

# Investigation of the Effects of Graphene Oxide Nanoparticles and Multi-Wall Carbon Nanotubes on Conductivity and Surface Morphology of Polyester-Viscose Fabric

Hamid Akbarpour, Abousaeed Rashidi, Mohammad Mirjalili\*, and Ali Nazari

**Abstract**-In this work, the specimen of the fabrics (polyester/viscose blend) was first placed under microwave irradiation at different times, and then the optimum treatment of treated fabrics (8 min) was selected for investigating physical properties and surface morphology. Graphene oxide (GO) and carbon nanotube (CNT) with different percentages were measured using dispersing agent, washing performance and wash stability, and physical properties of the fabric. Surface morphology of the specimens was also photographed by SEM electron microscopy. Finally, the conductivity properties of the specimens were measured according to AATCC 2005-76 standards, and analyzed by K/S, R%, and Lab specimens and the changes were obtained from the experiments using reflection spectrophotometer analysis. The optimum electrical conductivity was found for viscose polyester fabric containing 9% nanoparticles, and more interestingly, the electrical resistivity for the values of 7 and 5% of CNT were approximately the same as those of 9 and 7% of GO.

**Keywords:** polyester/viscose blend fabric, multi-wall carbon nanotubes, graphene oxide nanoparticles, conductivity properties and reflective spectrophotometer, statistical analysis of the central composite design (CCD)

## I. INTRODUCTION

Recent developments in the textile industry have led to significant improvements in the performance of non-woven fabrics. There exists the use of new materials with special characteristics, development of new structures and a uniform process to increase the ability to maintain information basically based on electrical conductivity [1]. The existence of multi-functional properties on textiles,

via a similar process, is also interesting and useful in terms of technology and economics [2]. Conductive fabrics can be used to produce smart textiles with a set of different sensors or electronic designs [3,4]. Nanoparticles increase the physical and biological textile properties in a wide range [5,6]. There are different methods for producing conductive textiles. For example, the insertion of metal fibers into fabrics is reported. However, stretching and bending in the fabric cause fracture of the fibers [7]. Other methods such as the use of carbon derivatives [8] or polymeric film syntheses [9-11] were used on the fabric. Various conductive fabrics exist in the coating of conductive metals on the surface of the fabric, such as carbonate and metal compounds, which have an electrical conductivity with optical properties, high elasticity and elasticity. They are used in special applications, including electromagnetic interference protection, microwave absorption and heat generation [12]. Fabric coating with carbon nanotubes allows the production of widespread electronic textiles for many applications, such as high-performance sportswear, coverable areas, and embedded health monitoring devices that are not feasible in conventional electronic technology (due to light weight and flexibility of the fabric) [13,14]. Carbon nanoparticles were discovered in 1991, and their applications have been developed due to their remarkable physical and chemical properties. High flexibility and complete return function, high conductivity and high electrical semi conductivity are considered as their physical and mechanical properties, and based on the counting of the walls, they are divided into two types: single-wall and multi-wall [15]. In a study by Montazer *et al.* [15], it was found that the electrical resistance of wool fabric was reduced relative to the use of carbon nanotubes by smudging. The use of sodium hypoxylbutyric acid and citric acid helps the absorption of nano-tubes on the surface of the wool. The researchers also found that single-wall carbon nanotubes compared to the multi-wall counterpart, is more effective in lowering the electrical resistance of woolen fabrics. In another study done by Ebrahimbeiki Chimeh *et al.* [16]

H. Akbarpour, M. Mirjalili, and A. Nazari  
Department of Textile Engineering, Yazd Branch, Islamic Azad University, Yazd, Iran.

A. Rashidi  
Department of Textile Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran.

Correspondence should be addressed to M. Mirjalili  
e-mail: dr.mirjalili@iauyazd.ac.ir

on the properties of optical activity and conductivity of polyethylene terephthalate fabrics, using carbon nanotubes and titanium dioxide, it was discovered that the electrical conductivity of polyethylene terephthalate (PET), due to the presence of carbon black (CBS) on the surface of the PET fabric, increases slightly. In this study, it was also observed that the distribution of nanoparticles of titanium dioxide and nano-carbon black with the use of sodium hypoxybutyric acid and citric acid works and improves the conductivity of the PET fabric. On the other hand, the discovery of graphene and its derivatives opened up a new branch in physics and materials science. The unique electrical, mechanical, optical or thermal properties of graphene show a wide range of applications [17]. In a scientific study on the surface of acrylic yarn with graphene oxide by conventional dyeing and reduction of sodium hydrosulfite, the electrical resistance range of  $10^2$  to  $10^{10}$  (cm/ $\Omega$ ) was confirmed by the amount of graphene in the conduction layer [18]. Molina *et al.* [19] through chemical reduction of graphene oxide on polyester fabric, observed the conductivity on its surface. In addition, Shateri Khalilabadi and Yazdanshenas [20] processed cotton fabric with graphene/polyethylsiloxane and reported a new method for making conductive and super-hydrophilic cotton fabrics.

In another study done by Moazami *et al.* [21], the electrical resistance of the coated samples decreased from  $2.3 \times 10^6$   $\Omega$ /square to  $0.002 \times 10^6$   $\Omega$ /square by increasing the amount of GO from 0.05 w/v% to 1 w/v% in the impregnating bath.

## II. EXPERIMENTAL AND METHODS

### A. Materials

Viscose polyester fabric, which is used to manufacture military clothing, with a ratio of 65% polyester and 35% viscose, a count of 32/2 (Ne) warp and weft and with a repeat of 2/1z was used. Multi-wall carbon nanotube was purchased from Sigma Aldrich. Graphene nanoparticles 7% were purchased from Islamic Azad University of Yazd. Acetic acid with a pH of 5/5 from Merck (Germany), the dispersant material Ekalin F from Sandoz (Holzkirchen, Germany), and benzoic acid as a carrier from Sigma Aldrich were used in this study.

