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Characterization and Evaluation of Polyester and Silk Fabrics Treated Using Plasma as Clean Energy Advanced Technique

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IN this article we studied the effect of surface modification of polyester (PET) and silk fabrics by their exposure to cold plasma. The cold plasma was carried out using oxygen as a working gas and different plasma device parameters have been studied such as: different time, different current and different hydrostatic pressure using plasma/Oxygen. Treated fabrics are characterized by the measurements and evaluation of mechanical properties, air permeability, Electron Spin Resonance (ESR) and the changes in surface morphological of pretreated fabrics were characterized by Scanning Electron Microscope (SEM) and Energy Dispersive X- Ray Analysis (EDX)). The nano-silver particles were prepared by green synthesis method, then were characterized by Transmission Electron Microscopy (TEM) and Zeta Potential and particle size. The exposed plasma fabrics at optimum conditions were modified with the prepared nano-silver. The antibacterial activity properties for treatedfabrics against gram positive bacteria (*Staphylococcus aurous*) and gram negative bacteria (*Escherichia coli*) were examined. The SEM results confirmed that there was a significant increase in roughness of the surface for all treated fabrics. The results of mechanical properties showed that plasma treatment had not destructive effect on the physical properties of the fabrics. The results obtained clarify that the ultraviolet protection factor (UPF) values increase for polyester exposed fabrics but the increase is not significant for silk fabrics while antibacterial properties were highly improved by all treated fabrics.

Keywords: DC plasma discharge, Oxygen, Polyester, Silk, Mechanical properties, ESR, TEM, Antibacterial properties.

Introduction

Plasma treatment is environmentally friendly and economic process. The application of plasma treatments for improved wet-ability has been done on all possible fiber types, with varying success [1]. It offers numerous advantages over the conventional chemical processes. Nano-material is often defined as a material that is less than 100 nano-meters in at least one dimension, as one nanometer is a millionth of a millimeter, or a billionth of a meter. Nano-materials may be either entirely new chemical structures or already known chemical structures at a smaller scale [2]. As a result of their small size, nano-materials may have entirely different properties and functions. Nanotechnology is concerned with forming and using these small structures. Most of the presented methods for stabilizing of inorganic nano-structured materials on the textile surfaces need several steps of preparation, functionalization, final treatment, drying, curing and so on. This is forced high cost and it is very time consuming for high-scale manufacturing production. Many treatments were conducted using "silver", it was then called "high-tech", as well as the high pricing. However, the amount of silver should not exceed a certain level for it may cause harmful effects [3]. Many investigations concerned the treatment of textile surfaces using silver-nano-particles,

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where they applied new method to stabilize nano-silver on the textile surfaces for gaining permanent antibacterial activity, where, silver is a safer antibacterial agent in comparison with some possible organic antibacterial ones that have been avoided because of the risk of their harmful effects on the human body. When germs of many kinds approached silver-nano-particles, it has the characteristic of easy combining and entering the cell. After the penetration, it will rapidly combine with sulfur and hydrogen based molecule to stop germs from repopulation. Therefore, silver-nano-particles are naturally safe to all living bodies [4].

Experimental work

Materials and chemicals

Polyester fabrics 108 g/m^2 is provided by "OUF" son's Company, Cairo. Yarn counts of the fabric were 24 in the warp yarn and 18 in the weft.

Silk fabrics 65 g/m^2 is provided by Central Silk Board, India.

Plasma production

The schematic diagram of the experimental set-up of exposing samples surface to oxygen plasma or oxygen argon mixed gases plasma is shown in Fig. 1, the discharge takes place between the copper cathode and on a cylinder body of copper as anode with applied potential difference V. So the electrons are accelerated by V and propagate through the cylinder body of anode (I) to the expansion region (II). There they collide with the gas atoms and form the plasma. The discharge gas is pumped to have pressure of 0.1 torr before filling in with the oxygen or oxygen/ argon mixed gases. The working pressure is controlled by needle valve. The cathode is connected to the negative potential terminal of the power supply, whereas the anode was ground [5].

The samples were treated with oxygen plasma or oxygen / argon mixed gases plasma at different conditions of pressure, current, and time. The working pressures used for treatment of samples are: 0.2, 0.3, 0.4 torr. The discharge current applied for each samples is ranged from 30 to 55 mA. The exposure time for each sample is ranged from 15 second to 2 minutes.

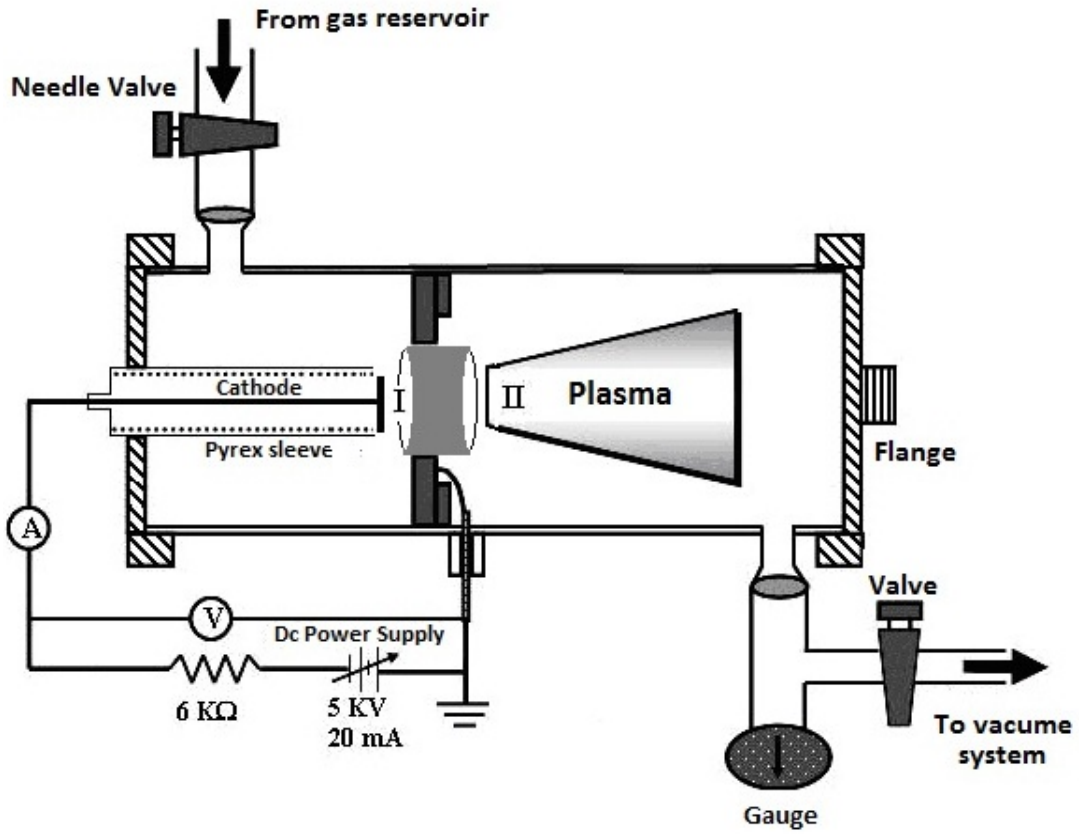


Fig. 1. The schematic diagram of DC pseudo plasma discharge device [5].

Synthesis of nano- silver particles:

Synthesis of nano- silver particles was carried out according green synthesis method of silver nano particles [6] by using Hydroxyethyl cellulose (HEC) as reducing and stabilizing agent, silver nitrate as precursor, water as solvent, and sodium hydroxide to bring alkaline reaction medium of pH 12. The reaction conditions that were used HEC: $AgNO_3$of 2: 0.17 (g/100 ml) at temperature 70^o C for 120 minutes with continuous stirring at pH 12.

The produced nano-silver was characterized by using different characterization tools involved:

Zeta Potential and particle size determination

Particle size was also measured by dynamic light scattering (DLS) using a Malvern Zetasizer Nano model: Nano-ZS (Malvern Instruments Ltd., UK).

Transmission Electron Microscope (TEM)

TEM images of the samples were obtained by a JEOL (JEM-1400 TEM) Japan, with an accelerating voltage of 100 kV.

