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Study of the effect of plasma treatment on the triboelectric properties of Polyethylene (PE) and Polypropylene (PP) slabs

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Abstract. The dielectric barrier discharge (DBD) is a convenient way to modify the surface properties of polymers. The aim of this study is to evaluate the effect of atmospheric DBD treatment on the triboelectric properties of polymers in sliding contact. The experiments were carried out on two polymers that were rubbed against each other: PP and PE. The pairs of samples were exposed to the DBD, and then taken to a triboelectric test bench for friction charging. The distribution of electric potential at the surface of the tribocharged samples was measured by an electrostatic voltmeter. The triboelectric behavior of the considered polymers depends on the conditions of DBD treatment: thickness of the dielectric barrier and duration of the exposure to the non-thermal plasma.

1. Introduction

The use of polymers has considerably increased in recent times, due to their excellent electrical and mechanical properties, their availability in the market, as well as their low cost. However, the knowledge of the polymer-polymer contact is not perfectly mastered and understanding the tribological processes of this contact is crucial in the design of such components [1].

The generation of electrical charges by friction between two insulating materials is influenced by many factors: nature and surface state of the materials that are rubbed, ambient conditions, relative velocity of the surfaces in motion, contact pressure, etc. [2-5]. Among the various technologies for surface modification, plasma treatment is currently one of the most effective [6].

Previous studies have clearly shown the unpredictable effect of plasma surface modification on tribological behavior of polymers [7-10]. For example, Bekkara et al [9] and Natsuta et al [10] have shown that a dielectric barrier discharge (DBD) treatment improves the wettability of the polymer and that a longer plasma exposure increases the roughness of the material, which helps to enhance the number of contact points at the sample surface and the tribo-charging ability. However, there is a need to collect more information on the influence of DBD on the tribocharging of polymers.

The aim of this paper is to study the effect of DBD on the frictional conformal contact electrical tribocharging of two polymers that are widely used in industry. It also studies the influence of several parameters of the DBD to quantify the amount of charge that will be produced by the tribocharging and to increase or decrease this charge according to the industrial need.

2. Materials and experimental setup

2.1. Materials and preparation

The experiments were carried out on 4.5-mm-thick slabs of PE and Polypropylene PP.

Each plate was cut into two samples of different dimensions (A): 100 mm x 15 mm, and (B): 50 mm x 180 mm. Pairs of samples (A) + (B) of the two polymers were taken into the DBD cell for treatment with atmospheric plasma in order to modify their surface. They were then transferred to the triboelectric test bench and finally the distribution of the electric charge at the surface of the (B) sample was scanned using an electrostatic probe, the measured values of the electric potential being directly recorded on a PC, using LabView software.

2.2. DBD cell

The surface treatment of the polymer samples was performed with an atmospheric DBD under ambient temperature conditions (temperature: 20.9 °C – 23.7 °C, relative humidity: 45% - 50%).

Figure 1 represents the configuration of the DBD cell composed essentially of two horizontally disposed parallel electrodes: copper adhesive tapes (0.36 mm x 70 mm x 160 mm) glued directly on the dielectric glass barriers (dimensions: 180 mm x 260 mm). The upper electrode was connected to a high-voltage supply (22.5 kV, 800 Hz), while the bottom one is grounded. The air-gap was maintained constant at 10 mm.

The thickness of the barrier was varied (5 mm, 4 mm and 3 mm) as well as the duration of plasma exposure (from 30 to 90 seconds), to evaluate the influence of these factors on the tribocharging of the samples.

