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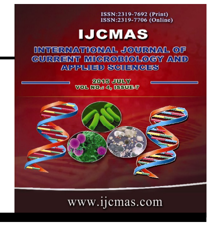

Original Research Article

Microwave and Plasma Treatments for Functionalization of Polyester Fabrics

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Keywords

Plasma, Microwave, Polyester, functionalization, Silver nanoparticles

A B S T R A C T

This work will focus on the use of recent developments, mainly nanotechnology, plasma, and microwave for functionalization of textile fibers which refers to improvement in dyeability, interaction with metal nanoparticles mainly (silver nanoparticles) to impart antibacterial activity to the fabric. Microwave dyeing was carried out under a variety of conditions in terms of the power and time of a microwave. It was observed that the microwave treatment significantly improves dye ability, and eliminates the use of (carrier). Plasma treatment was carried out under a variety of conditions in terms of (time, flow rate and types of gas).To investigate the effects of microwave and plasma on the dye ability of polyester fabrics (PE)the surface morphological changes of the fibers were observed by scanning electron microscopy (SEM). Scanning electron microscope results displayed that structural modifications take place, which outcome surface roughness and voids that improve the dye uptake. It was found that plasma treatment enhancethe dyeing ability of the polyester as well as the fastness properties. The quantity of silver on the fabrics was determined by the use of the corresponding composition analysis (EDX). The antibacterial activity of functionalized fabrics was tested according to American Society for Testing. Silver nanoparticles antibacterial activity found to be with an acceptable level(>80%).

Introduction

Textile materials have intrinsic properties that make them very valuable in terms of flexibility, light weight, strong strength, and large surface to volume ratio, good touch, softness, etc. They are excellent for imparting additional functionalities. Typical examples of such functionalities are hydrophobic, oleophobic or antibacterial. To achieve this, traditional wet methods were used for applying those finishes that require large amounts of chemicals, water and energy. On the contrary microwave and plasma are dry processing techniques that provide a solution to reduce the use of these three resources.

The mechanism of microwave heating can be explained as follows. Many materials with large dipole moments, such as water, are rotated or vibrated vigorously in the presence of a magnetic field caused by the frequency of the alternating current of a microwave (the 2,450 MHz microwave is used in Japan), and are then heated by quick energy conversion from the above kinetic energy. As a result, microwaves can usually heat various materials more quickly and homogeneously than conventional methods, which indirectly uses low-heat transmission, such as heat conduction or heat convection [1-6].

Microwave irradiation has been successfully applied to a number of classical reactions [7-11]. The most important advantages of microwave irradiations are that it is a non-contact, localized, rapid, uniform, energy saving and pollution free heating process. The textile industry has extensively investigated uses of microwave energy for heating, drying, dye fixing, and finishing with short heating time and low energy cost.[12-15].Microwave is a volumetric heating (fast), whereas conventional is a surface heating (slow) as shown in figure 1.

Plasma technology is an environmentally friendly technology and a step towards creating solid surfaces with new and improved properties that cannot be achieved by conventional processes [16].

Compared with current standard finishing processes, Plasma is considered a dry process which has the crucial advantage of reducing the usage of chemicals, water and energy [17]. Moreover, they offer the possibility to obtain typical textile finishes without changing the key textile properties [18, 19]. No wonder the interest in plasma for textile materials processing is increasing. Since the first adaptors are appearing from the textile side and plasma equipment manufacturers are showing an increasing interest in the textile market.

In this work microwave and plasma treatment were applied to improve dye ability of PE fabric, eliminate or reduce the use of chemicals (carrier) and interaction with (silver nanoparticles) to impart antibacterial activity to the fabric

Experimental

Materials and instrumentation

Washed unfinished Polyester fabric (PE) having 1/1 plain weave structure and of 122 g/m^2 weight. Fabrics purchased from Misr for Spinning and Weaving Company, Mahalla El-Kobra, Egypt. Disperse dyes, Coloring substance used in this work was: Disperse red 19 as shown in figure2from dye star company.

Microwave treatment: Daewoo electronic - Coria, Model KqG-1N4A of maximum power 1000 W.

Plasma treatment

Dyeing of polyester fabrics using conventional method

PE fabric samples (1.5g each)(untreated-treated with microwave- treated with plasma)were dyed with the disperse dye under our study at liquor ratio (LR) of 1:50. Dyeing was performedat different concentrations of dye (1, 2, 3% respectively based on the fabric weight). The dispersing agent was addeddrop wise ($2gm/dm^3$) tothe dye, thenthe dye was suspended in a fine dispersion ready for use in dyeing. The dye bath (1:50 liquor ratio), Containing $5gm/dm^3$ carrier, 3% acetic acid at PH 5.5, was brought to 40°C, the polyester fabric was filed and continued for 15 min. the fine dispersion of the dye was supplemented, and the temperature was elevated to (85°C-95°C) within 30 min, dyeing was maintained at this temperature for about 1h, then the dyed material was washed off and soaped with 2% nonionic detergent as exhibited in figure 3.

