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Effect of ambient air relative humidity on the triboelectric properties of Polypropylene and Polyvinyl Chloride slabs

Omar Tilmatine, Thami Zeghloul, Karim Medles, Lucian Dascalescu, Aurelian Fatu

PPRIME Institute, CNRS-University of Poitiers-ENSMA, 16000 Angoulême, France
lucian.dascalescu@univ-poitiers.fr

Abstract. The humidity of ambient air has always been known to be a major factor in the triboelectric charging of polymers. A study on the influence of this factor was conducted in a climatic test chamber on square-cut Polypropylene (PP) and Polyvinyl Chloride (PVC) plates of dimensions (110 mm x 110 mm x 4.5 mm) rubbed with Aluminum (Al) samples of dimensions (100 mm x 15 mm x 5 mm). The samples were left at least 12 hours in the climatic test chamber at fixed temperature (25 °C) and three different values of air relative humidity (20%, 40% and 80%), then rubbed together in a triboelectric charging test bench. The tribocharged PP and PVC samples were then placed under an electrostatic probe to measure the electric potential generated on the surface of the sample. The results of the experiments show that the sign of the tribocharge reverses when the two polymers are exposed to low or high ambient humidity.

Keywords – surface electric potential, controlled humidity and temperature, tribocharging, polymer materials

I. INTRODUCTION

In many industries, triboelectricity is a major source of hazards [1]. On the other hand, the triboelectric effect is instrumental in more and more electrostatic applications, including but not limited to separation of insulating materials from granular mixtures [2] - [5], motion sensing [6], [7], and energy harvesting [8]. The level of triboelectric charge acquired by the materials having a significant influence on the outcome of each of the above-mentioned processes, consistent research and development efforts are made to improve the tribocharging methods.

The problem is that tribocharging of materials is influenced by their nature, surface state, contact pressure and relative motion, but also by the ambient relative humidity and temperature [9] - [12]. Less electrostatic shocks due to rubbing between various objects, such as shoes and carpets or clothes and vehicle seats, are experienced in summer than in winter, which means charge is partly suppressed at high ambient humidity.

According to numerous experimental and theoretical studies, the water molecules that adhere to the surface of the materials, forming a layer of a few nanometers, play an important role in charge transfer [13] - [22]. The presence of such water layers strongly alters the triboelectric charging of insulating materials [20-24] though water is not a necessity

for the charge exchange [25] its presence together with large electric fields can favor it.

The presence of water molecules at the surface of materials is most often related to the level of ambient humidity. The higher conductivity related of humid air will also increase the leakage of charges from the surfaces [14,17,21]. From their studies on fluidized beds composed of various polymer particles, Németh and coworkers concluded that the charge transfer mechanism is dominated by electrons at low humidity; at a higher humidity adhered water and ions contribute to electrostatic charging [13]. Another mechanism of tribo-electric charging might be the exchange of functional groups of the polymers, which are transferred to the surface of the beads when they are swelling at high humidity levels [13,26]. To summarize, there is as yet no complete picture of the role of humidity on the triboelectric charging.

Therefore, this paper was aimed at an accurate evaluation of the effect of ambient humidity on the triboelectrification of two polymers, PP and PVC, by measuring the surface electric potential generated by friction, under well-defined conditions. The experiments were carried out in ambient air, at constant temperature, 25°C, and for a wide range of relative humidity (20% to 80%).

II. MATERIALS AND EXPERIMENTAL PROCEDURE

A. Triboelectric test bench

A linear tribometer represented schematically on Fig. 1 was used for the frictional charging of the different material samples [27]. The design of the experimental bench was carried out to provide a conformal (plane/plane) contact between the pair of samples, using two sample holders: the top one is for the sample (A) and the bottom one is for the sample (B). The uniformity of the plane/plane contact, which is one of the most recurrent problems in the field of tribology, was adjusted by meticulous mechanical processing to ensure the flatness of both samples and by attaching the top one to a ball joint device.

A rail guide system ensured the horizontal displacement of the sample (B) holder in back-and-forth motion, at a speed that was varied and controlled using a linear electric actuator. A system of vertical guide bars maintained a constant contact normal force to the surface of the lower sample (B). This force was adjusted using a mechanical force control system that includes an appropriate sensor. Two other sensors were

used for measuring the tangential force and relative displacement between the top and bottom samples.

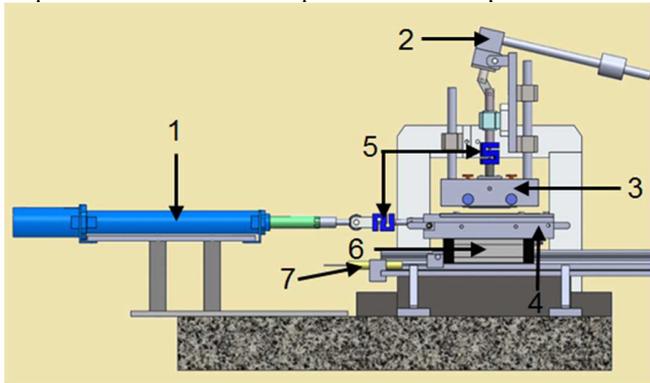


Fig. 1. Triboelectric test bench; (1) Electric motor; (2) Vertical force control system; (3) Top sample holder; (4) Bottom sample holder; (5) Force sensor; (6) Horizontal guide system; (7) Displacement sensor.

