PENETRATION OF PLASMA PARTICLES INTO DIFFERENT NON-WOVEN LAYERS

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By using a DBD plasma, several layers of PET non-woven are treated to study the penetration of plasma into the textile material. The influence of the pore size and of the power on the penetration effect is investigated. By using a horizontal wicking experiment, the plasma effect is quantified.

Key words: Dielectric barrier discharge, non-woven, penetration, horizontal wicking

1 Introduction

Surface treatment of polymer films and textiles is usually necessary to improve surface wetting and adhesion characteristics. Conventional liquid chemical processes involve a high consumption and pollution of water. The costs for waste water processing are high and drying of wetted fibers is time and energy consuming. Plasma surface modification offers numerous advantages. The technology is environmentally friendly because it does not require the use of water and chemicals [1]. Moreover, it is a versatile technique, where a large variety of chemical functional groups can be incorporated into the polymer, leading to a changed surface chemistry. The possible aims of this are improved wettability, adhesion of coatings, printability, induced hydrophobic properties, etc. In addition, plasma treatment is a very fast technique, just a few minutes or even seconds [2].

Plasma treatment changes only the outermost layers of a polymer film without changing the bulk properties [3]. However, textiles are porous structures, which consist of a complex web of fibers and threads distributed over the textile thickness, which can reach values up to several millimeters. It is sometimes required that the textile is treated throughout the entire thickness. To ensure this effect, the active plasma species must be able to penetrate though the textile material without losing their modifying ability. The penetration of plasmas into porous structures like textiles has not been studied in depth by many authors and much knowledge still lacks about this process [3,4].

Using a dielectric barrier discharge (DBD) at medium pressure (1 kPa – 10 kPa), the influence of the pore size and power on the penetration of plasma particles in several layers of PET non-woven fabric is studied. The hydrophilicity induced by the plasma treatment of the non-woven is evaluated using a horizontal wicking experiment.

2 Experimental set-up

2.1. DBD set-up

A schematic diagram of the DBD configuration can be seen in figure 1(a). Two circular copper electrodes (diameter = 7 cm) are placed within a cylindrical enclosure. Both electrodes are covered with a glass plate (thickness = 2 mm) and the distance between the plates is 7 mm. The upper electrode is connected to an AC power source (frequency = 5 kHz), the lower electrode to the earth. Between the glass plates, air (Air Liquide – Alphagaz 1) is fed into the system at a constant flow of 0.2 l/min. A pump is connected to the gas outlet and the pressure in the plasma chamber is kept constant by using valves.

The discharge current is obtained by measuring the voltage over a small resistor (50 Ohm), connected in series to the ground, whereas the applied voltage is measured using a high voltage probe (Tektronix P6015A). The current and voltage waveforms are recorded using an oscilloscope (Tektronix TDS210-60MHz), connected to a computer. The resistor can be replaced by a capacitor (10 nF). The voltage across this capacitor is proportional to the charge stored on the electrodes. Together with the applied voltage, this results in a Lissajous figure. From measuring the area of the Lissajous figure, the electrical power can be calculated.

Plasma treatments are carried out at different pressures, ranging from 1 kPa to 10 kPa, and for different treatment times (0 – 15 s). During the experiments, five layers of a 100% PET non-woven (Sontara) are placed on the lower glass plate. Each layer is labeled, as shown in figure 1(b). Three different types of non-woven are used.

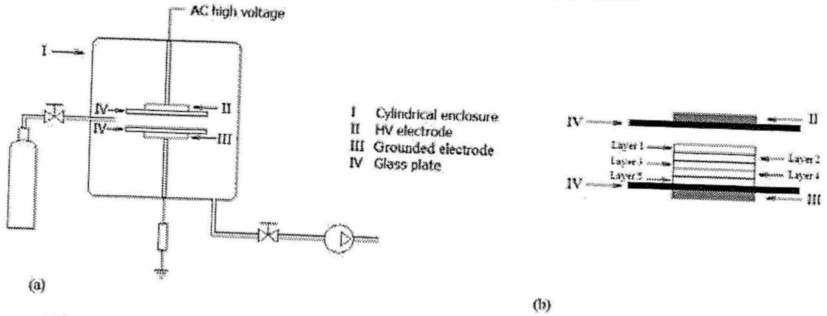

Fig. 1. Experimental set-up (a) and labelling of the different textile layers (b).