### B. Methods

#### B.1. Microwave Test

LG Electronics CG-2872BC 230 V, 50 Hz MAX.2400 W manufactured by LG Electronics Inc. was utilized to absorb more nanoparticles and create pores on the surface of the fabric. Samples (viscose polyester fabrics) were placed in a household microwave oven to absorb more nanoparticles

and create pores on the surface for 4, 8, and 12 min (back and front of the fabric) at 900 W under microwave radiation. SEM images of textiles show that by increasing the duration to 8 min, the surface becomes porous and creates a sponge-like condition, which, by increasing the duration to 12 min causes the destruction of the fibers (Fig. 1).

#### B.2. BET Test

The BET surface area was evaluated using the nitrogen adsorption (Micromeritics Gemini III 2375, USA). This test was also carried out for radiation to prove the previous stage.

#### B.3. Bending Lengths and Tensile Strength Measurement

The bending lengths of the fabrics in the warp and weft directions were determined using a Drapometer M003B (SDL), according to ASTM D1388-96. The tensile strength of the fabrics was evaluated using an Instron TE-500 from Farayab with a gauge of 20 cm and across-head speed of 25 cm/min, after conditioning the specimen for 24 h and 65 per cent relative humidity and 20 °C (ASTM D2256).

#### B.4. Determination of Moisture Regain

Moisture regain was calculated according to ASTM method 2654-76 using the following equation:

$$\text{Moisture regain \%} = \frac{(W_1 - W_2)}{W_2} \times 100 \quad (1)$$

Where,  $W_1$  is the weight (g) of the sample after saturation at the standard humidity, and  $W_2$  is the weight (g) of the sample dried to the constant weight.

#### B.5. Colorimetry Analysis

CIELAB color co-ordinates ( $L^*$ ,  $a^*$ , and  $b^*$ ) of samples were determined using a Gretagmacbeth COLOREYE 7000A spectrophotometer integrated with a computer. CIELAB color co-ordinates ( $L^*$ ,  $a^*$ , and  $b^*$ ) were calculated from the reflectance data for 10° observer and illuminant D65.

#### B.6. SEM

A scanning electron microscope (LEO1455VP), made in England, was used in order to investigate the surface morphology of the fiber.

#### B.7. Treatment with Nanoparticles

Mixtures containing various amounts of nanoparticles (3, 5, 7, and 9% owf), 2% owf acetic acid (pH 5.5), 1% owf carrier, and 10% owf dispersing agent were

prepared. Then, the fabrics were added to the mixtures and placed in a dyeing machine. The temperature, time and pressure were set as 100 °C, 90 min and 7 bar, respectively. The liquor to good ratio (L.G.) was 50:1. After the process, the fabrics were washed in a batch containing 10% owf NaOH and 10% owf Na<sub>2</sub>S<sub>2</sub>O<sub>4</sub> at 70 °C for 30 min.

Ekalin F from Sandoz Company (Holzkirchen, Germany) and benzoic acid from Sigma Aldrich were used as the dispersing agent and carrier, respectively.

### B.8. Washing Procedure

The fabrics were washed in a batch containing 3% owf NaOH and 5% owf non-ionic detergent at 60 °C for 30 min. The washing was continued for 5 cycles.

### B.9. Conductivity Test

A. Room-temperature conductivity of samples was measured according to a standard four-probe method, using a MCP-HT450 conductivity meter (Dia-instruments Co., Ltd.).

B. Electrical conductivity of the dried fabrics composite was determined at ambient room temperature (25 °C) using a Digital Multimeter. Electrical measurements were recorded by the means of an electrical circuit made by a Hewlett Packard 6634B System DC Power Supply and a digital Hewlett Packard 34401A Multimeter.

C. The electrochemical tests were conducted on the CHI430a electrochemical workstation (USA) with a conventional three-electrode system.

### B.10. Design of Experiment

The central composite design (CCD) was used for experimental plan with two variables [29], including irradiation time and percent of nanoparticles. The ranges of these variables were calculated 4.8–12 min for irradiation time and 3.1–8.9 % for percent of nanoparticles using trial version of Design Expert 8.0.1.0 software from Stat-Ease, Inc. (USA).

The details of the design of polyester/viscose fabric samples with irradiation time and percent of nanoparticles are presented in Tables VII and VIII (Run 1–8). Also the influence of the variables on the results Y<sub>1</sub> (electrical

resistivity) and Y<sub>2</sub> (surface resistance) was adjusted using the following third-order polynomial function:

$$Y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum c_i X_i^2 \quad i \geq j \quad (2)$$

$i, j = 1, 2, 3$

In this equation, b<sub>0</sub> is an independent term according to the mean value of the experimental plan, b<sub>i</sub> are the regression coefficients that explain the influence of the variables in their linear form, b<sub>ij</sub> are the regression coefficients of the interaction terms between variables, and c<sub>i</sub> are the coefficients of quadratic form of variables.

## III. RESULTS AND DISCUSSION

Before the samples were treated with nanoparticles, first they were irradiated with microwave energy [22] for different durations. The optimal mode for treating the surface of the fabric with nanoparticles was selected, which was found to be 8 min irradiation duration (based on the results of SEM images (Fig. 1)). As shown in Table I, it is clear that BET values increased with increasing the radiation time. This increase is for the 8 min sample. Increasing the time to 12 min resulted in a decrease in the surface area, indicating the destruction of the fibers and the process of getting stuck together. On the other hand, according to the values given in Table IV, it is clear that the strength of the fabrics is diminished by irradiation. The magnitude of the increase in length and the degree of rupture after irradiation increased until 8 min of irradiation and after that decreased. The reduction of strength can be due to the formation of pores on the surface of the fibers. Creation of pores also increases the absorption of moisture in the sample. This increase in recycled moisture causes a plasticization phenomenon to occur, and increases the length of the rupture.

