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Study of DC Pseudo Plasma Processing for Surface Treatment of Polyester

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Abstract

The surface treatment of polystyrene and polyester using the DC Pseudo-glow Discharge is studied in this paper. The DC Pseudo-glow Discharge was systematically employed as a function of plasma device parameters under different operating conditions including different current (I) (15-50 mA), different time (t) (10-60 s), different distance (d) (1, 3 and 5 mm) between inter-electrodes, different mesh anode transparency (T) (19, 46 and 65%), distance between the polyester sample and the mesh anode (D) (2-12 mm) and different air pressure in plasma exposure system (P) (2-8 torr). The best optimization of these parameters were performed by the measurements and estimation of mechanical properties and water absorbency which supported by the Infrared (IR) test and Yellowness (color) test.

Keywords: DC pseudo plasma discharge, polyester, surface treatment.

Introduction

Plasma is defined as the ‘fourth state of matter’, is an electrically neutral ionized gas (quasi-neutral) and contains a significant number of free electrically charged particles, these free electrically charged particles make electrically conductive [1]. DC Pseudo Plasma Discharge is a special type of discharge in which the plasma is performed using a bulk cathode and mesh anode, where the discharge (plasma) takes place behind the mesh anode [2-4]. Cold (non-thermal) plasma is become one of common technique which used in surface modification of materials specially the textile surface as it is found that most textile materials are heat sensitive polymer [5-7]. The cold (non-thermal) is a quasi-neutral gas with electron temperatures much higher than ion temperatures, these low-energy molecular species and high-energy electrons initiate reactions in the plasma volume without excessive heat causing substrate degradation. Textiles treatment using plasma technology is a significant method for interact with the surface of the textile only without modifying or affecting the bulk properties of the materials [8]. Plasma treatment of textiles is used to increase wettability, which allows for solvent free dyes to absorb and bond very strongly, or to make the textile a hydrophobic fibre by coat the textile surface with a specialized layer with varying characteristics, this features of plasma treatment of textile is

attributed to the free radicals, electrons and heavy particles inside plasma which contribute in surface modification [9]. When there is a contact between the plasma and the textile surface an additional energy transfers from the plasma to allow for subsequent reactions to take place on the material surface [10], so the surface treatment using plasma rises the surface energy of the material to improve characteristics of the bonding [11]. This energy, which transfers from the plasma to the material, are dissipated within the solid by an assortment of physical and chemical processes to result in a unique type of surface modification that reacts with surfaces in depths from several hundred angstroms to 10μm without changing the bulk properties of the material [12]. Also, the plasma treatment of the materials surface is considered to be anti-pollution technique and enhances the excess of micro roughness and production of radicals to obtain hydrophilic surfaces [13, 14]. Surface modification using plasma is considered economical and effective technique for many materials, which gets a scope attention in textile engineering [15]. Plasma treatments are attaining popularity in the industry of the textile for their plentiful advantages over traditional wet processing techniques. Surface modification using plasma technology shows innovative solutions to wetting and adhesion problems in many industries. The extremely crystalline structure of the polyester and its polarity lack which make it resist the absorbance of the water so it is classified as a hydrophobic fabric [16, 17]. The plasma treatments application for improving wettability of all possible fibre types was obtained with varied success degrees [18]. Such a treatments on natural fibres like, cotton and wool, and on synthetic polymers helps to enhance their wetting properties.

Experimental setup

DC pseudo discharge plasma

Figure 1 shows the A schematic diagram of the experiment setup. The DC pseudo discharge plasma system consists of a 20 cm length Pyrex tube, 5.8 cm outer diameter and 5.6 cm inner diameter. Two aluminum plates are used to maintain the Pyrex tube at its terminals. Mesh anode and plate cathodes, which are made of stainless steel, are enclosed inside the discharge tube. The plate cathode is a plane circular disk of 5.5 cm in diameter. The mesh anode is a movable circular mesh of 5.5 cm in diameter (with different mesh transparency). The transparencies of the mesh anode are determined from the mesh wire diameters and the separation between them. The distances at which the mesh anode place in front of the cathode are chosen to be 1, 3 and 5mm. The transparencies of the mesh anode are chosen in this work to cover a wide range of transparencies, including low (19%), intermediate (46%), and high (65%).

