New Approach in Burn out Printing with DBD Plasma Technique on Linen Fabric and its Blend with Polyester

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Abstract: ***Dielectric barrier discharge (DBD) treatment was applied to linen and PE/Linen fabrics with air and oxygen at various discharge power levels and exposure times. The results showed the probability of achieving burn out effect on fabrics with no chemicals used in the printing paste. Also significant effects from plasma-type, discharge power and exposure time- on the tensile strength and weight loss were obtained. Oxygen plasma treatment generated the highest weight loss and decrease in tensile strength, than air plasma. It was found the treated samples for long time at higher discharge power were affected more. The changes in the surface morphology and properties were investigated using infrared spectroscopy IR and scanning electron microscope SEM. The printability of fabrics with reactive and pigment were enhanced to a great extent as well as their fastness properties.***

Keywords: Burn-out, DBD plasma, Linen, polyester linen, Printing.

1. Introduction

Nowadays, printing is a very important thing for the textile sector. Printing makes clothes attractive and changing every day with the fashion trend. Printing process has many styles; burn out is one of them and its main technique is destroying the cellulosic portion of the fabric with Acid/chemical found in the printing paste. A fabric can be printed with a print paste containing the burn out chemicals, and after fixation, the cotton portion is destroyed and only the polyester remains. This allows a patterned lacey design to be imparted to the fabric. This process is very corrosive and requires special screens and special care in handling (1). This style is mainly based on fabric etching which could be carried out with other safer and eco-friendly methods.

In recent years, plasma technology for surface modifications of textile substrates has attracted more attention (2-5). The collision of plasma species (radicals, metastable molecules, photons & charged particles such as ions and electrons) with the textile surface results in a transfer of energy to the molecules of the substrate (cellulose in the case of linen fabric). This leads to the formation of a variety of new species such as free radicals & ions on the substrate surface. These are chemically active species (6) that cause etching. The application of plasma technology as a pretreatment for textiles has become very popular because they are dry and eco-friendly process which changes only the outermost layer of the substrate without altering the bulk properties.

In the last years, atmospheric plasma treatments have gained considerable popularity for the surface modification of materials (7-10). In particular, the plasma treatment with dielectric barrier discharge (DBD) has been proved to be an efficient method for the enhancement of the wettability of different fabrics which in turns increase the color intensity of the printing.

The present study has two aims; 1st is producing printed linen and polyester/linen fabrics having the burn out effect with no chemicals in the printing paste depending on the etching effect caused by plasma treatment in order to achieve texture in fabric surface, 2nd is overcoming the inhomogeneity & surface stiffness of printed linen and its blend fabrics caused when using pigment printing (11).

2. Experimental

2.1. Materials

2.1.1. Fabrics

Linen fabric (supplied by Textile Industries, Egyptian Co., Ointex Egypt) was semi-finished for dyeing and printing. Fabric specifications were; weight 280 g / m^2, warp 28 threads cm^{-1}, 20 tex, weft 26 threads cm^{-1}, 20 tex.

Linen/ polyester blend (80/20) of 155 g/m^2 Supplied by El-Kamah, Cairo- Egypt).

The fabrics were scoured at 100°C. For 60 minutes with a solution containing 1 g/L non-ionic detergent and 2 g/L sodium carbonate, then washed and air dried at room temperature.

2.1.2. Chemicals

Nonionic detergent, urea, sodium carbonate, Ammonium persulfate $(NH_4)_2S_2O_8$ Merck, Germany as thermal initiator, Bercolin metal CM supplied by Berssa, Turkey as thermal curing binder, were of laboratory grade chemicals.

2.1.3. Dyestuffs

Reactive dye namely, Cibacron Brill. Red T2B-E were kindly supplied by Ciba Co., pigment dye, orange 5 AldrichCPR Empirical Formula (Hill Notation) $C_{16}H_{10}N_4O_5$ Molecular Weight 338.27 MDL number MFCD00059524.

2.1.4. Thickener

Bercolin CPK, supplied by Berssa, Turkey as thickening agents , Commercial sodium alginate of higher viscosity type supplied by Fluka Chemie GmbH CH-9471 Buchs, Sigma-Aldrich Chemie GmbH.

2.2. Methods

2.2.1. Treatment with plasma

Experimental set up

The schematic diagram of DBD cell used for treatment of linen fabric and its blend is shown in Figure (1).

The DBD cell was consisted of two parallel plate electrodes. The upper electrode was Al- sheet of dimensions 25 × 25 cm2 pasted on dielectric glass plate of thickness 1.5 mm and the lower electrode was stainless steel plate of the same dimensions. The gap distance between the dielectric glass plate and lower electrode was 2.5 mm. Plasma discharges were generated by a 25 kV/30 mA AC power supply of 50 Hz frequency. The two electrodes were connected to the high-voltage AC power supply. The textile was placed in the gap between two electrodes. The plasma gas (oxygen) was fed through a gas flow meter to the space between the two electrodes where the electric discharge was generated in this space.

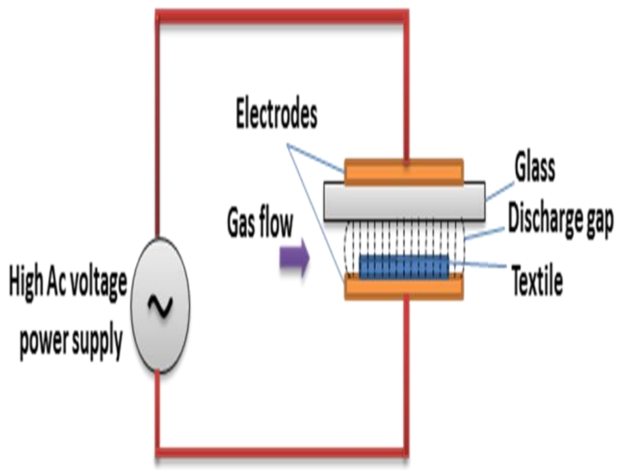

Figure 1: The schematic diagram of DBD cell used for treatment of linen and polyester/linen

The voltage across discharge electrodes was measured using a resistive potential divider (1:1000) which was connected in parallel with the discharge electrodes. The discharge current has been measured by measuring the voltage drop across resistor R (100Ω) through a digital storage two channel oscilloscope (HAMEG HM407-40MHz). The dissipated power during the discharge has been estimated which connected in series with the discharge cell to calculate charge flow through the cell.

Fabric Treatment with plasma

Linen and polyester/linen fabric samples (25x25 cm) were placed between two electrodes and exposed to low temperature plasma of air and oxygen at atmospheric pressure. Different conditions of plasma discharge powers (5&10 watts) and exposure times (3, 5, 7, 10 &15) were applied.

2.2.2. Fabric Printing

Preparation of Printing Pastes for pigment color & reactive dye

The pigment printing pastes were prepared according to the following recipe:

Pigment	50 g
Binder*	50 g
Thickener	40 g
Initiator*	10 g
Distilled water	Y
Total	1000 g

The reactive dye printing paste used was prepared according to the following recipe:

Alginate stock (Thickener)	600 g
Urea	100 g
Reactive dye*	40 g
Sodium carbonate	30 g
--	
Water to make up to	1000 g

2.2.3 Fixation and washing of the pigment & reactive dyes prints

- Pigment color fixation

Thermo fixation at 100^oC for 8 minutes

- Reactive dye's fixation
- Steaming at 100-103oC for 15 minutes followed by washing.

Washing of the printed samples was carried out through five stages:

- Rinsing thoroughly with cold water.
- Treatment with hot water.
- Treatment near the boiling temperature (90–95 ^0C) with 2 g/L non ionic detergent.
- Washing with hot water.
- Rinsing with cold water.

Finally, the samples were dried and assessed for color strength measurement.

2.3. Measurements and Material Characterization

2.3.1. Bulk Properties

- (%) Fabric Weight Loss

The weight of linen samples before and after plasma treatment was measured. Weight loss (%) was determined from the weight difference as follows:

$$(\%)\ \text{Weight loss} = \frac{W_0 - W_1}{W_0} \times 100$$

Where:
W_0 and W_1 are the weights of linen fabric before and after plasma treatment respectively [12]

- Tensile Strength

Fabric tensile strength test was conducted according to **ASTM -1682** standard test method for breaking force and elongation of textile fabrics [12].