UV/Visible spectral analysis

For the sensitized nano-silver was characterized by determining the UV-Vis spectrum of nano-silver 50 ppm, where the measurements were carried out using Colour Eye 3100 Spectrophotometer SDL, England.

Application of synthesis nano- silver on exposed fabrics

Oxygen plasma treated polyester and silk samples at optimum conditions were separately treated with nano-silver metal. Nano-silver colloidal solutions were shacked using magnetic stirrer before every treatment for homogeneity, then plasma treated samples were dipping and stirred for 15 minutes at 150 rpm in nano-silver colloidal solutions. The treated fabrics were then dried at room temperature without rinsing.

Characterization of treated samples

Air permeability

The treated and untreated samples of polyester and silk were tested for their air permeability using SDL Air permeability tester, England. The measurements were carried out according to the standard method [7].

Mechanical measurements

The treated and untreated samples of polyester and silk were tested for their tensile strength and elongation behaviors using a Shimadzu Universal Tester of (C.R.T) type S-500, Japan. The results listed in this paper are the mean of five times measurements [8].

Electron Spin Resonance Spectroscopy (ESR)

The ESR spectra of blank (untreated polyester and silk) and plasma treated fabric samples under the effect of different treatment conditions of time, pressure and current was recorded using an X-band ESR spectrometer (Bruker, EMX) at room temperature using high sensitivity standard cylindrical cavity (ER4119HS) operating at 9.7 GHz with a 100 kHz modulation frequency [9,10].

UV Protective Factor (UPF)

The UPF (ultraviolet protection factor) is a numerical rating given to clothing to indicate how effectively the fabric blocks ultraviolet (UV) radiation. The transmittance and UPF values of the examined fabric samples were measured using a Varian (UV-VIS-NIR) spectrophotometer according to the reported standard test method (AS/NZS 4399, Sun protective clothing-evaluation and classification [11]. The tested samples were classified according to their UPF values: <15 Poor, 15 to 24 Good, 25-39 Very Good, > 39 Excellent [12, 13].

Characterization of plasma treated polyester and silk samples at optimum conditions

Treated polyester and silk samples exposed to plasma at the optimum conditions for each factor including, time, pressure and current are subjected to the following testes:

Scanning Electron Microscope (SEM)

Surface morphological changes of blank untreated and those plasma treated fabric samples using oxygen gas were determined using Scanning Electron Microscope (SEM) Model Quanta 250 FEG (Field Emission Gun) and the treated plasma exposed polyester and silk samples at optimum Conditions with nano-silver in the attached EDX Unit (Energy Dispersive X-ray Analyses), with accelerating voltage 30 K.V., magnification14x up to 1000000 and resolution for Gun.1n) in The Egyptian Mineral Resources Authority Central Laboratories Sector.

Antibacterial properties

Antibacterial behaviors of blank, plasma exposed and nano-silver treated samples were evaluated according to the standard method [14], Antibacterial activity Assessment of Textile Material: parallel streak Method). The Antibacterial properties of the fabric samples (1 cm diameter) were investigated by incubating

bacteria solutions of both *Staphylococcus aureus* (Gram-positive) and *Escherichia coli* (Gram-negative) at 37◦C for 18-24 hours.

Results and Discussion

Optimization of plasma treatment of silk and polyester fabrics using oxygen gas.

The textile samples were exposed to pseudo plasma discharged of power ranging from 1-20 W. The textile sample of 7.5 cm diameter was placed in front of the mesh anode at an axial distance Z= 6 cm from the mesh. The samples were studied under different conditions of time, pressure and current. The effect of different exposure conditions on air permeability, mechanical properties, UV protective factor (UPF) and electron spin resonance spectroscopy (ESR) were discussed.

The effect of different exposure time on silk and polyester fabrics

Silk and Polyester fabrics were exposed to pseudo plasma using oxygen gas at different exposure time intervals (15–30–45–60-90-120) sec at Current 45 m.A. and Pressure 0.3 Torr.

UV Protective Factor (UPF)

Table 1 shows the results of UPF values of different exposure time on silk and Polyester treated fabrics. We notice that the UPF values has no significant effective for silk fabrics, while for polyester fabrics it increase by increasing the exposure time, it reach from (14.15) poor protection for blank to (38.65) very good protection. The natural fibers like silk have lower degree ultra violet protection than synthetic fibers such as polyester fabrics [15].

Air permeability

The results in Table 1 illustrated the air permeability for the treated silk and PET fabrics at different exposure time. We found that for silk fabrics the air permeability increase by increasing of exposure time but for polyester fabrics the air permeability increase in the time range from 15 sec up to 30 sec that may be related to the formation of new pores due to surface etching that occurs by oxygen plasma treatment. so the porosity increase of the plasma treated PET and silk samples [16], then start to decrease in the time range from 45 sec to 120 sec for PET fabrics this may be due to the possibility of saturation to occur at extended time which may results in two competing processes—binding of oxygen atoms to the surface and breaking up of polymer chains to result in the production of low molecular weight fragments [9]**.**

Tensile strength

The results of tensile strength for the treated silk and PET fabrics at different exposure time are shown in Table 1. For silk fabrics the tensile strength increase up to 30 sec and then slightly decrease it may be due to the oxidation effect of oxygen plasma on silk fibers which can cause the reduction of the tensile strength. However, the maximum loss in tenacity was (2.21%) for samples treated with oxygen. This maximum reduction in strength is still in the acceptable range.

The results of tensile properties measurements confirm that plasma treatments can be used on silk yarn without significant adverse effect on the physical properties of the fibers, especially when applied at durations up to (30) sec [17].

While for polyester fabrics it increase up to 30 sec this is due to increase the amorphosity of treated fabric samples by plasma exposure then decrease gradually by continuous exposure time which may be due to the thermal effect of this treatment on the fabric structure of the exposed polyester fabrics [17].

TABLE 1. The effect different exposure time on silk and PET treated fabrics.

Time (sec)	UPF		Air permeability ($cm^3/cm/S$)		Tensile strength (Kgf)	
	Silk	PET	Silk	PET	Silk	PET
Blank	4.45	14.15	30.61	9.82	67.80	102.76
15	4.46	15.54	30.68	9.83	67.00	102.40
30	5.62	18.60	31.12	11.29	66.30	116.20
45	5.64	19.67	31.20	10.89	66.10	112.25
60	6.31	20.36	31.29	10.21	65.80	110.75
90	7.10	21.45	32.62	8.18	64.80	95.20
120	7.90	38.65	34.70	6.31	64.35	117.05

The effect of different plasma exposed current on silk and PET fabrics

Silk and PET fabrics were exposed to pseudo plasma using oxygen gas at different plasma exposed current (30, 45, 55 m.A.) at Pressure 0.3 torr and exposure time 30 sec.

UV protective factor (UPF)

The results in Table 2 illustrated the UPF values at different plasma exposed current for the treated silk and PET fabrics. By increase the plasma exposed current the increment is not effective for silk fabrics it still poor protective and slightly effect for polyester reach to 16 which it become good protective [18].

Air permeability

Table 2 shows the results of air permeability at different plasma exposed current for the treated silk and PET fabrics. We found that air permeability of treated silk fabric increase by increase current and for polyester fabrics it increase by increase current up to 45 m.A. then it decrease with an increasing by a percent of (15%) for oxygen plasma, This result is due to the increase in the porosity of the plasma treated polyester sample these results verified the effect of plasma exposure on decreasing the strength of the irradiated samples and hence their ability to pass air through its structure, resulting in increasing their air permeability values [19].

Tensile strength

The result of tensile strength for the treated silk and PET fabrics at different plasma exposed current shown in Table 2. The tensile strength for treated silk fabric increase by increase current up to 45 m.A. then it decrease while for treated polyester fabrics it increase by increase current. These results clarify that increasing on the plasma applied current the fabric melted by the thermal effect of plasma to the extent that results in the compactness and crystallinity of the fabrics and hence increasing of the tensile strength values of those pretreated samples [17].