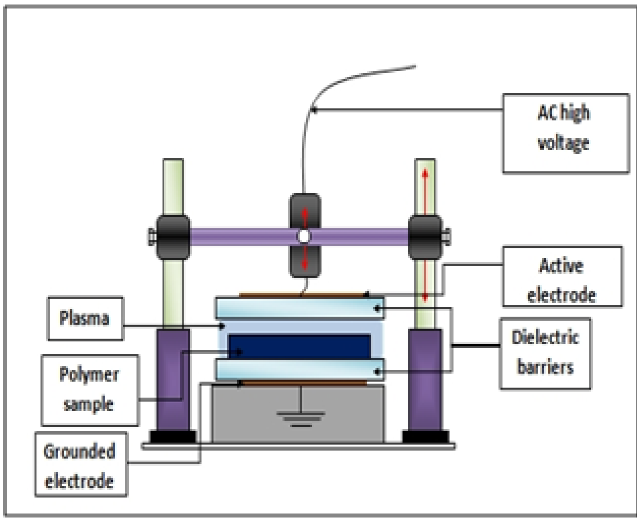

Figure 1. DBD configuration.

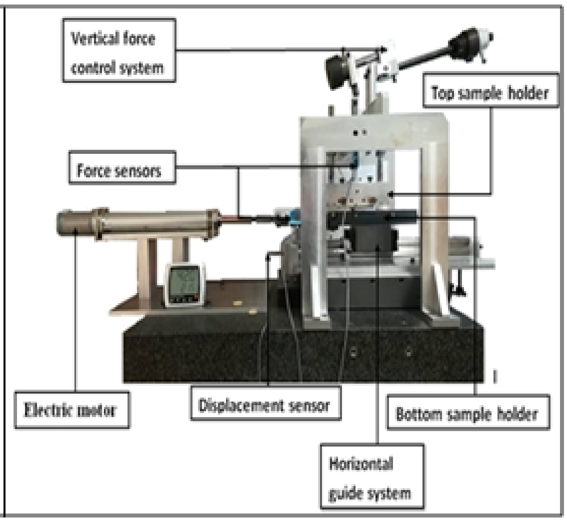

Figure 2. Triboelectric bench test.

2.3. Triboelectric test bench

The triboelectric test bench (figure 2) has the role of charging the polymer samples by friction with each other. Designed to ensure a plane/plane contact between the pair of polymers, the bench is composed of two sample holders, the top one is for the small sample (A), and the bottom one is for the large sample (B). These two holders will ensure the uniformity of contact between the two samples.

The bench also has a rail guide system that ensures the horizontal displacement of the lower holder in back and forth motion. The speed of this movement can be varied and controlled using an electric motor. The bench also contains a system of vertical guide bars that maintain the normal force perpendicular to the surface of the lower sample. This force can be adjusted using the mechanical force control system and measured by a force sensor. In addition to this sensor, two other sensors for tangential force and displacement are included in the system.

Measurements data are transferred to a computer using LabVIEW software. The same software and the same data acquisition card are used to trigger the start and stop of the back-and-forth by controlling the power supply of the electric motor.

The different parameters of the bench remained unchanged throughout the experiments: normal force = 10 N, the translational speed is 10 mm/s, the stroke of the bottom sample holder is 55 mm, and the number of a tribocharging (rubbing) cycle is 50.

The electric potential at the surface of the bottom sample is measured by the capacitive probe (Trek, model 6300-7) of an electrostatic voltmeter (Trek, model P0865). The measurements are usually made from the centre to the edge of the sample. They enable the characterization of the charge distribution at the surface of the respective sample [11].

3. Results and discussion

The results presented in figures 3 and 4 are those obtained by scanning the electric potential at the surface of type (B) PP samples, rubbed against type (A) PE samples. Similar results were obtained for type (B) PE samples when rubbed against type (A) PP samples.

The four cartographies in Figure 3 represent the electric surface potential at the surface of tribocharged PP samples treated with the DBD for different durations. The first one represents a sample that has not been exposed to DBD treatment (t = 0 s) and for which the value of the peak of potential was -1606 V. For DBD exposures of 30 s and 60 s, the surface potential reached respectively the values of-2242 V, and -7394 V. The longest processing time of 90 s lead to the highest value of the potential peak: -9156 V. The results show that multiplying by three the duration of the DBD treatment, the value of the peak of potential acquired after the tribocharging process increases in a similar proportion.