Method of preparing Nano silver particles

The nano sliver particles in this study was prepared according to method described in literature [20].

SEM and EDX photographs

The Scanning Electron Microscope (SEM) photographs and the corresponding composition analysis (EDX) performed for samples using QUANTA FEG 250, company FEI. They are used to analyze the surface morphology of conventionally and microwave, and plasma treated polyester fabrics.

Color Strength (K/S) measurement

The color strength was performed using spectrophotometer; model CM-3600A, manufacturer KNOICA MINOLTA, Japan.

Mechanical testing

The tensile strength and percentage elongation at break of untreated and treated samples were accomplished according to the Standard Method (ASTM 2000) using a Shimadzu Universal Tester of (C.R.T)-type S-500 Japan.

Antibacterial activity test

The antibacterial activity was assessed quantitatively against gram positive bacterium (S. aurous) and gram negative bacterium (E. coli) of the untreated and treated polyester fabrics with a colloidal solution of silver nanoparticles using reduction (extraction,) method [21].

Assessment of color fastness

Fatness to washing was performed using AATCC.61 Test method [22]. Fastness to light was performed using AATCC.16 Test method [23]. Fastness to rubbing was evaluated according to AATCC.8 Test method[24].

Results and Discussion

Factors affecting dyeing of microwave treated fabrics

Dye concentration

As is evident in figure 4, increasing the dye concentration from 1% to 3% brings about a noticeable increase in the K/S value, this probably due to more amount of dye diffuses into and react with the polyester fiber.

Increasing K/S of the microwave treated fabric than untreated fabrics when using 1% dye may be attributed to the structural rearrangements of the molecular chains as a result of the microwave radiation. Interacting with molecular chains of PE, forcing them to reorient and arrange in a compact form. The changes may be attributed not only to heat, but also to electromagnetic field of microwave interacting with polymer chains.

The crystallites grow and orientation of chains takes place with new structure having minimum energy. In the process voids are formed, oligomers come out and are seen by SEM and dyeing experiments. Once these chains come near to each other intermolecular bonds are formed and a new cohesive structure results yielding higher crystallinity, so microwave treatments can be highly beneficial for enhancing the dyeing properties [25].

Effect of treatment time

The effect of treatment time on k/s of the PE fabrics has been carried out at different concentration (1%,2%,3%). Figure5 shows that at concentration 1%, increasing time of microwave treatment significantly improve k/s (15.16), however for high concentration (2%, 3%) the k/s decreased to (12.22, 18.51) respectively.

Effect of microwave power

As shown in figure6the power of microwave will impact on the k/s of the treated fabric and the best result obtained at (100%)[26, 27].

Effect of carrier

One of the advantage of microwave radiation that it reduce or eliminate the use of chemicals. As shown in figure7, dyeing without carrier after microwave treatment resulted in abetter K/S than conventional dyeing.

Factors affecting dyeing of plasma treated fabrics.

Figure 8(a,b) show that increasing K/S of the treated fabric with plasma than untreated fabrics when using 1% dye may be attributed to hydrophilic group and a more cross-linked surface in polyester.[28,29] It is suggested that the building-up of the polar groups was higher at (medium, high) radio frequency while a good hydrophilization effect can be already obtained after a short time (maximum 4 min). The attachment of surface polar groups increases the wettability of the polyester thus improving the adsorption of dye. Better adsorption consequently leads to better treatment.

Fastness properties

Fastness to washing

The color fastness to washing of the different examined dyed samples was determined according to standard methods. The results of washing fastness for all of the examined samples are summarized in table (1). These data showed that the microwave, plasma treatment has no diverse effect on washing fastness.

Fastness to light

The light fastness results are good and acceptable showing little fading of light shades in the untreated dyed polyester fabrics. These data presented that there was a slight effect of Microwave, plasma treatment in improving light fastness. The results of light fastness for all of the examined samples are summarized in table(1) and ranged (5-6).

Fastness to rubbing

The results of rubbing fastness for all of the examined samples are summarized in table (1). The results obtained revealed that dyed fabrics (treated-untreated) have excellent fastness levels to both wet and dry rubbing.

Effect of microwave and plasma treatment on the mechanical testing of PEfabrics

The changes in the mechanical properties (tensile strength and percentage elongation) of blank untreated PE fabrics and those exposed to plasma and microwave treatments are assessed and the attained results are symbolized in table (2).In the case of microwave treatmentthese results showed that the tensile strength increase initially and then decreasedue to fact that increasing time of treatment considerably deteriorate the tensile properties of polyester fabric and the deterioration of polyester fabric may be attributed to formation of weak spot on fiber surface due excessive etching process however, in plasmathis slight enhancement in the tensile properties may be a result of the plasma etching of the fibre surface, which causes severity of surface roughness and thus the combined effect of fibre to fibre friction due to etching (30).

