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Synthesizing and Using Iron Oxide Nanoparticles as Nanocomposite in Cotton Fabrics Nanofinishing

Hoda Sharouf* ***Ziad Saffour***

Department of Textile Engineering, Faculty of Petroleum and Chemical Engineering, AL Baath University, Syria.
*Corresponding author: hsharouf@albaath-univ.edu.sy
E-mail address: zsaffour@hotmail.com

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Abstract:

Metal oxide nanoparticles, including iron oxide, are highly considered as one of the most important species of nanomaterials in a varied range of applications due to their optical, magnetic, and electrical properties. Iron oxides are common compounds, extensive in nature, and easily synthesized in the laboratory. In this paper, iron oxide nanoparticles were prepared by co-precipitation of (Fe^{+2}) and (Fe^{+3}) ions, using iron (II and III) sulfate as precursor material and NH_4OH solution as solvent at 90°C. After the synthesis of iron oxide particles, it was characterized using X-ray diffraction (XRD), infrared spectroscopy (FTIR), and scanning electron microscopy (SEM). These tests confirmed the obtaining of iron oxide nanoparticles with a crystalline structure in the form of (spinel), and the size of nanoparticles ranging from 13-24 nm.
Iron oxide and polyaniline nanocomposite were used to apply in cotton fabrics. The iron oxide nanoparticles were dispersed with different percentage concentrations 0.5, 1, 2, 5, and 10% in the polymeric solution. Then the cotton samples were treated with the prepared nanocomposite. The electrical conductivity was measured using the four probes method, and it was found that the treated cotton fabrics acquired the electrical conductivity that they did not have before. The ultraviolet transmittance of the treated samples was also measured, and it was noted that the transmittance of the treated samples decreased compared to the untreated sample due to the absorption of ultraviolet rays by iron oxide particles, especially in the UVC field.

Keywords: co-precipitation, electrical conductivity, nanoparticles, polyaniline, UV protection.

Introduction:

Over the past few decades, nanomaterials have grown in an extraordinary way in the textile industries, whose fields of use are diversified, due to the increasing demand for the manufacture of functional and protective garments. Nanomaterials can provide wrinkle-freeness, flame retardant, electrically conductive, antibacterial, and UV protective textiles [1]. Due to the extensive use of cotton fabrics in everyday life, the incorporation of new functional properties into cotton fabrics has attracted specific attention. Metals, metal oxides, semiconductors, and polymers are mainly used to impart distinctive properties to cotton fabrics [2]. Nanostructured metal oxides also show wide application in dye-sensitive solar cells, smart screens and windows, biosensors, lithium batteries, and supercapacitors [3].
Because of its small size, the nanostructure has attracted a significant concern for its unique properties that cannot be obtained from the bulk structure. Nano crystallized semiconductor, is an important element with multifunctional utilization in industry through the solar cells, optical filters, sensors, photo catalysts, and lithium ion batteries, and other devices are inexpensive due to the high absorption coefficient 104 cm^{-1} and small band gap 1.2 eV [4].
Iron oxide Fe_3O_4 (magnetite) is the first magnetic material referred to in human history. It is the magnetic mineral found in the lodestone [5]. Among magnetic nanoparticles, Fe_3O_4 has attracted particular interest. This is due to its ease of preparation, minimal toxicity with proper surface functionalization [6]. Fe_3O_4 differs from other iron oxides in that it has divalent and trivalent iron. Fe_3O_4 displays the lowest resistivity among the iron oxides because to its small band gap 0.1 eV [7, 8, 9]. A variety of methodologies exist for the synthesis of iron oxide including co-precipitation, sol-gel,

microemulsion, electrochemical methods, and hydrothermal synthesis and biosynthesis methods [10]. The co-precipitation method is a conventional and perhaps the simplest method for assembling iron oxide nanoparticles. The advantages of the co-precipitation method are high yield, high product purity, no need for organic solvents, easy repeatability, and low cost [11].

Protective textiles have its place in an enormous group of technical textiles, including protection from insects, heat, and fire, protection from biological agents, and protection against ultraviolet (UV) or electromagnetic shielding. Fabrication of low-weight, long-lasting protective effects, good comfort, and breathability, along with low cost, have been required by the market, thanks to the introduction of nanotechnology in textile finishing [12].