- X-Ray Crystallinty

X- Ray crystallinity was measured with a PW 3710 diffracto- meter (Phillips) (XRD) using Cu $_{k\alpha}$ radiation at an operating voltage of 40 KV and a current of 35 mA from 5 to 60 angles. Pellets were prepared from 0.25gm fiber and crystalline size was calculated from the equation.

$t = k\lambda / \beta \cos\theta$……………….. Where

t = the size of crystal (Å), k = shape factor (0.94),

λ=wave length of x-ray (1.542Å), β=half-width (radian), θ =Bragg angle.

2.3.2. Surface Morphology and Properties

- Infrared Spectroscopy (IR)

FT-IR spectra were recorded on a JASCO FT-IR spectrometer (ATR) was used to analyze the spectrum of the untreated and treated samples. The tester collected transmittance of the infrared in the film between 400 and 4000 cm^{-1} are examined.

- Scanning Electron Microscope (SEM)

The untreated and plasma treated fabrics were investigated by a Scanning Electron Microscope (SEM) JSMT-20, JEOL-Japan, magnification range 1500-2000x, resolution 200A°, and accelerating voltage 19 kV. Before examinations, the fabric surface was prepared on an appropriate disk and coated randomly by a spray of gold. These investigations were carried out at the department of physical chemistry, NRC.

2.3.3. Printing Properties

- Color Assessment

The color yield (K/S) of each printed sample was measured using a Data Color SF 600plus Colorimeter using a measured area with diameter of 9mm. All the (K/S) values were calculated by subtracting the (K/S) value of the printed untreated sample from the (K/S) values of the printed treated samples. (I.e. values obtained are relative color strength).

- Stiffness

Changes in roughness values were measured for the printed untreated and treated linen samples using a surface roughness measuring instrument SE1700α.The results obtained were the average values of three readings.

- Fastness Properties

The color fastness of the printed fabrics was assessed by the **AATCC** Test Method **16-2001**(color fastness to light), AATCC Test Method 61-2001(color fastness to laundering) and AATCC Test Method 8-2001(color fastness to rubbing).

3. Results and Discussion

3.1 Electrical parameters of DBD reactor characteristics

Voltage and current waveforms of the DBD reactor (using open Air and Oxygen at constant flow rate 3L/min as working gases) were measured at different applied voltages. Figure 2 shows the waveforms of the voltage applied to the reactor and the associated discharge current at $V_{pp.}$ (a) 11.1 kV and (b) 20.11 kV respectively.

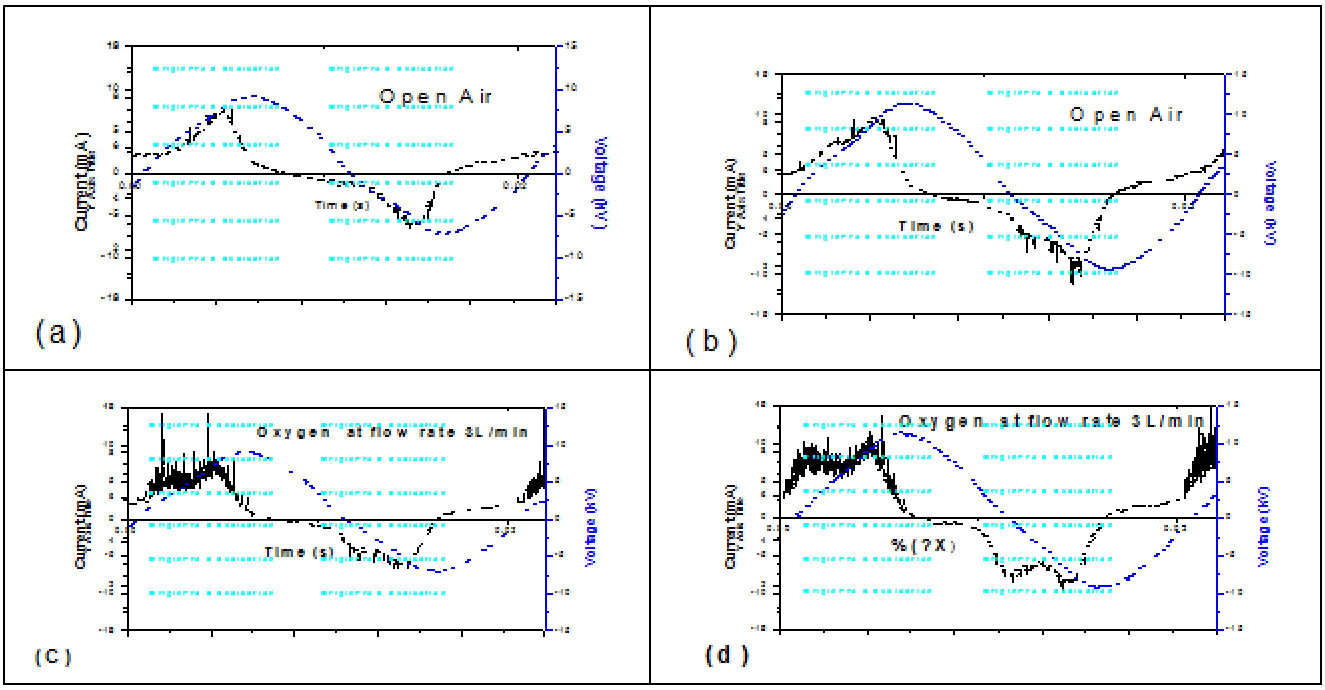

Figure 2: The voltage and current waveforms at applied voltages Vpp. 11.1 kV & 20.11 kV for air plasma (a &b) and xygen plasma (c &d) respectively

From the figure, it can be seen that, a streamer discharge was formed, which is characterized by discrete current spikes. The amplitude and the number of these spikes increase with the increase in applied voltage and the number of these spikes is larger in oxygen plasma than open air plasma. These spikes were related to the formation of micro discharges (filaments) of tens of nanosecond duration in the gap space [(13).]

When the AC voltage applied to the DBD reactor reaches the onset value, the discharge starts in the gas gap inside the reactor in the form of filamentary streamers. The filaments are randomly distributed over entire electrode surface. The streamers cross the discharge gap and spread on the surface of the dielectric barrier, building up surface charges, which produce electric field opposite to that of the applied voltage. So after short time (several ns) the streamer activity in that spot is extinguished, followed by streamer initiation in another location. Streamers start again when the voltage applied to discharge gap reaches the onset value during the next half-cycle [(14)].

When applied voltage is rising, additional micro discharges are initiated at new locations because the presence of residual charges on the dielectric has reduced the electric fields at positions where micro discharges have already occurred. When the voltage is reversed, however, the next micro discharges will form at old micro discharge locations.
The peak of each individual spike is related to the number of instantaneous microfilaments that were formed at this instant, and hence a high current spike indicates that a high number of micro discharges are initiated almost simultaneously, because high voltages tend to spread the micro discharges and increase the number of instantaneous filaments [(15)].

Power Measurements

The discharge power of DBD reactor was determined from a voltage–charge Lissajous figure (U-Q diagram). The trick is to use the time-integrated current, the charge, rather than trying to resolve individual micro discharge current peaks. This can be achieved in a simple way by putting a capacitance in series with the DBD experiment. The voltage across this measuring capacitor is proportional to the charge. It can be strongly shown that the area of (U-Q diagram) always represents the energy consumed during one period [(16-18)]

Lissajous diagrams were taken at different applied voltages where the voltage difference between the two electrodes has been measured as a function of the charge transferred within the discharge gap. Figure 3 shows Lissajous diagrams at V_{pp} 8.48-28.33 KV for (a) air plasma (b) oxygen plasma respectively. It was noticed that, the area of parallelogram increases with the increase of applied voltage because; the consumed power is proportional to the area of the parallelogram.