SEM analysis

SEM observation of the polyester fibers reveals that the untreated fabric has fairly smooth surface, but the surface morphology of the treated fabrics has been changed dramatically and there are different features on the surface of the fibers, such as grooves and voids and surface roughness, the plasma and microwave treated fabric has holes on the fiber surface which serve as entry sites for dye molecules leading to better dyeing rates. The ablation effect of this treatment which is characterized by holes in Figure 9(a-c) [31] could have added to the surface area of the fiber which coupled with the enhanced wetting due to the attachment of surface polar groups provided better wetting and hence cause a possible enhancement of dyeing rates.

Antibacterial activity

Antibacterial effect of silver nanoparticles on polyester fabrics

The SEM images of the polyester fabrics in Figures 10(a-c)reveal that the untreated fabric has fairly smooth surface, but the surface morphology of the treated fabrics show the homogeneous deposition of silver nanoparticles on polyester fabrics after treatment with silver nanoparticles.

Figures 11(a-c), Figure12 (a,b)SEM-EDX micrograph confirmed the presence of silver nanoparticles which (bound to the fibre surface - bound to the edge of the fiber - incorporated into fibre). These results exhibited development of the quantity of silver nanoparticles that incorporated into fiber than on fiber surface or on the edge of the fiber.

Table [3] displayed that implementation of PE fabrics with small-sized silver nanoparticles has superior antibacterial effect, which can be correlated with the deposition of silver nanoparticles, so very small amount of colloidal silver can supply the textile fabrics with good antibacterial activity. [32].

Conclusion

The present work aimed to green processing of polyester fabrics using recent innovative technologies, viz., microwave, plasma and nanotechnology for functionalization of fabrics which refers to improvement in dyeability, interaction with silver nanoparticles to impart antibacterial activity to the fabric. These recent technologies are economically feasible, secure, and acquire superiority over other traditional methods such as, reduce chemicals and auxiliaries need for dyeing polyester fabrics. The influence of microwave treatment on polyester fabric was investigated.It is observed that the microwave irradiation eliminated the use of (carrier). Also, the color strength expressed as K/S of microwave treated PE was higher than untreated one. In case of plasma it is found that plasma treatment improves dyeability due to increment of polar groups which increases the wettability of the polyester thus improve the dye uptake.

Table.1 Fastness properties of PE fabrics

No. of sample		Fastness to washing		Fastness to light		Fatness of rubbing	
Microwave treatment		T	U	T	U	T	U
M	3 min	4-5	4-5	5-6	4	5	4
plasma treatment		T	U	T	U	T	U
P	4 min	4-5	4-5	5-6	4	5	4

T= treated; U= untreated
M : treated PE fabric with microwave for 3 min with 1% dye.
P : treated PE fabric with plasma for 4 min at radio frequency(RF): HI with 1% dye.

Table.2 The changes in the mechanical properties of the treated PE Fabrics with microwave irradiation and plasma treatment

fabric	Tensile strength (Kg.f)	Elongation (%)
untreated	31	32%
microwave		
Treated 1 min	32	33%
Treated 2 min	31.5	32%
plasma		
Treated L2	32	34%
Treated L5	33	34%

L2 : treated PE fabric with plasma for 2min at radio frequency(RF): low
L5 : treated PE fabric with plasma for 5 min at radio frequency(RF): low

Table.3 The antibacterial properties (bacterial reduction) of PE fabrics treated with nano-sized silver colloid

Fabric	Bacterial reduction (%)	
	S. aureus	*E. coli*
Blank	0	0
Treated with silver nanoparticles	96.4 %	96%

Figure.1 Microwave heating (volumetric) versus conventional heating (surface)