Air is taken as the working gas. A rotary pump with double stage is used to evacuate the discharge tube. A needle valve connected to the discharge cell to control the rate of flow. To apply a potential difference up to 1 kV and a current up to 250 mA a DC power supply is used, where the a rheostat of 6 kΩ is used to control the value of the current.

Materials

Polyester samples 5.5 cm in diameter were cut from a large piece, which are maintained by a hollow cylindrical of metal, which can be introduced behind the mesh anode at desirable distances.

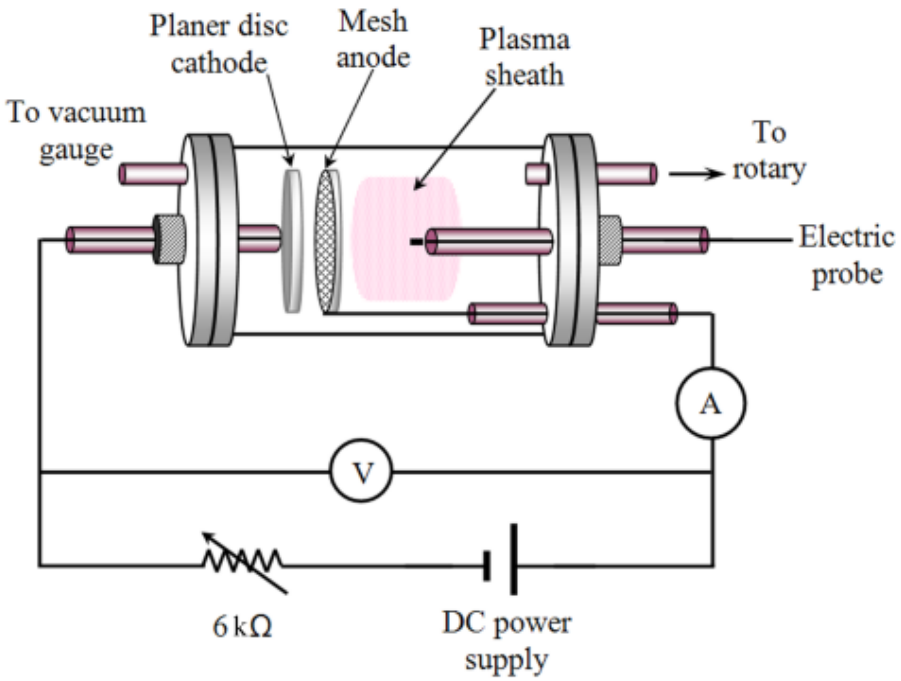

Figure 1 Schematic view of the discharge system

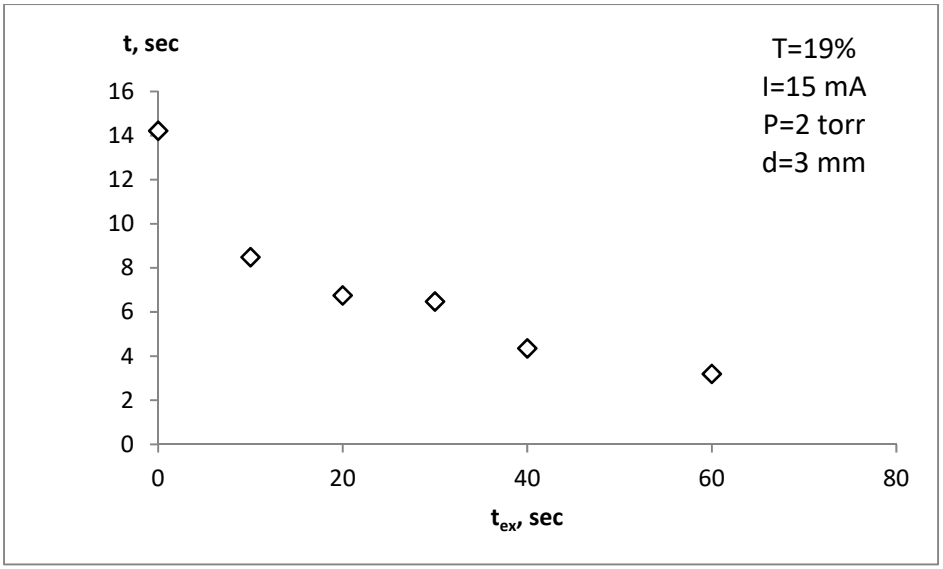

Figure 2. Effect of the exposure time on the water absorption of a polyester fabric using DC pseudo discharge for air

Fourier transforms infrared spectroscopic analysis (FTIR)

The treated and untreated polymer samples were tested by the IR test. Nicolet 380 (FTIR) Spectrometer, USA. This device in the textile metrology lab, at the National institute of standards in Giza, Egypt.

Color Strength (K/S) Determination

Color eye 3100 spectrophotometer SDL, England, in the textile metrology lab, at the National institute of standards.

Mechanical testing

TiniusOlsen, SDL, UK, in Textile Metrology Lab, at the National institute for standards.

Results and discussion

The treated samples were undergoing many tests to know the changes of their surface after plasma treatment. The measurements, which carried out on the polymer samples, are the mechanical properties, the water absorbency test, the IR analysis test, the color test. The experimental parameters which considered in the treatment are the discharge