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Influence of surface roughness on the tribo-electric process for a sliding contact between polymeric plate materials

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Abstract. Polymers are used in many industrial applications due to their good mechanical and thermal properties. Studies have shown that electrical insulators, such as the polymers, are generating electrostatic charge by frictional contact. This tribo-charging effect influences de sliding conditions, and the level of charge depends of several factors. The aim of this paper is to validate two paradigms: (I) the electrostatic charge increases with contact pressure; (II) the level of charge is influenced by the number of contact points on the surface. The tribocharging experiments were carried out with samples cut from two polymers: Acrylonitrile-Butadiene-Styrene, 5 mm x 15mm x100 mm, roughness: $R_a = 0.4 \mu\text{m}$; and Polyvinyl Chloride, 5 mm x 50 mm x 180 mm, with various roughness values: $R_a = 3\text{-}12 \mu\text{m}$ and $R_{Sm} = 150\text{-}350 \mu\text{m}$. The modification of asperity density was accompanied by changes in the electric potential measured at the surface of the PVC samples. Thus, its average value V increased from -0.33 to -0.85 kV, and its maximum value V_{max} , from -1.56 to -4.83 kV.

1. Introduction

Polymers are more and more used as materials for sliding machine components, due to their low cost, ease of manufacturing, as well as good mechanical and thermal properties [1-8]. Their triboelectric charging (i.e., acquiring an electric charge after they come in frictional contact with a different material) is a phenomenon which is not totally understood [8].

Recent studies have shown that the electrical charge generated by such contact between insulating materials has an important effect on the rubbing process, especially in the case of lubricated sliding [9-12]. The charge generation 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 [13]. The contact between surfaces is usually made on a number of points related to the surface roughness. When the surfaces slide with respect to each other, a point from one of the surfaces may remain in contact with the other surfaces for a while. After a short displacement the point of contact will give way to a new one. In the course of time multiple points of contact will be involved [13-14]. This consideration has given rise to two paradigms: one (I) according to which the electric charge increases with pressure and the second (II) that says that the electric charge increases with the multiplication of contact points, the Volta-Helmholtz hypothesis [13-14]. A method to change the number of contact points is to modify the roughness of the surfaces involved in the tribocharging process. The aim of this paper is to validate the two paradigms, by investigating the influence of surface roughness on tribocharge generation in the case of polymeric materials.



2. Methods and materials

Two types of samples (A): 5 mm x 15 mm x 100 mm and (B): 5 mm x 50 mm x 180 mm are employed for the electric tribo-charging experiments. They are cut from two polymers: Polyvinyl chloride (PVC) and Acrylonitrile Butadiene Styrene (ABS). The samples are chosen in conformity with the tribo series to provide a good triboelectrification [13]. The residual charge at the surface of these samples is neutralized using an ionizing system (electrode ECA 88 BS and high-voltage supply SC 04 B, 5 kV, 7 mA, manufacturer: ELCOWA, Mulhouse, France).

Tribocharging process is carried out using a linear tribometer (figure 1) to generate the electric charge by friction between a pair of samples (A) and (B). The A-type sample is connected to a top holder (2) fixed in a vertical guiding system and using an adjustable arm (3) to vary the normal force. The B-type sample is placed in a holder attached to a back-and-forth sliding motion system (1), actioned electric actuator (4). The tangential and normal forces, as well as the relative displacement of the samples are continuously measured. This triboelectric laboratory bench enables the control of several factors that affect the electrostatic charge generation: relative sliding speed, normal contact force, and number of back-and-forth cycles.

Room temperature and relative humidity are also important factors in electric surface charging experiments, and they were read with a thermo- hygrometer. Their values were respectively set in the intervals 20 – 24°C and 40 to 50%, using a dehumidifier.