SEM images of fabric containing nanoparticles (Figs. 2 and 3) show that for both nanotubes CNT and GO, increasing the amount of nanoparticles to 7 and 9% by weight causes the appearance of some nanoparticles on the fiber surface, the presence of which is a lot more at the 9%. In the less than 7% amounts used, the nanoparticles are predominantly contained within the fiber. Particles on the surface usually decrease in their final washings (Figs. 2 and 3). The results of strength

TABLE I  
BET TEST VALUES FOR RAW AND MICROWAVE OPERATED SAMPLES

| Time of radiation (min) | 0      | 4      | 8      | 12     |
|-------------------------|--------|--------|--------|--------|
| BET                     | 4.11   | 4.28   | 4.86   | 2.89   |
| V <sub>m</sub>          | 0.506  | 0.521  | 0.582  | 0.355  |
| C                       | 21.526 | 35.365 | 29.748 | 42.752 |

TABLE II  
RESULTS OF STRENGTH MEASUREMENT AND MOISTURE REGAIN TEST OF MICROWAVE SPECIMENS

| Time of radiation (min)  | 0     | 4     | 8     | 12    |
|--------------------------|-------|-------|-------|-------|
| Force-at-break (kg.f)    | 22.13 | 20.32 | 16.11 | 11.54 |
| Elongation-at-break (%)  | 7.78  | 7.97  | 8.75  | 7.83  |
| Bending length-warp (cm) | 5.84  | 5.18  | 4.88  | 5.36  |
| Bending length-weft (cm) | 5.24  | 5.02  | 4.57  | 5.17  |
| Moisture regain (%)      | 7.21  | 7.85  | 8.23  | 7.05  |

TABLE III  
RESULTS OF STRENGTH MEASUREMENT OF MICROWAVE SPECIMENS (8 MIN) WITH DIFFERENT AMOUNTS OF NANOPARTICLES

| Nanoparticles value (%)  | 3     |       | 5     |       | 7     |       | 9     |       |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Type of nanoparticles    | CNT   | GO    | CNT   | GO    | CNT   | GO    | CNT   | GO    |
| Force-at-break (kg.f)    | 22.63 | 22.21 | 23.15 | 22.41 | 24.28 | 22.87 | 12.02 | 11.32 |
| Elongation-at-break (%)  | 7.12  | 7.39  | 6.98  | 7.09  | 6.56  | 6.77  | 7.67  | 7.95  |
| Bending length-warp (cm) | 6.11  | 6.01  | 6.58  | 6.13  | 6.01  | 5.85  | 5.12  | 5.11  |
| Bending length-weft (cm) | 5.98  | 5.86  | 6.25  | 5.99  | 5.48  | 5.51  | 4.89  | 4.98  |

TABLE IV  
MEASUREMENT OF WASH STABILITY OF THE FABRICS TREATED WITH NANOPARTICLES

| Nanoparticles value (%)  | 3    |      | 5    |      | 7    |      | 9   |     |
|--|------|------|------|------|------|------|-----|-----|
| Type of nanoparticles  | CNT  | GO   | CNT  | GO   | CNT  | GO   | CNT | GO  |
| Increase of initial weight (%)   | 2.88 | 2.81 | 4.29 | 4.21 | 6.12 | 6.02 | 7.2 | 7.1 |
| Increase of weight after washing (%) /<br>1 cycle-relative to raw fabric | 2.79 | 2.79 | 4.1  | 3.98 | 5.95 | 5.89 | 5.6 | 5.4 |
| Increase of weight after washing (%) /<br>5 cycle-relative to raw fabric | 2.61 | 2.57 | 3.95 | 3.84 | 5.88 | 5.81 | 3.7 | 3.2 |

measurements also show that the nanoparticles used at the 7% scale are at best (Table III).

Table IV shows the wash stability values of the fabrics treated with nanoparticles. The results of the wash stability indicate an increase in CNT uptake compared to GO in the fabric.

Moreover, the conductivity test was carried out in three ways. At first, the electrical resistance of the fabric was

measured using a digital multimeter, the results of which are given in Table V. In another way, the conductivity testing of nanoparticles treated with a digital multimeter and a DC voltage source under the AATCC 1995-76 method at 25 °C was carried out. In this work, two copper electrodes with a size of (20×20 mm<sup>2</sup>) were separated at a distance of 20 mm, and then, a 1 kg weight was placed on the fabric sample (30×60 mm<sup>2</sup>). Afterwards, the surface resistance ( $R_s$ ) was

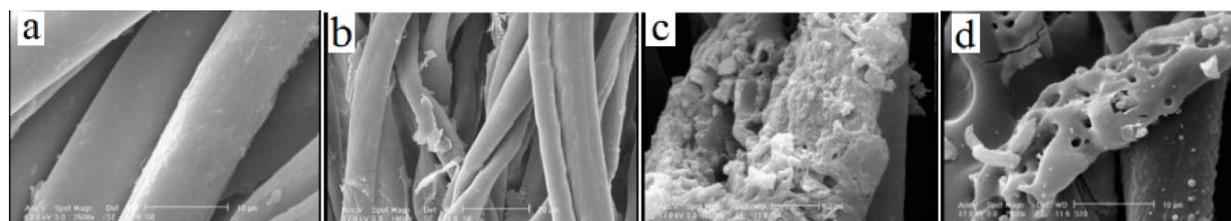


Fig. 1. SEM images of the P/V blend fabric sample under microwave treatments: (a) raw, (b) treated for 4 min, (c) treated for 8 min, and (d) treated for 12 min.

