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The Effect of Functionalized Multi-walled Carbon Nanotubes (MWCNTs) on Properties of Polyester Fabric Dyed with MWCNTs

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ABSTRACT

In this study, MWCNTs were functionalized with nitric acid. The prepared MWCNTs were incorporated in polyester fabrics by the conventional dyeing process. The dyeing process was carried out by the exhaustion method. The polyester fabric was immersed in the MWCNTs dispersion and maintained in motion for a certain period of time and temperature. The effects of MWCNT functionalization on morphological, thermal conductivity properties of fabrics were investigated. Colorfastness properties of dyed fabrics were also studied.

Keywords: Carbon nanotubes, MWCNTs, polyester fabric

I. INTRODUCTION

The development of nanotechnology has stimulated research on applications of nanosized particles in textile processing [1]. Nanotechnology is now being applied to textiles to add novel functionalities such as UV protection [2, 3], self-cleaning, water and oil repellency [4], fire retardancy [5], and electrical conductivity [6]. It is important to improve the fabrics mechanical and chemical stability as well as their thermal resistance and electrical conductivity. Among the most promising nanomaterials for textile applications, carbon nanotubes has challenging properties, such as high thermal and chemical stability, high thermal conductivity, hardness and stability [7]. It is well known that CNTs have high aspect ratio, high surface area and intrinsic van der Waals attraction among tubes which causes to the agglomeration and makes difficult to achieve homogeneous dispersion in various matrices [8]. There are two approaches available to disperse CNTs in aqueous media, including either chemical functionalization of CNTs by introducing polar groups or the noncovalent physical adsorption of surfactants and polymers to the CNTs [9]. The functionalization of CNTs allows tuning their properties. Carbon nanotubes can be dispersed in common solvents using chemical modification methods. Dyeing process provides a useful pathway for incorporating carbon nanotubes into textile materials. The process involves bringing textile and dyes into contact through a suitable medium [5,10].

In this study, MWCNTs were functionalized with nitric acid. The prepared MWCNTs were incorporated in polyester fabrics by the conventional dyeing process commonly used to dye polyester fabrics, replacing dyes by MWCNTs dispersions. The dyeing process was carried out by the exhaustion method. The polyester fabric was immersed in the MWCNTs dispersion and maintained in motion for a certain period of time and temperature. The effects of MWCNT functionalization on morphological, thermal conductivity properties of fabrics were investigated. Colorfastness properties of dyed fabrics were also studied.

II. EXPERIMENTAL

2.1. Materials

Multiwalled carbon nanotubes (MWCNT) were purchased from MK Nano, Canada. External diameters and length of MWCNTs are 10–20 nm and 10–30 μm, respectively. The purity was higher than 95%. H_2SO_4 (95%) and HNO_3 (65%) were purchased from Merck, (Germany) and used for functionalization of MWCNTs. A rib knitted 100% polyester fabric was used as matrix material; wale and course densities are 8 wale/cm, 18 course/cm respectively. The basis weight of polyester fabric is 293 g/m2.

2.2. Functionalization of MWCNTs

In order to produce MWCNTs with a strong acidic character and a large amount of oxygen-based surface groups, 1 g of MWCNTs were bath sonicated with the mixture of H_2SO_4/HNO_3 (3:1) at room temperature for 5 h. After the acid

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treatment, the functionalized MWNTs were filtered with a PTFE membrane filter (pore size 0.2 µm). The acid treated MWNTs were neutralized by thorough rinsing the nanotubes with deionized water 3 times, followed by drying at 100 °C under atmospheric conditions.

2.3. Dyeing of Fabric

The acid modified MWCNTs and neat MWCNTs were incorporated in polyester knitted fabric by the conventional dyeing process commonly used to dye polyester substrates. In this process, dyes were replaced with MWCNTs. MWCNTs were bath sonicated in water for 15 minutes to obtain well dispersed nanotubes. Afterwards, they were incorporated in polyester fabrics. In these experiments, auxiliary dyeing agents such as 1-2 drop acetic acid and 1 g/L sodium carbonate used as acidifier and buffer, respectively. These chemicals were introduced in the initial MWCNT aqueous solution, using the ratio of 20 ml of dispersion per gram of fabric. The weight percentage of MWCNTs added to the dispersion was determined according to the weight of the polyester fabric, and the concentration of MWCNTs and acid modified MWCNTs (A-MWCNT) was fixed at 1 wt% with reference to the weight of polyester fabric. The dyeing process was carried out at 130 °C for 30 min, and then cooled to the room temperature. The MWCNTand A-MWCNT dyed polyester fabrics were washed with distilled water and then left to dry in an oven at 100 °C.