Composites of polymer based such as matrix, ceramics as filler receive increased attention due to their electrical and optical properties, such as acoustic emission of sensors, electronic container in some potential applications and optoelectronics as device elements such as LEDs and solar cells [13].

Nanocomposite materials (polymer-metal oxide) can be prepared according to two different methods, namely, (*in situ*) and (*ex situ*) techniques. In the first case, metal nanoparticles can be produced inside a polymer matrix by decomposition, or by chemical reduction of the metallic precursor material inside the matrix. As for the (*ex situ*) method, nanoparticles are first produced, and then dispersed in the polymer [14]. Polymeric nanocomposites are used in a wide variety of applications, due to the synergistic effect of the components included in their composition, which are the conductive polymer as well as the metallic nano-oxides. The importance of polymeric nanocomposites is due to several reasons, the most important of which is the dispersal of metallic nanoparticles (NPs) within the polymer matrix and thus reducing their self-assembly and agglomeration, in addition to the fact that incorporation of metallic nanoparticles can give the polymer distinctive properties such as low electrical resistance, good mechanical stability, high chemical stability, thermal stability, surface appearance and electrical conductivity [14, 15].

Because conductive fabrics can blend well with clothing, they are ideal as a sensing element for wearable human motion control systems [16]. An electrically conductive fabric with superparamagnetic properties was developed using PEDOT/magnetite nanoparticles, by Sedighi et al. EMI attenuation, antibacterial efficiency, magnetic behavior and UV protection activity of PEDOT/iron oxide deposited PET fabric was also studied [17]. Yu, M. et al. described a facile approach to construct superhydrophobic cotton@Fe_3O_4 for oil/water separation. Cotton fabrics with super-wettability surfaces were fabricated by precipitation Fe^{2+} /Fe^{3+} ions onto cotton using PVP as a coupling agent [18]. Sharaf et al. fabricated an electronic fabric using PANI and CuO nanoparticles. They found that the cotton fabric finished with PANI-CuO nanocomposite showed superior antibacterial activity and good electrical conductivity [19]. Abo El-Ola et al. studied the effects of nanofinishing (zinc oxide nanoparticles and nano-polyurethane nanocomposite) on the ultraviolet protection properties of polyester fabric [20].

In this paper, iron oxide nanoparticles were synthesis by co-precipitation, using iron (II and III) sulfate and iron (II and III) chloride as precursor materials, and NH_4OH solution as solvent at 90°C. After the iron oxide particles were synthesized and characterized using X-ray diffraction, infrared spectroscopy, and scanning electron microscopy. Iron oxide and polyaniline nanocomposite material were used for application on the cotton fabric samples using ultrasonic irradiation at (20°C). Polyaniline was polymerized by the chemical oxidation method. Then the iron oxide nanoparticles were dispersed with different percentage concentrations 0.5, 1, 2, 5, and 10% in the polymeric solution with the help of ultrasonic irradiation. After that, the cotton samples were treated by (the pad-dry) method, with continuing use of ultrasound during immersion. After drying the samples, the electrical conductivity was measured using the four probes method. The UV-transmittance was also measured using a spectrophotometer. The aim of this research is treating cotton fabrics to have functional properties, which are electrical conductivity and UV resistance. Theses fabrics can be used in technical textiles.

Materials and Methods:

Material:

Iron (III) chloride ($FeCl_3.6H_2O$), iron (II) chloride ($FeCl_2.4H_2O$), and ammonium persulfate ($(NH_4)_2S_2O_8$) were purchased from (Riedel-deHaën). Iron (III) sulfate ($FeSO_4$) was purchased from (BDH), iron (II) sulfate ($FeSO_4.7H_2O$) and aniline (C_6H_7N) were purchased from (Lobachemie). Ammonium hydroxide (NH_4OH, 25%) was purchased from (Roth), and hydrochloric acid (HCl, 36.5%) was purchased from (PRS Panreac). Plain-woven 100% cotton fabric with weights of (185 g/m^2) was obtained from the local market. Nm 20, 16 yarn was used in warp and weft

directions, respectively. The density was 33 cm^{-1} for warp and 18 cm^{-1} for weft.