current (I), the gas pressure (P), the duration time of treatment (t), the separation distance between the two electrodes (d), the separation distance between the mesh anode and the polymer sample (D), and the mesh transparency (T). The standard considered conditions are at P=2 torr, I=15 mA, D=3 mm, T=19% and t_{ex}=30 s.

The water absorbency test

The wettability of the polymer samples is measured before and after the plasma treatment using a drop of water test. This test measures the time that the polymer sample needs to absorb a drop of water on its surface according to the reported standard test method. This test is considered to be the main test in this work so it's done for different for different experimental parameters which mentioned before. Figure 2 shows the effect of the plasma exposure time on the water absorption for polyester samples. It is observed that the relation between two times is inversely proportion. For longer plasma duration time, the surface of the treated sample has more ability to interact with plasma species so the treatment is better hence the time of the water absorption get lower which means the wettability is higher [19-21].

Figure 3 shows the effect of the discharge current on the water absorption for polyester fabric samples using mesh transparency of 19%, air pressure of 2torr and inter-electrode distance of 3 mm at constant plasma exposure time of 30 s. The water absorbance time is reversely proportional to the discharge current. This is because of when the current increases the number of free species, which react with the polymer surface, will increase, so the surface of the polyester fabric is more efficiency absorbs water [19-21].