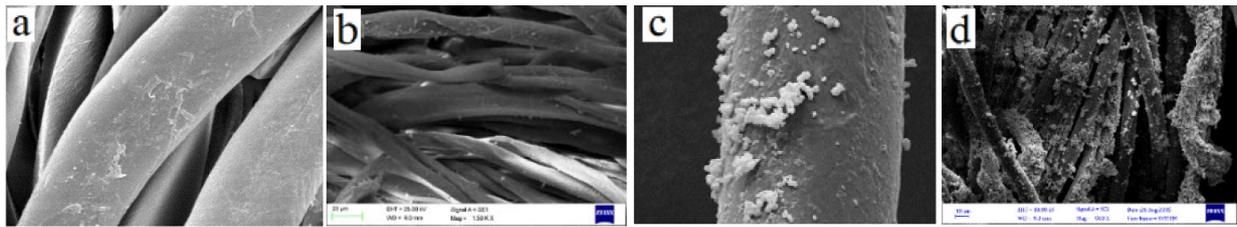


Fig. 2. SEM images of the P/V blend fabric sample under 8 min microwave treatments: (a) CNT 3%, (b) CNT 5%, (c) CNT 7%, and (d) CNT 9%.

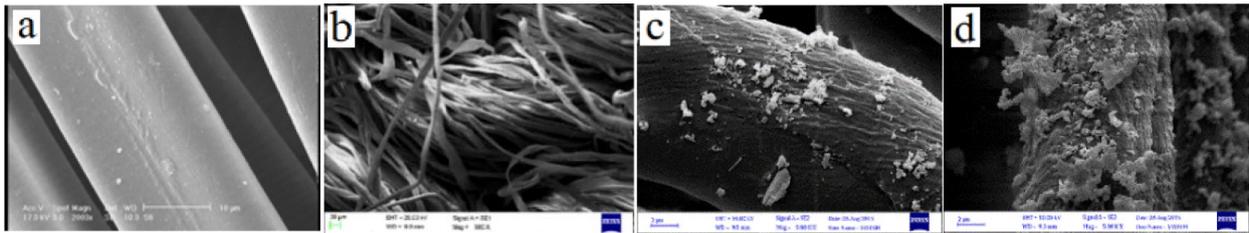


Fig. 3. SEM images of the P/V blend fabric sample under 8 min microwave treatments: (a) GO 3%, (b) GO 5%, (c) GO 7%, and (d) GO 9%.

estimated by Eq. (2):

$$R_s (\Omega / \text{wquare}) = \frac{W}{D} R \tag{3}$$

Where, R is the resistance measured by the multimeter, and W and D are the width of the sample and the distance between the two electrodes, respectively.

As shown in Table V, the best electrical resistance is observed in the amounts of 9% consumable nanoparticles, however, a similarity is observed between 7 and 9% graphene oxide nanoparticles and 5 and 7% nano-particles of carbon nanotubes. Moreover, the resulted quantities indicate an increase in surface resistance and upward trend with increasing carbon nanoparticles, while in grapheme oxide, there is an increase in surface resistance up to 7% nanoparticles, and then the surface resistance decreases. On the other hand, the results show the superiority of surface strength and carbon nanotubes compared to graphene oxide. In the third step, the conductivity of fabric treated with nanoparticles was measured using a CHI430A electrochemical workstation (USA), which has a three-electrode system including a working electrode (modified

GCE), auxiliary electrode (platinum wire) and a reference electrode (Ag/AgCl). All experiments were conducted at room temperature. Cyclic voltammetry (CV) was used for characterizing the electrode resistance performance. 5 mM  $[\text{Fe}(\text{CN})_6]^{3-4-}$  was used as probe, and 0.1 M KCl was used as supporting electrolyte. The results of the test are shown in Figs. 4 and 5 of the conductivity (flow-to-voltage) of the microwave treated samples, for a duration of 8 min, for different voltammetric nanoparticles.

Also, as shown in Table VI, the K/S values of the samples increase with increasing percentage of nanoparticles and decrease the R% values. However, it can be observed that there are similarities between the numerical values of K/S and R% and samples treated with 3% nanoparticles for MWCNT and 5% nanoparticles for GO, respectively, which is the equivalent of the coefficient equal to the propagation of samples. On the other hand, with respect to the values in the Table, the values of  $L^*$ , C, and  $h^0$  are decreased with increasing the nanoparticle contents, and the values of  $a^*$  and  $b^*$  are decreased with increasing the amount of nanoparticles for MWCNT and increased for GO and then decreased. This phenomenon indicates that the carbon nanoparticles have

TABLE V  
ELECTRICAL RESISTIVITY AND SURFACE RESISTANCE OF A SAMPLE OF FABRICS UNDER 8 MIN OF MICROWAVE IRRADIATION TREATED WITH MWCNT AND GO NANOPARTICLES

| Nanoparticles value (%) | 3      |        | 5      |         | 7      |        | 9      |        |
|-------------------------|--------|--------|--------|---------|--------|--------|--------|--------|
| Type of nanoparticles   | CNT    | GO     | CNT    | GO      | CNT    | GO     | CNT    | GO     |
| R (Ω)                   | 131251 | 20045  | 10368  | 26719   | 5369   | 10360  | 1610   | 5714   |
| σ (S/cm)                | 0.0023 | 0.0016 | 0.0247 | 0.00135 | 0.0651 | 0.0198 | 0.2335 | 0.0125 |