Preparation of Nano Iron Oxide:

The co-precipitation method involves mixing ferric and ferrous ions (Fe^{+3}, Fe^{+2}) in very basic solutions, by using ammonium hydroxide at (90˚C). The reaction mechanism can be simplified as [9]:

$$Fe^{+2} + 2Fe^{+3} + 8OH^{-1} \leftrightarrows Fe(OH)_2 + 2Fe(OH)_3 \rightarrow Fe_3O_4\downarrow + 4H_2O$$

Iron (II and III) sulfates were used to synthesize the first amount of iron oxide nanoparticles. The second amount was synthesized using Iron (II and III) chloride. After that, the two oxides were left to precipitate. Then washed three times with water, and dried in the oven at 150˚C until it is completely dry. Two oxides were compared after characterization by FTIR, and one of them would be chosen.

Aniline Polymerization:

Polyaniline is prepared by chemical polymerization of aniline using ammonium persulfate as an oxidant, and hydrochloric acid (HCl) is used to provide charge carriers which give the electrical conductivity for polyaniline. Based on a previous study [21], the best electrical conductivity values for polyaniline were for aniline concentration 3% and the ratios of other substances (ANI: HCl: APS) were 1: 4: 0.5.

Fabric Finishing:

A pretreatment process was performed on the fabric using sodium hydroxide and oxygen peroxide before starting the finishing process. This is to remove the starch and increase the wettability of the fabric to absorb the post-processing chemicals.

The treatment was carried out according to the following steps:

a. Preparation of the monomer solution: 30 ml of hydrochloric acid is added to 10 ml of aniline gradually to avoid overheating, with continuous stirring using the magnetic stirrer for 1 hour at room temperature.
b. Preparation of the oxidant solution: simultaneously with the preparation of the monomer solution, the oxidant solution is prepared by dissolving 5 g of ammonium persulfate in 45 ml of distilled water while stirring with a magnetic stirrer. Then 10 ml of hydrochloric acid is added and stirring continues until the solution is homogeneous.
c. Polymerization: the oxidant solution (prepared in step b) is gradually added to the monomer solution, and the polymerization reaction continues in an ultrasonic bath, (Digital Ultrasonic Cleaner Jeken PS-40A), for 2 hours at room temperature.
d. The metal oxide is added according to the appropriate concentration, Table 1, to the previously prepared polymeric solution, and then placed in the ultrasonic bath for 30 minutes at room temperature to disperse the oxide in the monomeric solution.
e. The cotton sample is placed in the solution obtained from step (d) and left them in the ultrasound bath for 60 minutes.
f. The sample is removed from the treatment solution, passed over the squeezing by padder, and then dried at room temperature.

The application of nano-oxides on textiles through ultrasonic irradiation has been demonstrated to be an effective method. Ever since metal oxide nanoparticles have a large specific surface area, so they can be spread evenly and thinly on the surface of fabrics.

Table 1. Naming the samples according to the percentage of oxide used.

Sample No.	Untreated	PAni	1	2	3	4	5
Percentage of oxide (%)	-	-	0.5	1	2	5	10

Characterization Techniques:

Functional groups present in the synthesized iron oxide nanoparticles, synthesized by two different types of precursors, were found by FTIR spectrometer (Jasco FTIR/4100) at a region of 400-4000 cm^{-1}. The X-ray diffraction pattern was achieved by (PHILIPS XRD-PW 1840) diffractometer having the Co-Kα (λ=1.778 A) radiation source. The morphology of prepared nanoparticles was realized by (VEGA II XMU) scanning electron microscope where the diameter of the nanoparticles was determined using ImageJ software.

After applying the nanofinishing to cotton samples, the functional properties acquired by the fabric were described as follows. First, the electrical conductivity was measured using the four-probe method. The device consists of four linear probes manufactured by (SIGNATONE), in addition to a power supply (KEITHLEY220) and voltmeter (KEITHLEY617). The measurement method depends on passing currents of different intensities between the two external probes and recording the resulting voltage values between the two internal probes. Then it draws the best lines that pass through the experimental points and measures the slope (V/I), from which the specific resistance is

calculated using Eq.1, and the specific electrical conductivity using Eq.2:

$$\rho = G\frac{V}{I} \ldots\ldots\ldots 1$$

$$\sigma = \frac{1}{\rho} \ldots\ldots\ldots 2$$

I The electric current in the sample
V Electrical voltage
σ specific electrical conductivity ($S.cm^{-1}$)
ρ specific electrical resistance (Ω.cm)
G Correction factor related to the sample's geometric shape, dimensions, the position of the probes on it, and the distance between the probes. Depending on the experimental data, we find that the correction factor is equal to 4.4516.

