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COMPARATIVE STUDY OF ELECTRICAL CONDUCTIVITY BETWEEN TREATED COTTON AND WOOL FABRICS VIA SINGLE-WALLED CARBON NANOTUBE AND CARBOXYLATED SINGLE -WALLED CARBON NANO TUBE

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ABSTRACT

Cotton and wool fabrics were treated with single wall and carboxylated single wall carbon nanotubes without using any additional auxiliaries by sonicator dyeing. The electrical conductivity of these two kind of natural fabrics was compared to introduce better electrical conductivity of treated fabric with single wall carbon nanotube. The morphology of the modified surfaces has been investigated using scanning electron microscopy (SEM). The surface morphology of treated samples was confirming the carbon nanotubes on the surface of cotton and wool samples. With increasing the time of treatment, it was revealed more amounts of CNT particles on the surface of the fabrics. Electrical resistance of treated samples was also assessed. According to the results, the electrical resistance of treated cotton and wool fabrics with carbon nanotubes reduced significantly. However, more amounts of CNT observed on the surface of cotton and wool fabrics in the case of using carboxylated single wall carbon nanotubes and is more useful to increase the conductivity. In the short time of treatment cotton fabrics were shown better electrical conductivity and in 45min CNT treatment wool fabrics had higher electrical conductivity. The total, electrical conductivity of the CNT treated cotton is better than wool in similar conditions. The washing fastness of treated samples was studied and almost good results were obtained.

KEY WORDS

Cotton; Wool; Carbon nanotube; Electrical conductivity; Coating.

1. INTRODUCTION

Cotton contains mainly cellulose of high molecular weight and the cellulose structure consists of long chains of α-D-glucose units joined by β-1, 4-glycosidic links. The anhydroglucopyranose units that are in a chair conformation together with β-1, 4-glycosidic links make cellulose to have a rigid structure unlike starch amylose that has α-glycosidic links between the 1, 4-anhydroglucose units. Apart from cellulose, the major component of cotton (more than 95%), other constituents in cotton include lignin and hemicelluloses such as xylose or mannose (Adebajo et al 2006). And wool is a natural protein in multi-cellular staple fiber

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form, composed of proteins and organic substances, the building blocks of proteins are about twenty aminoacids (Lewis et al 2000, Zahn et al 2005, Zahn et al 1997)

CNT is one of the most promising new materials in textile science. They are sub-microscopic, hollow fibers of pure carbon. To the naked eye, they look like black powder, but their true fiber nature becomes apparent under the electron microscope. Not only CNT fibers are immensely strong but they also possess two special characteristics: they have excellent electrical and heat conductivity (www.csiro.au, 2013).

Textile fibers are actually uniquely suited to transforming into electronics when combined with the seemingly ubiquitous carbon nanotube. Fibers made of cellulose, like cotton and wool, are highly porous and can absorb large amounts of water and other polar solvents. When single-walled carbon nanotubes are placed near polymers like these fibers, they have large van der Waals interactions with them, and can be treated with acid that helps them form hydrogen bonds with the fabric. This allows the carbon nanotubes to wrap around the fibers in very high volumes, as the porous fabric gives the nanotubes a large surface area to work with (Johnston C, 2010).

Single-walled nanotubes are an important variety of carbon nanotube because they exhibit electric properties that are not shared by the multi-walled carbon nanotube (MWNT) variants. In particular, their band gap can vary from zero to about 2 eV and their electrical conductivity can show metallic or semiconducting behavior, whereas MWNTs are zero-gap metals. Single-walled nanotubes are the most likely candidate for miniaturizing electronics beyond the micro electromechanical scale currently used in electronics (Wang et al, 2009, Dekker et al, 1999 & Martel et al, 2001). Compared to other nanoscale materials, single-walled carbon nanotubes (SWCNT), possess particularly outstanding physical and chemical properties. SWCNTs are remarkably stiff and strong, conduct electricity, and are projected to conduct heat even better than diamond, which suggests their eventual use in nanoelectronics. Steady progress has been made recently in developing SWCNT nanodevices and nanocircuits (Bachtold et al, 2001 & Derycke et al 2001).A lot of methods were applied to coat CNT on the textile fibers but in this project focus on the basic coating method for applying CNT on the cotton and wool fabrics to compare the electrical conductivity better (Kang et al, 2011, Liu et al, 2008 & Hin et al,2013).