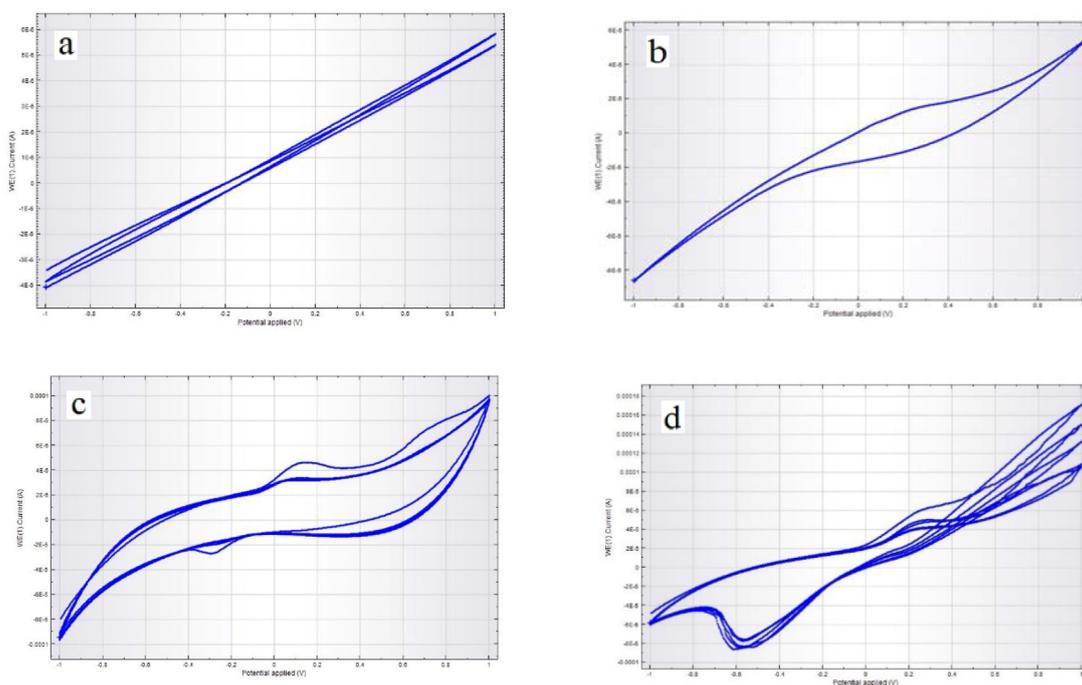


Fig. 4. Flow rate diagram to the voltages of the samples exposed to microwave radiation for 8 min: (a) 3% GO, (b) 5% GO, (c) 7% GO, and (d) 9% GO.

higher quality and uniformity, which proves the optimal conductivity according to the previous experiments.

*A. Statistical Analysis*

Optimization of nanoparticles utilization displays a basic

role in improving the performance of textile fabrics [23]. Unlike conventional optimization, statistical optimization methods can be considered as well as the interactions of variables in generating process responses. RSM is a powerful statistical technique of testing multiple variables

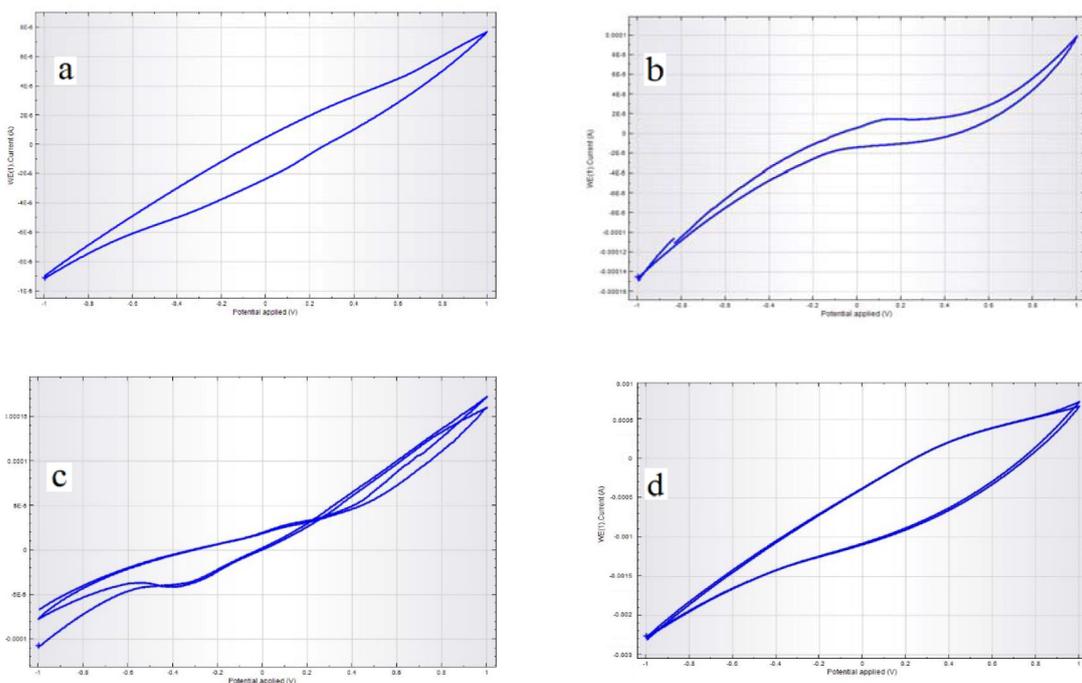


Fig. 5. Flow rate diagram to the voltages of the samples exposed to microwave radiation for 8 min: (a) 3% CNT, (b) 5% CNT, (c) 7% CNT, and (d) 9% CNT.