2.4. Characterization

The morphology of the fabrics was investigated by scanning electron microscopy (SEM; JEOL Ltd, JSM-5910LV). Optical microscopy images of coated cotton fabrics were taken with Olympus SZ60 microscope. The colour measurements were performed by Datacolor SF600+, using SAV aperture and SI mode, and the colour differences were calculated in accordance with the CIELab system with D65/10° Observer values. The heat conduction apparatus was used to measure the thermal conductivity of the MWCNT coated cotton fabrics according to the TS 4512 Standard.

III. RESULTS AND DISCUSSION

3.1. Morphological Analyses

From Figure 1, it was observed that the fabric turned grey from white after dyeing with MWCNT and the fabric turned black from white after dyeing with A-MWCNT. Even with a low level of MWCNT loading (only 1 wt%), the color change was obvious.

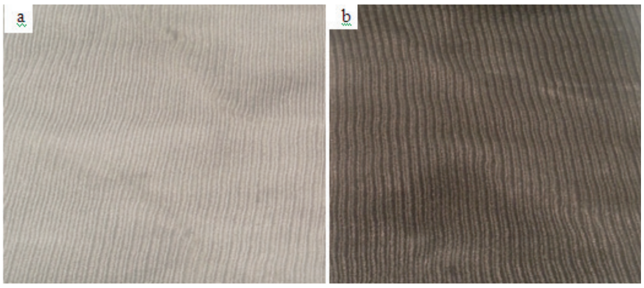

Figure 1. Digital images of (a) untreated MWCNT dyed polyester fabric, (b) A-MWCNT dyed polyester fabric

Figure 2 shows the optical microscopy iamges of polyester fabrics. From the figure, it can be seen that the addition of MWCNTs to the fabric by dyeing method was performed successfully. From the Fig. 2 (b), the agglomeration of MWCNTs within fibers can be seen clearly. Unlike the Fig. 2 (b), in Fig. 2 (c), there are not any visible agglomerations of A-MWCNTs within the fibers. Moreover, homogeneous dyed, uniform A-MWCNT distribution can be seen. To obtain the stable MWCNT dispersion in water, samples were bath sonicated before their addition to the dyeing process. The ultrasonic treatment was necessary to achieve a uniform distribution of MWCNTs throughout the polyester fabrics.

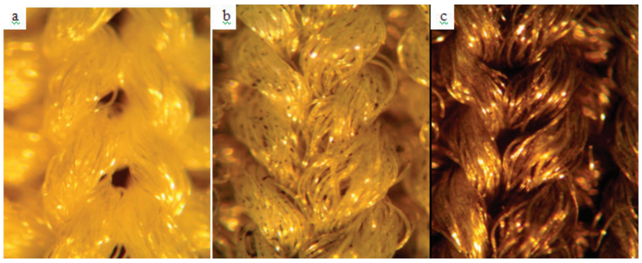

Figure 2. Optical microscopy images of (a) polyester fabric, (b) MWCNT dyed polyester fabric and (c) A-MWCNT dyed polyester fabric.

Figure 3 shows the SEM micrographs of the neat and MWCNT dyed fabrics. In the MWCNT dyed fabric (Fig. 3 c, d), a higher number of MWCNTs agglomeration can be observed on the fabric surface, which can also be explained by the lower dispersion of the untreated MWCNTs in water. From Fig. 3 (e, f), it is possible to observe that there were no aggregation of MWCNTs on polyester fabric surface. This may suggest that A-MWCNTs are entrapped in the pores of the polyester fibers during the dyeing process. This is probably due to the higher dispersion of A-MWCNT in water. It is known from the literature that the carboxylic acid modification shortens the MWCNTs and improves the dispersion stability of MWCNTs. Thus, to improve dyeing efficiency, smaller and better dispersed MWCNTs are required. Smaller MWCNTs can easily diffuse into the fibers. Therefore, the nanotube dispersed in the fibers makes the fabric darker than the untreated MWCNT dyed polyester fabric (Fig. 1).

3.2. Color Fastness Properties

Table 1 shows the L*, a*, b*, C*, h, Whiteness of the polyester fabrics. It was observed that the MWCNT dyed polyester fabric is more darker than the untreated polyester fabric, while the A-MWCNT dyed polyester fabric is the darkest (see L* values in Table 2). Also, from the whiteness values, it can be clearly seen that the A-MWCNT dyed fabric has the darkest color.