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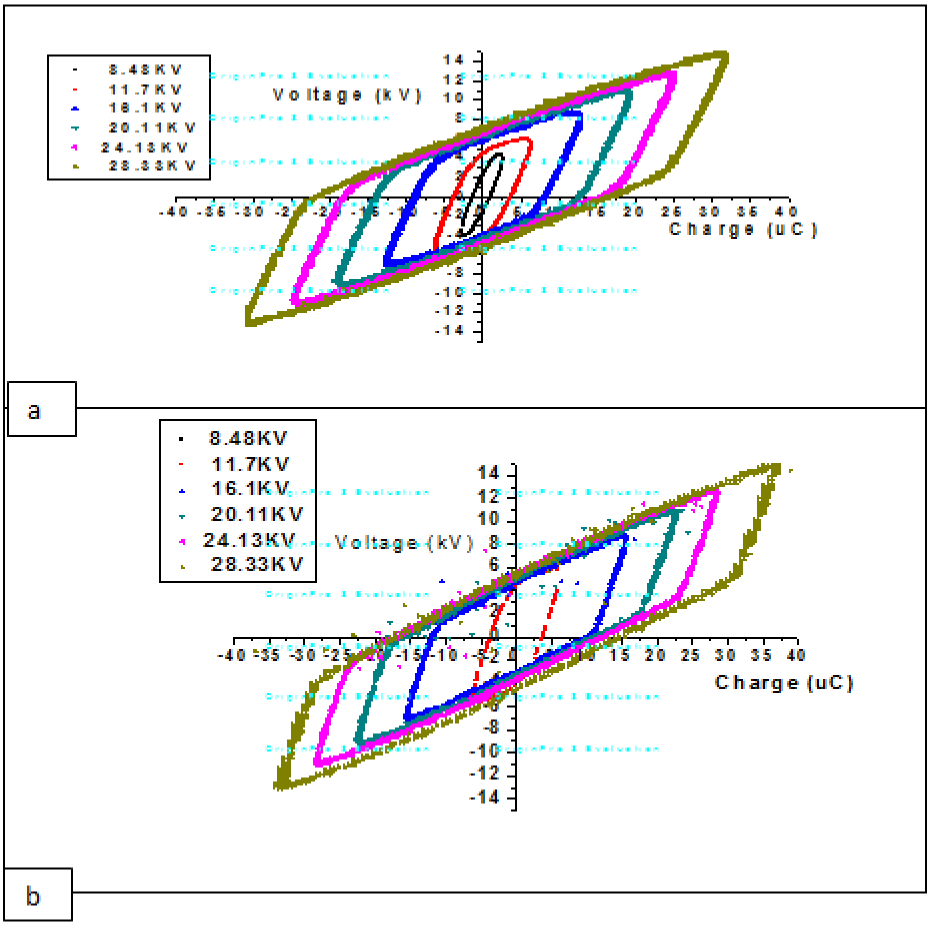


Figure 3: U-Q Lissajous figure at applied voltages 8.48- 28.33 KV

The consumed power has been calculated by multiplying the area of the parallelogram by the frequency of the used AC power supply (50 Hz). Table I shows the values of consumed power at different applied voltages across the DBD cell.

Table I: The relation between the applied voltage and the consumed power in the DBD cell

Applied voltage peak to peak (V_{pp})	Consumed power in watts	
	Air	Oxygen
8.48	0.1	0.35
11.7	2.79	2.44
16.1	8.14	9.15
20.11	13.98	15.9
24.13	19.7	19.57
28.33	27.61	26.32

It is noticed that, the type of gas has no a considerable influence on the values of the consumed power and these values of consumed power within the DBD reactor have been found to be very low (less than 30 W). This result may be referred to the characterized filamentary discharge behavior where, the time of the filament is very short (few tens of nanoseconds).

3.2. Bulk Properties

- (%) Fabric Weight Loss

Figures 4 & 5 plot % weight loss of linen and polyester/linen fabrics, respectively versus plasma exposure time at different discharge powers. It is cleared that, exposure time, discharge power and plasma type affected the percent of weight loss of the linen & its blend.

It is very obvious in Figure 4 that, oxygen plasma has a higher effect on increasing the % weight loss compared to air which may be attributed to using a great amount of oxygen plasma that is found in the air plus the oxygen supplied alone. For example, the % values of weight loss obtained at conditions; 15 minutes & 5 watts are 0.72 & 0.84% for air and oxygen plasma respectively. Also the Figure cleared the effect of plasma discharge power where at higher power 10 watts the values were 0.80 & 1.0 % with respect to the same order of plasma types. The plasma exposure time is also affected the results where, at the beginning of the treatment (3 minutes), the values were 0.4 & 0.5% at power 5 watts for the same order of gases.

The same trend holds true for the treated PE/linen fabric as shown in Figure 5 but the results obtained were lower compared to linen due to the lower percent of linen in the blend (PE/L 80/20) which is always affected more by plasma. The treatment caused a surface reactivity due to the presence of effective pore size that is created owing to the etching process carried out via plasma treatment.

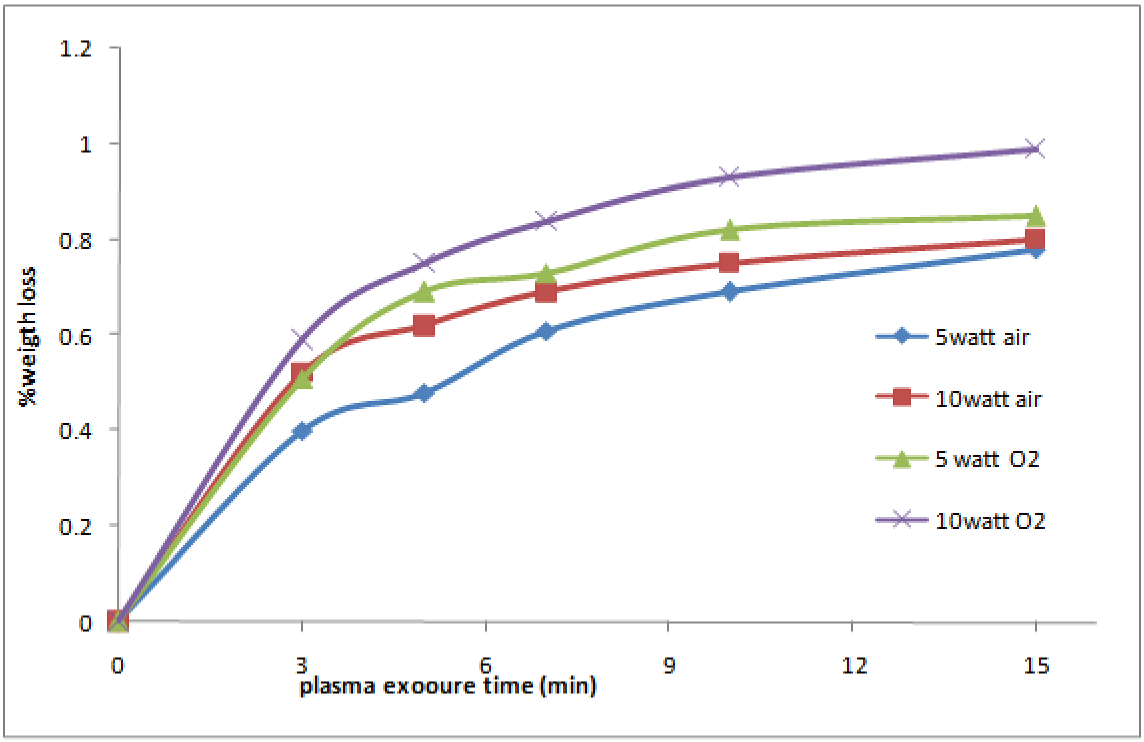


Figure 4: % Weight loss of linen fabric treated with DBD- air & oxygen plasmas at discharge powers 5 &10 watts

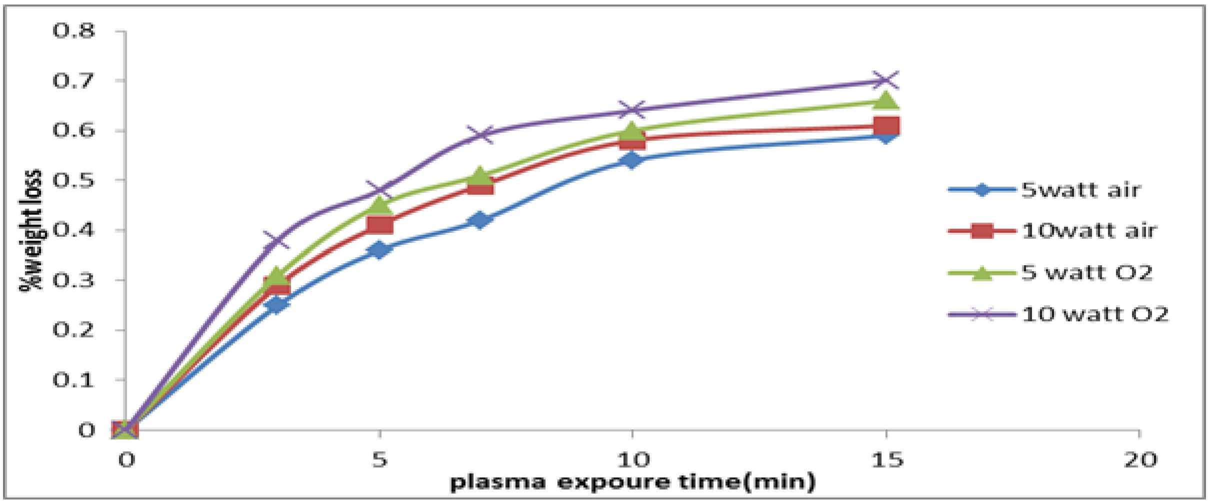


Figure 5: % Weight loss of PE/linen fabric treated with DBD-air & oxygen plasmas at discharge powers 5& 10 watts

- Tensile Strength

The tensile strength of both linen and PE/linen fabrics are measured before and after exposure to air and oxygen plasma. The tensile strength of the original linen and its blend are 32.5 & 42.5 Kg respectively. Figures 6 & 7 show the tensile strength versus plasma exposure times at levels 5 & 10 watts of discharge power.