TABLE VI  
K/S, R%, CIELAB AND CIECH VALUES OF SAMPLES OF MICROWAVE-IRRADIATED FABRICS FOR 8 MIN UNDER TREATMENT OF MWCNT AND GO NANOPARTICLES

| Nanoparticles value (%)           |       | Raw   | 3     | 5     | 7     | 9     |
|-----------------------------------|-------|-------|-------|-------|-------|-------|
| K/S<br>(λ <sub>max</sub> =400 nm) | MWCNT | 0.068 | 4.9   | 5.94  | 9.916 | 10.9  |
|                                   | GO    |       | 3.9   | 4.925 | 8.053 | 9.14  |
| R%<br>(λ <sub>max</sub> =700 nm)  | MWCNT | 84.34 | 14.87 | 9.88  | 6.87  | 5.84  |
|                                   | GO    |       | 19.71 | 14.73 | 9.88  | 8.82  |
| L*                                | MWCNT | 92.49 | 44.82 | 36.82 | 30.33 | 29.21 |
|                                   | GO    |       | 49.56 | 40.91 | 33.39 | 30.38 |
| a*                                | MWCNT | -0.32 | 3.12  | 2.87  | 2.02  | 2.01  |
|                                   | GO    |       | 1.29  | 1.63  | 1.63  | 1.59  |
| b*                                | MWCNT | 4.12  | 7.52  | 6.88  | 5.35  | 5.42  |
|                                   | GO    |       | 3.47  | 6.35  | 5.66  | 5.11  |
| C                                 | MWCNT | 4.13  | 6.69  | 5.25  | 4.86  | 4.67  |
|                                   | GO    |       | 7.08  | 6.55  | 5.89  | 5.24  |
| h'                                | MWCNT | 94.45 | 74.17 | 69.91 | 61.36 | 57.62 |
|                                   | GO    |       | 79.89 | 75.6  | 73.94 | 70.66 |

because of fewer required experimental trials as compared to the “one-factor-at-a-time” method [24,25]. Also, it is an efficient mathematical approach of optimizing complex processes which are able to generate an empirical model for evaluating relationship among a set of controlled experimental factors and the observed results. This technique is extensively utilized in different chemical, biochemical, and nanochemical processes to analyze the effect of independent variables and optimize the process responses using proper values of the factors [26-28]. This study is carried out based on CCD and RSM. Eight experimental CCD designed runs were conducted according to Tables VII and VIII. In this model, the influences of independent variables including irradiation time and nanoparticles

percent were assessed on response surfaces. This justified the electrical resistivity and surface resistance properties of treated fabric samples.

Final equation in terms of actual factors related to electrical resistivity and surface resistance of sample of fabrics treated with GO nanoparticles and MWCNTS are presented in Eqs. (3) to (6), respectively:

$$\begin{aligned}
 R (\Omega) &= +1.07474E+06 \\
 \text{Irradiation time} &= -81871.50831 \\
 \text{GO nanoparticle} &= -1.94625E+05 \\
 \text{Irradiation time} \times \text{GO nanoparticle} &= +4904.81355 \\
 \text{Irradiation time}^2 &= +2737.98968 \\
 \text{GO nanoparticle}^2 &= +9884.99003
 \end{aligned}
 \tag{3}$$

TABLE VII  
CCD FOR ELECTRICAL RESISTIVITY AND SURFACE RESISTANCE OF A SAMPLE OF FABRICS TREATED WITH GO NANOPARTICLES AT DIFFERENT IRRADIATION TIMES

| Run | Factor                 |                     | Responses |           |
|-----|------------------------|---------------------|-----------|-----------|
|     | Irradiation time (min) | GO-nanoparticle (%) | R (Ω)     | Rs (S/cm) |
| 1   | 8                      | 6                   | 18540     | 0.01058   |
| 2   | 8                      | 6                   | 18500     | 0.0105    |
| 3   | 8                      | 6                   | 18584     | 0.01065   |
| 4   | 4.8                    | 4.2                 | 198768    | 0.00258   |
| 5   | 4.8                    | 7.8                 | 13060     | 0.02624   |
| 6   | 12                     | 6                   | 27810     | 0.01586   |
| 7   | 9.2                    | 8.9                 | 4913      | 0.01075   |
| 8   | 9.2                    | 3.1                 | 180110    | 0.0014    |

TABLE VIII  
CCD FOR ELECTRICAL RESISTIVITY AND SURFACE RESISTANCE OF A SAMPLE OF FABRICS TREATED WITH MWCNTS AT DIFFERENT IRRADIATION TIMES

| Run | Factor                 |                      | Responses |           |
|-----|------------------------|----------------------|-----------|-----------|
|     | Irradiation time (min) | CNT-nanoparticle (%) | R (Ω)     | Rs (S/cm) |
| 1   | 8                      | 6                    | 7868      | 0.0449    |
| 2   | 8                      | 6                    | 7810      | 0.0457    |
| 3   | 8                      | 6                    | 7895      | 0.0436    |
| 4   | 4.8                    | 4.2                  | 123915    | 0.0236    |
| 5   | 4.8                    | 7.8                  | 5671      | 0.2426    |
| 6   | 12                     | 6                    | 11802     | 0.0674    |
| 7   | 9.2                    | 8.9                  | 1384      | 0.2008    |
| 8   | 9.2                    | 3.1                  | 117936    | 0.0021    |

$$\begin{aligned}
 R_s \text{ (S/cm)} &= -0.052772 \\
 \text{Irradiation time} &= -0.000336 \\
 \text{GO nanoparticle} &= +0.019019 \\
 \text{Irradiation time} \times \text{GO nanoparticle} &= -0.001133 \\
 \text{Irradiation time}^2 &= +0.000423 \\
 \text{GO nanoparticle}^2 &= -0.000576
 \end{aligned}
 \tag{4}$$

$$\begin{aligned}
 R \text{ (}\Omega\text{)} &= +6.91773\text{E}+05 \\
 \text{Irradiation time} &= -49574.33147 \\
 \text{CNT nanoparticle} &= -1.30344\text{E}+05 \\
 \text{Irradiation time} \times \text{CNT nanoparticle} &= +2927.02482 \\
 \text{Irradiation time}^2 &= +1649.91329 \\
 \text{CNT nanoparticle}^2 &= +6906.98284
 \end{aligned}
 \tag{5}$$

$$\begin{aligned}
 R_s \text{ (S/cm)} &= +0.066791 \\
 \text{Irradiation time} &= -0.028719 \\
 \text{CNT nanoparticle} &= -0.000051 \\
 \text{Irradiation time} \times \text{CNT nanoparticle} &= -0.006094
 \end{aligned}
 \tag{6}$$

$$\begin{aligned}
 \text{Irradiation time}^2 &= +0.003547 \\
 \text{CNT nanoparticle}^2 &= +0.007596
 \end{aligned}$$

Response surfaces were drawn via achieved statistical models (Eqs. (3) to (6)), and the relation between each independent variables and also the electrical resistivity and surface resistance of fabric samples were obtained. Therefore, the response surfaces of the fabric samples are presented in Figs. 6 and 7, respectively.