The effect of different plasma hydrostatic pressure on silk and PET fabrics

Silk and PET fabrics were exposed to pseudo plasma using oxygen gas at different plasma hydrostatic pressure (0.2, 0.3, 0.4 torr.) at current 45 m.A. and exposure time 30 sec.

UV protective factor (UPF)

The results in Table 3 illustrated the UPF values at different plasma hydrostatic pressure for the treated silk and PET fabrics, the UPF values increase by increase the plasma pressure for polyester it become excellent protective at 0.4 torr because the fabric melted by the thermal effect of plasma to the extent that provides increasing of the compactness and crystallinity of the fabrics which cause[20]decreasing in the porosity of the polyester fabric that increase the UPF whereas it reflect more UV rays, making the fabric more compact and lower transmission thus increasing UPF reaches to be very good[17],while it has no significance effective for silk fabrics it still poor protective.

Air permeability

Table 3 shows the results of air permeability at different plasma hydrostatic pressure for the treated silk and PET fabrics. As the plasma pressure increase the air permeability of treated silk fabric increase and for polyester fabrics it increases up to 0.3 torr. then it decrease this can be explained in view of the effect of pressure on energy of the charged particles leading to a large effect on the fabric surface, thus increasing their permeability in air [16,19].

Tensile strength

The results of tensile strength for the treated silk and PET fabrics at different plasma pressure shown in Table 3.The tensile strength for both treated fabrics increase by increase plasma pressure up to 0.3 torr, then it decrease. For silk fabric it may be due to the oxidation effect of oxygen plasma on silk fibers which can cause the reduction of the tensile strength, then by increasing the plasma pressure the fabric damage by the thermal effect of plasma [21]. While for polyester fabric is due to the melting of fabric by the thermal effect of plasma to the extent that results in the compactness and crystallinity of the fabrics and hence increasing of the tensile strength values of those pretreated samples [17].

Effect of plasma exposure on Electron Spin Resonance Spectroscopy (ESR) using oxygen gas

Effect of different time

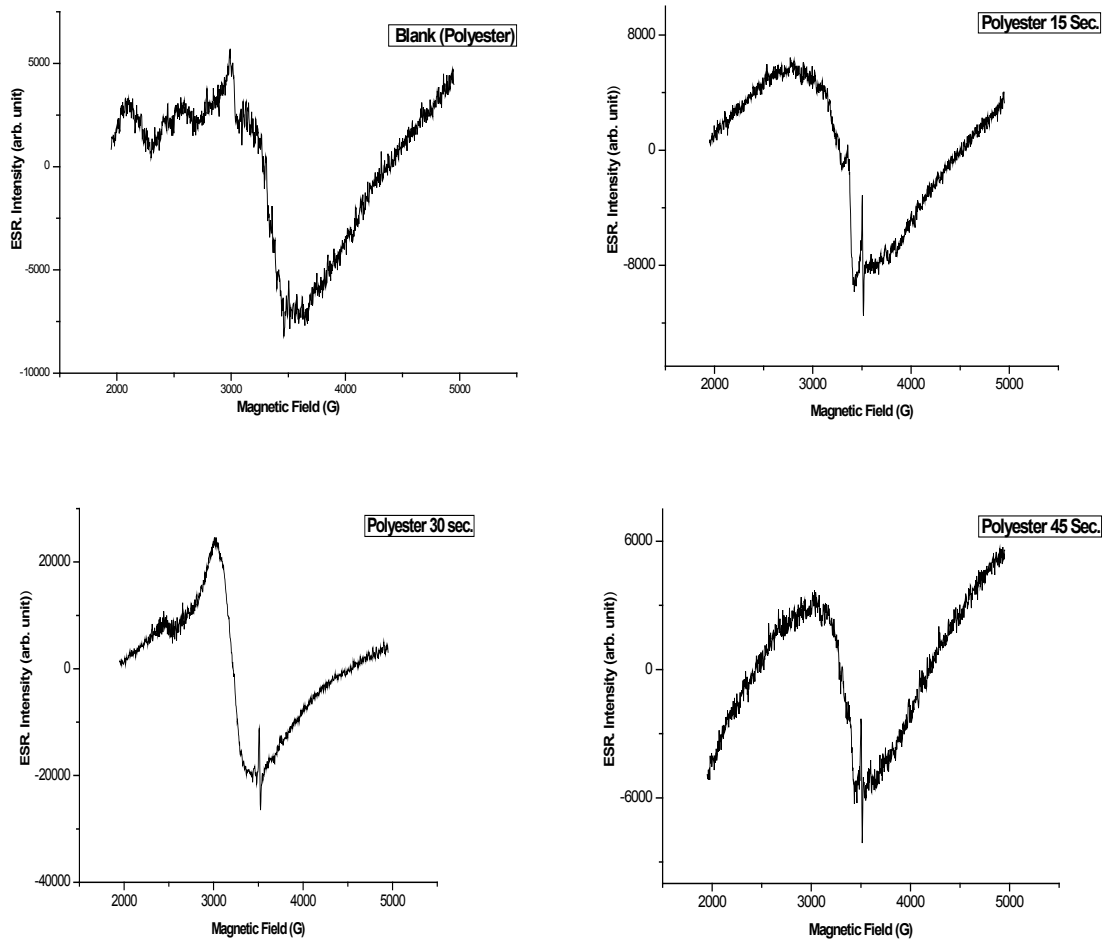
Figures 2 & 3 show the change in ESR Intensity of plasma treated polyester and silk fabrics respectively using oxygen gas at different times intervals (15 – 30 – 45 – 60 – 90 - 120 Sec.), pressure 0.3 Torr and current 45 mA. By following up of the variations in the figures we can conclude that plasma treatment of both silk and polyester samples resulted in more surface activation of them till 30 sec.

TABLE 2. The effect different plasma exposed current on silk and PET treated fabrics.

Current (m.A.)	UPF		Air permeability ($cm^3/cm/S$)		Tensile strength (Kgf)	
	Silk	PET	Silk	PET	Silk	PET
Blank	4.45	14.15	30.61	9.82	67.80	102.76
30	5.06	16.12	30.85	10.24	66.40	113.3
45	5.62	18.60	31.12	11.29	66.30	116.20
55	5.72	16.25	33.46	7.14	65.00	117.30

TABLE 3. The Effect of Different plasma hydrostatic pressures on Silk and PET treated fabrics.

Pressure (torr)	UPF		Air permeability ($cm^3/cm/S$)		Tensile strength (Kgf)	
	Silk	PET	Silk	PET	Silk	PET
Blank	4.45	14.15	30.61	9.82	67.80	102.76
0.2	5.30	14.20	30.84	9.84	67.40	103.00
0.3	5.64	18.60	31.12	11.29	66.30	116.20
0.4	11.22	19.67	34.67	6.99	64.05	91.50