Second, a JASCO 530 spectrophotometer was used, within the 200-400 nm UV range. By using this device, transmittance values (T %) are determined at different wavelengths. The percentage of ultraviolet rays that pass through the fabric can also be calculated for (UVR), (UVA), (UVB), and (UVC) using Eq.3 [22]:

$$UV_{transmission}(\%) = \frac{\sum_{\lambda_1}^{\lambda_2}(\lambda)}{\lambda_2 - \lambda_1} \ldots\ldots\ldots 3$$

Where: λ_1 and λ_2 are the wavelengths (nm) at the beginning and the end of the studied spectra. The UV spectrum is separated into three regions: UVA (400-320 nm), UVB (320-290 nm), and UVC (290-200 nm).

Results and Discussion:

Fourier Transform Infrared Spectroscopy (FTIR):

The synthesized iron oxide nanoparticles, prepared using Iron sulfate and chloride, were characterized by the FTIR spectroscopy technique to discover the functional groups present in the synthesized particles. In the first sample, ($FeSO_4.7H_2O$) and ($FeSO_4$) were used, and in the second sample, ($FeCl_4$) and ($FeCl_4.6H_2O$) were used. Fig. 1. and Fig. 2. show the infrared spectrographs of the resulting oxides.

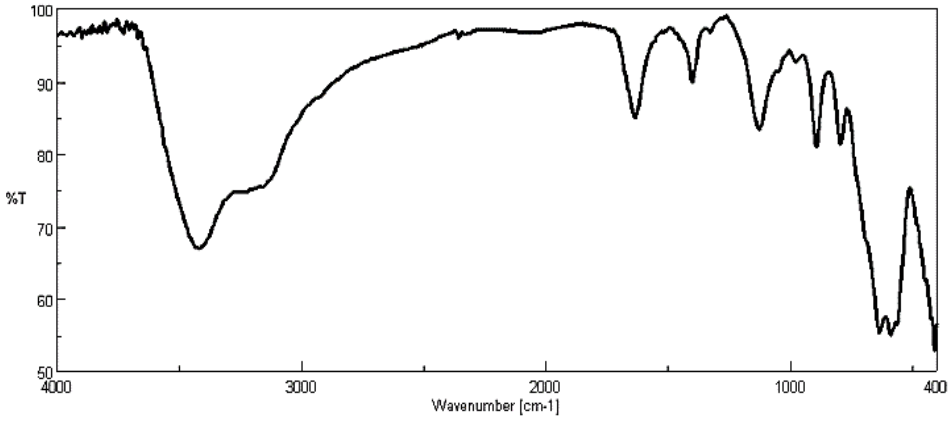

Figure 1. Infrared spectrum of iron oxide prepared using iron (II and III) sulfate

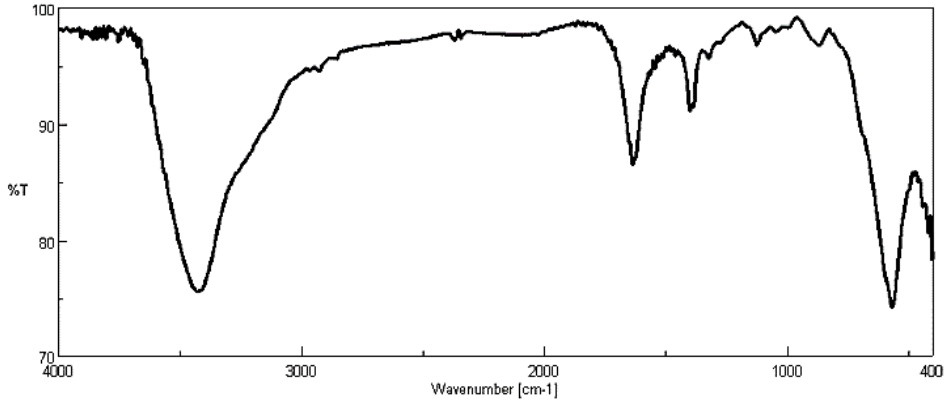

Figure 2. Infrared spectrum of iron oxide prepared using iron (II and III) chloride