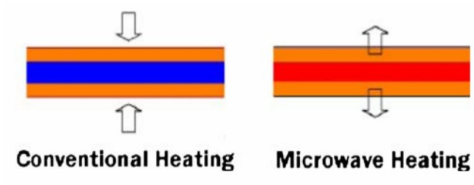


Figure.2 Chemical structure of disperse red 19

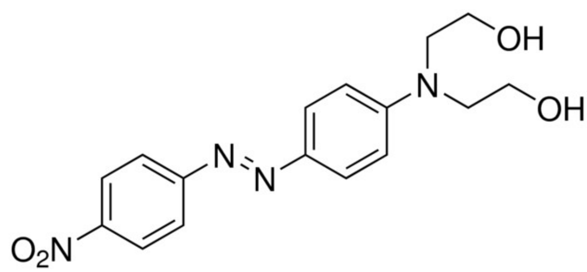


Fig.3 Dyeing method of PE fabrics

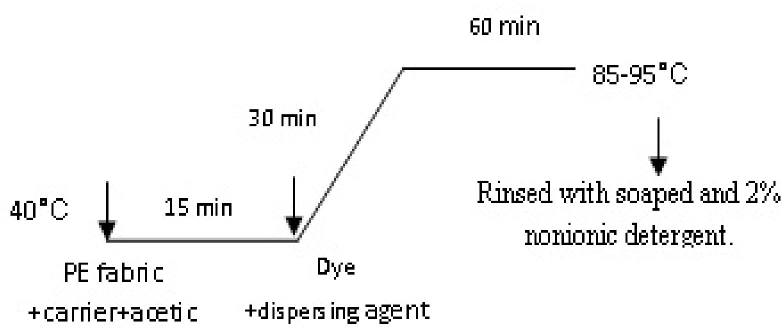


Figure.4 Effect of concentration of dye on the K/S of the treated PE fabrics