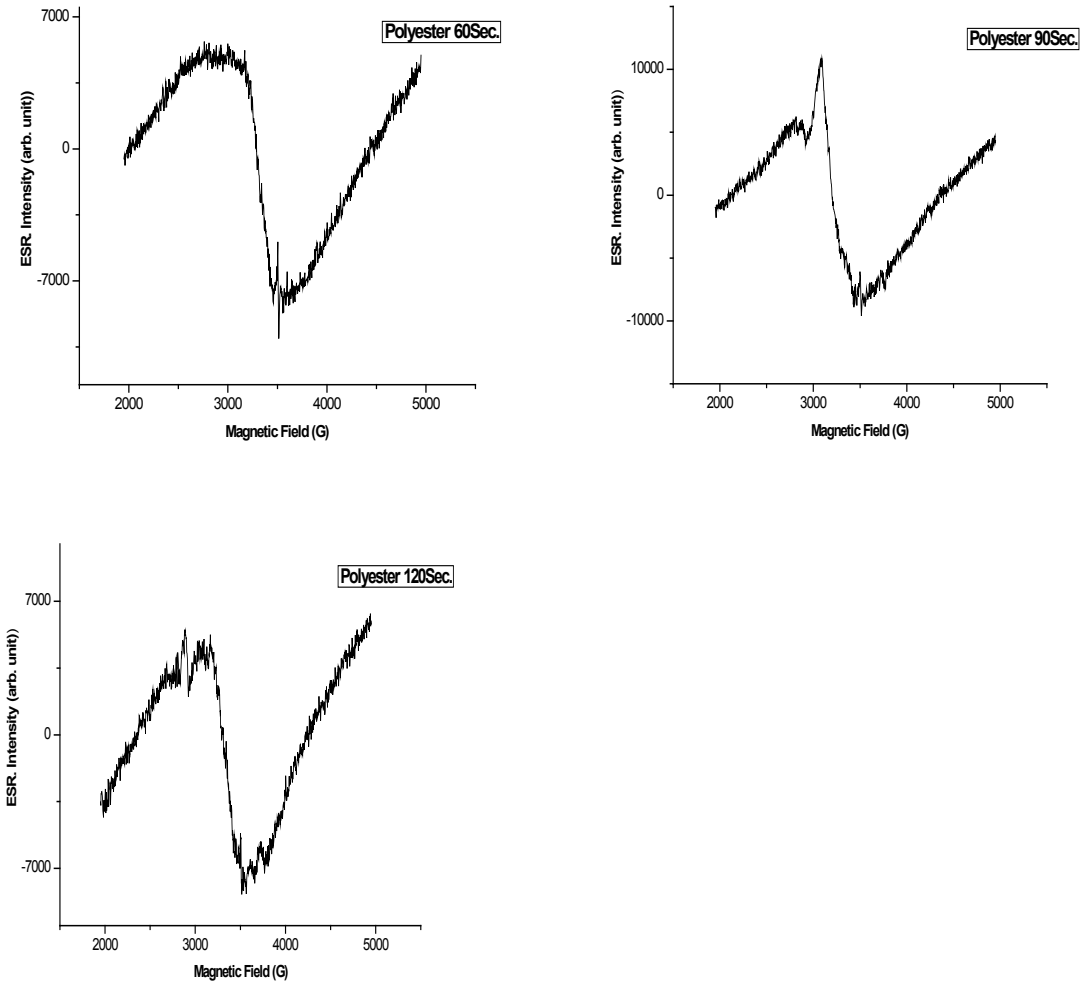
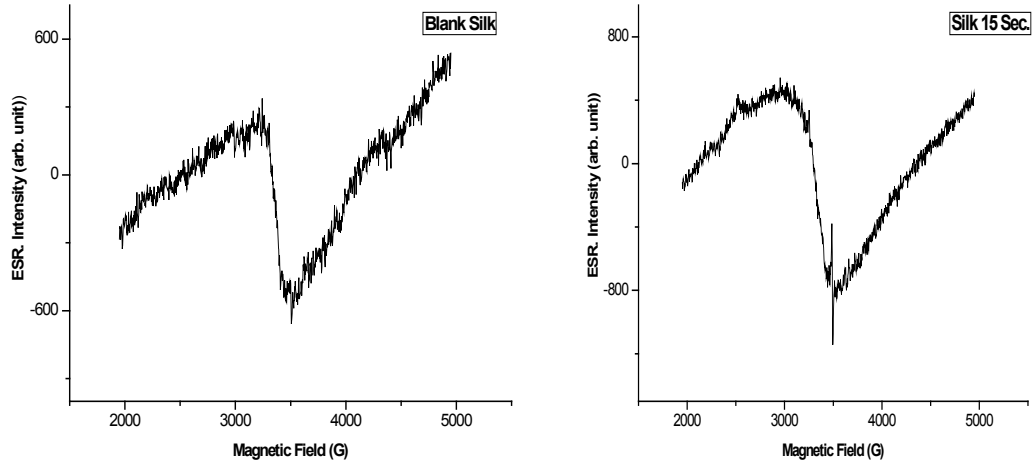


Fig. 2. The change in ESR Intensity of plasma untreated and treated polyester samples at different exposure times



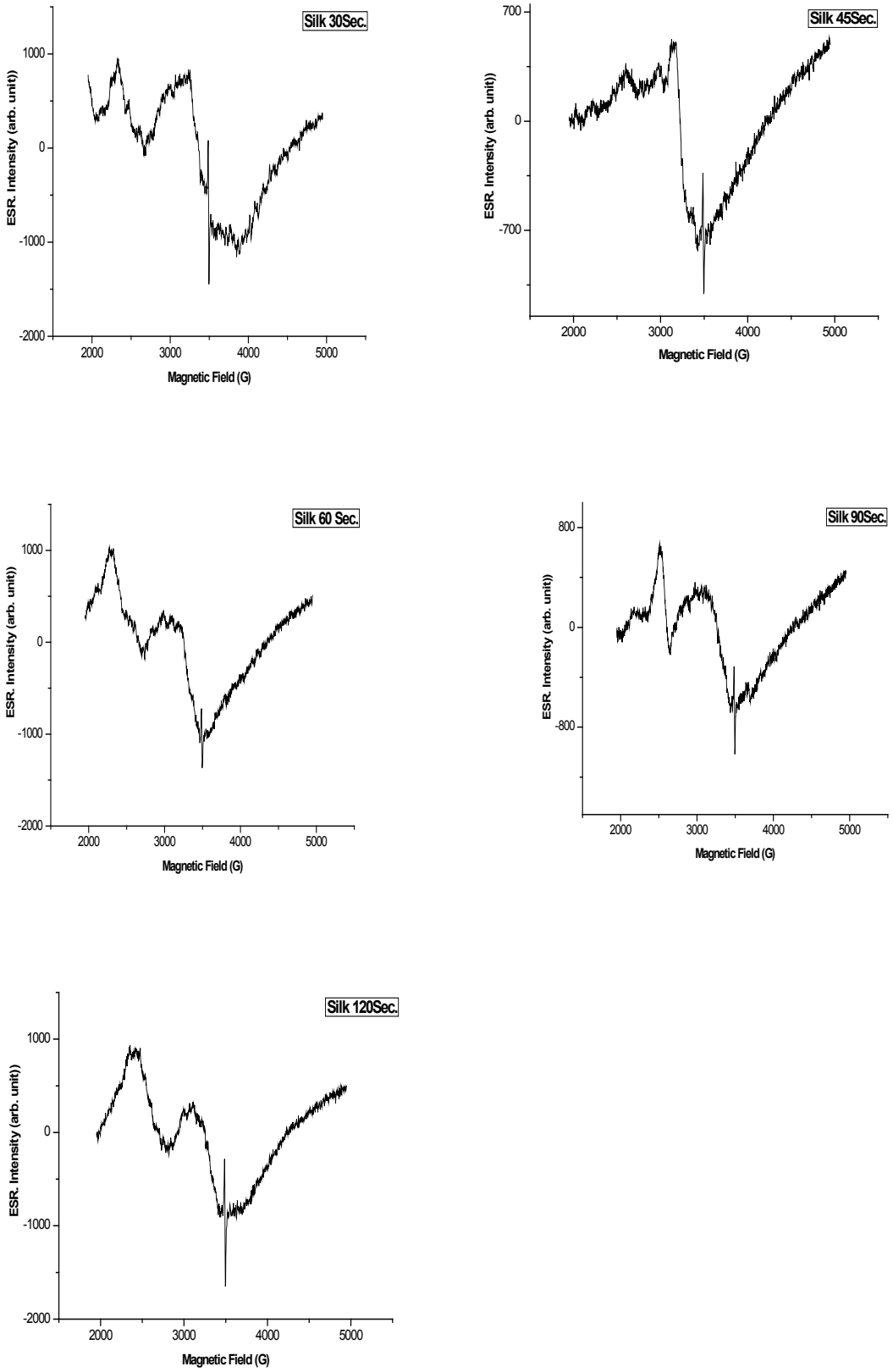


Fig. 3. The change in ESR Intensity of plasma untreated and treated silk samples at different exposure times.

Effect of different plasma pressure

Figures 4 & 5 show the change in ESR intensity of plasma treated polyester and silk fabrics respectively using oxygen gas at different plasma hydrostatic pressure (0.2, 0.3, 0.4 torr.) at current 45 m.A. and exposure time 30 sec. It is clear that there is an increase in peak intensity values for plasma treated silk indicating more surface activity of them up to (0.3) torr. As the same plasma treatment of polyester samples resulted in more surface activation which is influenced by increasing amplitude of pressure extending to 0.3 torr [14].