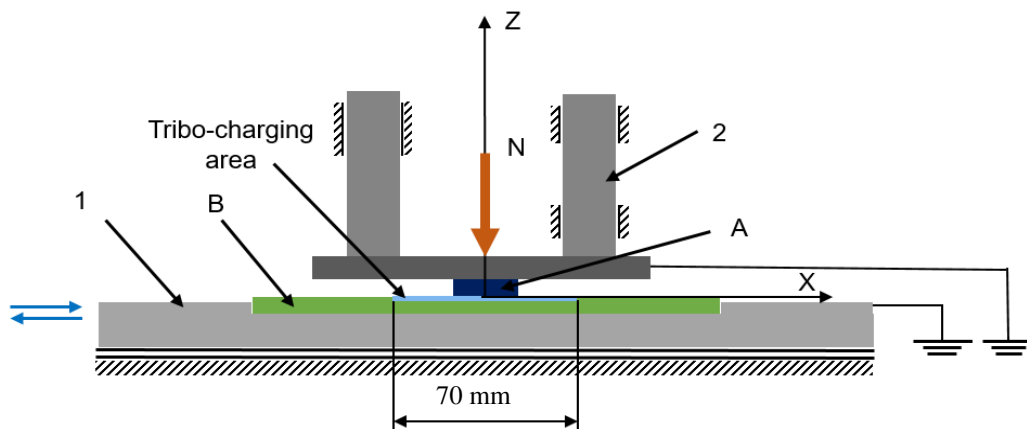
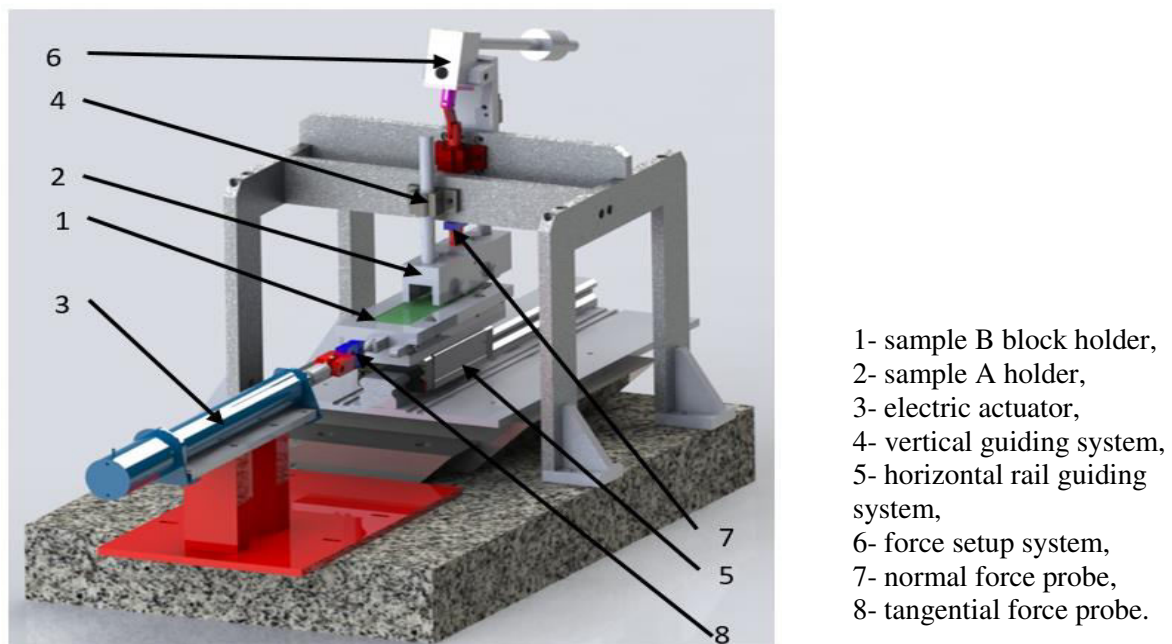


Figure 1. Schematic representation of the laboratory bench for triboelectric charging

The electric potential mapping techniques can give an image of the tribo-electrically generated charge at the surface of the samples. A proportional relationship exists between the electric potential and the electric charge. Thus, the distribution of electric charge at the surface of the B-type samples was measured with the induction probe of an electrostatic voltmeter.

After charging, the sample is transferred in a 2-axis device that facilitates the cartography of the surface potential. The measurement is performed in 5×19 points beginning with line L1 (figure 2). For each experiment, the average and the maximum absolute values of the electric potential were used to evaluate the level electric charge across the rubbing area.

The material pair ABS-PVC was chosen for this experiment. To highlight the correlations of the number of contact points with the level of electric charge generated by friction, the ABS sample A had a smooth initial surface, characterized by a roughness $R_a = 0.4 \mu\text{m}$. The surface state of PVC sample B was modified using the P120, P80, and P40 abrasive discs. The roughness obtained was in the interval $R_a = 3\text{--}12 \mu\text{m}$.

