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Operation of DCSBD plasma reactor in laboratory conditions

Działanie reaktora plazmowego DCSBD w warunkach laboratoryjnych

Abstract

Low-temperature plasma treatment has been used in the last years as a useful tool to modify the surface properties of different materials like textile, glass, wood. Plasma technology applied to textiles is a dry, environmentally and worker friendly method to achieve surface alteration without modifying the bulk properties of different materials. In the present work low-temperature plasma was used to treat surface of cotton fabric. We used laboratory line for plasma surface modification - plasma reactor using DCSBD (Diffuse Coplanar Surface Barrier Discharge) plasma systems with flat and curved electrode with active plasma area 200 x 100 mm for continuous treatment of common textiles and polymeric materials. We described laboratory line for plasma surface modification and safety at work with this low-temperature plasma reactor. Also we defined a temperature distribution in cotton fabric during plasma treatment using thermal camera BCAM FLIR. The surface morphology of the untreated and plasma-treated cotton fabrics was analyzed by scanning electron microscopy (SEM).

Keywords: *low-temperature plasma, DCSBD, thermovision, health and safety, SEM microscopy*

Streszczenie

Obróbka plazmą w niskiej temperaturze była w ostatnich latach wykorzystywana jako przydatne narzędzie do modyfikacji właściwości powierzchni różnych materiałów, takich jak: tkaniny, szkło, drewno. Technologia plazmy zastosowana do tkanin jest suchą, przyjazną środowisku i pracownikowi, metodą zmiany powierzchni bez modyfikacji dużej masy właściwości różnych materiałów. W niniejszej pracy wykorzystano plazmę o niskiej temperaturze celem obróbki powierzchni materiału z bawełny. Celem modyfikacji powierzchni wykorzystano linię w laboratorium – reaktor plazmowy z zastosowaniem systemów plazmowych DCSBD (Rozproszona Równoległa Bariera Powierzchniowa) z elektrodą płaską i zakrzywioną z czynną powierzchnią plazmy 200 x 100 mm mm celem ciągłej obróbki popularnych tkanin i materiałów polimerycznych. Opisano linię laboratorium wykorzystaną do modyfikacji powierzchni za pomocą plazmy oraz bezpieczeństwo pracy z reaktorem plazmy o niskiej temperaturze. Określono również rozmieszczenie temperatury w materiale z bawełny podczas obróbki plazmą przy użyciu kamery cieplnej BCAM FLIR. Przeanalizowano skład powierzchni niepoddanego i poddanego obróbce plazmą materiału z bawełny za pomocą skaningowej mikroskopii elektronowej (SEM).

Słowa kluczowe: *plazma niskotemperaturowa, DCSBD, termowizja, zdrowie i bezpieczeństwo, mikroskopia SEM*

1. Introduction

Plasma treatment is commonly used for surface activation and modification of different materials like textiles, composite materials, glass and others.

What is plasma? Plasma, the „4th state of matter" is an electrically neutral ionized gas (i.e. electron density is balanced by that of positive ions) and contains a significant number of electrically charged particles not bound to an atom or molecule. The free electric charges make plasma electrically conductive, internally interactive and strongly responsive to electromagnetic fields. Although there are plenty in nature (it is estimated that plasmas are more than 99% of the visible universe), plasmas can also be effectively produced in laboratory and industry [1].

Why plasma in textile industry? Plasma treatments are gaining popularity in the textile industry due to their numerous advantages over conventional wet processing techniques:

- Plasma surface modification changes surface properties without affecting the bulk properties of materials.
- More energy efficient – dry process, reducing water consumption and energy to dry the treated materials compared to conventional treatments.
- Environmental – reduction the amount of water and chemicals over the conventional wet processing techniques.

The textile applications of plasma include for example sterilization, adhesion improvement, wettability and hydrophobicity, dyeability enhancement, flame retardant and antimicrobial finishing and surface cleaning [2-5].

There are numerous types of plasma and it is therefore very difficult to carry out a universal classification. However, a first simple and objective way to classify different kinds of plasma is to divide it into two categories: thermal and non-thermal [5]. In thermal plasma, temperature of several thousand degrees is reached which is of a destructive nature and no material can stand their action. Non-thermal plasmas are „cold" plasmas where the chemically active environment is achieved at nearly room temperature and this one is used for surface modification of textiles.