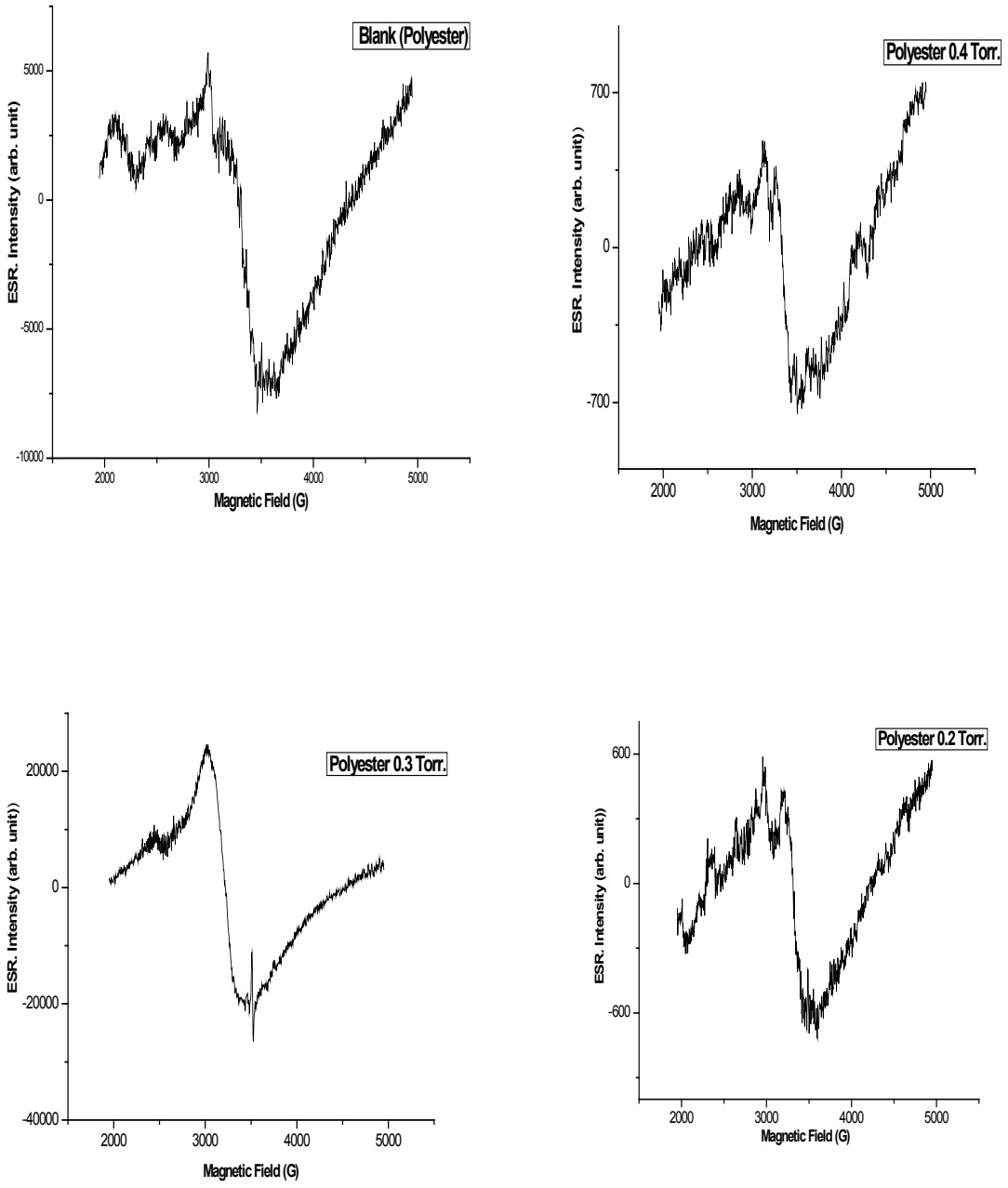


Fig. 4. The change in ESR intensity of plasma untreated and treated polyester samples at different plasma pressure.

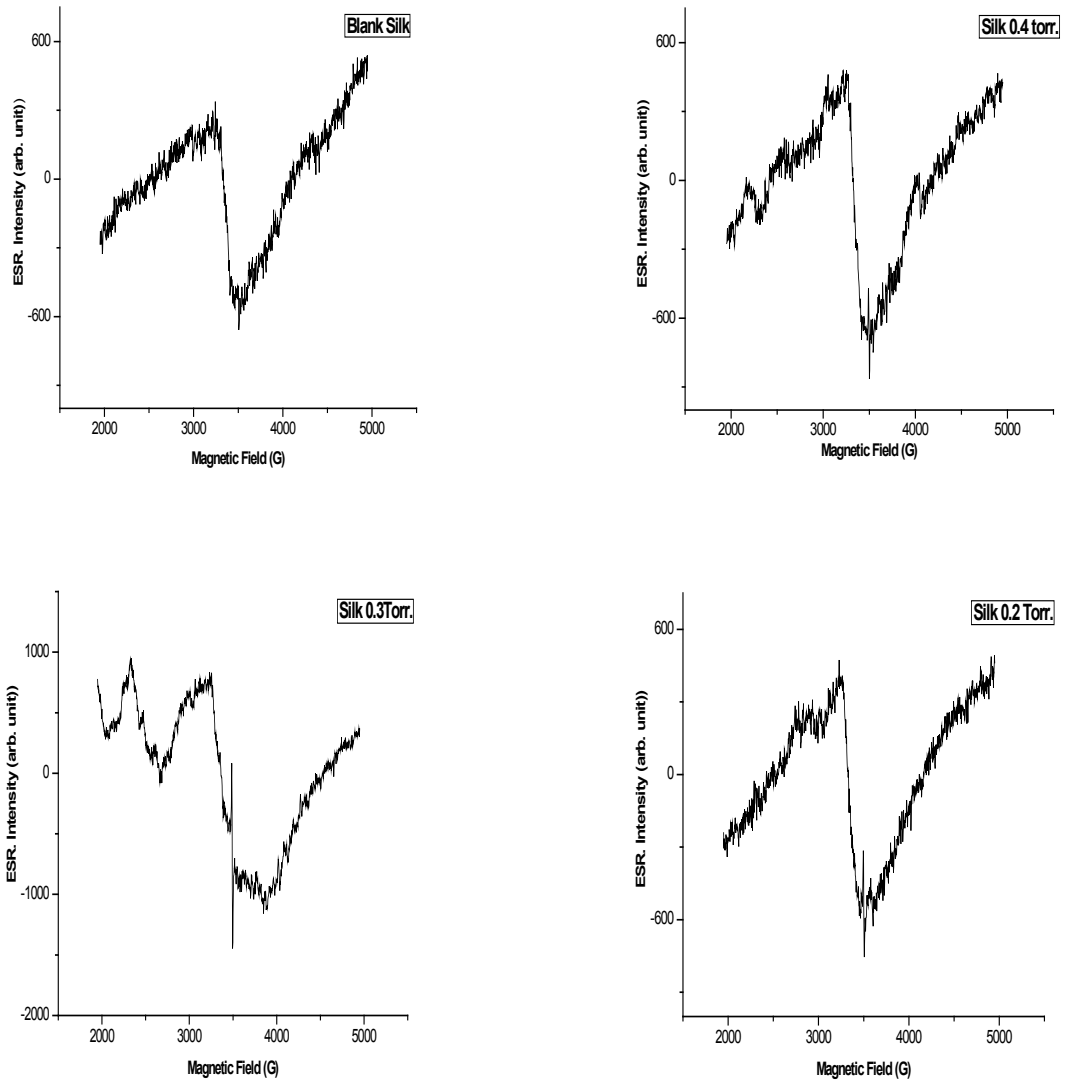


Fig. 5. The change in ESR intensity of plasma untreated and treated silk samples at different plasma pressure.

Effect of different plasma current

Figures 6 & 7 show the change in ESR intensity of plasma treated polyester and silk fabrics respectively using oxygen gas at different plasma exposed current (30, 45, 55 m.A.) at Pressure 0.3 torr and exposure time 30 sec. We can illustrate that there is an increase in peak intensity values for plasma treated silk and polyester samples indicating more surface activity of them up to (45) m.A.