The optimum condition of the characteristics of electrical resistivity and surface resistance of fabric samples were found by means of Design-Expert software which is illustrated as number irradiation time 8 min for both GO nanoparticles and CNT. Analysis of variance (ANOVA) was applied to analyze the data for obtaining the interaction between independent variables and responses. The results were then analyzed by ANOVA to assess the

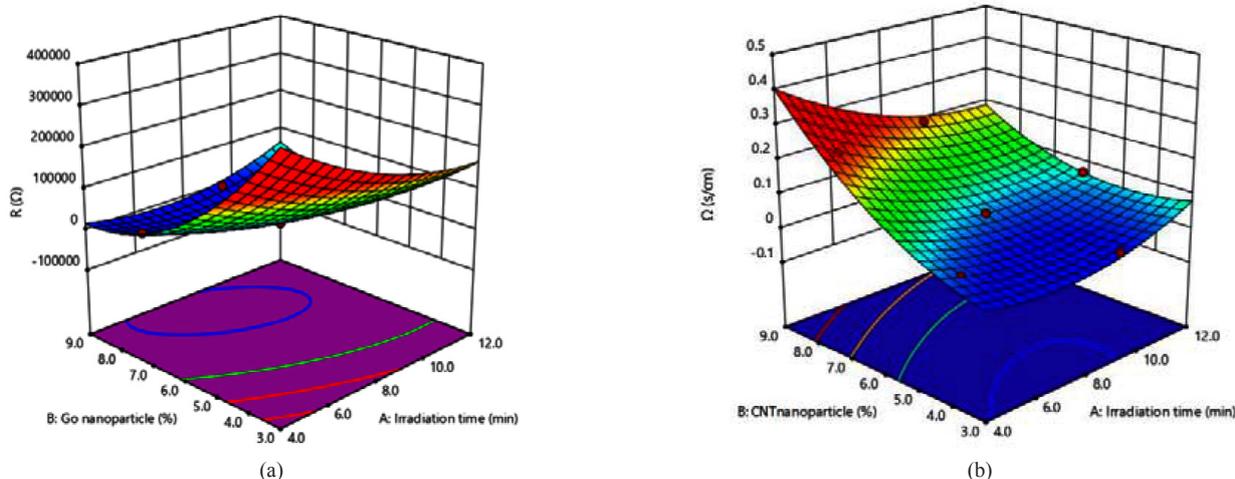


Fig. 6. Response surfaces for: (a) electrical resistivity and (b) surface resistance as a function of irradiation time and GO nanoparticles for fabric samples.

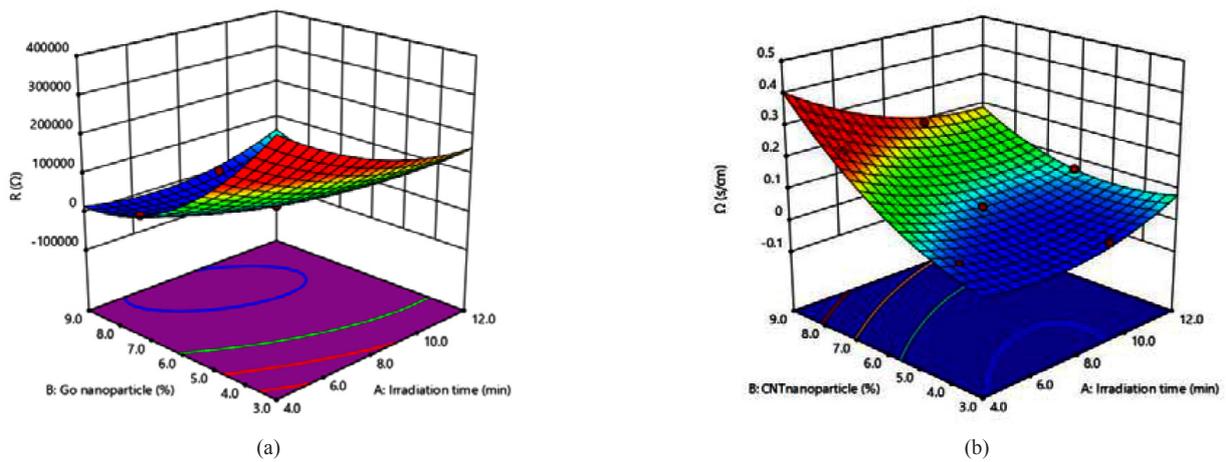


Fig. 7. Response surfaces for: (a) electrical resistivity and (b) surface resistance as a function of irradiation time and CNT nanoparticles for fabric samples.

electrical resistivity and surface resistance of fabric samples (Tables IX-XII).

It was observed that designed model of fabric samples with GO nanoparticles and MWCNTS for electrical resistivity is statistically significant at F-value of 5.11E+06 and 2.070E+06, respectively and values of

prob>F (<0.0001) (Tables IX and XI). Also, it was noticed that chosen model of treated fabric samples with GO nanoparticles and MWCNTs for surface resistance was significant at F-value of 14893.3 and 9623.67, respectively and values of prob>F (<0.0001) (Tables X and XII).