Many compounds related to iron oxide nanoparticles were characterized by FTIR spectrum. The peaks at 1700 cm^{-1} and 1850 cm^{-1} exhibited the C=O stretching vibrations. The broad peak nearby 3400 cm^{-1} showed the OH stretching bond vibration which was due to the water adsorption on the surface of iron oxide nanoparticles. The absorption bond of Fe-O at the range 550-600 cm^{-1} is detected matching to inherent stretching vibrations of metal-oxygen at a tetrahedral site ($Fe_{tetra-O}$), which indicates that the obtained oxide is magnetite. From the absorption appears at 3600-3200 cm^{-1} area, it can be concluded that the synthesized compounds resulted in this condition were still mixed with $Fe(OH)_2$, which is a remainder from the reaction that did not convert to an oxide [23- 26], and that is noticed in Fig. 1.

However, it is noticed that the bond peak (Fe-O) for the oxide prepared using iron (II and III) sulfate is longer, which indicates the prepared nanoparticles are smaller in size. So it is selected for the finishing of cotton fabrics. Further characterization of this oxide was tested using a scanning electron microscope and an X-ray diffraction device.

Scanning Electron Microscope (SEM):

Scanning electron micrograph of the synthesized iron oxide nanoparticles -prepared by the co-precipitation method using iron (II and III) sulfate- is presented in Fig. 3. The size of nanoparticles is measured by ImageJ and ranges between 13 nm and 24 nm. By calculating the average diameters of nanoparticles, it is found to be equal to 19.45 nm. It is noticed that the nanoparticles of iron oxide powder were assembled, and formed agglomerates because of self-assembly in nanomaterial.

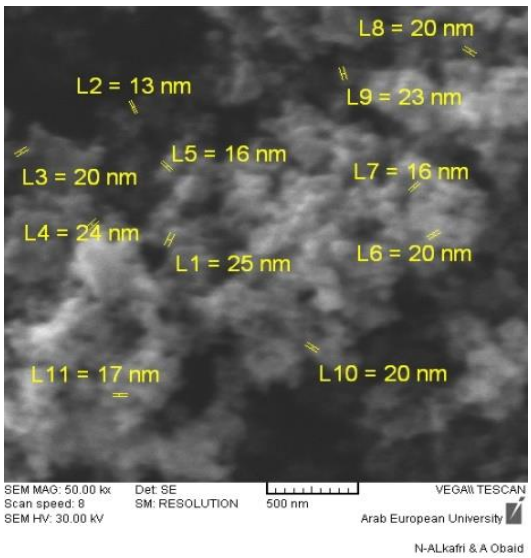

Figure 3. Micrograph of a (Fe_3O_4) powder

X-ray Diffraction (XRD):

The phase structure of synthesized Fe_3O_4 nanoparticles was estimated using X-ray diffraction spectra. The XRD pattern of the sample in Fig. 4 was similar to the standard values reported in (JCPDS 19-0629). The typical X-ray diffraction patterns of magnetite (Fe_3O_4) and the cubic structure of magnetite nanoparticles are consistent. The crystalline peaks which are observed at the diffraction angles (2θ) of 42.1, 51, 67.8, and 74.8 degrees are related to the 311, 400, 511 and 440 crystallographic planes, respectively. It corresponds to the references [6, 9, 26]. The intensity of the diffractogram peaks found in this study is relatively high. Fe_3O_4 with a cubic crystal structure differs from most other iron oxides in that it contains divalent and trivalent iron. Fe_3O_4 shows the lowest resistance among iron oxides due to its small band gap [9].