The analysis of the results shows a slight decrease in the tensile strength of the blend-treated with O_2 plasma – from 42.5 – 30 Kg at exposure time 15 min and power 10 watts while a severe tensile strength reduction from 32.5 – 12.5 Kg for linen fabrics treated with O_2 plasma at the same conditions of treatment. The behavior of the two fabrics is expected where plasma has a great effect on the cellulosic part more than the synthetic one and the blend is only contained 20% of linen which is more affected by plasma etching process as mentioned before. Generally, the reduction in tensile strength for the two fabrics- regards to its values- may be attributed to surface bombardment by plasma species (electrons, ions & excited atoms) which may cause breakage of the cellulosic molecular bonds.

From the above we can achieve a great feature, in which we can obtain burn-out fabrics with different textured surface by applying oxygen plasma with high voltage.

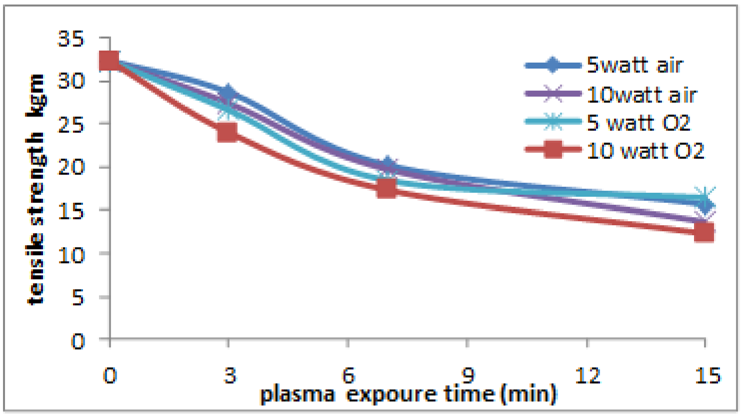


Figure 6: The effect of plasma exposure time on the tensile strength of the treated linen fabric at discharge powers 5& 10 watts.

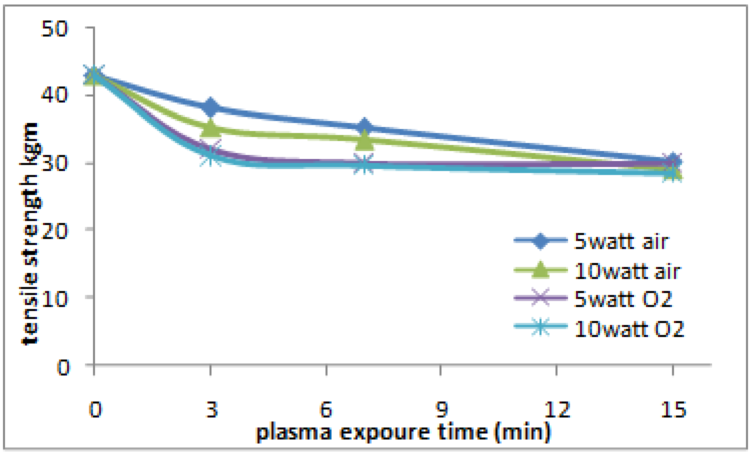


Figure 7: The effect of plasma exposure time on the tensile strength of the treated PE/linen fabric treated at discharge powers 5 &10 watts

- X-Ray Crystallinity

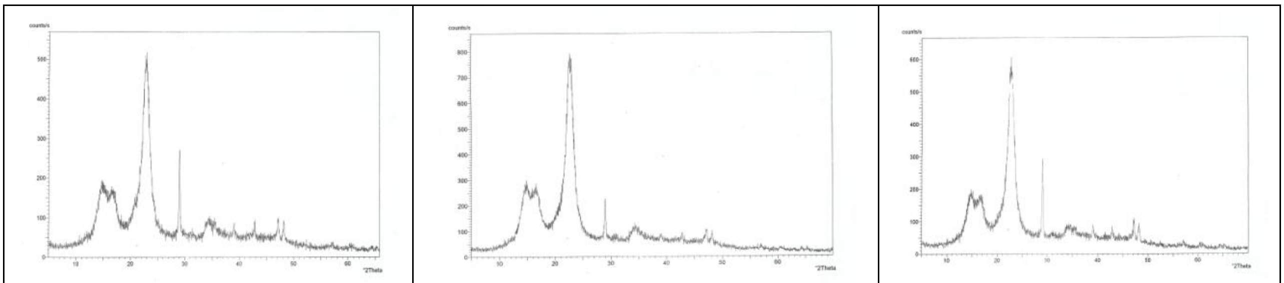
The difference in untreated and plasma-treated samples primarily consists of their degree of crystallinity. Figures 8 & 9 represent the crystallinity of the untreated fabric (a), air and oxygen plasma treated fabrics (b &c) for linen and PE/linen respectively while, Table II represents the crystallite size for the two fabrics.

It is well- known that, lower crystallite size indicates higher amorphous regions and this is clear in Table II where, the size is decreased from 7.98- 4.07 and from 16.8- 6.31 for linen and PE/linen fabrics respectively. These results mean that a great improvement is carried out and the amorphous areas are increased for the two fabrics which agree with the color strength results that are increased too much compared to the untreated printed fabrics (as discussed before)

Table 2: Crystallite size (Ǻ) of linen and its blend samples treated with air & oxygen plasma at 7 min. exposure time and 10 watt discharge power.

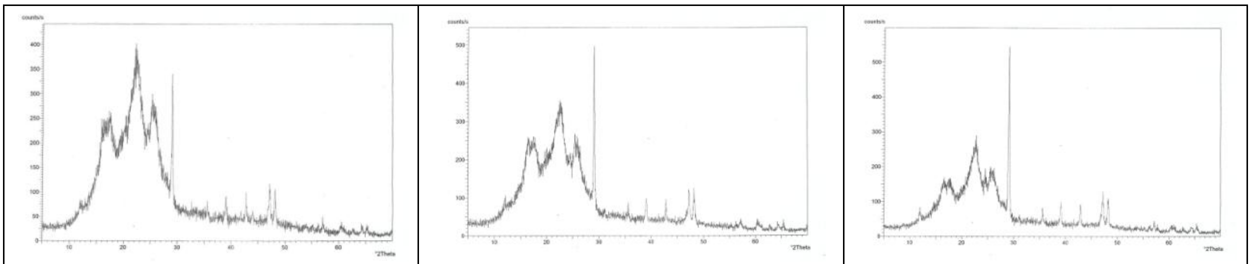
Type of fabric	Crystallite size (Ǻ)values of the untreated and treated linen fabrics treated for different exposure times and discharge power
Untreated of linen fabric	7.98
Treated linen with air plasma	5.02
Treated linen with O_2 plasma	4.07
Untreated poly/ester /linen	16.8
Treated blend with air plasma	7.34
Treated blend with O_2 plasma	6.31

Figure 8- a declared that, the untreated linen surface is smooth and free from roughness, indicating that no damage occurs on the fiber surface. However, Fig 8-b & c illustrate a damage in the fibre surface morphology compared to the untreated one. It is very obvious that oxygen plasma treatment has a more severe damage for the surface due to the plasma ablation caused by oxygen and leads to certain degrees of etching which in turns caused the burn out effect with no chemicals (as mentioned before).