To verify the first paradigm, a set of experiments was made with samples B of similar roughness, prepared with the P40 abrasive disc, at three values of the normal force: $F = 2 \text{ N}$, 6 N and 10 N , using a sliding speed $v = 75 \text{ mm/s}$, for a number of sliding cycles $n = 10$. The experiments for verifying the second paradigm were performed with samples B of different roughness, at constant normal force $F = 2 \text{ N}$, sliding speed $v = 75 \text{ mm/s}$, and number of back-and-forth cycles $n = 10$. The variables measured during the process of rubbing were the normal and tangential forces, as well as the relative displacement of the samples in contact.

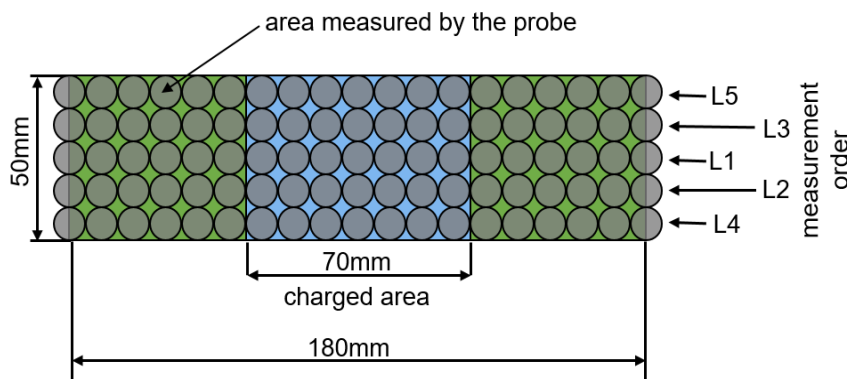


Figure 2. Mapping of the electric potential at the surface of the bottom sample.

The roughness measurements were performed using the roughness meter Mitutoyo SJ210 according to the standard ISO-1997. The measurements were repeated three times, for a sampling length of 15 mm . The roughness test was made in the same direction with the sliding. Two roughness coefficients were measured: R_a which is defining the average of the peaks and valleys, and R_{Sm} defining the average distance between two consecutive peaks.

3. Results and discussions

In the first set of experiments, carried out with samples of similar roughness $R_a \approx 10 \mu\text{m}$, the surface potential (SP) was found to increase is increasing with the normal load (figure 3). The contact surface between sample A and B being constant, it can be inferred from this that the SP increases with the average pressure applied, which confirms the first paradigm.

Two typical cartographies of the electric potential measured at the surface of B-type PVC samples can be examined in figure 4. The electric potential is less uniform at the surface of the smoother surface. For surfaces characterized by a high roughness, the peaks are higher and less dense. The higher deformation per peak gives a more uniform distributed contact with the smooth surface. For a low R_a , the surface undulations generate local high pressures.

In figure 5 is represented the contact between surfaces characterized by different roughness coefficients. The contact point density decreases with the roughness. The global pressure for every sample is constant and is given by the normal force of 10 N divided by the nominal area of contact.

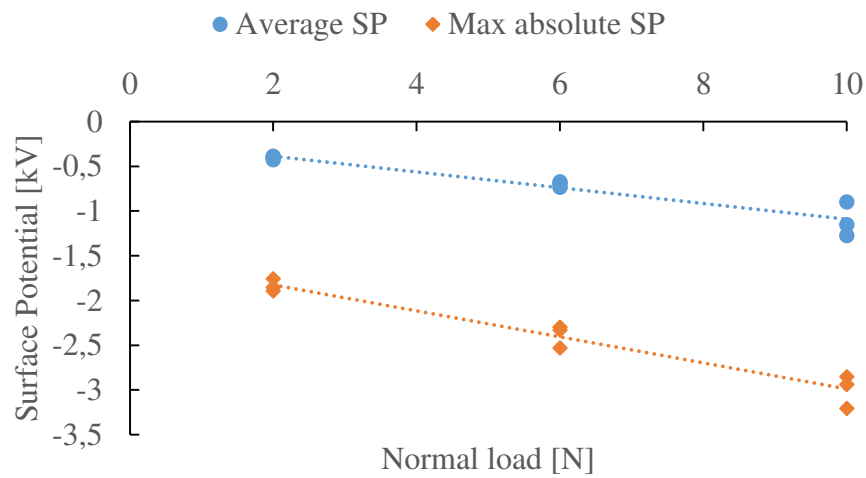


Figure 3. Relation between the surface potential and the normal load.