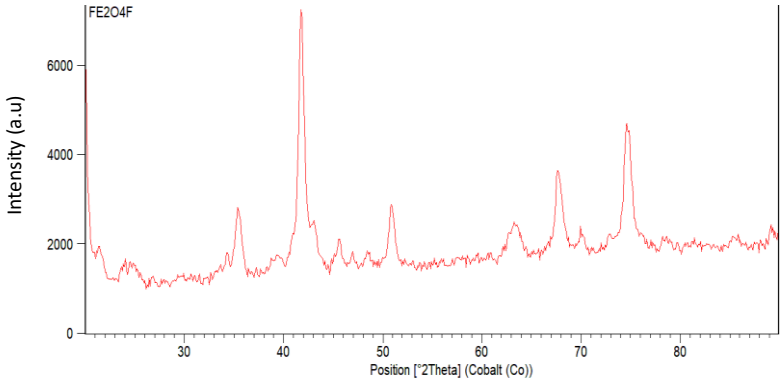

Figure 4. Diffraction spectrum of iron oxide

Measuring Electrical Properties Using the Four Probes Method:

Eq. 1. was used to calculate the values of specific electrical resistance and then to calculate the electrical conductivity from Eq. 2. The results of all samples are shown in Table 2:

Table 2. Conductivity and resistivity values for treated fabrics.

sample	electrical resistivity ($R*10^3$) (Ω)	Thickness (t) (cm)	Correction factor (G)	specific electrical resistivity (ρ) (Ω.cm)	specific electrical conductivity (σ) ($S.cm^{-1}$)
untreated	9.77E+12	0.023	4.4516	1.00E+09	10^{-9}
PAni	7.24E+02	0.068	4.4516	2.19E+02	0.005
(0.5%Fe_3O_4+PAni)	3.00E-01	0.039	4.4516	5.E-02	19.20
(1%Fe_3O_4+PAni)	1.00E+00	0.043	4.4516	2.E-01	5.224
(2%Fe_3O_4+PAni)	1.70E+00	0.048	4.4516	4.E-01	2.753
(5%Fe_3O_4+PAni)	6.00E-01	0.053	4.4516	1.E-01	7.064
(10%Fe_3O_4+PAni)	1.35E+02	0.056	4.4516	3.E+01	0.030

The conductivity and resistivity values of the samples are illustrated in Table 2. The electrical resistance of untreated cotton fabrics was about 10^7 Ω.m [27]. Polyaniline has a high electrical conductivity, and the influence of different iron oxide concentrations, which are added to the same amount of polyaniline, on substrate cotton samples for the electrical resistivity, was examined in this study, and the results are presented in Fig. 5. The results showed a clear decrease in resistivity (increase in electrical conductivity) when comparing the treated samples with the untreated one and with that was treated with only polyaniline. There is no clear relationship between the concentration of iron oxide and the electrical conductivity. Maybe the reason belongs to the difference in the sample thickness, which indicates inhomogeneous covering of the surface of treated samples. It was found that the smallest concentration of iron oxide, leads to the highest electrical conductivity 19.20 $S.cm^{-1}$. Thus, it can be concluded that iron oxide nanoparticles have an efficient role in improving the electrical conductivity of the fabric. Moreover, the electrical conductivity produced by iron oxide is higher than by polyaniline.

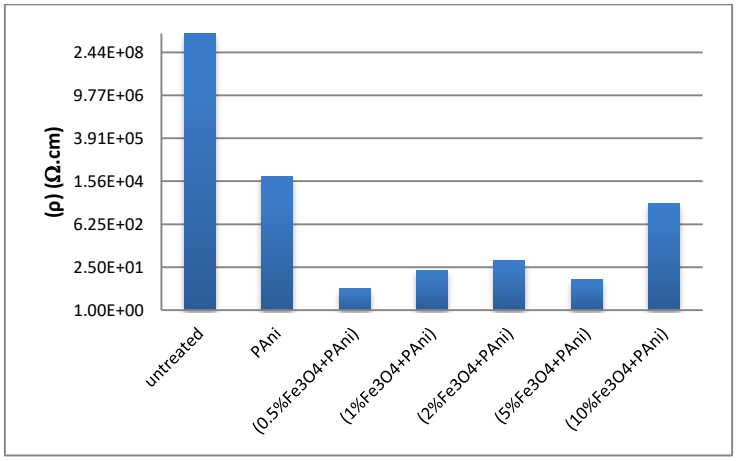

Figure 5. specific electrical resistivity of cotton samples

Measurement of UV Transmittance:

The purpose of this test is to measure the amount of ultraviolet radiation passing through the tested samples and to compare the differently treated samples with each other on the one hand, and with an untreated reference sample, on the other hand, to determine the ability of these samples to block ultraviolet radiations and prevent their transmittance to the other side of the treated fabric.