(a) blank linen | (b) linen Air | (c) linen O_2

Figure 8: X-Ray Crystallinity for treated and untreated linen fabrics were (a) represents blank sample, (b) plasma air treated sample and (c) oxygen plasma treated sample



(a) blank LE/linen | (b) Air LE/linen | (c) Oxygen LE/linen

Figure 9: X-Ray Crystallinity for treated and untreated LE/linen fabrics were (a) represents blank sample, (b) plasma air treated sample and (c) oxygen plasma treated sample

3.3. Surface Morphology and Properties

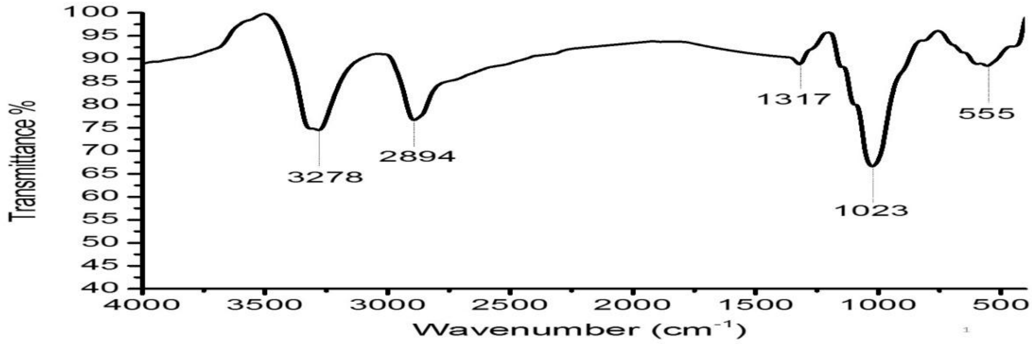
- Infrared Spectroscopy (IR)

Infrared IR spectroscopy is a chemical analytical technique determines the chemical functional groups in the sample. The characteristics bands of the untreated and plasma treated fabrics are represented by figures 10 & 11 for linen and PE/linen respectively, and their spectra are illustrated in table III & IV.

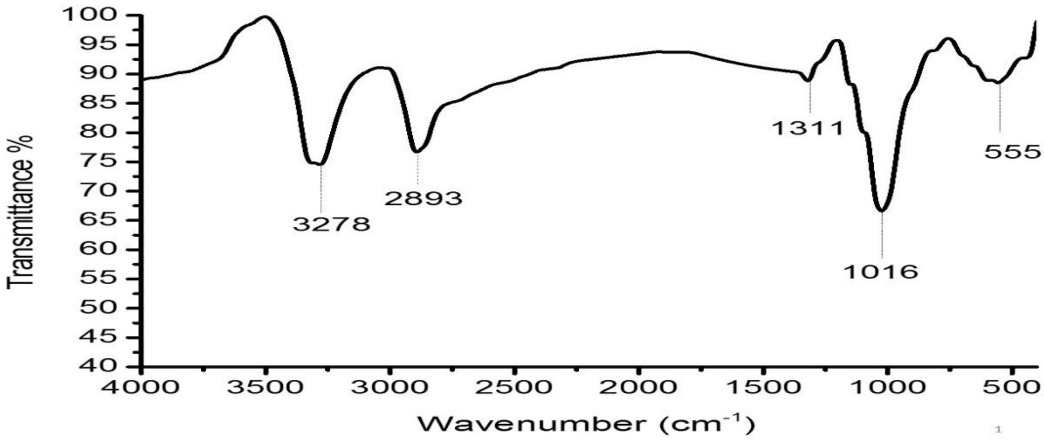
Figure 10 & 11 show the spectra in the range of 500-4000 cm^{-1}. They represent the spectra of the untreated linen& its blend (a, a*) while (b, b* & c, c*) represent the treated fabrics with air & oxygen plasma respectively with respect to the fabrics order.

Linen fabric surface is activated by air plasma contains reactive species such as oxygen atoms which will react with organic contaminations that are present on the substrate surface. In many cases such as organic contaminations consist of loosely bound hydrocarbons. Both H & C will react with oxygen; leaving the substrate surface in the form of volatile H_2O & CO_2. At this moment, the surface molecules becomes free and can react with oxygen atoms forming carbonyl CO_2, carboxyl COOH or hydroxyl OH functional groups on the substrate surface [19]. After plasma treatment, the relative intensities of the hydroxyl and carboxyl groups decreased with plasma exposure time, indicating an increase in the amount of these groups on the fiber surface and hydrogen bonds were developed among these groups, thus the active sites present on the treated linen surface were increased and improved its surface properties [20]. The surface chemical analysis oxygen plasma treated higher absorption intensity in the FTIR spectra of linen fabric and its blend than air plasma where oxygen plasma treatment showed enhanced peaks of alcohol (O-H stretch), aldehyde (C=O stretch) and carboxylic acid (COOH stretch).

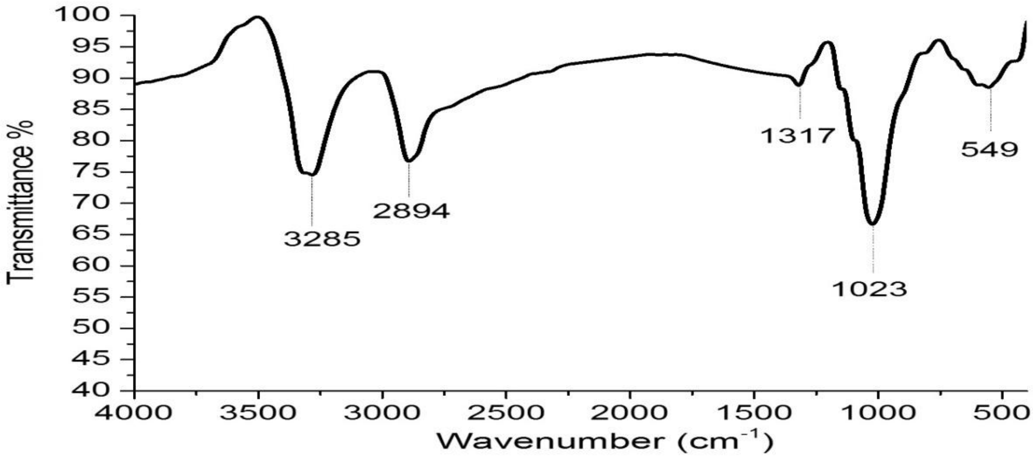
On the other hand, we can easily illustrate that elements such as oxygen and nitrogen could be increase when the DBD plasma was applied to cellulosic fabrics and its blends. Etching may provide chain scission in groups C-H, C-O, C-N, N-H and the formation of free radicals, causing the measured carbon content to decrease. Other surface reactions with air Dosage plasma can occur to produce reactive species such as O^-, N, N^+, O, OH-, O_3 [21] which would also result in carbon decrease and increase of nitrogen and oxygen atoms.



(a)

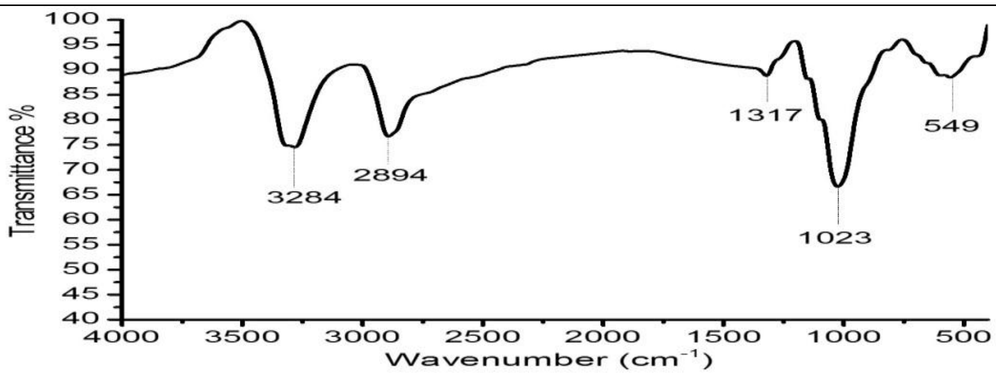


(b)



(c)

Figure 10: FTIR Spectra of untreated (a) and plasma treated linen fabrics with air (b) and oxygen (c) at discharge power 10 watts & exposure time 7 minute.