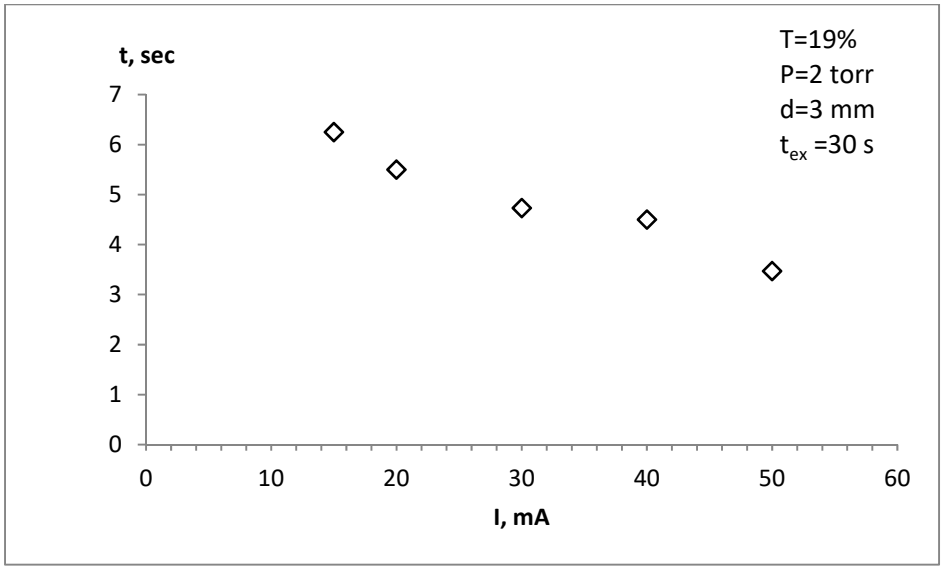

Figure 3. Effect of the plasma discharge current on the water absorption of polyester fabric samples

Figure 4 shows the time of water absorption as a function of the distance between the polyester sample and the mesh anode. The mesh transparency is 19%, the air pressure is 2 torr, the discharge current is 15 mA, the electrode separation is 3 mm and the plasma exposure time is fixed at 30 sec. It is observed that as the distance between the sample and the mesh anode increases, the water absorption time increases. Behind the mesh directly, the ions are more energetic and active but when the species go farther distance, they lose much of their energy due to collisions, so when the polyester samples are located at a short distance from the mesh anode, its surface is treated better as it will interact with high energy plasma species. However, for farther distance from the mesh anode the density of plasma species, which react with the surface, will reduce the efficiency of treatment so the water absorbance time is longer and the wettability of the samples are lower [19-21].

Figure 5 shows the water absorbance time of the polyester samples as a function of the gas pressure. The mesh transparency is 19%, the discharge current is 15 mA, the electrode separation is 3 mm and the plasma exposure time is fixed at 30 s. It is observed that the time of water absorbance is decreasing by increasing the gas pressure. Increasing of the gas pressure increases the plasma density, which means that the number of electrons and ions which interact with the sample surface increase. This is a better method of changing the surface properties of the sample, which reduces the absorption time by increasing the pressure [19-21].