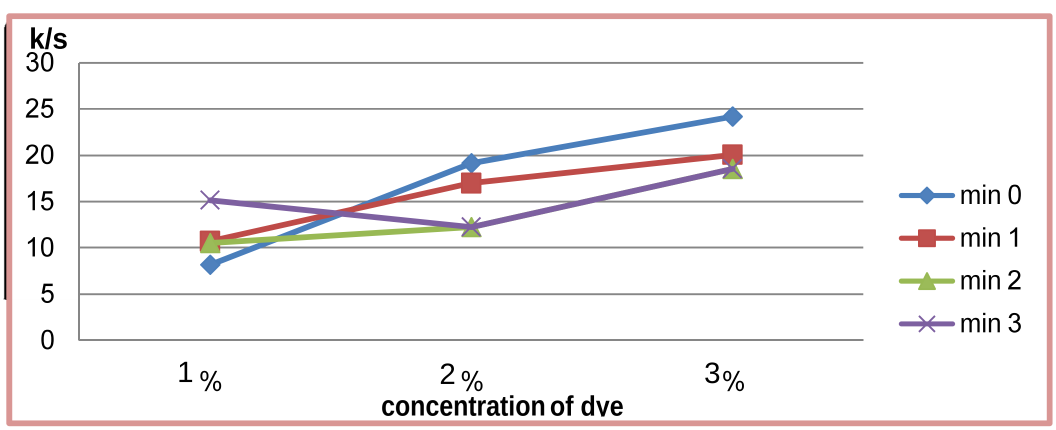


Figure.5 Effect of time of microwave on the k/s of the treated PE fabrics

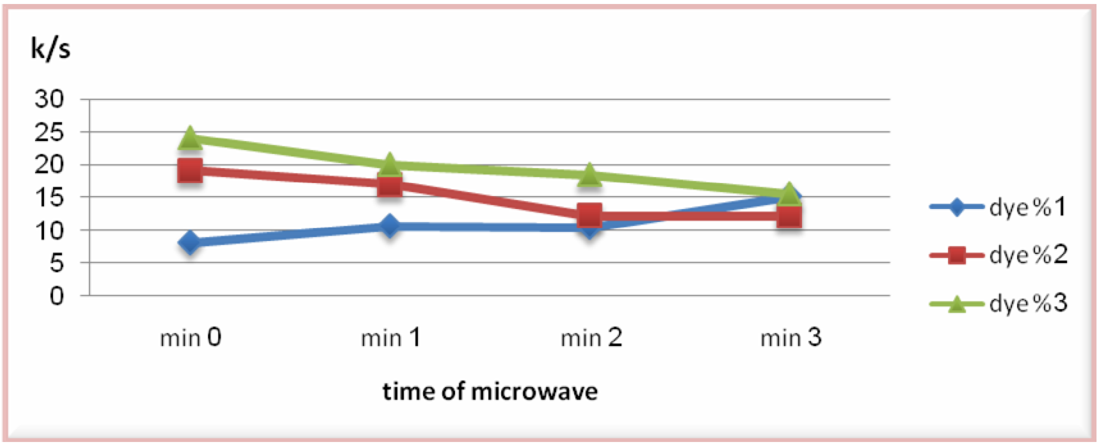


Figure.6 Effect of power of microwave on the K/S of the treated PE fabrics

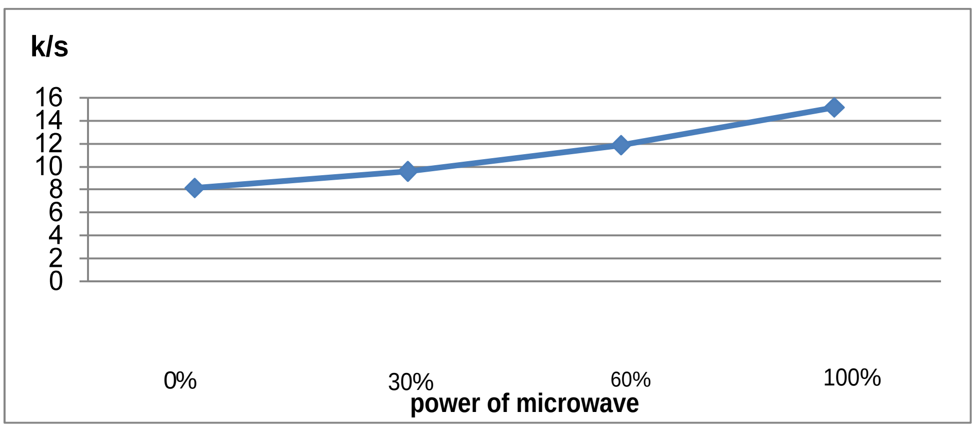


Figure.7 Effect of carrier on the k/s of the treated PE and untreated PE fabrics