Characterization of the sensitized Nano-silver

The size of the obtained nano particles was found in the range of 7–75 nm using Zeta- sizer technique.

Transmission electron microscopy (TEM)

Figures 8 (a, b) show the shape and size of the resultant particles were eluci-dated with the help of TEM which suggest that the sizes of the particles were around 20-30 nm and the particles were of spherical shape.

UV-Vis spectrum of nano-silver

Figure 9 shows the UV-Vis spectrum of Nano-silver 50 ppm. colloidal solution recorded between (350-600) nm., it is well know that silver nanoparticles show an absorption band in the range of 350-450nm due to the surface Plasmon vibrations of conducting electrons of silver [22,23]. Thus confirming the formation nano- silver in the desiredat 420nm.

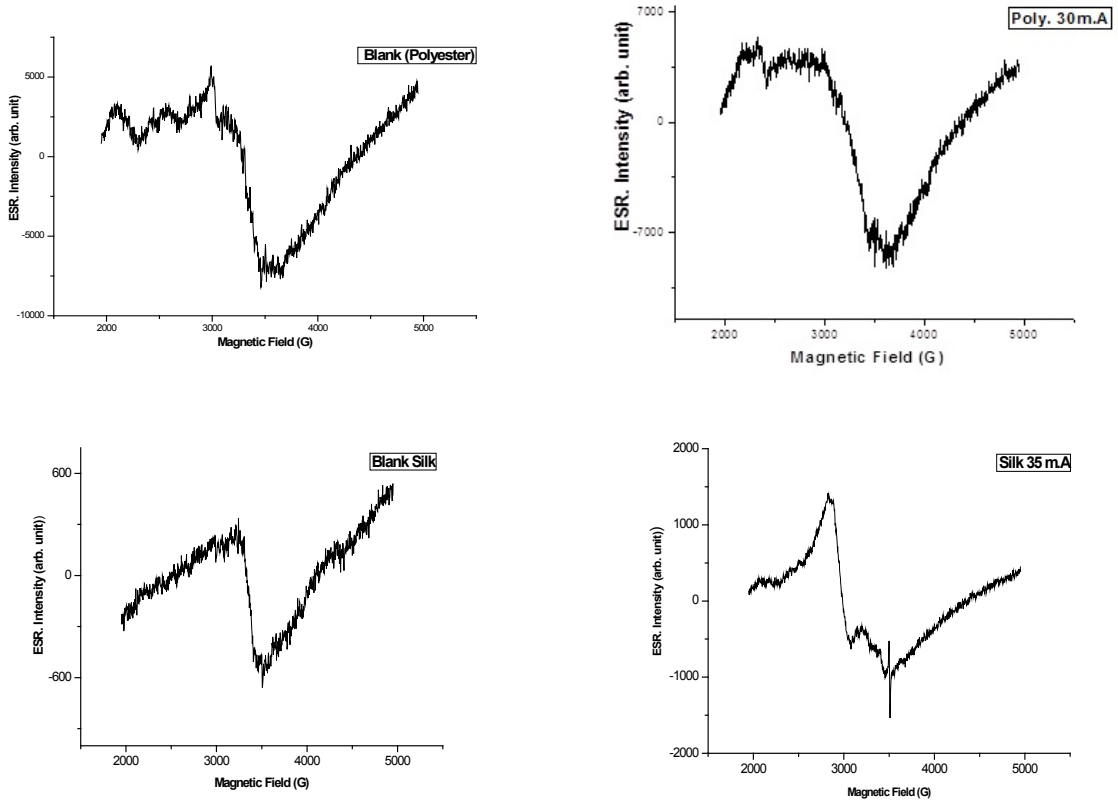


Fig. 6. The change in ESR Intensity of plasma untreated and treated polyester samples at different plasma current.

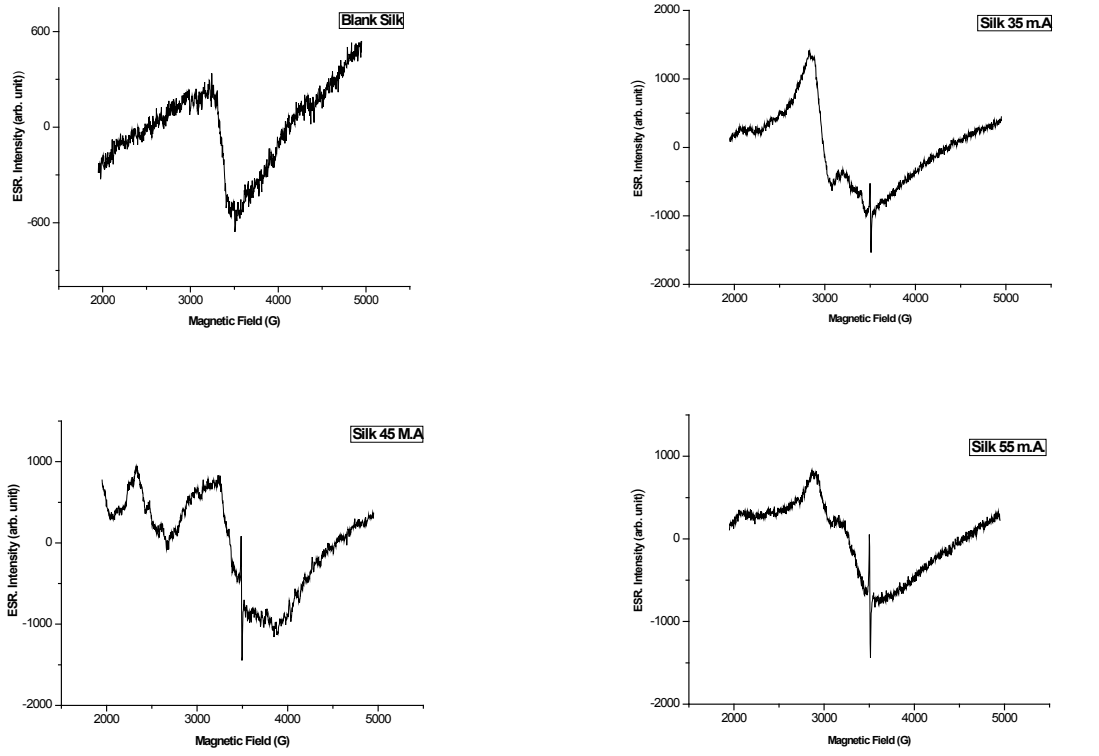
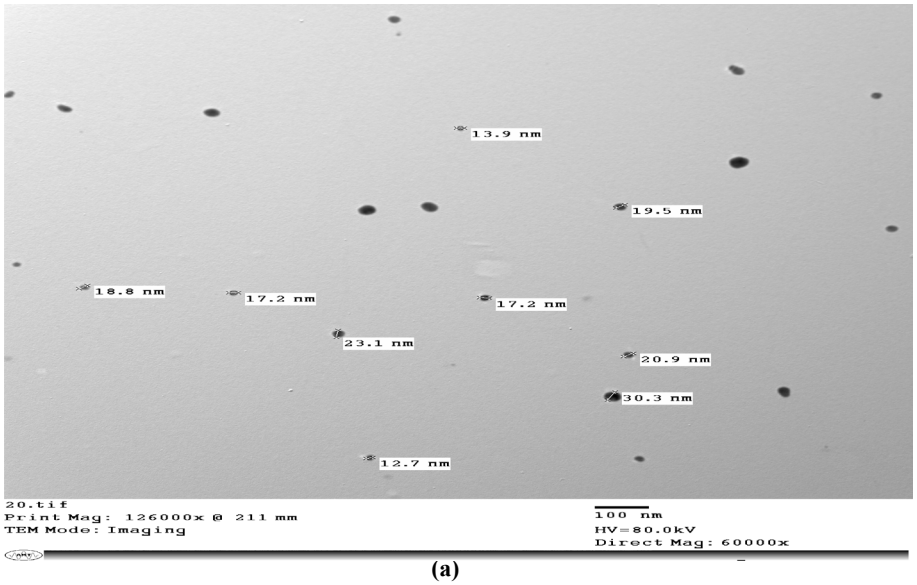
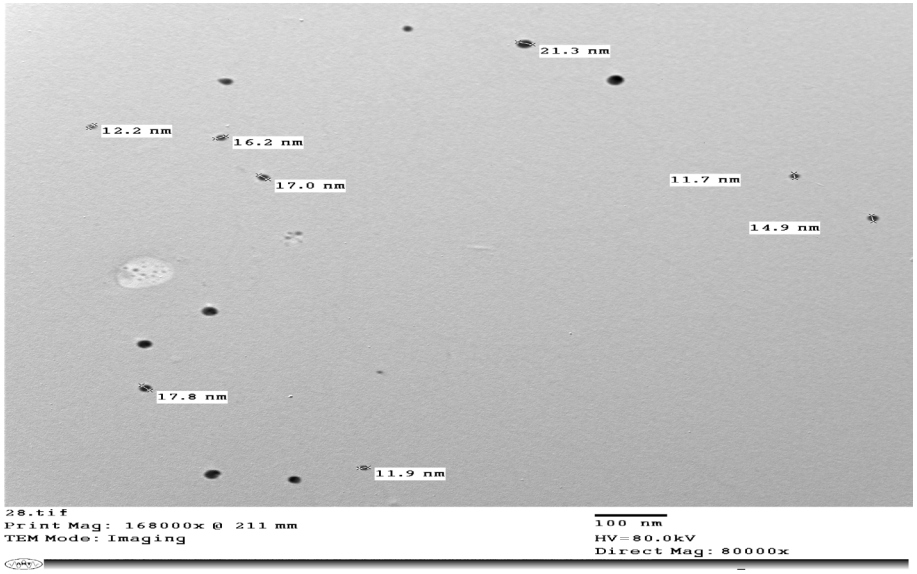


