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Study of the effect of duration of non-thermal plasma treatment on the surface properties of polymers

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Abstract. One of the factors affecting the electric charge acquired through friction between the polymers is their surface roughness. The dielectric barrier discharge (DBD) treatment is known to modify the surface characteristics of polymers. The aim of this study is to quantify the effect of atmospheric DBD exposure, in a well-defined configuration on the triboelectric behavior of polymers. Thus, Polytetrafluoroethylene (PTFE) plate samples characterized by different surface roughness were rubbed against bronze plate samples in a triboelectric test bench and then the electric potential at their surface was measured. The results were compared with those obtained for surfaces previously exposed to DBD treatment duration of which did not bring any change in their roughness. It was found that the roughness of the surface of the treated polymers hardly changed for rather short DBD exposure time (a few minutes). Significant changes were noticed for longer treatment duration (30 minutes and more). The samples that had undergone a longer treatment period modification acquired higher levels of electric charge by triboelectric effect.

1. Introduction

For several years now, whether in the field of industry or the medical field, the use of polymers is more and more widespread and all that is thanks to their mechanical, electrical and thermal properties. Therefore these new materials have become increasingly the focus of scientific research. Despite the extent of such research, knowledge about the mechanical and electrical properties of polymers as well as about the electric charge generated by friction between them are not perfectly mastered [1-3].

Polymer surface properties like morphology and topography can be modified by means of different chemical and physical treatment techniques. These techniques are used in many fields: from automotive and aerospace industries, to the manufacturing of electronic and bio-medical devices.

Among various surface modification techniques, plasma treatment is probably one of the most used for polymer surface treatment, as it is very easy to implement in the industry, requiring simple and flexible configurations with regard to electrode geometry. Moreover, it has high efficiency and processing speed, very low electrical energy consumption and excellent operating costs [4-7].

Previous studies have clearly shown the unpredictable effect of plasma surface modification on tribological behavior of polymers [8-10]. For example, Bekkara et al [8] and Natsuta et al [9] have shown that a DBD treatment modifies the wettability of certain polymers (Polypropylene (PP), Polyethylene (PE), polyethylene terephthalate (PET) and polyvinyl chloride (PVC)) and that a longer plasma exposure increases the roughness of the material. On the other hand, Al.Maliki et al [10] showed that the roughness of the materials (Polyetheretherketone and Polycaprolactame) may decrease and then increase with the duration of the treatment.



The aim of this paper is to study the effect of the duration of the DBD on the roughness of the Polytetrafluoroethylene (PTFE) known as Teflon. It also investigates the effect of variation in roughness on the triboelectric properties of PTFE in an attempt to find a relationship between the amount of charge that will be produced and the roughness of the friction surfaces.

2. Materials and experimental setup

2.1 Materials and preparation

The samples chosen during this study are a PTFE / metal sample pair. This choice is justified because the PTFE is one of the most used polymers in industry field and especially in medical applications, such as orthopedic implants and vascular grafts. [6]. It has excellent mechanical properties, high chemical resistance, a very low refractive index and the lowest known dielectric constant of all polymers.

For the metal used in this study, a bronze sample (consisting essentially of copper and tin) was selected. The dimensions of the bronze sample (A) were: 100 mm x 15 mm x 5 mm, and those of the PTFE samples (B) were: 50 mm x 180 mm x 6.5 mm. The PTFE samples (B) were first taken for a roughness measurement to ensure that the surface condition is uniform. In order to reduce their surface roughness, some of these samples have been polished with alumina abrasive discs with a P400 grain content, and continuous lubrication with water. The polishing was manual and each sample was held against the abrasive disk for a period of 5 minutes. The PTFE sample was then taken into the DBD cell for treatment with atmospheric plasma. They were then transferred to the triboelectric test bench and finally the distribution of the electric charge at their surfaces after tribocharging was scanned using an electrostatic probe. The measured values of the electric potential have been directly recorded on a PC, using LabView software.

2.2 DBD cell

The surface treatment of the polymer samples was performed under ambient temperature conditions (temperature: 20 °C – 24 °C, relative humidity: 50% - 55%).

Figure 1.a represents the configuration of the DBD cell composed essentially of two horizontally disposed parallel electrodes: an aluminum discs with 120 mm of diameter and 6 mm of thickness and the active electrode that is made mobile by a sliding system and can be adjusted up and down to change the discharge gap. The grounded electrode is covered by square glass plate as dielectric barrier of 180 mm x 260 mm with the thickness of 4 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 3.5 mm and the duration of plasma exposure was modified for each experiment. Three samples were treated for each of 4 different durations of treatment: 5, 10, 20, and 30 minutes.

2.3 Triboelectric test bench

The triboelectric test bench (Figure 1.b) has the role of charging the metal/polymer samples by friction with each other. Designed to ensure a plane/plane contact between the pair of samples, the bench is composed of two sample holders: the top one is for the bronze sample (A) and the bottom one is for the PTFE 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 actuator. 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.