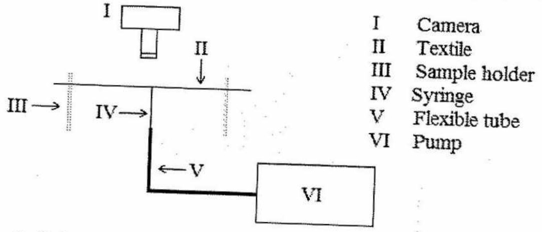

Fig. 2. Schematic set-up of the horizontal wicking experiment.

2.2. Hydrophilicity measurement

The hydrophilicity induced by the plasma treatment of the different non-woven layers is evaluated using a horizontal wicking experiment (see figure 2), since contact angle measurements are not possible on porous substrates [5]. A needle which provides a continuous supply of distilled water at a rate of 1,066 ml/min makes contact with the test specimen. The water is absorbed by the fabric to form a wetted spot and the area of the wetted spot after 15 s of water supply (A_{15s}) is taken as a measure of the hydrophilization effect. A picture of the wetted area A_{15s} is taken with a digital camera and analysed by imaging-processing software. Each measurement is repeated three times and an average and standard deviation are calculated. Standard deviations vary from 3% to 15%; no difference is found between the hydrophilicity of the upper and lower side of the non-woven.

3 Results and discussion

3.1. DBD characterization

Figure 3 shows the voltage and current waveforms at a pressure of 3 kPa. At other pressures similar waveforms are observed. The amplitude of the applied voltage is approximately 4 kV. Superimposed on the capacitive current, there are several short peaks. These peaks are an indication of the microdischarge activity in the DBD plasma. Every current pulse corresponds to a series of microdischarges.

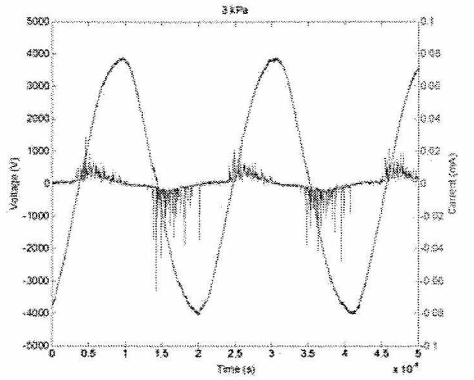

Fig. 3. Current and voltage waveforms of the DBD discharge at 3 kPa.

3.2. Plasma treatment results

For each plasma treatment, 5 layers of non-woven are treated at the same time. Three different types of non-woven material are used (Sontara 8001, Sontara 8000 and Sontara 8004). They are all 100% PET non-woven, with the main difference the pore size, the 8001-type having the largest pore size and 8004 the smallest.

Increasing the plasma treatment time, results in a higher hydrophilic character of the non-woven layers. This means that the wetted area, A_{15s}, will become larger and saturates after a treatment of 10s to 15s. In figure 4 A, results are shown for treatments performed at 1 kPa, for the Sontara 8000 non-woven. For other pressures or types of non-woven, similar results are obtained. In order to make a good comparison between the results at different pressure, in stead of the treatment time, the energy density is used. Treatment time can be easily converted into energy density using the electrical plasma power calculated from the Lissajous figure and the following formula:

Energy density (J/cm²) = treatment time (s) × plasma power (W)/ electrode area (cm²)

To visualize the pressure effect, in stead of looking at the energy density to reach the saturation value of A_{15s}, the energy density needed to reach half the saturation value ($A_{1/2}$) is preferred. Figures 4 B-D show the experimental results for the 3 different types of non-woven. For the 3 types, and for every pressure, layer 5 is the most hydrophilic after plasma treatment, followed by layer 1 and 4. Layer 2 and 3 are always the least hydrophilic after treatment. Layer 5 lies directly on the dielectric surface, where the microdischarge channels spread into a surface discharge covering a larger region than the original channel diameter. Almost the entire dielectric surface is covered by plasma and therefore, the lowest layer (layer 5) is in strong contact with the plasma. Also layer 4 takes benefit from the spreading of the microdischarges. Layer 1 is in direct contact with the plasma above, explaining its relatively good treatment. Layer 2 and 3 are completely dependent on the penetration of plasma species.