The main purpose of the research was producing conductive wool and cotton fabric applying single walled carbon nanotube and carboxylated single walled carbon nanotube and comparing the electrical conductivity between these two treated natural fibers without using any auxiliaries. The surface morphology of them was investigated by SEM and washing fastness of the samples was studied.

2. MATERIALS AND METHODS

2.1. Materials

A desized, scoured, and bleached plain weave 100% cotton fabric with 36wraps/cm and 26wefts/cm was supplied by Momtaz Fabrics Company (Tehran, Iran).

The wool fabric used in this work was produced by Iran Merinos Co., Iran. The fabrics were woven by 20 denier warp and weft yarns composed of 36 filaments per cross section. For sample preparation, the size residues and contaminations on the fabrics were removed by conventional scouring processes, and the fabrics were washed in 0.5 g/l sodium carbonate and 0.5 g/l anionic detergent solution (dilution ratio to water = 1:10) at 80 °C for 80 min and then washing was conducted twice with distilled water at 80 °C for 20 min and once at ambient temperature for 10 min.

Single-walled carbon nanotube with above 90% purity and 1-2 nm Od and 30 µm length and above 380 m^2/g SSA(Special Surface Area)and carboxylated single-walled carbon nanotube with above 90% purity and 1-2 nm Od and 30 µm length and above 380 m^2/g SSA and –COOH groups contents 2.73% from Neunano co. were used. Sodium dodecyl sulfate (SDS) as a dispersing agent (Sigma Chemical Company) was also used.

2.2. loading procedure of SWCNT & CSWCNT on cotton and wool fabrics

Stabilization of SWCNT& CSWCNT on cotton and wool were produced by three-step method. First, colloidal dispersions were prepared by mixing 0.6% SWCNT, 5 gr/l sodium dodecyl sulfate (SDS) and deionized water (molar ratio of 1:40). The colloidal dispersions were then homogenized by means of an ultra sonic machine at 40°C for 2h to improve the dispersion. Then the fabrics were immersed in prepared bath. The process temperature was initially set at 40 °C and then gradually raised to the 60°C for three different times(15, 30 and 45 min.). The samples were thoroughly rinsed with water, squeezed and dried at room temperature. Table 1 shows the identification of the samples. This method of CNT treatment was obtained from a lot of experiments and the better condition of the treatment was selected.

Table1: Identification of the samples

Sample cotton	Sample wool	SWCNT	CSWCNT	Time of treatment (min)
1	8	-	-	-
2	9	*		15
3	10	*		30
4	11	*		45
5	12		*	15
6	13		*	30
7	14		*	45

SWCNT: Single-walled carbon nano tube; CSWCNT: Carboxylated single-walled carbon nano tube

2.3. Scanning electron microscopy

The surface of the fibers was investigated using a Scanning Electron Microscope (SEM, Philips, XL30, and Made in Netherland). The surface of each sample was first coated with a thin layer of gold (10 nm) by Physical Vapor Deposition using a sputter coater (SCDOOS, BAL-TEC, Swiss made).

2.4. electrical resistivity measurement

The electrical resistance measurements were performed on all samples after conditioning the samples in a standard atmosphere and temperature (20˚C). The resistance was measured ten times on each side of the samples and the average values were taken. The AATC 76 – 1995 was used to measure the resistance of the samples and the surface resistivity of the fabric was calculated as follows.

$$R = Rs\ (I/W) \qquad (1)$$

Where R is the resistance in ohms, Rs is the sheet resistance or surface resistivity in ohms/square, I is the distance between the electrodes in cm, W the width of each electrode in cm.

2.5. Determination of washing fastness

The wash-fastness properties of the samples were measured according to ISO 105-C01. The color hue changes of the fabric and the degree of staining on the adjacent fabrics were measured after drying.