There are two types of cold plasma which can be used for application on textiles, namely low-pressure plasma and atmospheric pressure plasma. The advantage of atmospheric plasma is that it is generated at atmospheric pressure and it does not need any vacuum chambers or pumps like low-pressure plasma, and this enables continuous plasma processing. Atmospheric pressure plasma is further classified as Corona Discharge (CD), dielectric barrier discharge (DBD) and atmospheric pressure glow discharges (APGD)[6].

Corona sources contain in homogeneous initial electric fields formed around pointed electrode elements. Barrier discharge sources are characterized by the presence of insulating layers on one or both electrodes, or in the gas-filled gap between the electrodes. Both these sources allow the production of large-area plasmas. Corona discharges have a strong filamentary character, whereas barrier discharges are significantly more homogeneous.

Diffuse Coplanar Surface Barrier Discharge (DCSBD) was originally designed to fulfill the specific requirements of the textile nonwoven industry for hydrophilization of lightweight (i.e. with the thickness on the order of 0.1 mm only) polypropylene nonwoven fabrics, which are widely used in personal care absorbent products, such as feminine hygiene products, diapers, adult incontinent products, and medical products as gowns and surgical drapes [7].

Low-temperature plasma under atmospheric pressure is suited for surface modification because most textile materials are heat sensitive polymer. During the plasma treatment of textile the thermovision experiments were done. Some results are in the chapter 4. For our study we selected the cotton fabric. This cotton fabric was treated by plasma for improving surface properties. The untreated and plasma-treated cotton fabrics were characterized by scanning electron microscopy (SEM). The safety at work with this low-temperature plasma reactor was described, too.

2. Plasma laboratory equipment KPR 20

All experiments were carried on using plasma laboratory equipment KPR 20 (Figures1, 2). This equipment is designed for textile surface treatment on the basic of DCSBD (Diffuse Coplanar Surface Barrier Discharge). A unique feature of the plasma source based on DCSBD is a possibility of generating homogeneous plasma under atmospheric pressure with virtually any working gas composition without usage of expensive inert gases such as He and Ar. Extremely high power density of plasma up to 100 W/cm^{-3} allows short plasma exposure times and thus high speed processing. This allow plasma reactor KPR 20 produced by Research Institute for Man-Made Fibers (Svit/Slovak Republic).

Fig. 1. Description of plasma laboratory equipment KPR 20 – 1 Reel-off unit; 2 Take-up unit; 3 Concave curved electrodes; 4 Flat electrodes; 5 Control unit; 6 H-V power supplies; 7 Oil based cooling system.

Rys. 1. Opis osprzętu laboratoryjnego plazmy KPR 20 - 1 Reel-off unit; 2 Jednostka odbiorcza; 3 zakrzywione elektrody wklęsłe; 4 elektrody płaskie; 5 Jednostka sterująca; 6 zasilaczy H-V; 7 System chłodzenia oparty na oleju.

Source: own research.
Źródło: opracowanie własne.

Fig. 2. Panel with control unit (left) and flat electrode (right)
Rys. 2. Panel z jednostką sterującą (po lewej) i elektrodą płaską (po prawej)

Source: own research.
Źrógło: opracowanie własne.

Conditions of plasma aplication

Depth of generated plasma: 0.3 mm
Operation: in the atmospheric air
Power: 300-400 W
Exposure time: variable e.g. 19120 s
Distance of sample from electrodes: 0.1-0.5 mm

Using

Continuous double-sided surface modification of thin flat materials (polymers, textiles, metals, glass, Figure 3) and composites (foils with thickness of 50 μm-0.5 mm, thin flexible polymeric flat plates with thickness of 0.5-1 mm and thin textile materials as well as cords with diameter of 0.1-0.5 mm).

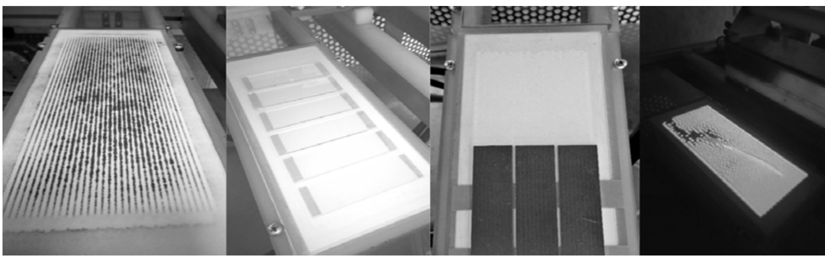

Fig. 3. Materials which can be used for DCSBD plasma treatment (powder, glass, textile)
Rys. 3. Materiały, które można wykorzystać do obróbki plazmy DCSBD (proszek, szkło, tkanina)

Source: own research.
Źródło: opracowanie własne.