TABLE IX  
ANOVA RESULTS OF ELECTRICAL RESISTIVITY FOR FABRIC SAMPLES WITH GO NANOPARTICLES AT DIFFERENT IRRADIATION TIMES

| Source             | Sum of squares | df | Mean square | F-value  | P-value  | Prob > F    |
|--------------------|----------------|----|-------------|----------|----------|-------------|
| Model              | 4.51E+10       | 5  | 9.02E+09    | 5.11E+06 | < 0.0001 | Significant |
| A-irradiation time | 2.98E+09       | 1  | 2.98E+09    | 1.69E+06 | < 0.0001 |             |
| B-GO nanoparticle  | 3.04E+10       | 1  | 3.04E+10    | 1.72E+07 | < 0.0001 |             |
| AB                 | 2.17E+09       | 1  | 2.17E+09    | 1.23E+06 | < 0.0001 |             |
| A <sup>2</sup>     | 2.06E+09       | 1  | 2.06E+09    | 1.17E+06 | < 0.0001 |             |
| B <sup>2</sup>     | 8.48E+09       | 1  | 8.48E+09    | 4.80E+06 | < 0.0001 |             |
| Pure error         | 3530.67        | 2  | 1765.33     |          |          |             |
| Cor total          | 4.51E+10       | 7  |             |          |          |             |

TABLE X  
ANOVA RESULTS OF SURFACE RESISTANCE FOR FABRIC SAMPLES WITH GO NANOPARTICLES AT DIFFERENT IRRADIATION TIMES

| Source             | Sum of squares | df | Mean square | F-value  | P-value  | Prob > F    |
|--------------------|----------------|----|-------------|----------|----------|-------------|
| Model              | 0.0004         | 5  | 0.0001      | 14893.3  | < 0.0001 | Significant |
| A-irradiation time | 5.49E-06       | 1  | 5.49E-06    | 974.19   | 0.001    |             |
| B-GO nanoparticle  | 0.0002         | 1  | 0.0002      | 36898.41 | < 0.0001 |             |
| AB                 | 0.0001         | 1  | 0.0001      | 20525.23 | < 0.0001 |             |
| A <sup>2</sup>     | 0              | 1  | 0           | 8704.42  | 0.0001   |             |
| B <sup>2</sup>     | 0              | 1  | 0           | 5113.43  | 0.0002   |             |
| Pure error         | 1.13E-08       | 2  | 5.66E-09    |          |          |             |
| Cor total          | 0.0004         | 7  |             |          |          |             |

TABLE XI  
ANOVA RESULTS OF ELECTRICAL RESISTIVITY FOR FABRIC SAMPLES WITH MWCNTS AT DIFFERENT IRRADIATION TIMES

| Source             | Sum of squares | df | Mean square | F-value   | P-value  | Prob > F    |
|--------------------|----------------|----|-------------|-----------|----------|-------------|
| Model              | 1.952E+10      | 5  | 3.904E+09   | 2.070E+06 | < 0.0001 | Significant |
| A-irradiation time | 1.260E+09      | 1  | 1.260E+09   | 6.682E+05 | < 0.0001 |             |
| B-CNT nanoparticle | 1.301E+10      | 1  | 1.301E+10   | 6.896E+06 | < 0.0001 |             |
| AB                 | 7.714E+08      | 1  | 7.714E+08   | 4.089E+05 | < 0.0001 |             |
| A2                 | 7.467E+08      | 1  | 7.467E+08   | 3.958E+05 | < 0.0001 |             |
| B2                 | 4.140E+09      | 1  | 4.140E+09   | 2.195E+06 | < 0.0001 |             |
| Pure error         | 3772.67        | 2  | 1886.33     |           |          |             |
| Cor total          | 1.952E+10      | 7  |             |           |          |             |

TABLE XII  
ANOVA RESULTS OF SURFACE RESISTANCE FOR FABRIC SAMPLES WITH MWCNTS AT DIFFERENT IRRADIATION TIMES

| Source             | Sum of squares | df | Mean square | F-value  | P-value  |             |
|--------------------|----------------|----|-------------|----------|----------|-------------|
| Model              | 0.0541         | 5  | 0.0108      | 9623.67  | 0.0001   | Significant |
| A-irradiation time | 0.0029         | 1  | 0.0029      | 2586.67  | 0.0004   |             |
| B-CNT nanoparticle | 0.0404         | 1  | 0.0404      | 35936.37 | < 0.0001 |             |
| AB                 | 0.0033         | 1  | 0.0033      | 2976.53  | 0.0003   |             |
| A <sup>2</sup>     | 0.0035         | 1  | 0.0035      | 3072.84  | 0.0003   |             |
| B <sup>2</sup>     | 0.0050         | 1  | 0.0050      | 4457.50  | 0.0002   |             |
| Pure error         | 2.247E-06      | 2  | 1.123E-06   |          |          |             |
| Cor total          | 0.0541         | 7  |             |          |          |             |

#### IV. CONCLUSION

In this research, polyester/viscose fabric (65/35) was stacked under microwave wavelengths and was subjected to physical and laboratory specification, and according to SEM microscopy, the optimal radiation state was considered to be 8 min. Afterwards, the samples were treated with nanoparticles MWCNT and GO with different percentages, and the results of the treatment were shown via microscopic imaging using SEM microscopy. In the next step, the conductivity test, the electrical resistance, surface strength and voltammetric charts of the fabric treated with nanoparticles were measured. The results indicated that the conductivity properties were optimized at higher percentage of nanoparticles, and the samples treated with MWCNT nanoparticles had better uniformity and conductivity compared with GO nanoparticles, which was also shown in the statistical results of the central composite design (CCD).

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