3. RESULTS AND DISCUSSION

3.1. Electrical resistivity measurement

Electrical conductivity is the phenomenon that describes the transport of electric charge through materials (Devaux et al., 2007). A new way of producing electrically conducting textiles is treatments with carbon nanotubes. The electrical conductivity of the CNT treated cotton and wool fabrics were measured by using electrical resistance. The test was done by two probe resistivity measurement in normal environment at 65%RH. The electrical resistance values were reported in Table 2 & 3. As it was expected by increasing the time of treatment, the electrical resistance decreases, so the electrical conductivity increases. In these test the result of CNT treatment on wool and cotton fabrics were investigated. As they were reported in table 2 & 3, in the samples that treated with SWCNT (2,3,9&10), the cotton samples have lower electrical resistivity than wool samples, thus in the equal condition SWCNT treated cotton fabrics were shown better electrical conductivity than SWCNT treated wool fabrics except in the samples that treated in 45min. In these samples (4&11) the results were inversed and wool sample was shown better electrical conductivity. So it can concluded that the treatment in the short period of time cotton samples have better electrical conductivity than wool samples and in longer time period of treatment wool sample was shown better result.

In the samples that treated with CSWCNT the results were shown lower electrical resistivity than the treated samples with SWCNT, and also the results were similar to the SWCNT treated samples. Thus it can concluded that the effect of CSWCNT on increasing of cotton and wool fabrics electrical conductivity is more than SWCNT and the effect in short period time of treatment on cotton fabrics was shown better results than wool fabrics. Also in 45min treatment of CNT, The wool fabrics have better electrical conductivity than the cotton fabrics.

According to the results of tables 2&3, the electrical conductivity of treated cotton with CNT become better than treated wool with CNT in average at the same condition.

Table2: Surface resistivity of cotton fabrics with regarding the time of carbon nanotube and carboxylated carbon nanotube treatments

cotton Sample	Time (min)	Surface resistivity of cotton fabrics (kΩ/sq)
1	0	very
2	15	60
3	30	38
4	45	27
5	15	53
6	30	23
7	45	9

Table3: Surface resistivity of wool fabrics with regarding the time of carbon nanotube and carboxylated carbon nanotube treatments

wool Sample	Time (min)	Surface resistivity of wool fabrics (kΩ/sq)
8	0	Very
9	15	300
10	30	48
11	45	10
12	15	185
13	30	32
14	45	5

3.2. Scanning electron microscopy

SEM examination also revealed the presence of CNT particles on the fiber surface and its uniformity. Scanning electron micrographs of cotton and wool fabrics applying with SWCNT and CSWCNT, with the exhaustion time varied from 15 to 45 minutes have been shown in Figures 1 & 2.

Scanning electron micrographs of cotton fabrics applying with SWCNT and CSWCNT, with the exhaustion time varied from 15 to 45 minutes have been shown in Figure 1. SEM examination also revealed the presence of carbon nanotubes on the fiber surface.

Figure 1 shows the SEM morphologies of cotton treated with single wall-carbon nanotube (SWCNT) carboxylated single wall carbon nanotube (CSWCNT) grown onto cotton fabric. There are some amounts of CNT particles observed on the surface of the cotton fiber exposed for 15 min. As the exhaustion time is increased to 30 min, the presence of CNT particles on the fiber surface is observed more. Even better and more uniform coverage of cotton fiber surface can be seen from micrograph shown in Figure 1 (SWCNT 45 min) where the exhaustion time has been increased to 45 min. It was observed that though the amount of carbon nanotubes on the substrate increased with increasing the exhaustion time. And also shows the micrographs of CSWCNT on cotton fabric with the exhaustion time of 15, 30 and 45 minutes. Much growth of CNT particles observed on the surface of cotton fabric in the case of using CSWCNT. Figure 1 (CSWCNT 45 min cotton-f) shows the case where the growth time is further increased to 45 min.

Based on the observations made above it can be inferred that, expectedly, the amounts of CNT particles on the surface of a cotton fiber can be increased with exhaustion time in both cases (SWCNT and CSWCNT). More amounts of CNT particles observed on the surface of cotton fabric in the case of using CSWCNT.