The effect of the thickness of the dielectric barrier (glass) on the tribocharging of the polymer samples is shown in Figure 4. The three cartographies represent the values recorded by the electrostatic potential probe. The charge acquired by the sample after its tribocharging is inversely proportional to the thickness of the dielectric barrier. The thinner the glass plates employed as dielectric barriers, the higher the absolute value of the peak electric potential measured at the surface of the samples. The results show that to obtain a better polymer charging, the thickness of the dielectric must be as thin as possible.

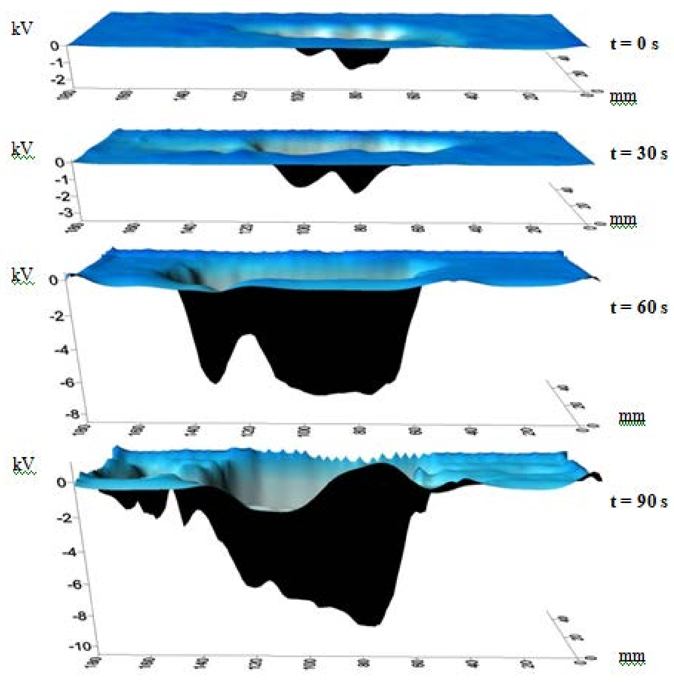

Figure 3. Cartographies of the electric potential at the surface of tribocharged polymer samples previously exposed to a DBD discharge for various durations t = 30 s, 60 s and 90 s.

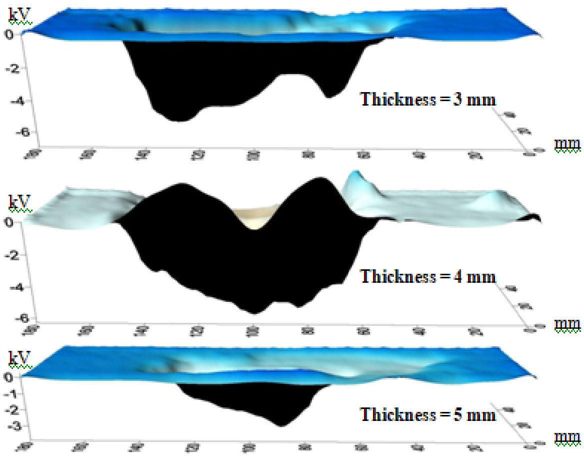

Figure 4. Cartographies of the electric surface potential at the surface of tribocharged polymer samples previously exposed to a DBD discharge for various dielectrics thicknesses, 3 mm, 4 mm and 5 mm.

4. Conclusions

The plasma treatment has a direct influence on the triboelectric properties of the polymers. A PP or PE sample treated with DBD will experience better tribocharging than that of an untreated sample, as the plasma modifies the surface of the polymer in a way that favors better contact during the frictional motion.

Each factor influencing the intensity of the discharge will consequently also influence the charge at the surface of the polymer after tribocharging.

The adjustable parameters of the DBD cell influence the triboelectric properties of the polymer. An increase of the processing time will be accompanied by a better tribocharging of the sample. On the other hand, an increase of the thickness of the dielectric barriers decreases the intensity of the discharge and therefore the charge acquired by the polymer after tribocharging will be less important.

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