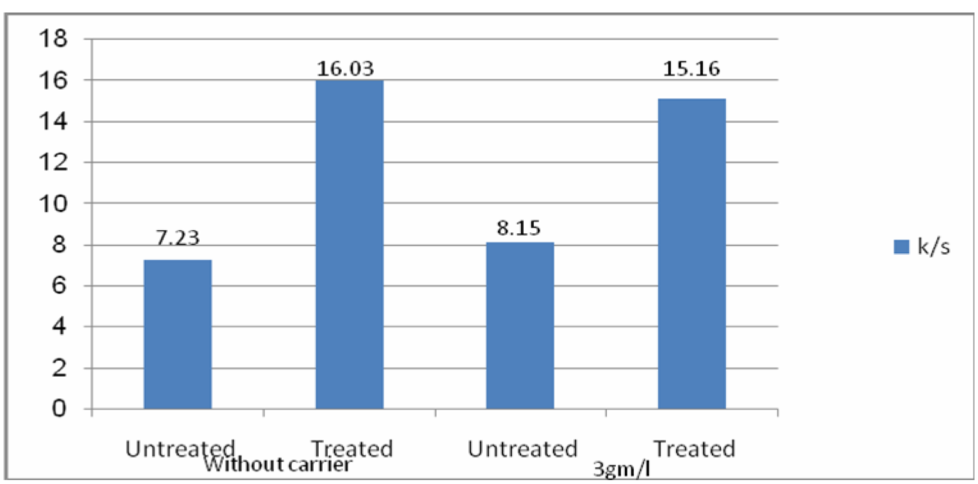


Figure.8 (a) Effect of time of plasma on the k/s of the treated and untreated PE fabrics, (b) Effect of RF of plasma on the k/s of the treated PE fabrics

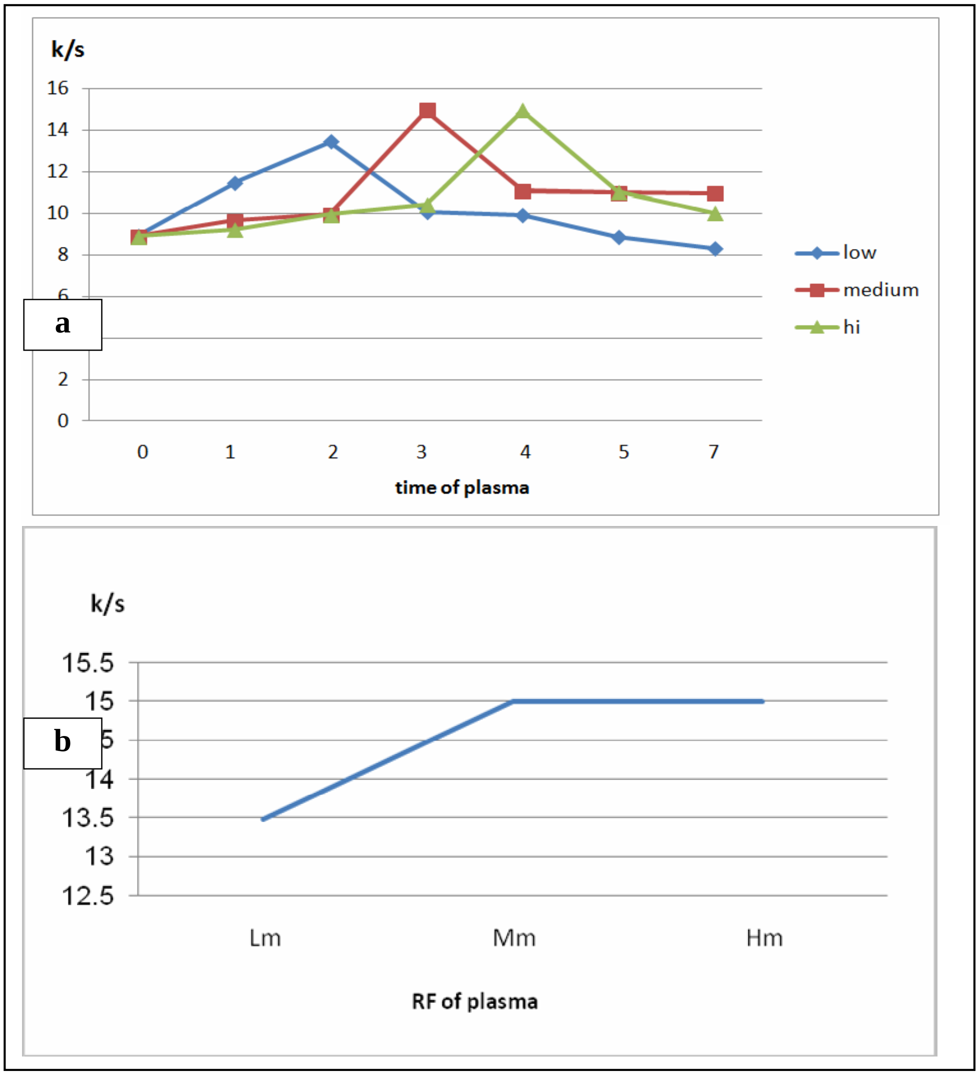
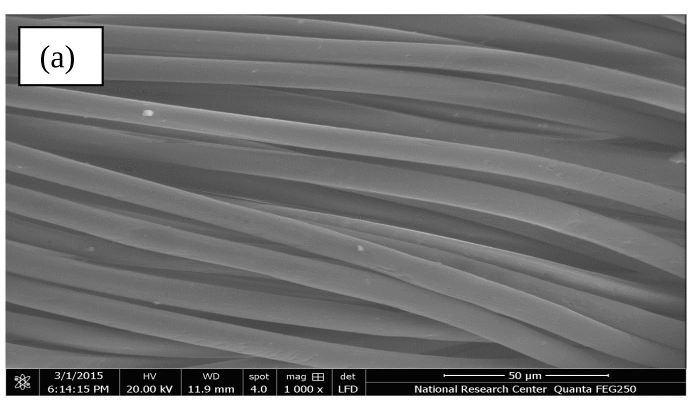