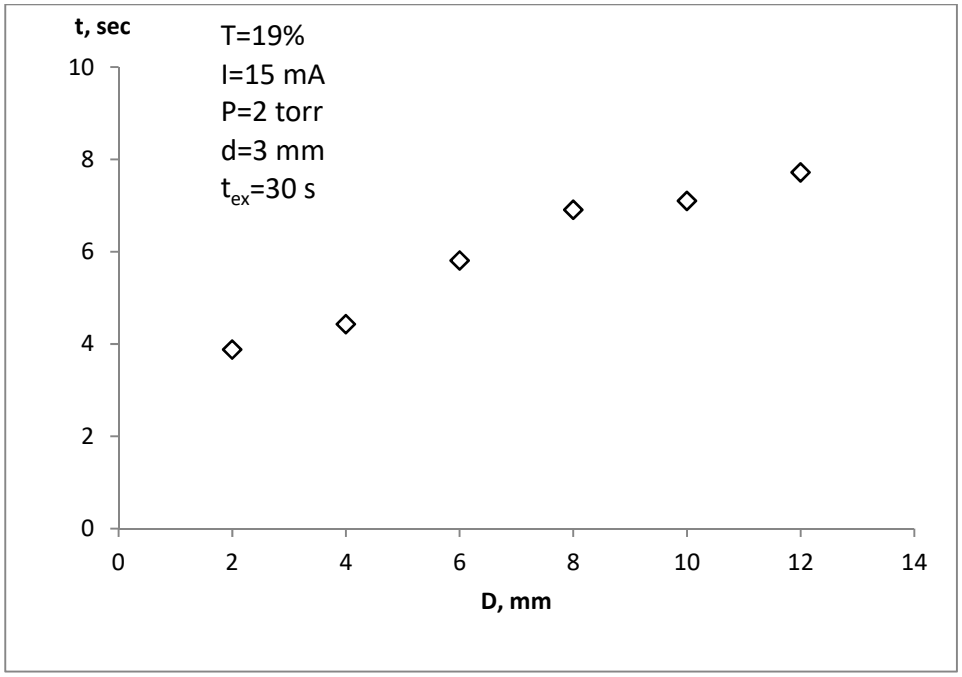

Figure 4. Effect of the distance between the polyester sample and the mesh anode on the water absorption of polyester fabrics

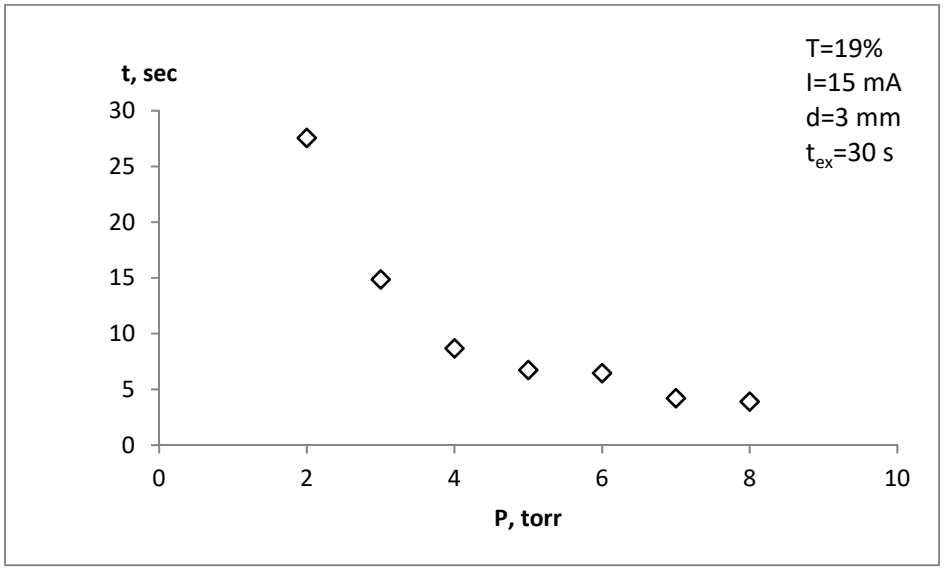

Figure 5. Effect of air pressure in plasma exposure system on the water absorption of polyester fabrics

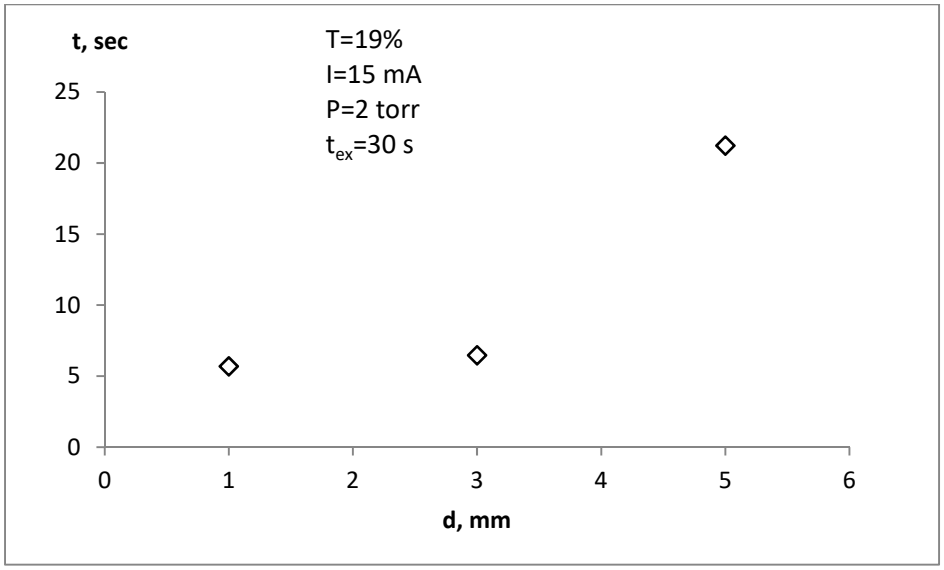

Figure 6. The water absorption time of polyester fabrics as a function of the inter-electrode distance