For our study was selected the cotton fabric (surface weight: 0.135 kg.m^2, thickness: 0.39 mm). Figure 4 shows a typical morphology of a cotton fabric. Conditions of plasma application: distance between the electrodes was 0.5mm;power 375 W, exposure time 7-35 s.

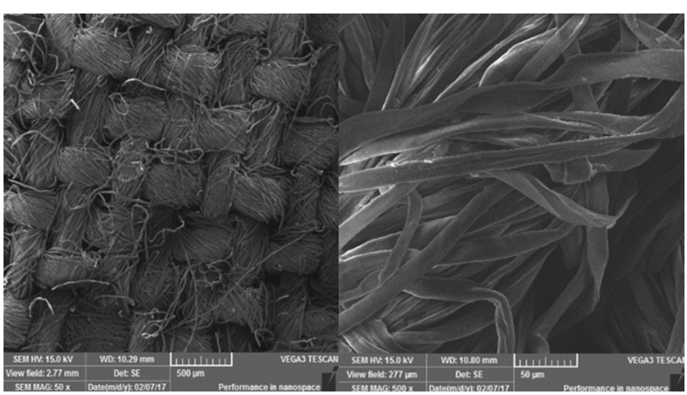

Fig. 4.SEM images of untreated cotton fabric 50x (left) and 500x (right)
Rys. 4. Obrazy SEM nietraktowanej tkaniny bawełnianej 50x (po lewej) i 500x (po prawej)

Source: own research.
Źródło: opracowanie własne.

3. Plasma applications

The research in the field of plasma applications for different materials treatments is very wide and we summarize only a few exemplary applications [3–9]:

- effective hydrophilization and activation of the surface of polypropylene fabrics, polymer films, metals, glass, wood, etc.;
- hydrophobic finishing of cotton and cotton/PET;
- improvement of surface wetting in synthetic polymers (PA, PE, PP, PET);
- antistatic finish of rayon;
- surface treatment of PP foils before printing or dyeing;
- adhesion improvement of PES cords to rubber in car tyres;
- flame-retardant feature for PAN, Rayon, cotton;
- surface cleaning.

Some of thesetreatments can be conducted using common gas plasma, butsome of them utilize specific chemicals in the formation ofplasma.By varying the process of parameters such as the type of gas, time and pressure, different finishes canbe obtained.

4. Health and safety

Contact with the human body and the plasma electrode system is not dangerous, but unless the contact occurs, it is not uncomfortable. During the plasma treatment the ozone is formed, but ozone is exhausted. The devices are always tailor-made for specific customer applications and are necessary to focus on work safety. Our plasma reactor has several drawbacks as unprotected rotating parts of the equipment. There is possibility of electrostatic charges and possibility of improper use of electrical wiring. The on/off (total stop) button is only on the control panel. There is possibility of burning during operation of the device. It has a high sound level.

6. Thermovision investigation of temperature fields distribution during plasma treatment of textile (cotton fabric)

Measurement of the temperature history of distribution of temperature fields on the surface of the textile sample was performed by an infrared thermal imaging camera BCAM FLIR Systems with a resolution of 0.1°C, from a distance of about 2 m, in a time interval of 20 s between two consecutive thermograms, in an average laboratory temperature 20°C at normal atmospheric pressure. Examples of results of thermovision investigations illustrate Figure 5.

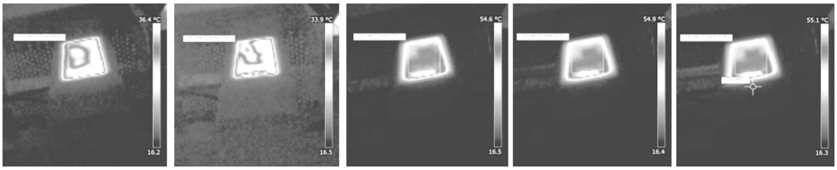

Fig. 5.Demonstration of a temperature field on the surface of tested textile sample.
Rys. 5. Demonstracja pola temperatury na powierzchni badanej próbki włókienniczej.

Source: own research.
Źródło: opracowanie własne.