Figure.9 (a)the SEM image of PE without treatment, (b) the SEM image of treated PE with microwave, (c) the SEM image of treated PE with plasma



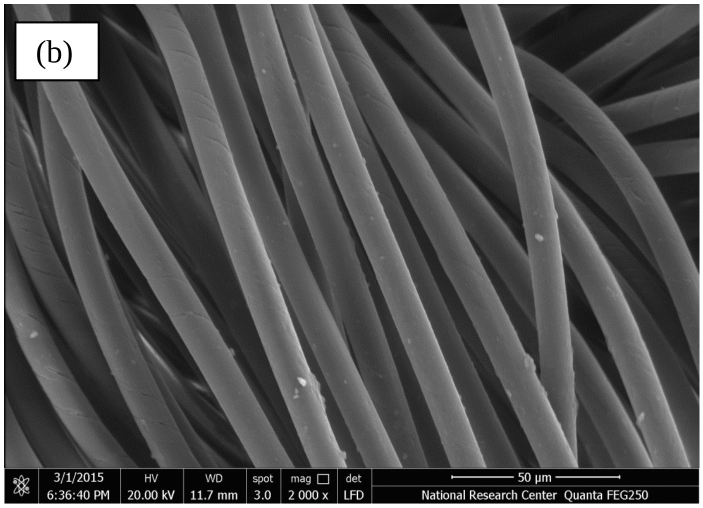
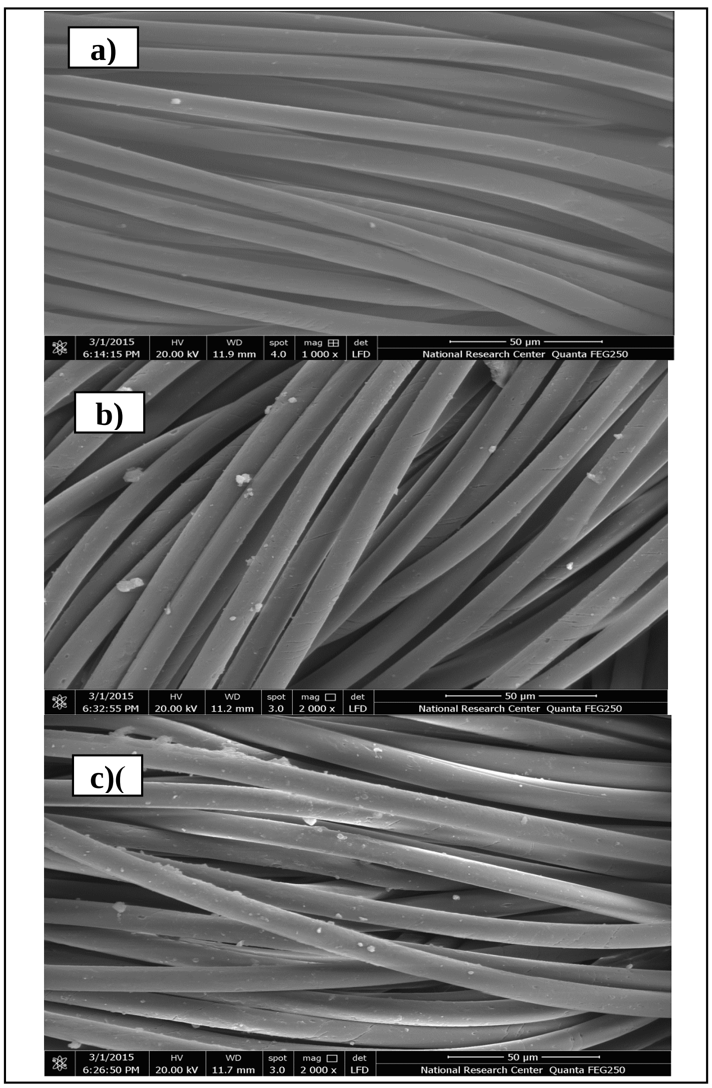
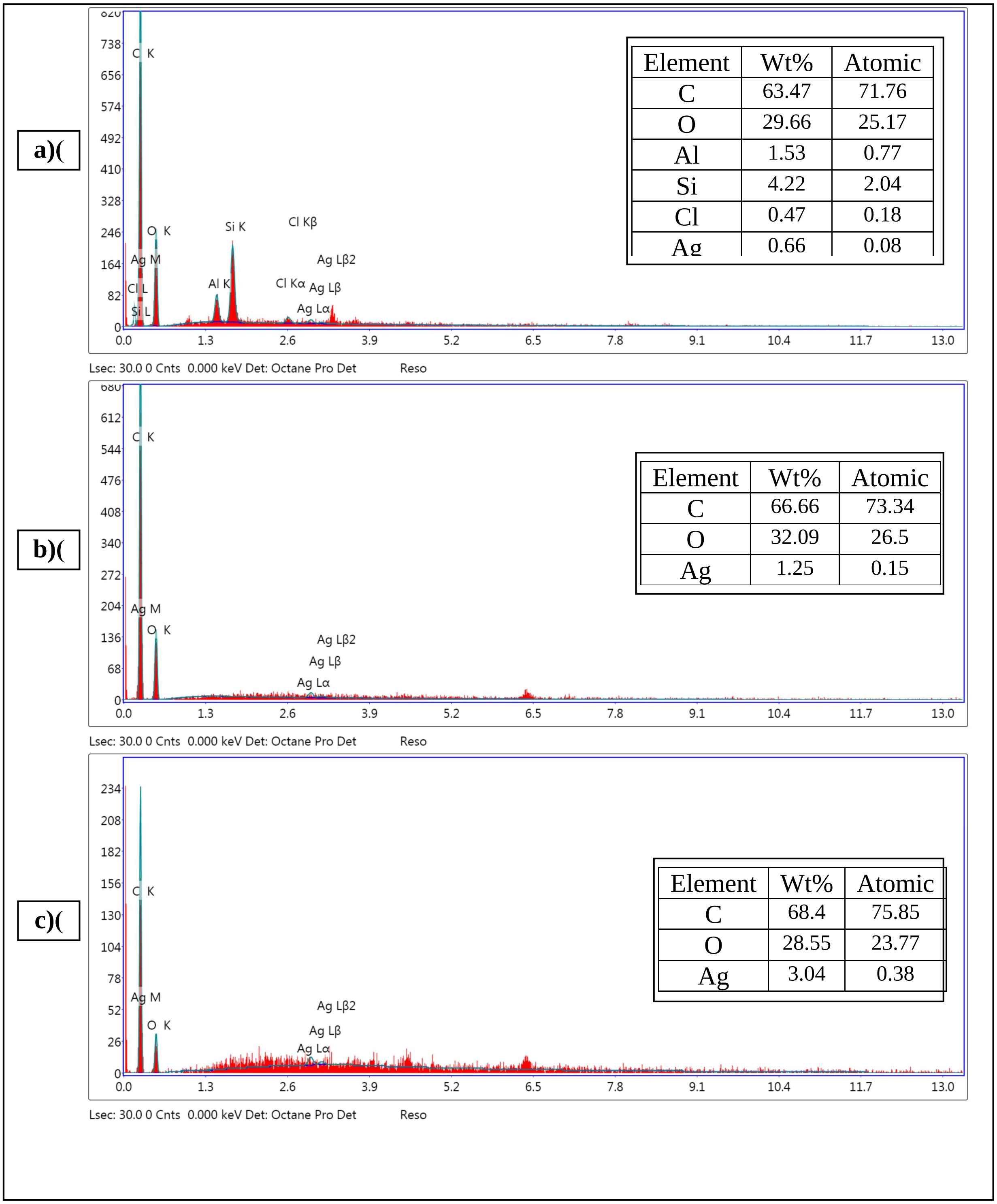