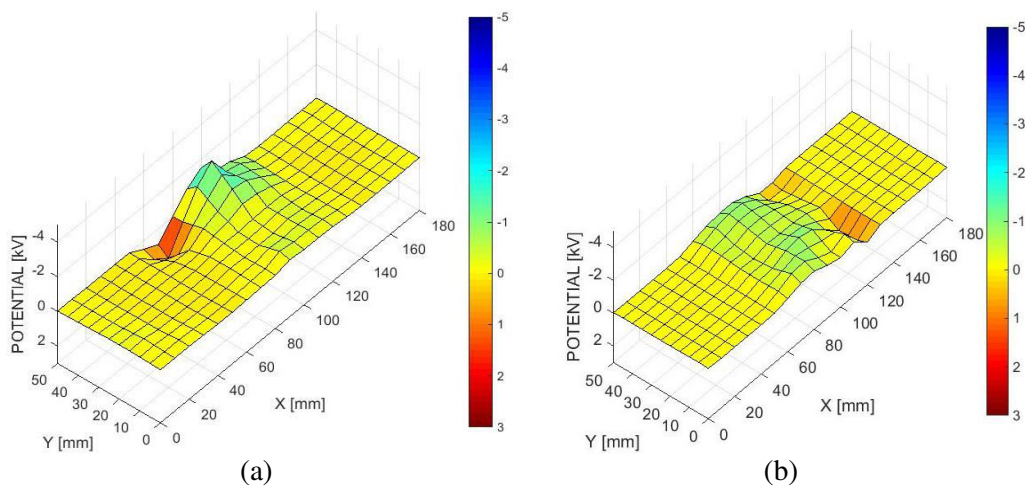


Figure 4. Surface potential mapping: (a) $R_a=3.7$, $R_{Sm}=152.6\mu\text{m}$
(b) $R_a=10.9$, $R_{Sm}=350.2\mu\text{m}$.

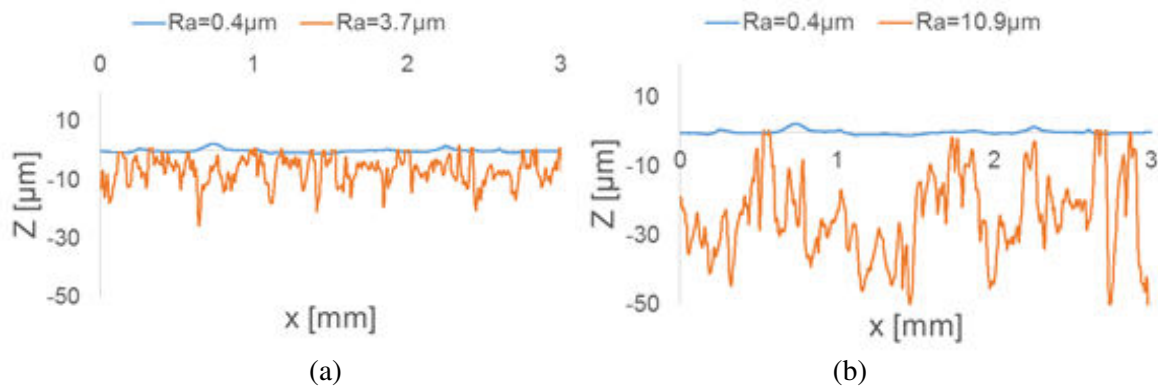


Figure 5. Contact due to the roughness asperities: (a) $R_a=3.7\mu\text{m}$; $R_{Sm}=152.6\mu\text{m}$;
(b) $R_a=10.9\mu\text{m}$; $R_{Sm}=350.2\mu\text{m}$.

The results of roughness measurements point out that R_{Sm} increases with R_a (figure 6), due to the aspect of the asperities of the abrasive disks used for surface preparation. For known R_{Sm} (i.e., the mean distance between two consecutive peaks), the density of peaks can be computed as follows: $\rho = 1/R_{Sm}$ [peaks/mm]. This means that roughness R_a increases when the density of the peaks ρ decreases.

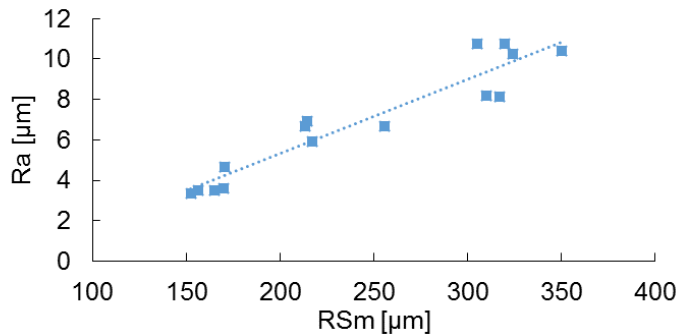


Figure 6. R_{Sm} vs R_a .