Figure 2(a), Shows the SEM morphology of untreated wool fabric. Figure 2(b, c and d) shows the SEM morphologies of wool treated with SWCNT and Figure 2 (e, f and g) related to CSWCNT grown onto wool fabric. There are some amounts of CNT particles observed on the surface of the wool fiber exposed for15 min (Figure 2(b)). As the exhaustion time is increased to 30 min, the CNT presence on the fiber surface is observed more (Figure 2(c)). Even better and more uniform coverage of wool fiber surface can be seen from micrograph shown in Figure 2(d), where the exhaustion time has been increased to 45 min. It was observed that though the amount of CNT on the substrate increased with increasing the exhaustion time. Figure 2(e, f and g) shows the micrographs of CSWCNT on wool fabric with the exhaustion time of 15, 30 and 45 minutes. Much growth of CNT particles observed on the surface of wool fabric in the case of using CSWCNT. Figure 2 (g) shows the case where the growth time is further increased to 45 min.

Based on the observations made above it can be inferred that, expectedly, the CNT amounts on the surface of a wool fiber can be increased with exhaustion time in both cases (SWCNT and CSWCNT).

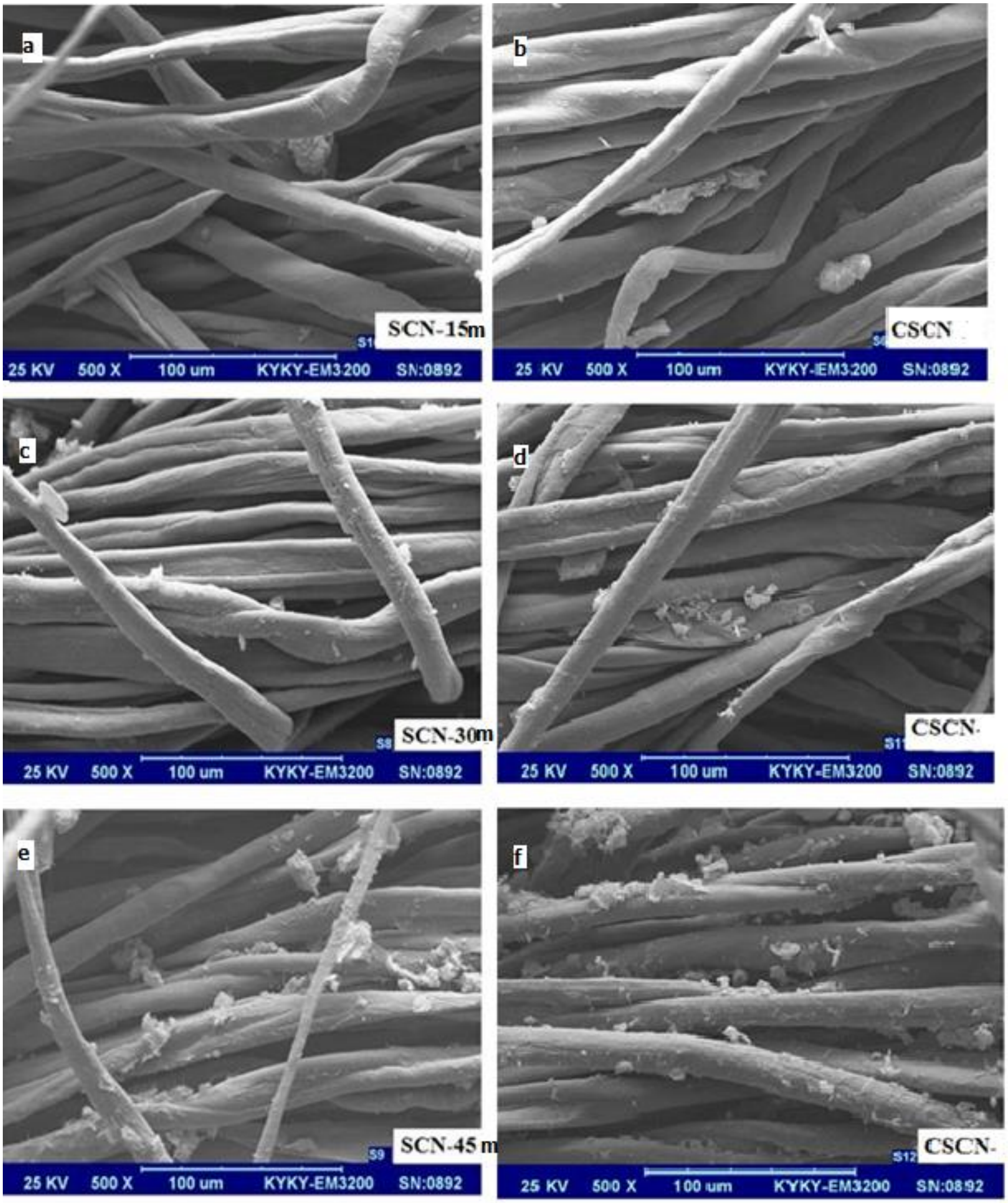

Figure1: SEM pictures of the cotton samples, SWCNT-15min(a), CSWCNT-15min(b), SWCNT-30 min(c), CSWCNT-30min(d), SWCNT-45min(e), CSWCNT-45min(f)