Based on the results of previous studies [27], the parameters of the bench remained unchanged throughout the experiments: the normal force, 20 N; the translational speed, 20 mm/s; the stroke of the bottom sample holder, 70 mm and the number of a tribocharging (rubbing) cycles, 20.

B. Electrostatic probe

The capacitive probe (Trek, model 6300-7) of an electrostatic voltmeter (Trek, model 341B) was used for scanning the electric potential at the surface of the bottom sample. To enable an accurate characterization of the surface potential distribution, the measurements were made from the near left to the distant right corner of the sample, along 20 lines distanced at 5 mm from each other.

C. Relative humidity and temperature control

In order to evaluate the effect of ambient relative humidity RH on the triboelectric properties of PP and PVC samples, the temperature in the climatic test chamber was kept constant ($T = 25\text{ }^\circ\text{C}$) for the three series of experiments, carried out at $RH = 20\%$, $RH = 40\%$ and $RH = 80\%$, respectively. For each experimental point, the desired humidity and temperature in the chamber was attained in less than two hours.

D. Neutralization process

The elimination of any residual electric charges that might existed before the start of the experiments was done with an anti-static bar (380 mm x 20 mm x 20 mm) (ELCOWA, model ECA88-BS), equipped with a 5 kV high-voltage generator (ELCOWA model SC04B). The bar was kept fixed at a height of 5 mm above the sample, which was passed four times under it at a low speed of 2 cm/s, to achieve effective charge neutralization.

E. Materials

The tribocharging experiments were carried out using PP, PVC and Aluminum sample pairs. This choice was justified

by the fact that PP and PVC are one of the most used polymers in industry because of their excellent mechanical properties [28] - [29].

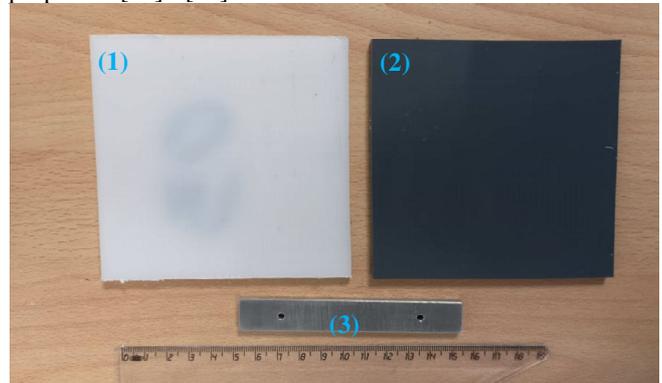


Fig. 2. Photographies of the samples used in the experiments; (1) PP sample; (2) PVC sample; (3) Aluminum sample.

For the metal used in this study, an aluminum sample was selected because preliminary tests had pointed out that it generated higher levels of triboelectric charge with PP and PVC samples than stainless steel or copper. The dimensions of the aluminum sample (A) were: 100 mm x 15 mm x 5 mm, and those of the PP and PVC samples (B) were: 100 mm x 100 mm x 4.5 mm, as shown in Fig. 2.

F. Experimental procedure

Before each series of experiments, two large PP and PVC plates were cut into several small samples according to the above-mentioned dimensions; each sample was then subjected to neutralization. The surface electric potential on the sample was measured by the electrostatic probe to ensure that there were no residual charges left before tribocharging.

The samples were left for at least 12 hours in the climatic test chamber, at previously-programmed values of the temperature and of the relative humidity, and then subjected to the tribocharging operation. After completion of the tribocharging, the electric potential at the surface of the sample was scanned and recorded on a PC, using LabView software.

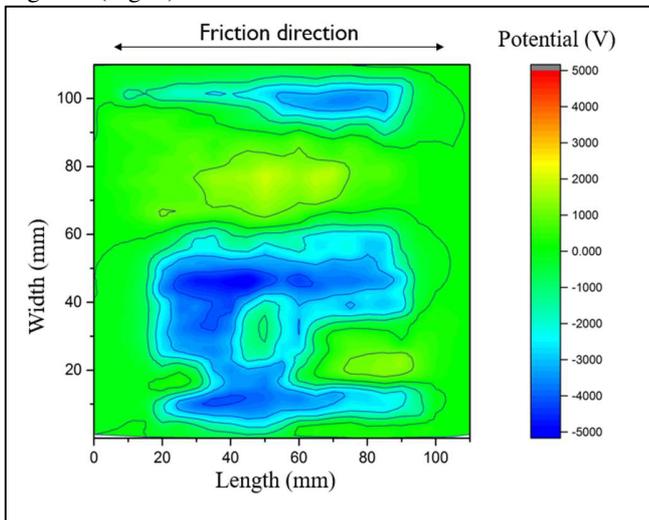
The aluminum plate was manually cleaned twice after each tribocharging operation, a first cleaning with sandpaper, and a second one with paper towels to remove any PP or PVC residues that may distort the results in future experiments.