Since the recorded temperature fields show a relatively high degree of inhomogeneity in the surface distribution, on the thermograms of surface temperature of the sample, the rectangular regions were selected in the FLIR QuickReport software environment to determine their average surface temperature at the moment of the thermogram scanning. These average temperatures were then subjected to statistical analysis in the Matlab® program environment. The evaluation of the statistical analysis of the history of the average surface temperature of the sample in graphical form is shown in Figure 6.

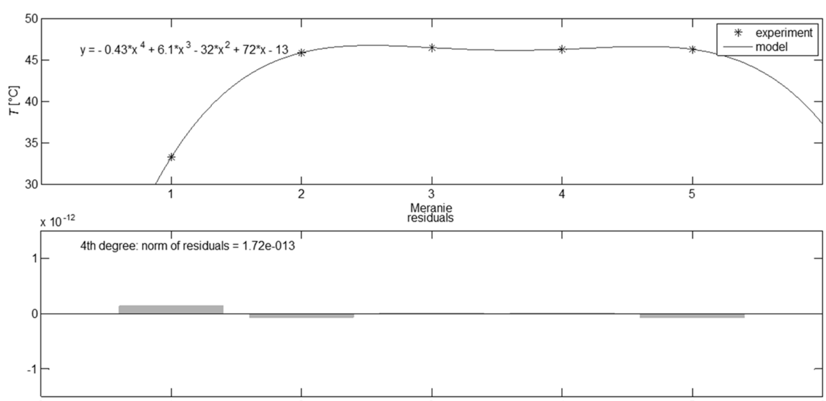

Fig. 6. History of the average surface temperature of the sample and its regression model.
Rys. 6. Historia średniej temperatury powierzchni próbki i jej modelu regresji.

Source: own research.
Źródło: opracowanie własne.

It can be seen that the regression model of average temperatures is well correlated with their experimental values, as evidenced by the relatively low difference between real and model data (residual value) given in the lower half of the figure and their relatively even distribution around the zero value. For the low number of modelling experimental data, however regression model found does not have a generalizable prediction of results at an interval exceeding the range of analyzed measurements.

SEM measurements

The surface morphology of cotton fabricswas examined by the VEGA3, TESCAN Scanning Electron Microscope, with an accelerating voltage of 0.20 kV to 30 kV and probe current of 1 pA to 35 μA at a high magnification between 50–50 000x. The selected untreated cotton fabric and treated sample can be seen from the SEM-images in Figure 7. The SEM images of plasma treated samples clearly showed that the low-temperature plasma under atmospheric pressure modifiedthe cottonsurface.

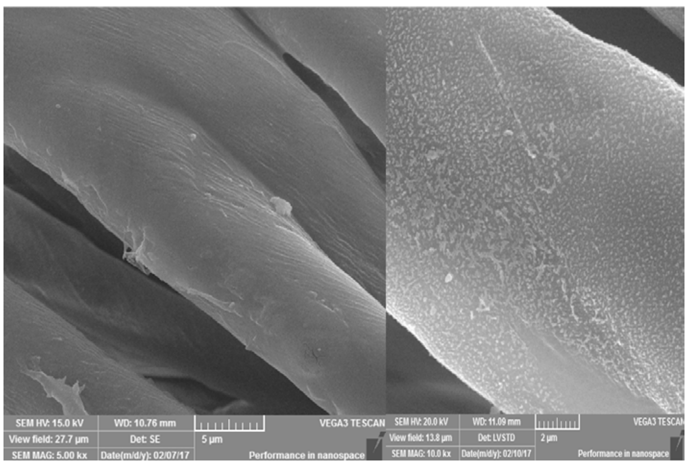

Fig. 7 SEM images of untreated cotton fabric (5kx, left) and plasma-treated cotton fabric at 375 W, 35 s (10kx, right).
Rys. 7. Obrazy SEM nietraktowanej tkaniny bawełnianej (5 kx, lewa strona) i tkaniny bawełnianej poddanej obróbce plazmowej przy 375 W, 35 s (10 kx, po prawej).

Source: own research.
Źródło: opracowanie własne.

6. Conclusion

In this study operation of DCSBD plasma reactor in laboratory conditions and safety at work was decsribed. During the plasma treatment of cotton fabricthe thermovision investigation was carried out.The surface morphology of the untreated and plasma-treated cotton fabric was analyzed by SEM microscopy. The SEM clearly showed that low-temperature atmospheric plasma modified the surface of cotton fabric.Nowadays the research work continues with evaluation the surface properties.

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