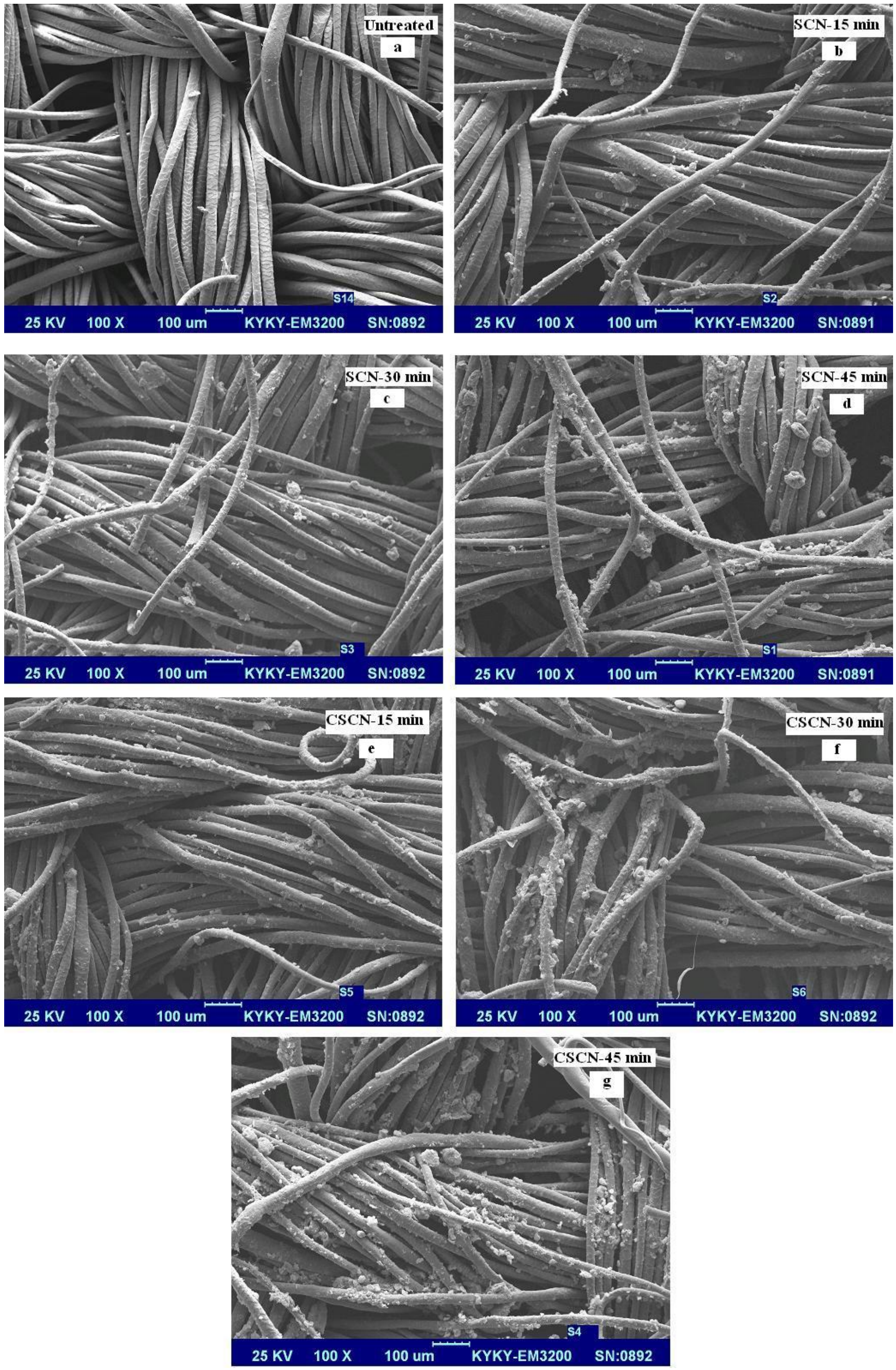

Figure2: SEM pictures of the wool samples, untreated wool (a), SWCNT-15 min (b), SWCNT-30min(c), SWCNT-45min (d), CSWCNT-15min (e), CSWCNT-30min (f), CSWCNT-45min (g)

3.3. Colour fastness

The results were obtained from the wash fastness tests are given in Table 4. They were shown that the wash fastness of wool and cotton fabrics treated with CSWCNT were better than SWCNT but in all samples the results were near each other and almost good. In fact the mechanism of absorption is adsorption and the Van Der Waals interaction help to attach the CNT particles on to the fabrics. The cotton and wool fibers are highly porous and can absorb large amounts of water and other polar solvents. When single-walled carbon nanotubes are placed near polymers like these fibers, they have large van der Waals interactions with them. This allows the carbon nanotubes to coat fabric in very high surface, as the porous fabric gives the nanotubes a large surface area to work with (Johnston C*,* 2010).

Table4: Wash fastness of the samples

Cotton Sample	Washing fastness	Wool Sample	Washing fastness
1	5	8	5
2	4	9	4-5
3	3-4	10	4
4	3-4	11	3-4
5	4	12	4-5
6	4	13	4-5
7	3-4	14	4

4. CONCLUSION

In this study cotton and wool fabrics were treated with Single-walled carbon nanotubes(SWCNT) and Carboxylated single-walled carbon nanotubes(CSWCNT) in the ultrasonic bath. CNT particles were grown successfully on cotton and wool fabrics and the tubes were found to anchor these substrates quite well.

