was done by rub tester. The bending lengths of the specimens were calculated based on ASTM D 1388-96 (2002). UV-blocking properties of the fabrics were evaluated according to AATCC test method 183-2004 (transmittance or blocking of erythemally weighted ultraviolet radiation through fabrics) with a Perkin-Elmer Lambda 35 UV–vis spectrophotometer, equipped with an integrating sphere. Also scanning electron microscopy (KYKY, SEM, EM3200, 26 kV) was used in order to determine the structure of nanomaterials on fabric.

Results and discussion

Microscopic analysis

Figure 1 shows the projection microscope images of paper yarns. As it shows, the papers are twisted in each yarn. Figure 2 is the SEM analysis of paper fabrics treated with various amounts of MWCNTs. Two magnifications of each sample are presented. As shown, all samples are completely coated with nanomaterials. It can be clearly seen that particle distribution is appropriately remarkable.

Abrasion resistance analysis

One hundred cycle of rubbing test was done for each paper fabric and the margin mass of the fabrics was calculated. The results are presented in Table 3. As it is mentioned, the abrasion resistances of the treated samples are higher than those of the untreated ones. The increase in abrasion

Fig. 1 Projection microscopic picture of paper yarn

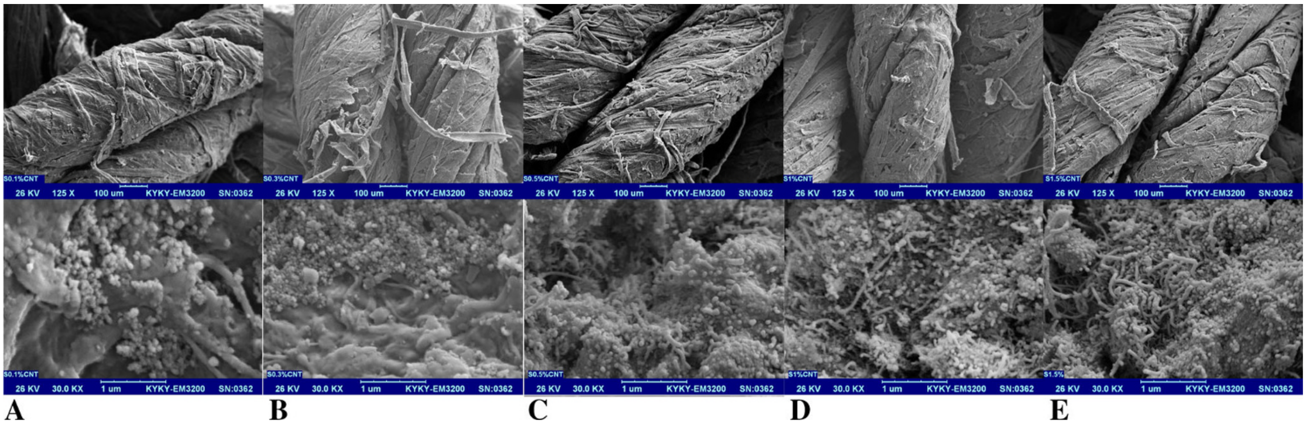

Fig. 2 SEM of treated paper fabrics with related samples code

Table 3 Abrasion test of paper fabrics

Sample	Fabric weight before abrasion (g)	Fabric weight after abrasion (g)	Loss weight (%)	Abrasion resistance (%)
A	1.81	1.74	3.86	96.14
B	1.85	1.79	3.24	96.76
C	1.91	1.85	3.14	96.86
D	1.21	1.19	1.65	98.35
E	1.70	1.68	1.17	98.83
F	1.22	1.16	4.91	95.09

Table 4 CRA, bending length and adsorption

Sample	CRA after first 5 min	CRA after second 5 min	Bending length (cm)	Water drop absorption (s)
A	50.0	54.0	7.5	2″:21‴
B	53.2	55.3	7.6	1″:99‴
C	54.9	56.9	7.7	1″:56‴
D	56.4	58.0	7.7	1″:45‴
E	60.2	61.8	7.8	1″:38‴
F	40.8	50.4	7.3	3″:45‴

resistance is due to the excellent mechanical properties of MWCNTs; it is clearly observable from the SEM pictures that the whole surface of the fabric is covered by MWCNTs.

Crease recovery, bending length and adsorption test

The samples were loaded on the folded specimens for two 5-min periods. The recorded vertical angle guidelines were aligned and the recovery angles were measured. The results of the study on the crease recovery angle (CRA) of the treated fabrics are summarized in Table 4 and Fig. 3. It is shown in Table 4 that CRA values of the finished fabrics are gradually increased by increasing MWCNTs. This can be attributed to the cross-linking of MWCNTs to the fabrics that leads to create a network and this reduces the flexibility of the chains. As the results indicate, the bending lengths of treated and untreated samples are very close. However, the samples treated with MWCNTs have a slightly higher bending length than untreated samples, which is based on mechanical properties of MWCNTs. This could be related to more deposition of MWCNTs on the fabric surface and/or higher cross-linking. In order to investigate the water adsorption of the samples, drop absorption time of the fabrics was calculated. As shown in Table 4, a small decrease occurred in water absorption time on the treated fabric. This can be attributed to the absorbent activity of carbon which results in increasing the water absorption of the fabrics.