Fig. 7. The change in ESR intensity of plasma untreated and treated silk samples at different plasma current.



(a)



(b)

Fig. 8 (a,b). TEM of synthesized silver nano-particles.

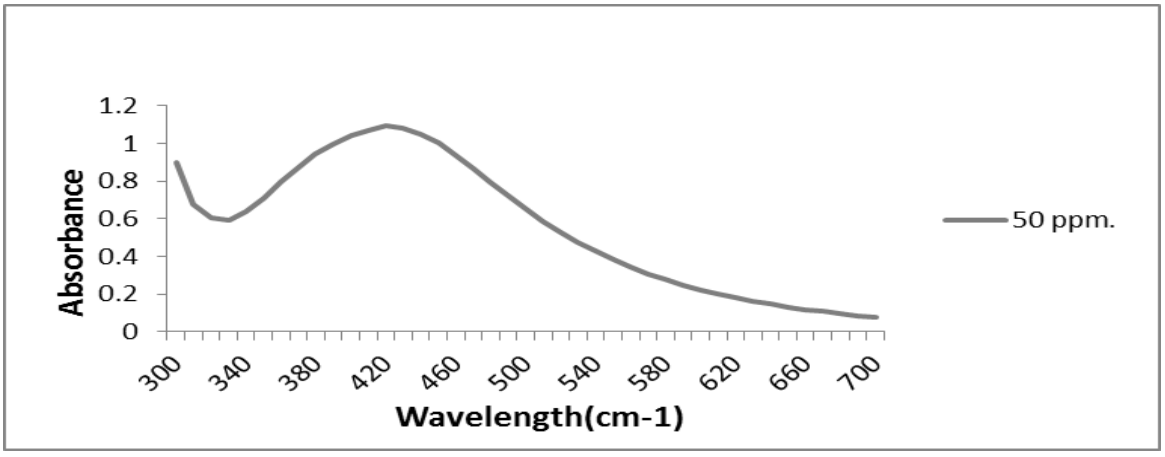
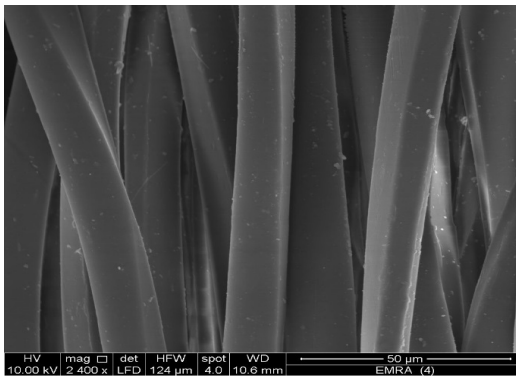


Fig. 9. UV–Vis spectra of 50ppm. Nano-silver colloidal solution.

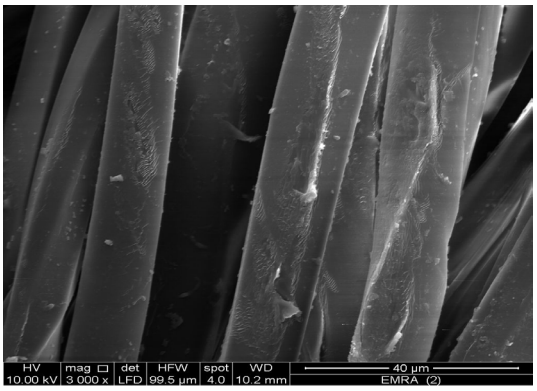
Characterization of optimum plasma treated silk and PET samples.

Scanning Electron Microscope (SEM) and Energy Dispersive X- Ray Analysis (EDX)

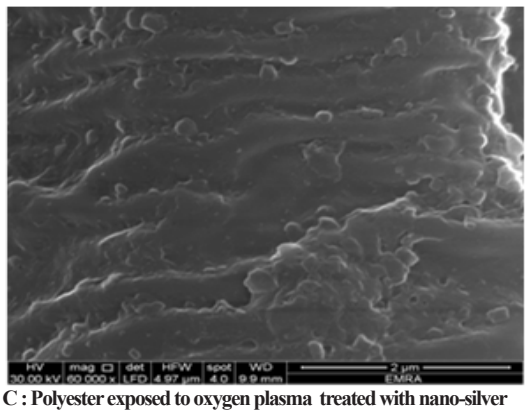
The changes in surface morphology of plasma treated polyester & silk samples in a medium of oxygen gas at the optimum conditions were studied by using Scanning Electron Microscope (SEM). We obtained from Fig. 10 (a-f) that the untreated polyester and silk fabrics have a smooth surface relatively with little grooves, while surface morphology of the exposed polyester and silk fabrics have increase in roughness of surface due to the etching effect of plasma active species bombardment of the fiber surface [24] it is well Known that the plasma treatment of fabrics surface leads to etching, cleaning and activation of the surface(25).While SEM images for polyester & Silk fabrics exposed to O_2 plasma treated with nano-silver the plasma exposure of polyester fabrics have no drastic deterioration in the polyester fibers with their swelling and appearance of some nodes on their surface compared to blank untreated one also treatment of polyester fabrics with nano-silver may resulted also in swelling of the fiber surface polyester with the appearance of some nodes on their surface [9].