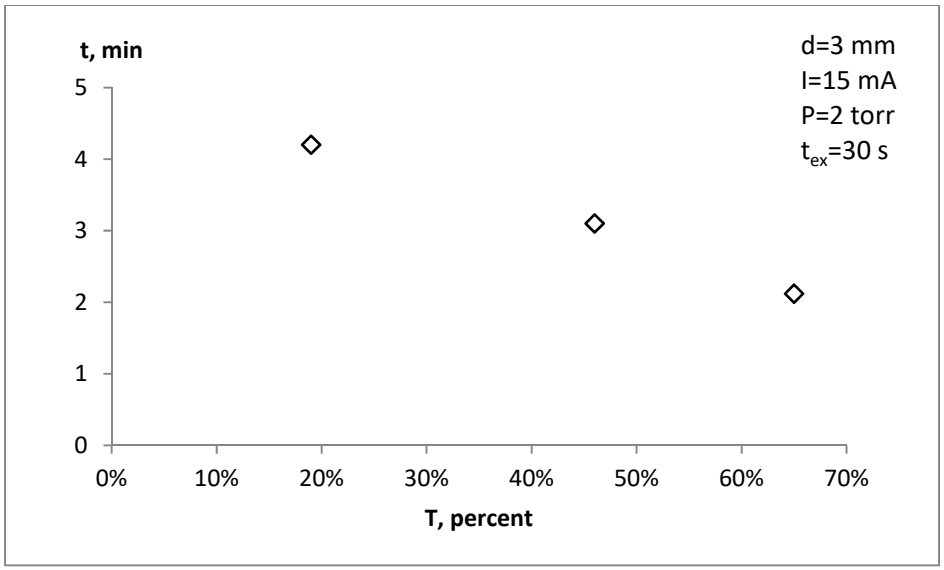

Figure 7. Effect of the mesh anode transparency on the water absorption time of polyester fabrics

Figure 6 shows the water absorption time of the polyester samples as a function of the separation distance between the two electrodes at constant mesh anode transparency of 19%, constant current of 15mA and constant work gas pressure of 2torr. The plasma exposure time for all polyester samples is fixed at 30 s. It observed that when the distance between the two electrodes increases, the water absorption time increases. When the distance between the two electrodes increases, the charged particles of the plasma travel longer distance behind the mesh anode and lose their energy due to collisions. Therefore, the treatment of the polyester samples takes place

with low energetic charged particles at long inter-electrode distance, which causes the wettability of the samples decrease [19-21].

Figure 7 shows the water absorption time as a function of the mesh anode transparency at constant air pressure of 2torr, constant current of 15mA, constant separation distance between the two electrodes of 3mm and constant plasma exposure time of 30 s. It observed that the time of water absorbance decreases with increasing the transparency of the mesh anode. When the transparency of the mesh anode increases, the number of free charged particles, which pass through the mesh anode increases, so the number of the charged particles, which interacts, with the surface of the polyester samples increases too. Therefore, the treatment of the samples is much better and the time of absorption is lower [19-21].

The mechanical test

The mechanical properties are presented in a tensile and elongation test by comparison between two treated samples and untreated polymer sample. The test was take place in the textile laboratory in National Institute for Standards, Tersa St., Haram Giza, Egypt. The two treated samples are different in the working current of the plasma of 40 mA and 50 mA and both of them are treated at constant mesh transparency of 19%, inter-electrode distance of 3 mm, gas pressure of 2 torr, distance behind the mesh of 4mm and plasma exposure time of 30 s [19, 20].