The transmittance spectra of samples in the UV regions from wavelengths of 200 up to 400 nm are depicted and compared in Fig. 6, to study the influence of nanocomposite on fabrics' UV-blocking functionalities. It is noted that both samples, untreated and treated with only polyaniline, are very similar in the amount of ultraviolet radiation passing through them. It is noticed that the UV transmittance of the polyaniline-treated sample is slightly greater than that of untreated in the field 200-320 nm. The reason is that the UV absorption peak of polyaniline is at 20 nm, while the absorption peak is located at 620 nm in the visible field.

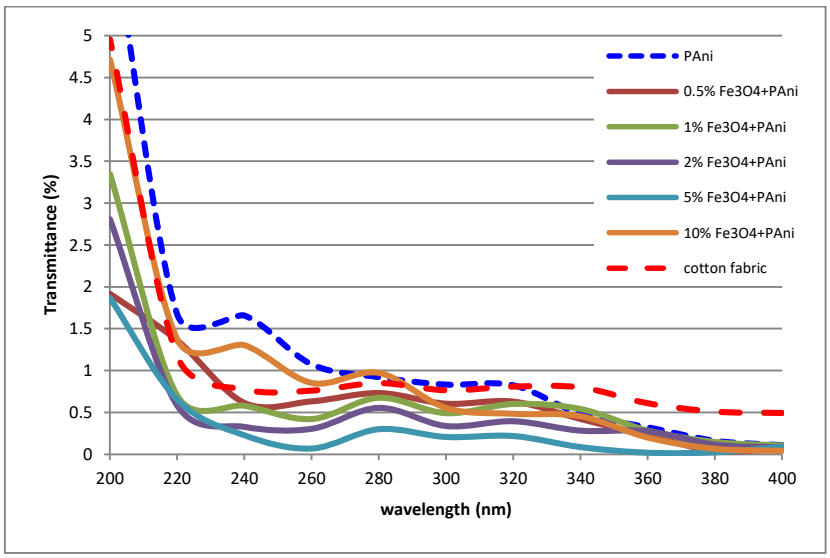

Figure 6. UV transmittance spectra of treated cotton fabrics

The untreated cotton samples used in this research have low UV transmittance when wavelengths are greater than 220 nm, due to the structure of the fabric itself in terms of warp and weft density and weight per square meter. Metal oxides, due to their distinctive optical properties, play an important role in absorbing very harmful ultraviolet rays located in the field below 220 nm, which cotton fabrics cannot block.

For samples treated with polyaniline and iron oxide, UV transmittance decreases with increasing oxide concentration up to only 5%, after that transmittance begins to increase when wavelengths are less than (290 nm).

In addition, UV (%) transmittance by treated cotton fabrics was calculated according to Eq.3; the results are in Table 3. It is observed from the data in Table 3 that significant damping occurred in UV transmission, with an increase in the Fe_3O_4 percentage from 0.5 to 5%, while keeping the polyaniline constant 3%. But when the concentration reaches 10% an opposite effect has happened, and the UV transmittance got increased. May be the reason is due to the irregular distribution of the nanoparticles on the surface of cotton sample, and the forming of agglomerates.

Table 3. UV transmittance by treated cotton fabrics (%).

sample	untreated	PAni	0.5% Fe_3O_4 +PAni	1% Fe_3O_4 +PAni	2% Fe_3O_4 +PAni	5% Fe_3O_4 +PAni	10% Fe_3O_4 +PAni
UVR(%)	6.25	7.25	3.62	3.94	3.03	1.88	5.50
UVA(%)	4.02	2.36	1.73	2.09	1.43	0.55	1.54
UVB(%)	6.06	6.44	4.92	4.41	3.21	1.81	5.01
UVC(%)	10.65	14.73	6.57	7.15	5.72	3.90	11.51

Conclusion:

In the present study, an iron oxide (Magnetite) nanoparticle has been effectually synthesized using the co-precipitation method with the precipitating agent NH_4OH. Iron (II and III) sulfate were used as precursor material. The obtained nanoparticles were then characterized using a variety of analytical techniques. The result of (FTIR) analysis displayed the production of Fe_3O_4 has shown three main functional groups, OH-, C=O and Fe-O group. X-ray Diffraction (XRD) analysis has established the presence of Fe_3O_4 structure in the nanoparticle system. Besides, Scanning Electron Microscopy (SEM) analysis showed that the powders consist of a mixture of nanoparticles with a mean particle size of (19.45 nm).