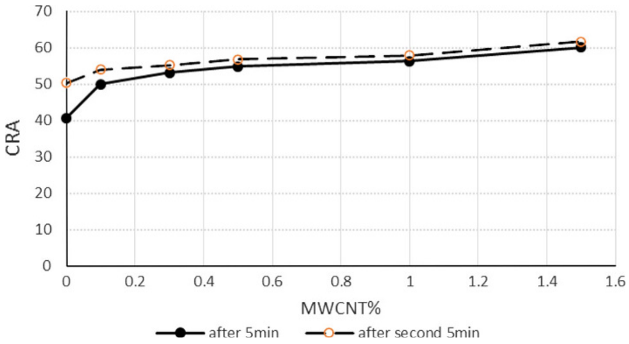

Fig. 3 CRA carve of fabrics

UV protection

Figure 4 shows transmittance spectra of the samples in the range of 280–400 nm. The upper line (F) is the UV transmittance curve of the untreated sample indicating that high percentage of the UV light can penetrate into the fabric. Line E is the UV transmittance of the sample E. As it shows, UV-blocking ability of the treated sample is higher than that of the untreated ones. It can be induced to be the result of MWCNTs ability of UV blocking indicating the increase of blocking.

Strength analysis

The strengths of paper yarns and paper fabrics are investigated (Table 5). As the results show, the strength of untreated sample is higher than that of the coated samples. It can be attributed to the pH of succinic acid and the confinement effect of MWCNTs. Acidity of cross-link agent leads to degradation of cellulose polymer chains, and this results in the reduction of strength.

Conclusion

This study investigated the effect of MWCNTs on mechanical properties of paper fabrics. Due to the excellent properties of MWCNTs, the abrasion resistance, bending length and water adsorption were improved. Using MWCNTs also causes an increase in UV blocking of fabric and prevents the influence of UV. Cross-linking of MWCNTs to the fabric leads to create a network and this reduces the flexibility of molecular chains and finally results in an increase in the crease recovery of paper fabric. The test of strength shows that acidity pH of used succinic acid as cross-link agent caused a decrease in strength of

Fig. 4 Transmittance spectra of the samples

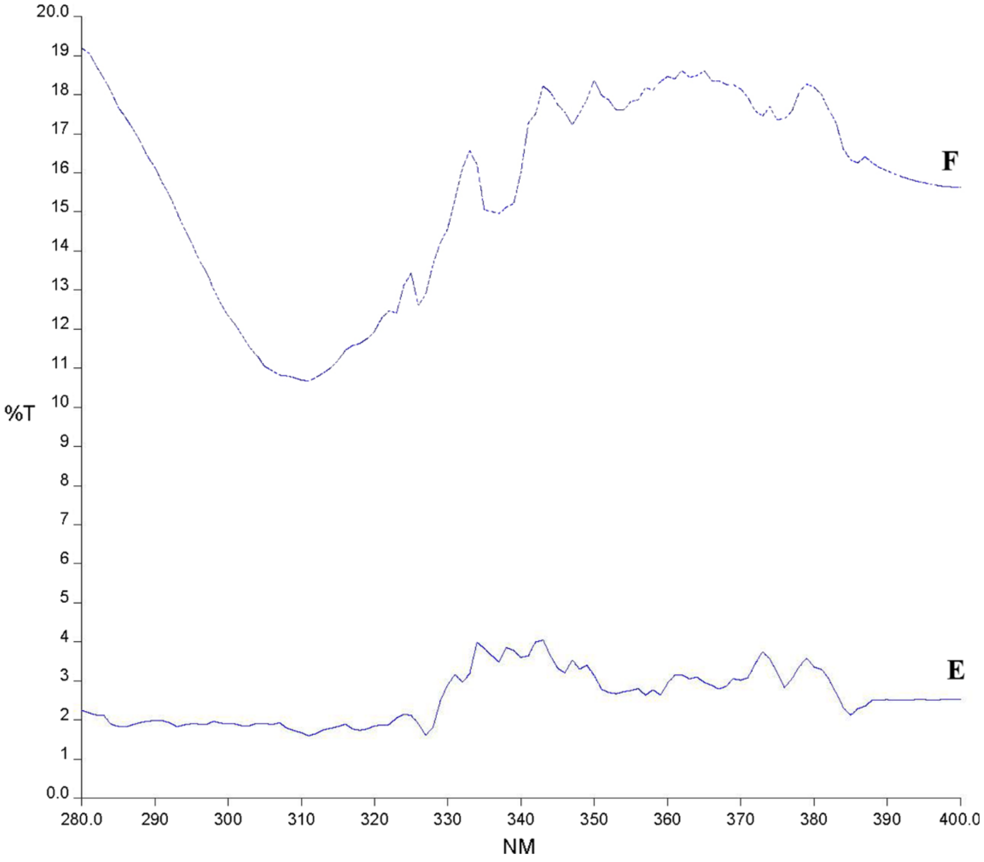

Table 5 Strength of paper yarns and paper fabrics

Sample	Strength of paper yarn (N)	Elongation of paper yarn (mm)	Strength of paper fabric (N)	Elongation of paper fabric (mm)
A	1.933	18.500	206.287	7.105
B	0.041	00.002	198.191	6.500
C	0.395	16.200	186.038	7.004
D	0.204	11.500	158.645	6.303
E	0.953	14.300	151.026	5.807
F	3.769	15.000	264.173	3.308

paper fabric. In general, treating the paper fabric by MWCNTs can improve the most physical and mechanical properties of fabrics, especially in UV blocking.

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