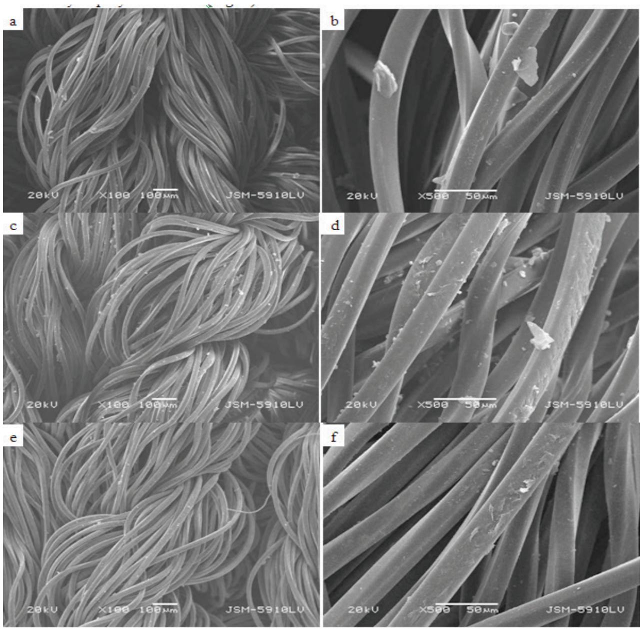

Figure 3. SEM images of polyester fabric (a, b), MWCNT-dyed polyester fabric (c, d), A-MWCNT-dyed polyester fabric (e, f)

Table 1. Effect of untreated and acid modifed MWCNTs on the CIE Lab values of polyester fabrics

Sample	L*	a*	b*	C*	h	Whiteness
100% PES	90.64	0.52	3.02	3.07	80.32	63.50
MWCNT/PES	59.37	-0.15	-0.89	0.90	260.16	33.4
A-MWCNT/PES	32.01	0.50	1.51	1.59	71.74	-8.3

Table 2. Effect of MWCNT modification on the color difference of the dyed polyester fabrics

		*ΔE
100% PES	**MWCNT/PES**	31.518
100% PES	**A-MWCNT/PES**	58.147

Table 3. Washing fastness, staining and dry and wet rubbing fastness of dyed polyester fabrics

SAMPLE	*WASHING FASTNESS*						*STAIN-ING*	*RUB-BING*	
	WOOL	*ACRYLIC*	*POLY-ESTER*	*POLY-AMIDE*	*COT-TON*	*ACE-TATE*		*DRY*	*WET*
MWCNT/PES	*4-5*	*4-5*	*4-5*	*4*	*4-5*	*4-5*	*4*	*1*	*2*
A-MWC-NT/PES	*4-5*	*4-5*	*4-5*	*4*	*4-5*	*4-5*	*3*	*1*	*2*

In Table 2 the color difference of MWCNT dyed polyester fabrics, based on the untreated polyester fabric is given. The color difference of untreated MWCNT dyed polyester fabric was small when compared to the A-MWCNT dyed polyester fabric. This difference between A-MWCNT and untreated MWCNT dyed fabrics indicates the effect of acid modification of MWCNTs on dyeing process.

Table 3 shows the washing fastness, staining, dry and wet rubbing fastness properties of dyed polyester fabric. From the table, it was observed that the washing fastness of dyed polyester fabrics is not dependent on the MWCNT modification. It was indicated that the washing fastness shows good values on generally used textile fabrics. It was also observed that the rubbing performance of both untreated and acid modified MWCNT dyed polyester fabrics is worse in dry condition than that of the wet condition.

3.3. Thermal Conductivity of MWCNT Dyed Fabrics

The thermal conductivity results were given in Table 4. From the results, it can be clearly seen that the thermal conductivity of MWCNT dyed polyester fabric showed an increase when compared with the untreated polyester fabric. There was a 12.6 % enhancement in thermal conductivity for the polyester fabric dyed with MWCNT. For the case of A-MWCNT dyed polyester fabric, the thermal conductivity decreased from 0.580 to 0.561 W/mK. However, the thermal conductivity of A-MWCNT dyed polyester fabric was showed ~9 % enhancement comparing to the untreated polyester fabric. Acid modification of MWNTs results in slight decrease of the thermal conductivity of dyed polyester fabric probably due to surface defects.

Table 4. Effect of MWCNT modification on the color difference of the dyed polyester fabrics

Sample	Thermal Conductivity (W/mK)
100% PES	0,515
MWCNT/PES	0,580
A-MWCNT/PES	0,561

IV. RESULTS AND DISCUSSION

In this study, polyester knitted fabrics were dyed with untreated and acid modified MWCNTs by traditional exhaustion method, used to dye polyester. In this process, dye material was replaced with MWCNTs to investigate the effect of acid modified MWCNTs on thermal conductivity and color fastness properties of polyester fabric. Digital images of polyester fabrics clearly showed that the A-MWCNT dyed fabric is darker than the untreated MWCNT dyed fabric. This means that the A-MWCNT dispersion in water was more stable than the untreated MWCNT. From the CIE Lab analysis results, it can be said that the A-MWCNT dyed fabric has the darkest color of all samples, which indicates that the acid modification of MWCNTs improve the dyeing performance of polyester fabric. From the results, the thermal conductivity of polyester fabric was increased 12.6 % with the untreated MWCNT and 9 % with the A-MWCNT when compared to the untreated polyester fabric.

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