(a)*

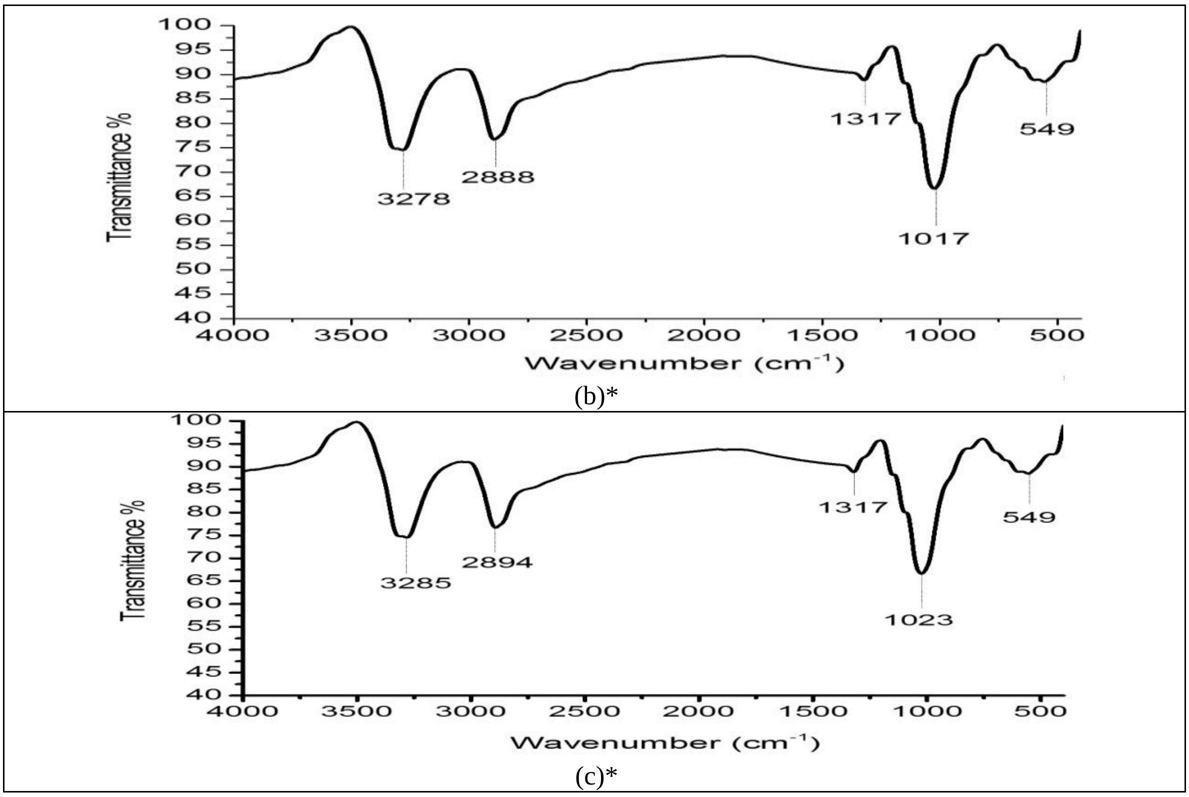


Figure 11: FTIR Spectra of untreated (a)*and plasma treated PE/linen fabrics with air (b)*and oxygen (c)*at discharge power 10 watt & exposure time 7 minute

Table 3: The characteristics bands of the untreated & treated linen fabric

Literature (cm^{-1})	Experimental peaks obtained (cm^{-1})			Peak characteristics
	Untreated linen fabric	Treated linen fabric with air plasma	Treated linen fabric with O_2	
3570-3200	3414.3496	3414.3496	3414.3496	H- bonded OH stretch
3000-2800	2899.45	2879.45	2880.45	C-H stretching
1728	2363.34	2363.34	2363.34	C=O stretch in -COOH
1650-1633	1641.13	1641.13	1641.13	Adsorbed H_2O, Asym. Carboxylate (COO^-) stretch
1450-1360	1430.92	1430.92	1430.92	Sym. Carboxylate (COO^-) stretch CH wagging (in plane bending)
1372	1372.10	1372.10	1372.10	CH bending (deformation stretch)

Table 4: The characteristics bands of the untreated & treated PE/linen fabric

Literature (cm^{-1})	Experimental peaks obtained (cm^{-1})			Peak characteristics
	Untreated linen/polyester fabric	Treated linen/polyester fabric with air plasma	Treated linen/polyester fabric with O_2	
3570-3200	3414.35	3414.35	3414.35	H- bonded OH stretch
3000-2800	2915.41	2904.41	2905.41	C-H stretching
1728	1726.084	1723.0848	1724.0848	C=O stretch in -COOH
1650-1633	1642.09	1642.09	1642.09	Adsorbed H_2O, Asym. Carboxylate (COO^-) stretch
1450-1360	1430.92	1430.92	1430.92	Sym. Carboxylate (COO^-) stretch CH wagging (in plane bending)
1372	1372.1	1372.1	1372.1	CH bending (deformation stretch)

- **Scanning Electron Microscope (SEM)**

Figure 12 represents the SEM images for the untreated linen (a) and plasma treated with air and oxygen (b &c) respectively. It is observed linen fabric has a smooth surface, while the plasma treated fabrics with air and oxygen shown in figure (12- b &c) are wrinkled and roughened. This reveals the formation of voids and cracks on the surface. The effect of oxygen plasma on the linen surface figure 12-c is very obvious and shows more great changes and sever damaged which may be due to the plasma ablation caused by oxygen in the atmospheric air as well as the plasma oxygen itself that leads to certain degrees of etching which in turns caused the burn out effect with no chemicals.

During the ablation process, the fibre surface is subjected to a certain degree of etching. The differential etching of crystalline and amorphous region may be the origin of the roughness. This process – some house-led to nearly break-down of a relatively small number of molecules on the fibre surface into very low molecular weight components which would eventually vaporize in the low pressure system. As a result, cracks developed along the fibre axis, [22] these results agree and explain the reason for the decrease in tensile strength. The same phenomenon holds true for PE/linen fabric represented by figure (13 a,b& c) with less changes compared with linen fabrics where, the most effected part will be the cellulosic one compared to the polyester part which is occupied only 20% of the blend.

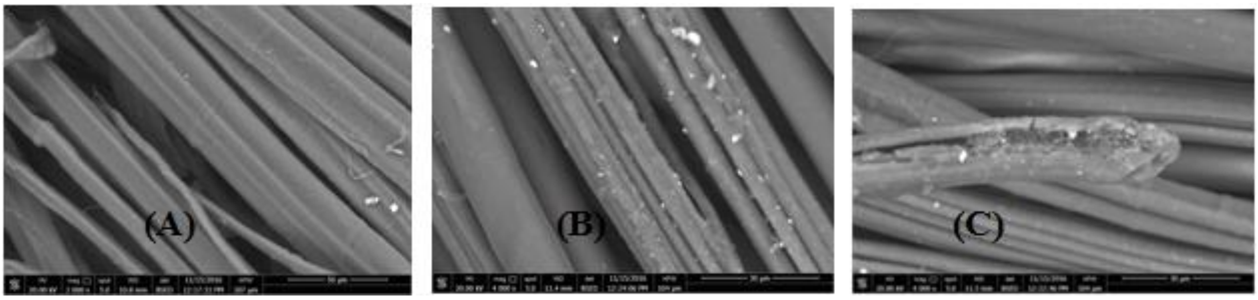


Figure 12: SEM images of the untreated linen (A) and treated with air (B) and oxygen (C) plasmas at discharge power 10 watts for exposure time 7 min.

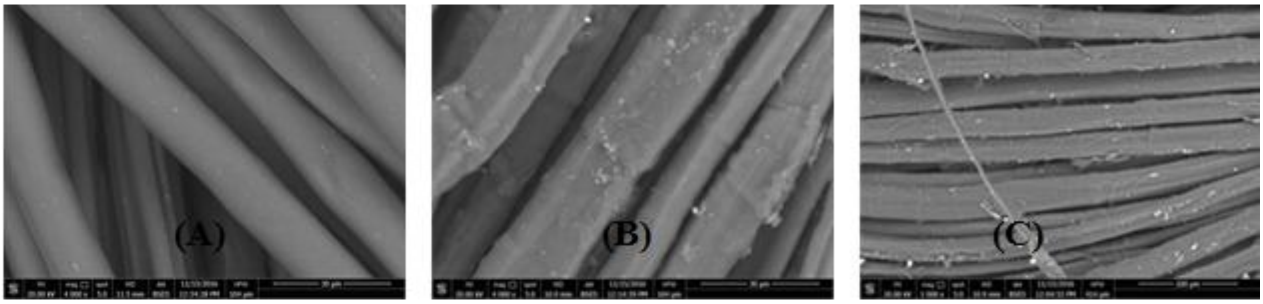


Figure 13: SEM images of untreated PE/linen (A) and treated with air (B) and oxygen (C) plasmas at discharge power 10 watts for exposure time 7 min.