These results were seen on the SEM figures. The SEM micrographs were revealed the amount and uniformity of placing the CNT particles on the fabrics. As it can be concluded from the figures, the more surface coated with CNT particles increased by more duration of time treatment. This treatment was found the effect of SWCNT and CSWCNT on the cotton and wool fabrics to be electrical conductive. The results were shown that in both fabrics the effect of CSWCNT on electrical conductivity was higher than SWCNT. Also in comparison between cotton and wool fabrics treated with CNT in similar condition, cotton fabrics had better electrical conductivity in the short time of treatment, and the effect was become inversing in the long time of treatment. According to the results, it can be concluded that the electrical conductivity of CNT treated cotton fabrics become better in the same condition of treatment.

The washing fastness of the treated fabrics was shown almost good results. It should be mentioned that because of focusing on the effect of only CNT particles coating on the fabrics, no auxiliaries were used. Treatment of fibers with CNT leads to the production of a wide variety of conductive textiles with different electrical properties. The wear performances of wool and cotton fabrics apply with CNT open the potentiality of producing composite materials for conventional and innovative applications, ranging from conventional apparel and sportswear to protective clothing (for static dissipation, anti-spark, electromagnetic interference shielding), heating equipment, automotive textiles, building covering, geo-textiles, biomedical textiles, etc.

It should be suggested for obtaining better wash fastness and absorption, applying with some auxiliaries can be helped and it will be done in next research.

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