Heating of rubbed surface has been monitored with a thermal camera (figure 7). As the sliding between the two samples was set up to 10 cycles per run, the rubbing process produces only a 1.5°C temperature rise of the sample B, and the secondary charging mechanism generated by heating can be considered not important when compared with the multipoint mechanism.

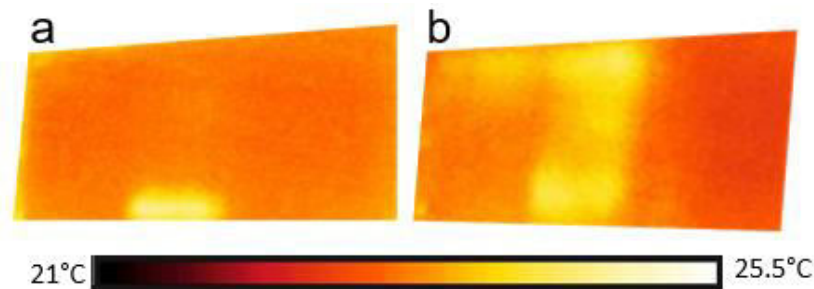


Figure 7. Thermal fields: (a) $R_a = 3.7$, $R_{Sm} = 152.6 \mu\text{m}$; (b) $R_a = 10.9$, $R_{Sm} = 350.2 \mu\text{m}$.

The non-uniformity of the thermic field is due to non-uniform pressure contact on the sample. From figures 4 and 7, it can be seen that the surface potential, which is proportional to the charge, follows the temperature pattern. With heating assumed to be co-related to the local pressure exerted between the two bodies in contact, this result validates once more the first paradigm: higher pressure is producing higher electric charge.

The average and maximum absolute values of the surface potential increase with the density of peaks (figure 8). Thus, the charge, which is proportional with the electric potential, increases with the number of contact points between the two bodies. This confirms the second of the two paradigms.

Keeping the same normal load and increasing the number of peaks implies a lower contact pressure per peak, but a constant average pressure. The results plotted in figure 8, obtained at constant average pressure, show that the surface potential is increasing with the density of the peaks. This means that the electric charge generation is more influenced by the number of peaks that enter in contact, than by the local contact pressure at each peak.

4. Conclusions

The increasing of the roughness R_{Sm} and of the distance between peaks is accompanied by a more uniform repartition of the normal force across the surfaces in contact, generating a uniform electrostatic charging.

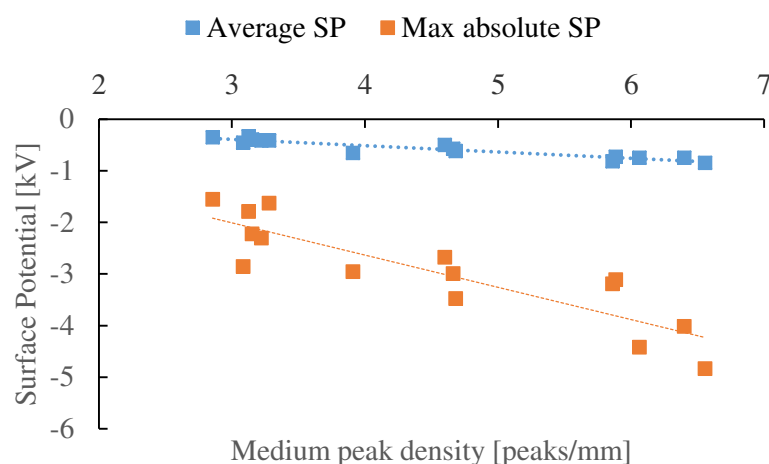


Figure 8. Correlation between the surface potential and the medium peak density.

The electrostatic charge generated by triboelectric effect increases with the pressure between the two surfaces that are rubbed together, which confirms the first paradigm.

The electrostatic charge generated increases with the peak density, as predicted by the second paradigm, the Volta-Helmholtz hypothesis.

The effect of the number of peaks is more important than that of pressure, but this phenomenon should be further investigated, to get a better understanding of the physical mechanisms involved.

Acknowledgement

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