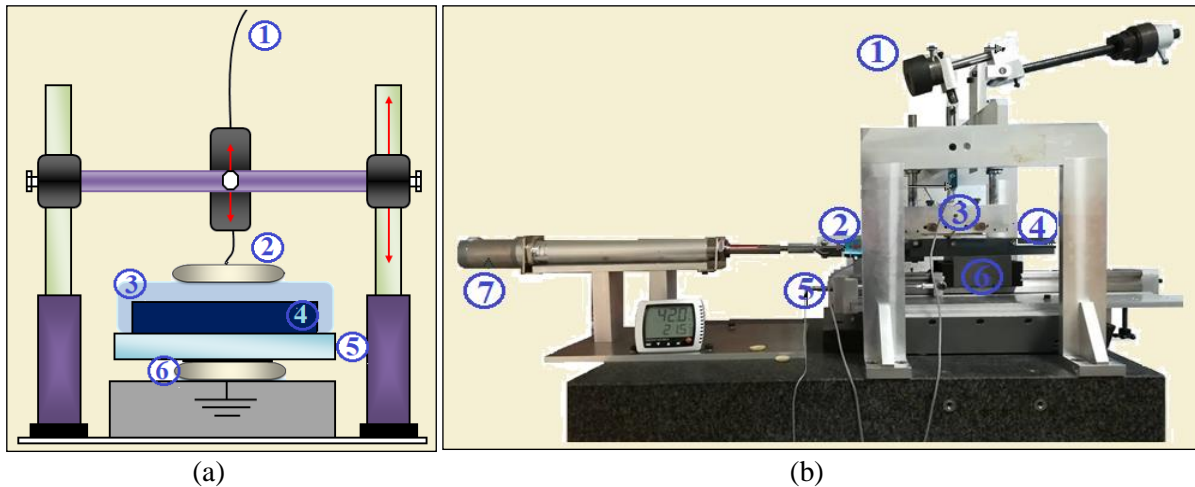


Figure 1. (a); DBD cell configuration; (1) AC high voltage; (2) Active electrode; (3) Plasma; (4) Polymer sample; (5) Dielectric barrier; (6) Grounded electrode, (b); Triboelectric test bench; (1) Vertical force control system; (2) Force sensor; (3) Top sample holder; (4) Bottom sample holder; (5) Displacement sensor; (6) Horizontal guide system; (7) Electric motor.

The different parameters of the bench remained unchanged throughout the experiments: the normal force is 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) cycles is 10 [1].

The electric potential at the surface of the bottom sample is measured by the auto-compensated induction probe (Trek, model 6300-7) of an electrostatic voltmeter (Trek, model P0865). 20 points of measurement were made on each sample and the highest values were recorded.

Before each experiment, any residual charges of the samples are eliminated with the charge neutralizer (ELCOWA, model ECA88-BS), equipped with a 5 kV high-voltage generator (ELCOWA model SC04B).

3. Results and discussion

In the first series of experiments, a comparative study on the effect of PTFE surface texture on the amount of charge generated after tribocharging was carried out. This results in 4 type of PTFE surface finishing. For each surface type, the same experiment was performed on 5 different samples.

The first surface condition was the “non-treated” one: a PTFE sheet was cut into 5 plates which, after neutralization, were directly taken to the tribocharger. After that, the charge generated on the surface of this sample was measured in the next minute. The measurements were recorded and the maximum value of the potential of the surface was determined for each charged sample.

The second surface condition was “polished”: before taking the 5 plates of PTFE to the tribocharger they were mechanically polished with abrasive paper. Their surface state has clearly changed and their roughness has significantly decreased compared to their initial state. The same procedure as for the “non-treated” samples was then used to determine the maximum value of the surface potential generated after tribocharging.

The third and fourth surfaces finishes were raw PTFE plates and polished PTFE plates treated with DBD for 30 minutes. After the DBD, the experimental procedure was similar to that described above. Figure 2 shows the obtained result, which is the maximum potential value recorded on the tribocharged surface. The highest potential was found on the surface of PTFE which was only polished, with a maximum value of -7600 V. A DBD treatment lasting 30 minutes with a polished surface reduced the potential generated by tribocharging to -6300 V. The lowest value measured of the potential is that of a surface that has not been polished or treated with cold plasma. The maximum potential of this surface has only reached a value of -2200 V, but unlike the previous case, a DBD treatment of 30 minutes of the non-polished surface increased the potential value up to -4300 V.