Figure.10 (a) the SEM image of PE fabric without treatment, (b) the SEM image of PE with silvernanoparticles (c) the SEM image of treated PE(plasma H10) with silver nanoparticles



Figur.11 (a) Silver nanoparticles bound to the fibre surface, (b) Silver nanoparticles bound to the edge of the fiber after cross section, (c) Silver nanoparticles incorporated into PE fibre

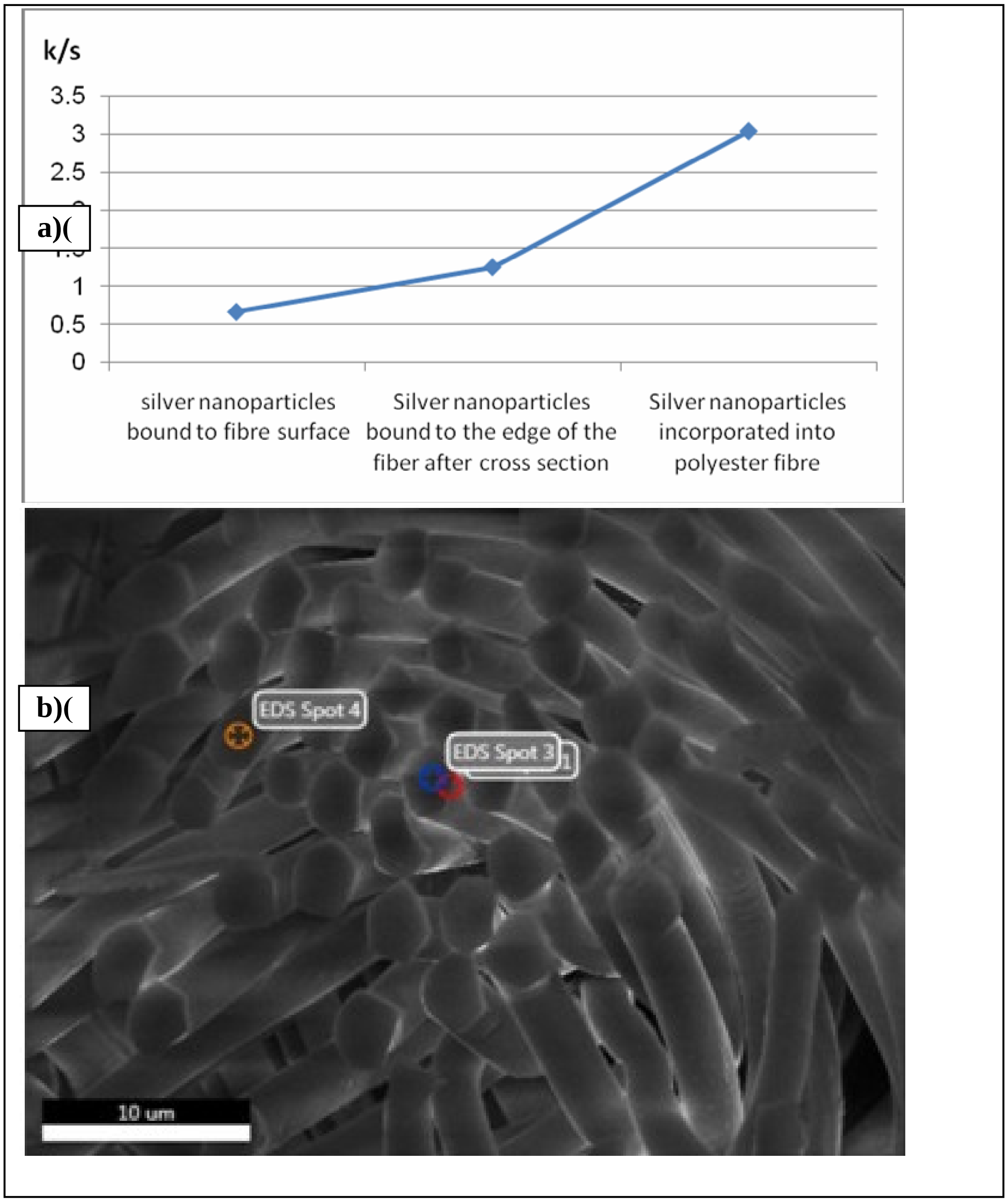


Element	Wt%	Atomic
C	63.47	71.76
O	29.66	25.17
Al	1.53	0.77
Si	4.22	2.04
Cl	0.47	0.18
Ag	0.66	0.08

Element	Wt%	Atomic
C	66.66	73.34
O	32.09	26.5
Ag	1.25	0.15

Element	Wt%	Atomic
C	68.4	75.85
O	28.55	23.77
Ag	3.04	0.38

Figure.12 (a) Methods of silver incorporation into fabrics, (b) Methods of silver incorporation into fabrics



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