Table 1 represents the effect of the treatment of the pseudo DC plasma discharge on the tensile and elongation percentage of the polyester samples according to warp test.

It observed from table 1 that the value of the elongation ratio and the tensile strength for treated samples are slightly higher than the untreated sample. This means that the materials get rougher and can resist more loads. This is proofing the plasma can increase the roughness of the material surface.

Table 1: Warp test for the treated and untreated polyester samples.

Warp sample	Elongation %	Maximum force Kgf
Warp untreated sample	5.48	25.98
Warp treated sample 1	6.10	28.88
Warp treated sample 2	6.30	29.25

FTIR analysis

Infrared test is one of the important analyzing tests in this work, the shows the bonds of polyester, which are broken and new bonds, which are created at the surface of the polymer. Figure 8 shows the IR test for untreated and treated samples of polyester. The treatment conditions of the sample were constant working pressure of 2 torr, current of 15 mA, inter-electrode distance of 3 mm, separation distance between the polyester sample and the mesh anode of 4mm and plasma exposure time of 60 s. It observed from Figure 8 that the hydrophilic

groups have appeared on the surface of the treated polyester samples, this means that the ability to absorb water of the polyester surface is increased. The O–H stretched group appears in Figure 8 at the peaks of wavenumbers of 3293.8 cm^{-1}, 3221.5 cm^{-1} and 3077.8 cm^{-1}.