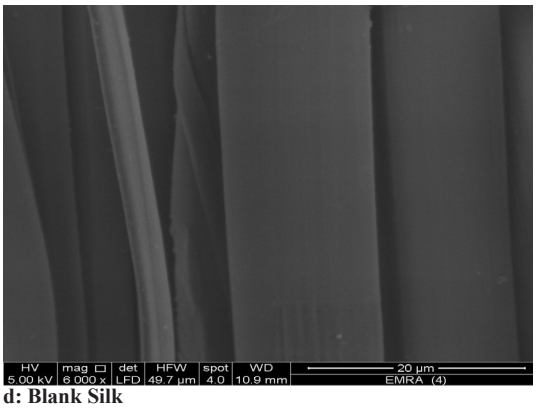
a: Blank polyester



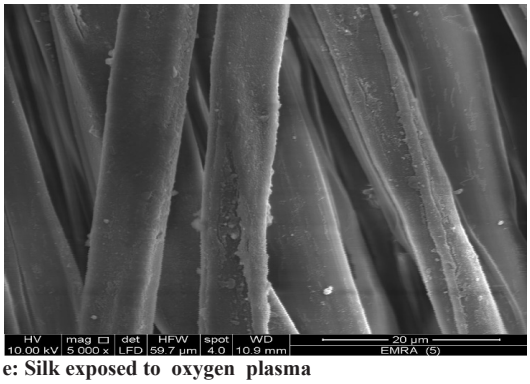
b: Polyester exposed to oxygen plasma



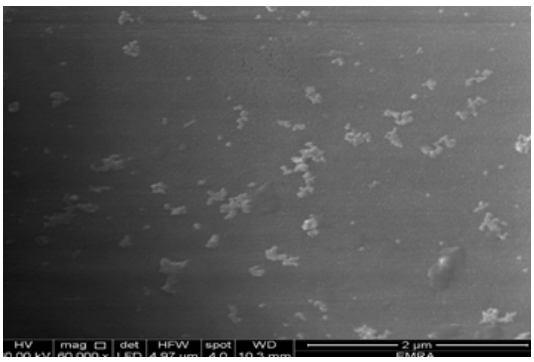
C : Polyester exposed to oxygen plasma treated with nano-silver



d: Blank Silk



e: Silk exposed to oxygen plasma



f: Silk exposed to oxygen plasma treated with nano-

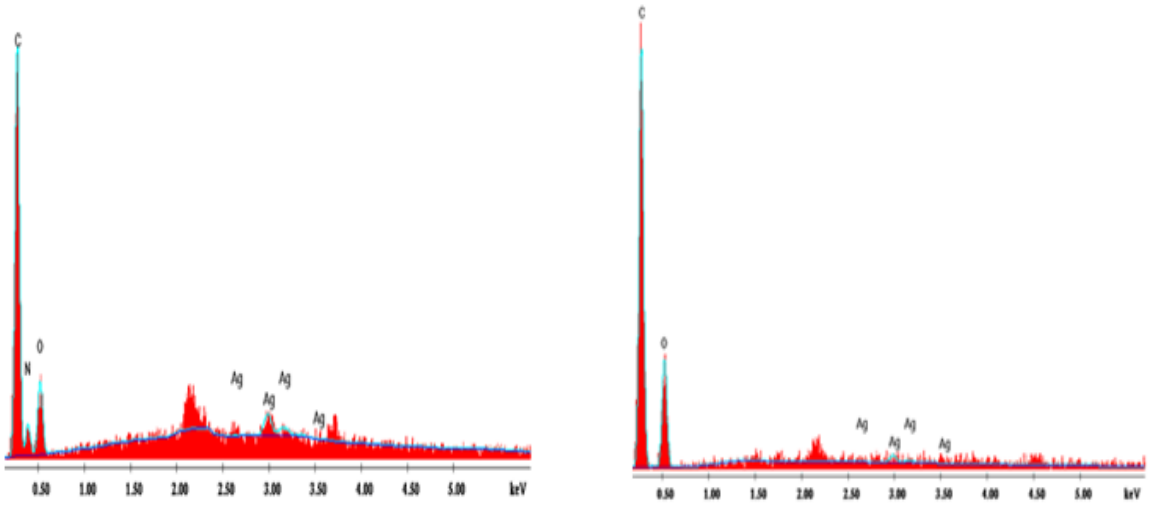
Fig. 10 (a-f). Scanning Electron Microscope (SEM) morphological changes of the samples caused by deposition of silver nano-particles either on polyester or silk samples treated with oxygen plasma.

Figures 11 (a, b) shows EDX spectrum of silver nano-particles treated samples these figures confirm the existence of silver nano-metal. The peak observed at ~ 33.5 KeV is corresponding to the binding energies of Ag no peaks of other impurity have been detected. The results obtained from EDX spectrum together with those of the SEM images are strong evidence of the deposition of silver nano-metal on the surface.

It is very clear from the SEM images that the interaction between the fabrics and the silver nano-metal results from plasma physical effect on the fabric surface, plasma causes in the formation of very small pores and cracks in the size of nanometer on fabrics surface [26].

Antimicrobial properties

The changes in antimicrobial properties of plasma treated polyester & silk samples in a medium of oxygen gas using the optimum conditions and 50 ppm. nano-silver was shown in Table 4, all examined silk and polyester fabrics was evaluated towards gram negative bacteria (*Escherichia coli*), and gram positive bacteria (*Staphylococcus aureus)* after the specified contact time (24h.), where the examined sample were washing and their activity were calculated by measuring inhibition zone against the growth of each bacteria type and the numbers is given in Centimeter. The results indicated that the combination of nano-silver and plasma treatment of polyester and silk fabrics showed very good activity against both type of bacteria by applying low content of nano-silver particles (50 ppm).



(a) (b)

Fig. 11 (a, b). EDX spectrum of silver nano-particles treated samples.

TABLE 4. The changes in antibacterial properties of different examined plasma treated Silk and polyester samples.

Fabric	Bacteria name	Blank	50ppm. AgNPs & oxygen plasma
Polyester	*Escherichia coli* (Gram-negative)	0	2.3
	Staphylococcus aureus (Gram-positive)	0	2.1
Silk	*Escherichia coli* (Gram-negative)	0	2.6
	Staphylococcus aureus (Gram-positive)	0	2.3

Note: Where the examined sample after washing, the numbers are given in centimeter.

Conclusion

In this article we evaluate the effect of treated silk and polyester fabrics using plasma oxygen and/or nano silver on mechanical properties, UPF and air permeability. The results showed that UPF values has no significance effective for silk fabrics but they still poor protective, while it increased for polyester and the treated polyester fabric became good or excellent protective. Also results of mechanical properties confirm that plasma treatments can be used on silk yarn without significant adverse effect on the physical properties of the fibers, while for treated polyester it increase up to 30 sec and increase by increasing exposed current and pressure up to 0.3 torr. Air permeability properties increase for treated silk fabric by increasing time, current and pressure of exposed but for treated polyester fabrics it increase up to 45 sec. time exposed, current 45mA and up to 0.3 torr of pressure. The SEM images showed that plasma and or nano silver treatment of polyester and silk fabrics increase in roughness of surface due to the etching effect of plasma, also SEM images show that the interaction between the fabrics and the silver nano-metal results from plasma physical effect on the fabric surface. Finally, antibacterial properties were highly improved by the treatment of fabrics.

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توصيف وتقييم أقمشة البوليستر والحرير المعالجة باستخدام تقنية الطاقة النظيفة المتقدمة

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يهدف هذا البحث إلى دراسة معالجة سطح أقمشة البوليستر والحرير من خلال تعريضها للبلازما الباردة المفرغة. فى البداية تم تعريض عينات القماش للبلازما من جهاز توليد البلازما المعد لذلك عند ظروف تشغيل مختلفة تشمل أختلاف الوقت , الضغط الهيدروليكى و التيار الكهربى باستخدام غاز الأكسجين. تم توصيف الأقمشة المعالجة عن طريق قياس وتقييم الخواص الميكانيكية ، ونفاذية الهواء ، والرنين المغزلي للإلكترون (ESR)، ودراسة التغيرات في التشكل السطحي للأقمشة المعالجةالتى تم تمييز ها باستخدام ميكروسكوب الماسح الالكترونى (SEM) وتحليل الأشعة السينية في تحليل الطاقة ((EDX) .

ثم تم إنتاج الفضة النانوية بتطبيق طريقة الأنتاج الخضراء لجزيئات الفضة النانوية وتم توصيفها ياستحدام المبكروسكوب الإلكتروني النفاذ (TEM) وفزق الجهد زبتا وحجم الجسيمات ، ثم تم معالجة الأقمشة المعرضة للبلازما في الظروف المثلى مع الفضة النانوية المحضرة. وقد تم تقييم النشاط المضاد للبكتيريا للأقمشة المعالجة ضد البكتيريا إيجابية الجرام (المكورات العنقودية الذهبية) والبكتيريا سالبة الجرام (الإشريكية القولونية). أظهرت النتائج ارتفاع قيم UPF لكل من الأقمشة المعرضة ولكن الزيادة ليست كبيرة في الأقمشة الحريرية بينما تم تحسين خصائص مضادة للجراثيم بشكل كبير عن طريق معالجة القماش.