3.4. Printing Properties

- **Color Assessment**

Figures 14 & 15 show the color strength of linen fabric treated with DBD – air and oxygen plasmas and printed with pigment color, and reactive dye respectively. While figures 16 &17 represent the PE/linen fabric with respect to the same aforementioned conditions.

It is very obvious that, all plasma conditions; exposure time, discharge power and plasma types are affected the color strength to a great extent. The color strength was increased with increasing of plasma exposure time and power. This can be attributed to the increasing number of plasma created polar groups (due to the surface energy reactivity) and roughness on the surface, due to etching and other chemical changes of the surface. As can be seen in Figures 14 & 15, the best color strength was obtained when linen fabric was treated with air and oxygen plasma for 15 min at discharge power 10 watts/cm^3. This phenomenon holds true for both pigment color and reactive dye regardless the plasma gas type; air or oxygen. The values obtained in Figure 14 were11 & 24 for air and oxygen compared to the blank value which is 9.5 respectively. While in case of reactive dye prints illustrated in figure 15, the values obtained were 20 & 25 with the same respect to gas type- compared to the blank value which is 10.5. It is also cleared that whether, the type of dye used and the fabric printed, after plasma treatment, there happens more increase in color strength when oxygen plasma is used due to the fabric surface oxidation that cause higher increase in surface roughness and area due to plasma etching-as said before.

The same trend is obtained on the plasma treatment for PE/Linen fabric represented by Figures 16 & 17. Overall, the printability after plasma treatment was quite acceptable where; it is nearly increased by 100%.

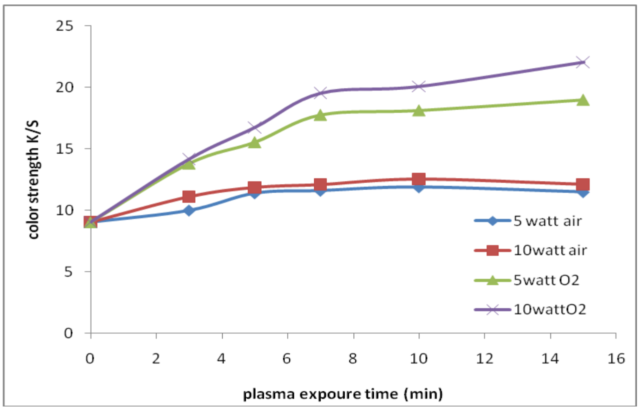


Figure 14: Color strength of linen fabric treated with DBD- air & oxygen plasmas at discharge powers 5& 10 watts and printed with pigment color

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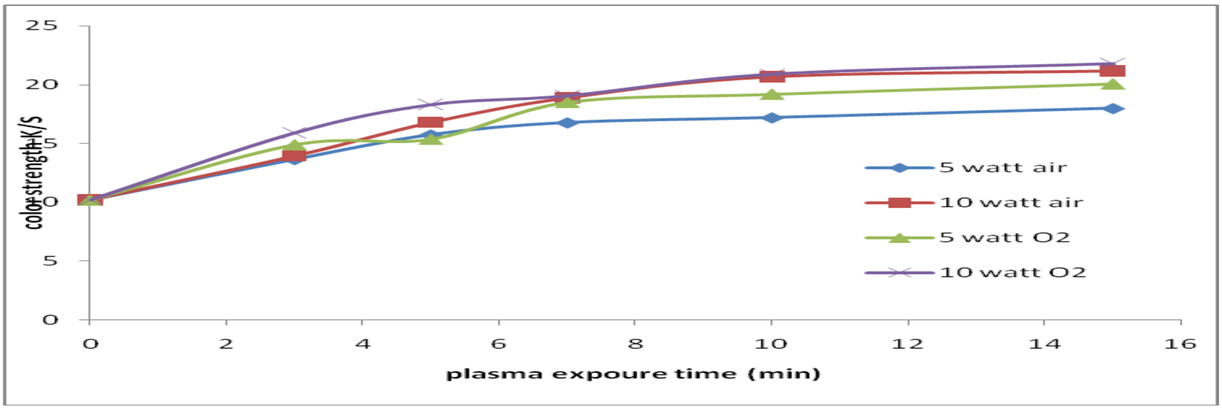

Figure 15: Color strength of linen fabric treated with DBD- air & oxygen plasmas at discharge powers 5& 10 watts and printed with reactive dye.

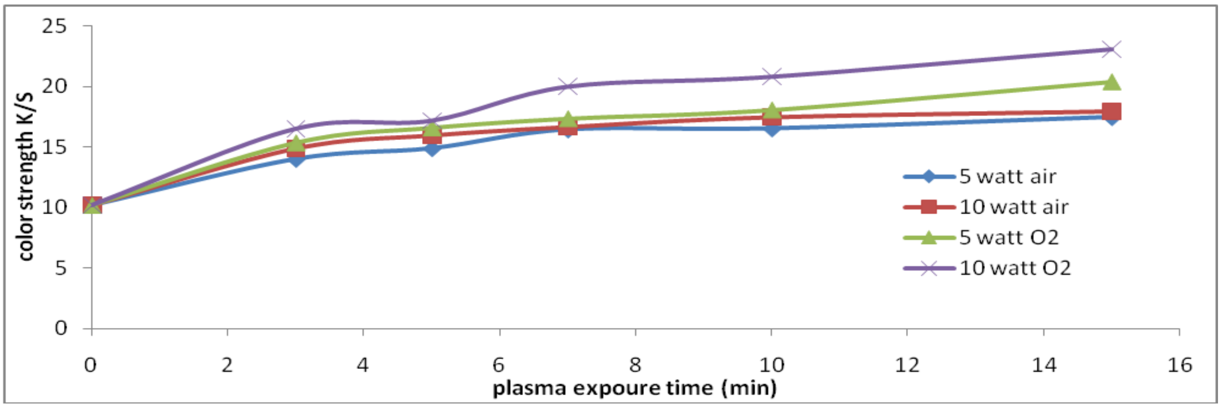

Figure 16: Color strength of PE/linen fabric treated with DBD- air & oxygen plasmas at discharge powers 5& 10 watts and printed with pigment color

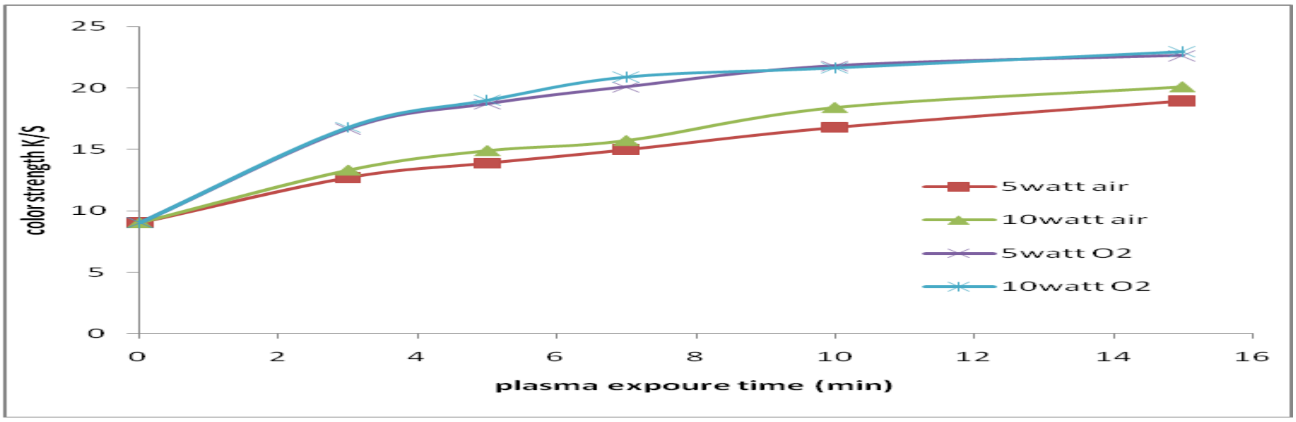

Figure 17: Color strength of PE/linen fabric treated with DBD- air & oxygen plasmas at discharge powers 5& 10 watts and printed with reactive dye.