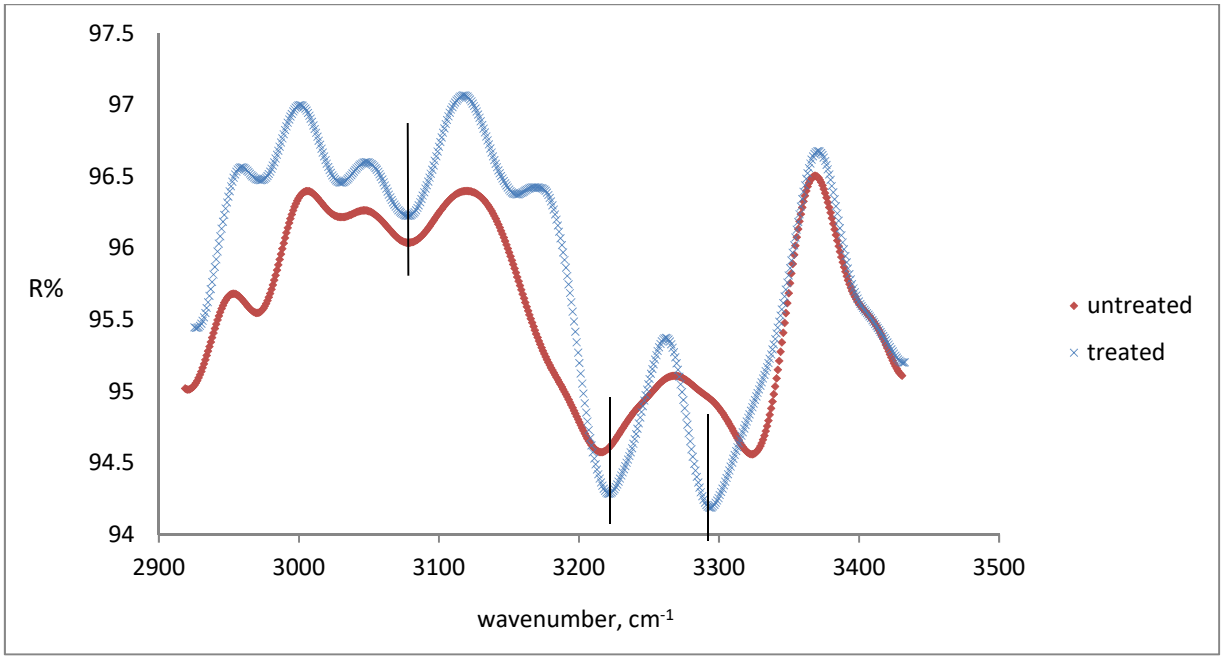

Figure 8. IR spectroscopy chart for treated and untreated polyester samples

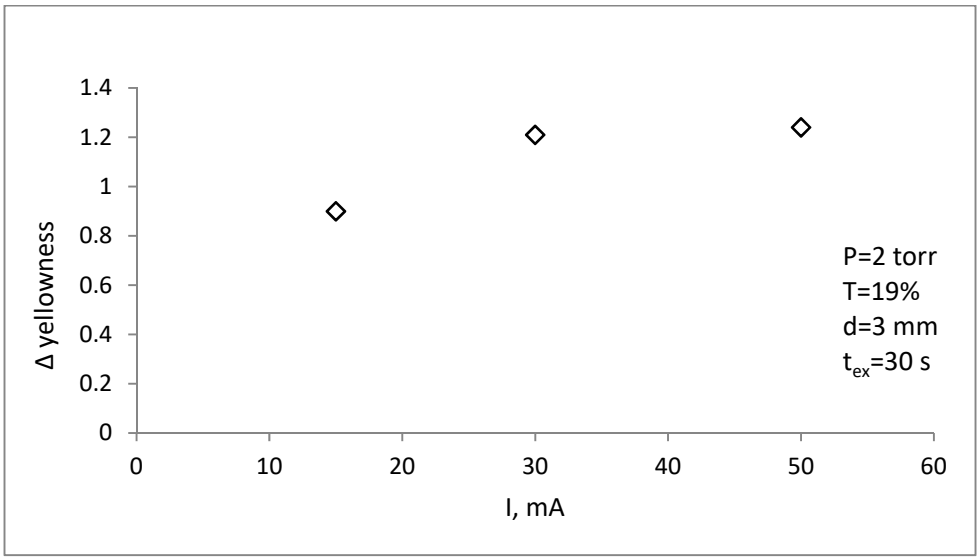

Figure 9. Effect of the discharge current on the whiteness and yellowness of the exposed polyester fabric

The color measurement

The effect of the pseudo DC discharge plasma on the whiteness and yellowness for the polyester samples was investigated by the color test. Figure 9 shows the effect of the plasma discharge current on the whiteness and yellowness of the polyester sample. It observed from the figure that as the plasma current increases the whiteness of the sample decreases while the yellowness increases [21]. This change of the sample color from the whiteness to the yellowness may be illustrated, as, when the plasma electric current increases, the ions are more energetic so the interaction between it and the surface of the polyester sample is strong which make its color turns into yellow.

Conclusion

The predominant function of textile surface treatment using plasma technique to enhance the properties of textile materials is reviewed. The main property of the textile material which is wettability is achieved for different operating conditions including different current (I) (15-50 mA), different time (t) (10-60 s), different distance (d) (1, 3 and 5 mm) between inter-electrodes, different mesh anode transparency (T) (19, 46 and 65%), distance between the polyester sample and the mesh anode (D) (2-12 mm) and different air pressure in plasma exposuring system (P) (2-8 torr). The textile wettability showed significant improvement by increasing the discharge current (I), exposuring time (t_{ex}), air gas pressure (p) and the mesh transparenty (T), while the wettability decrease by increasing the distance between the sample and the anode (D) and by increasing the inter-electrode distance (d). The maximum improvement in wettability obtained at I = 50 mA, t_{ex} = 60 s, p=8 torr and T= 65%. The IR test showed a hydrophilic groups (O-H stretched group) at wavenumbers of 3293.8 cm^{-1}, 3221.5 cm^{-1} and 3077.8 cm^{-1}. An increasing in the elongation ratio and tensile strength is observed for the treated samples than the untreated one.

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