Polyaniline containing modified Fe_3O_4 nanoparticles was successfully prepared via ultrasonic irradiation method. The polymerization of aniline was carried out in the presence of hydrochloric acid (HCl) and ammonium persulfate (APS) as oxidants. After that, the nanocomposite material was applied onto cotton samples. The electrical conductivity of untreated, polyaniline, and PAni/Fe_3O_4 nanocomposite was measured on four-point probe apparatus. It was found that the

conductivity was initially increased and then decreased due to the addition of Fe_3O_4 nanoparticles in the composites. Furthermore, the application of these materials for protection against UV radiation was also demonstrated. By measuring the UV transmittance by treated cotton fabrics, it is found that the addition of Fe_3O_4 nanoparticles to polyaniline, leads to enhancing the UV-blocking for treated cotton samples. Finally, it is concluded that the best sample in electrical conductivity value is 0.5% Fe_3O_4, and the best one in UV-blocking is 5% Fe_3O_4.

Authors' Declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are ours.
- The authors have signed an animal welfare statement.
- Authors signed ethical considerations approval
- Ethical Clearance: The project was approved by the local ethical committee in Al-Baath University.

Authors' Contributions:

H.S. and Z.S. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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تصنيع واستخدام جسيمات أوكسيد الحديد النانوي كمادة مركبة في المعالجة النهائية النانوية للأقمشة القطنية

هدى شروف زياد سفور

قسم هندسة الغزل والنسيج، كلية الهندسة الكيميائية والبترولية، جامعة البعث، سوريا.

الخلاصة:

حظيت الجسيمات النانوية لأكاسيد المعادن، ومنها أوكسيد الحديد، على تقدير كبير باعتبارها واحدة من أهم فئات الهياكل النانوية في مجموعة واسعة من الصناعات نظراً لخصائصها البصرية والمغناطيسية والكهربائية. تعد أكاسيد الحديد مركبات شائعة، منتشرة في الطبيعة، ويمكن تصنيعها بسهولة في المختبر. تم في هذا البحث تحضير جسيمات أوكسيد الحديد النانوية عن طريق الترسيب المشترك لأيونات (Fe^{+2}) (Fe^{+3})، باستخدام كبريتات الحديدوز وكبريتات الحديديك كمادة بادئة، ومحلول NH_4OH كمذيب عند الدرجة (90°C). تم توصيف جسيمات أوكسيد الحديد المحضرة باستخدام حيود الأشعة السينية (XRD)، طيف الأشعة تحت الحمراء (FTIR) والمجهر الإلكتروني الماسح (SEM). وقد أكدت هذه الاختبارات الحصول على أوكسيد الحديد النانوي ذو تركيب بلوري على شكل (spinel)، وحجم الجسيمات النانوية يتراوح بين (13-24 nm).

استخدمت مادة مركبة نانوية من أوكسيد الحديد والبولي أنيلين للتطبيق على قماش قطني. شتت أوكسيد الحديد النانوي بتراكيز مئوية مختلفة 0.5، 1، 2، 5، و10% في المحلول البوليميري. بعد ذلك، تمت معالجة العينات القطنية باستخدام المادة المركبة المحضرة. قيست الناقلية (التوصيلية) الكهربائية بطريقة المسابر الأربعة، وتبين اكتساب الأقمشة القطنية المعالجة خاصية التوصيل الكهربائي التي لم تمتلكها من قبل. كما قيست نفوذية العينات المعالجة للأشعة فوق البنفسجية، ولوحظ انخفاض نفوذية العينات المعالجة مقارنة مع العينة المرجعية بسبب امتصاص جسيمات أوكسيد الحديد للأشعة فوق البنفسجية ولاسيما في مجال (UVC).

الكلمات المفتاحية: الترسيب المشترك، التوصيل الكهربائي، الجسيمات النانوية، البولي أنيلين، الحماية من الأشعة فوق البنفسجية.