When looking at the influence of the pressure, the treatment efficiency can be enhanced by working at lower pressure (1 kPa to 3 kPa) for all layers, except for layer 5. For this layer, the influence of the pressure is minor. Also, there is no influence of the pore size on the pressure dependence of the penetration effect.

The influence of the electrical power is presented in figure 5, for treatments performed at a pressure of 5 kPa. The time (fig. 5 A) or energy density (fig. 5 B) needed to reach half the saturation value of the wetted area ($A_{1/2}$) is depicted in function of the applied power during treatment. Again, layer 5 is most hydrophilic, followed by layer 1 and 4. Layer 2 and 3 are the least hydrophilic after treatment. When raising the power, the treatment time can be reduced. This reduction is more pronounced for layer 2 and 3. When the results are plotted using the energy density, however, the treatment efficiency is not much affected by the electrical power.

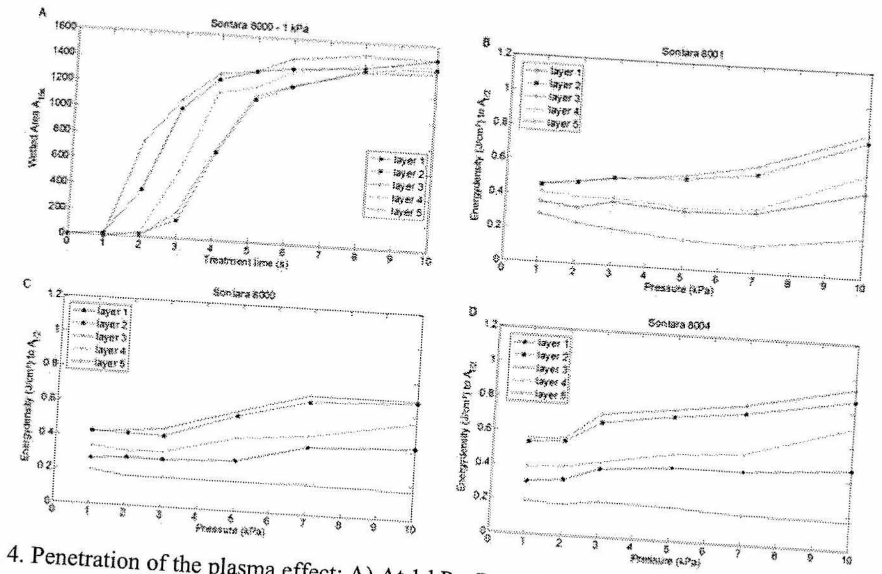

Fig. 4. Penetration of the plasma effect: A) At 1 kPa, B-D) Pressure dependence of the penetration of the plasma effect for the different types of non-woven.

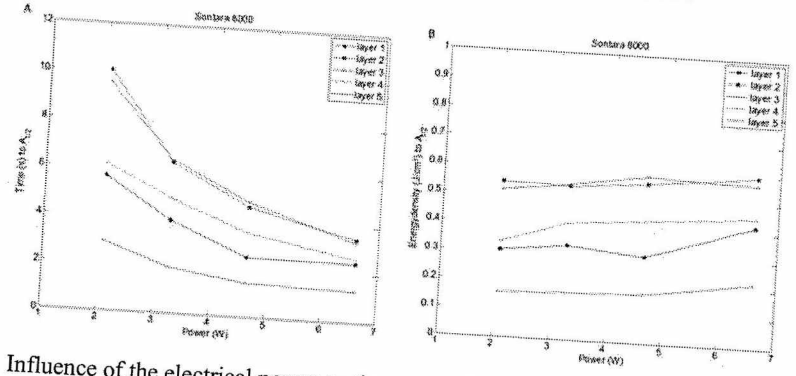

Fig. 5. Influence of the electrical power on the penetration of the plasma effect (pressure = 5 kPa).

4 Conclusion

The penetration of a DBD plasma into several layers of PET non-woven was studied. By working at lower pressure the treatment was more efficient and it was found that the pore size has no influence on the pressure dependence of the penetration effect. By using a higher power, the treatment time could be reduced.

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