- **Roughness/ Stiffness**

The surface roughness of the untreated and plasma treated linen and PE/Linen fabrics – at discharge powers 5&10 watts/cm^3 and time intervals 3-15 minutes is measured. The results obtained after their printing with reactive dye and pigment color are all represented in Tables V-VIII.

From the above tables, it is evident that, the surface roughness of the treated printed fabric is dependent – to a great extent – on plasma conditions; type, time & power and gives lower results than the untreated ones. This trend holds true for the two treated printed fabrics, regardless the dyes used. This result is expected and coincides with the results of color strength where plasma treatment caused surface area. On printing these voids are well filled with the printing paste giving higher color strength, decrease in the surface roughness and hence improving the handling of the printed fabrics to be softer.

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Table 5: Stiffness of linen fabric treated with DBD plasma and printed with reactive dye.

Discharge power (watts)	Stiffness values of printed * fabric treated with air &oxygen plasma for exposure times (min)									
	3		5		7		10		15	
	Air	O_2	Air	O_2	Air	O2	Air	O_2	Air	O_2
5	22.58	21.05	20.21	20.48	19.11	19.09	18.90	18.77	16.04	17.99
10	21.06	18.94	19.66	17.00	18.40	16.85	17.05	15.06	15.54	15.33

The untreated linen stiffness is 24.26 µm

Table 6: Stiffness of linen fabric treated with DBD plasma and printed with pigment color.

Discharge power (watts)	Stiffness values of printed * fabric treated with air &oxygen plasma for exposure times (min)									
	3		5		7		10		15	
	Air	O_2	Air	O_2	Air	O_2	Air	O_2	Air	O_2
5	20.78	22.83	18.94	21.89	17.23	20.21	16.44	18.65	16.32	18.30
10	17.53	17.21	18.95	16.99	16.95	16.51	15.24	16.50	14.22	16.23

The untreated linen stiffness is 25.63 µm

Table 7: Stiffness of PE/linen fabric treated with DBD plasma and printed with reactive dye.

Discharge power (watts)	Stiffness values of printed * fabric treated with air &oxygen plasma for exposure times (min),									
	3		5		7		10		15	
	Air	O_2	Air	O_2	Air	O_2	Air	O_2	Air	O2
5	20.36	19.20	19.40	18.60	19.05	17.60	18.99	16.89	18.5	15.68
10	20.06	19.07	18.45	17.98	18.77	16.97	17.94	16.14	17.09	15.31

The untreated PE/ linen is 24.50 µm

Table 8: Stiffness of PE/linen fabric treated with DBD plasma and printed with pigment color

Discharge power (watts)	Stiffness values of printed * fabric treated with air &oxygen plasma for exposure times (min),									
	3		5		7		10		15	
	O_2	Air	O_2	Air	O_2	Air	O_2	Air	O_2	Air
5	22.36	18.20	20.40	17.60	19.45	16.50	17.99	15.89	16.54	14.68
10	20.56	16.07	19.45	16.98	18.77	15.03	16.94	14.14	15.09	14.03

The untreated PE/ linen is 25.09 µm

- **Fastness Properties**

The fastness to light, perspiration, washing & rubbing of the linen and its blend printed with pigment color are represented by Tables IX & X respectively while, Tables XI & XII represent the same fabrics printed with reactive dye.

The results of Tables IX & X showed a significant improvement in all fastness properties of the plasma treated fabrics, regardless the gas type used. Also, it is obvious that, the higher exposure time used, the maximum improvement is obtained. Both the dry & wet rubbing fastness showed a great enhancement which emphasize solving the main problem of pigment printing that always cause a harsh surface for the printed fabric.

Table XI & XII represent the fastness properties of the printed fabrics with reactive dye where, the results cleared a great improvement in the rubbing fastness of the treated fabrics compared to the untreated ones. This reveals the importance of the plasma role in introducing polar groups to the fabric surface which in turn increase the covalent bond between the reactive dye and the treated fabric surfaces. Generally speaking, all Tables from IX-XII, the overall fastness results- to washing, perspiration & light- for the treated fabrics were good to very good or excellent.

Table 9: Fastness properties of untreated & plasma treated linen fabric printed with pigment color. Discharge power used is 10 watts for various exposure times

Plasma gas type	Plasma exposure time (min)	Washing fastness		Rubbing fastness		Perspiration fastness				Light fastness
						Acid		Alkali		
		Alt.	St.	dry	Wet	Alt	St	Alt	St	
Blank	_	4	4	2-3	2-3	5	4-5	4-5	4-5	6-7
Air	5	4-5	4-5	4-5	4	5	5	5	5	6-7
	7	4-5	4-5	4-5	4	5	4-5	5	5	7-8
	10	4-5	4-5	4-5	4	5	5	5	5	7-8
O_2	7	5	5	5	4-5	5	5	5	5	6-7
	9	5	5	4-5	4	5	5	5	5	6-7
	10	5	5	4-5	4	4-5	4-5	5	5	7-8

Table 10: Fastness properties of untreated & plasma treated PE/linen fabric printed with pigment color. Discharge power used is 10 watts for various exposure times

Plasma gas type	Plasma exposure time (min)	Washing fastness		Rubbing fastness		Perspiration fastness				Light fastness
						Acid		Alkali		
		Alt.	St.	dry	Wet	Alt	St	Alt	St	
Blank	-	4-5	4_5	2_3	2_3	5	5	5	5	4-5
Air	5	4-5	4-5	4-5	4-5	5	5	5	5	5-6
	7	4-5	4-5	4-5	4-5	5	5	5	5	6-7
	10	5	5	4-5	4-5	5	5	5	5	6-7
O_2	7	5	5	4-5	4-5	5	5	5	5	6-7
	9	5	5	4-5	4-5	5	5	5	5	7
	10	5	5	5	5	5	5	5	5	7

Table 11: Fastness properties of untreated & plasma treated linen fabric printed with reactive dye. Discharge power used is 10 watts for various exposure treatment times

Plasma gas type	Plasma exposure time (min)	Washing fastness		Rubbing fastness		Perspiration fastness				Light fastness
						Acid		Alkali		
		Alt.	St.	dry	Wet	Alt.	St.	Alt.	St.	
Blank	-	4-5	4-5	2-3	2-3	5	4-5	5	4-5	5-6
Air	7	5	5	4-5	4	5	5	5	5	6-7
	9	5	5	5	4-5	5	5	5	5	6-7
	10	5	5	5	4-5	5	5	5	5	7-8
O_2	7	5	5	4-5	4	5	5	5	5	6-7
	9	5	5	4-5	4	5	5	5	5	6-7
	10	5	5	4-5	4	5	5	5	4-5	7-8

Table 12: Fastness properties of untreated & plasma treated Linen /Polyester fabric printed with reactive dye. Discharge power used is 10 watts for various exposure treatment times

Plasma gas type	Plasma exposure time (min)	Washing fastness		Rubbing fastness		Perspiration fastness				Light fastness
						Acid		Alkali		
		Alt.	St.	dry	wet	Alt	St	Alt	St	
Blank	-	4-5	4-5	2-3	2-3	5	5	5	5	4-5
Air	5	5	5	4-5	4-5	5	5	5	5	6
	7	5	5	4-5	4	5	5	5	5	6-7
	10	5	5	5	4-5	5	5	5	5	6
O_2	7	5	5	4-5	4-5	5	5	5	5	6-7
	9	5	5	4-5	4-5	5	5	5	5	7
	10	5	5	5	5	5	5	5	5	7

4. Conclusion

- The effect of plasma treatment on the physical properties of linen and PE/linen were investigated. Air and oxygen plasma were applied under atmospheric pressure using the Dielectric barrier discharge (DBD).
- The results showed that O2 plasma generated higher % weight loss and caused a decrease in tensile strength than air plasma and reached to the burn out effect on the two fabrics without using any chemicals in the printing pastes.
- SEM images showed that oxygen plasma treatment has more severe damage for the fabric surface due to the plasma ablation caused by oxygen and leads to certain degrees of etching which in turns caused the burn out effect.
- The color strength of the treated fabrics printed with either reactive dye or pigment color was enhanced and the stiffness of the treated fabrics surfaces were improved and the problem of the harsh feeling of the pigment printing was nearly overcome
- The overall fastness properties to rubbing, washing, perspiration and light showed a great improvement for the plasma treated fabrics compared to the untreated ones.

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