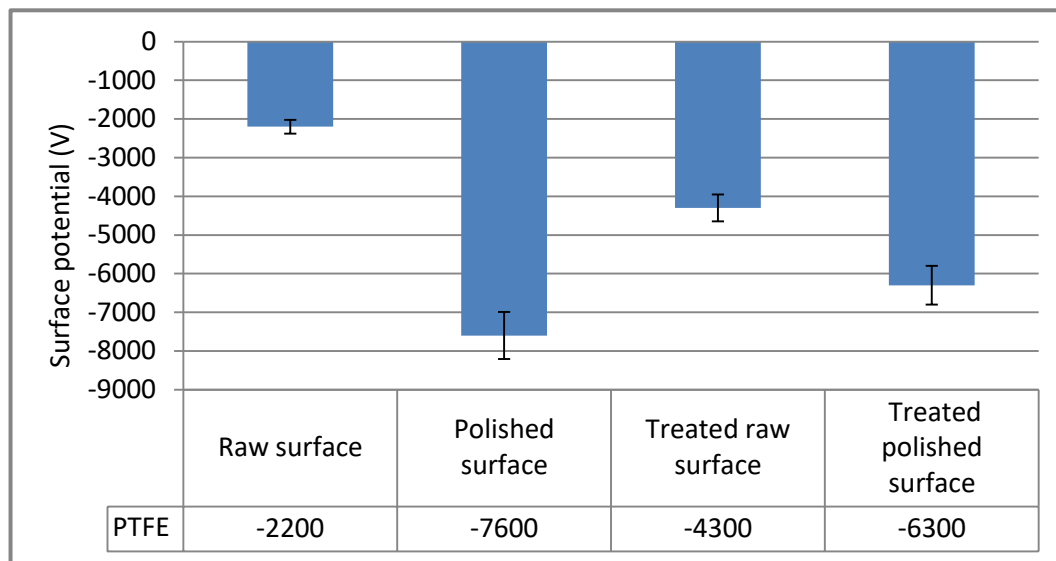


Figure 2. The maximum surface potential on different surfaces of PTFE rubbed with bronze.

The second series of experiments involved only raw (unpolished) PTFE plates, all of which underwent DBD treatment but with different treatment times. The treatment duration was 0 (untreated), 5, 10, 20 and 30 minutes. The procedure was the same as in the previous series of experiments: the same parameters of the DBD cell and of the tribocharging facility. Only the duration of the DBD treatment was varied.

Figure 3 shows that the treatment with DBD has an influence on the maximum value of the surface potential generated by tribocharging. A surface treated with DBD acquired a much greater potential than an untreated surface. The maximum value of the surface potential obtained on an untreated sample was -2200 V, while that of a sample treated for 5 minutes was -6400 V. However, a longer treatment time does not mean a higher generation of surface potential by tribocharging. The maximum recorded value of surface potential was obtained for 10 minutes treatment period. For a longer treatment time (30 minutes), the maximum value of the surface potential decreased.

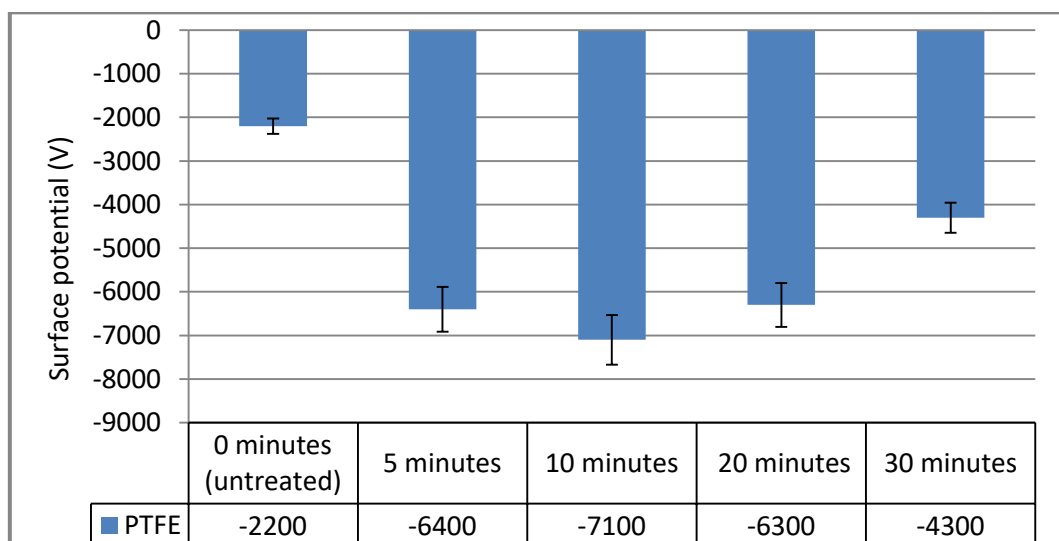


Figure 3. The maximum surface potential for different DBD processing times of PTFE rubbed with bronze.

4. Conclusions

The paper was focused on the study of the influence of the surface state of a polymer on its triboelectric properties after tribocharging, as well as the effect of the cold plasma and its treatment time duration on the triboelectric charge generation. The main conclusions that could be drawn from this study are:

- The surface state of the polymer may have a direct influence on its tribological properties: a smoother surface state allows generating a higher surface potential after tribocharging.
- Cold plasma (DBD) treatment also has a direct influence on the polymer triboelectric properties. Exposure of the polymer to the DBD allows it to gain a higher surface potential after tribocharging than that of an untreated one.
- A longer cold plasma treatment time does not necessarily mean a higher surface potential after tribocharging. The generated surface potential increases with the duration of treatment time to a certain value and then begins to diminish despite of the fact that the treatment time is longer.

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