The roughness of the aluminum sample was measured before and after the experiments to ensure that it preserved its characteristics. Thus, before the experiments, the values of Ra and Rq measured on the surface of the aluminum sample were $0.27\text{ }\mu\text{m}$ ($\pm 0.1\text{ }\mu\text{m}$) and $0.40\text{ }\mu\text{m}$ ($\pm 0.15\text{ }\mu\text{m}$) respectively. After the experiments, similar values were measured: $Ra = 0.27\text{ }\mu\text{m}$ ($\pm 0.07\text{ }\mu\text{m}$) and $Rq = 0.41\text{ }\mu\text{m}$ ($\pm 0.11\text{ }\mu\text{m}$).

III. RESULTS AND DISCUSSION

A. First test point ($T = 25\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$; $H = 80\% \pm 1\%$)

All experiments were repeated at least four and led to similar results; except for a slight difference in the distribution of the surface electric potential the average values measured on the four PVC samples were always negative (Fig. 3).



In these experiments carried out at a moderate relative humidity level, the PVC samples continued to be mainly negatively charged after rubbing with the Aluminum plates. However, several areas of positive potential were noticed, as shown in Fig. 5.

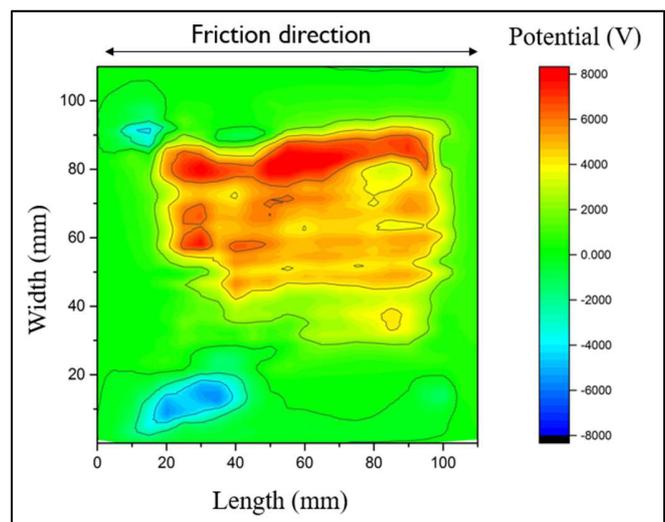
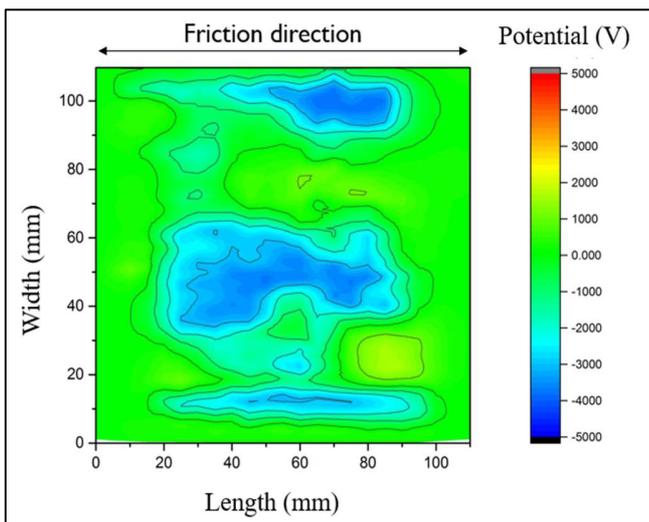
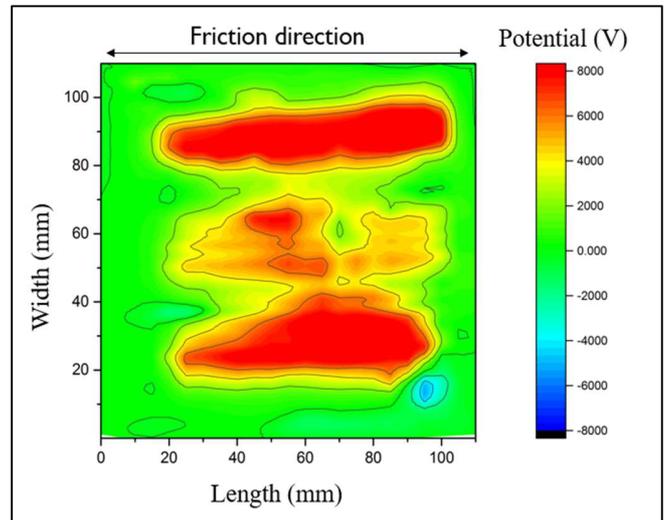


Fig. 3. Mappings of the electric potential measured at the surface of two PVC samples after tribocharging by rubbing against Aluminum plates, at $T = 25\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ and $RH = 80\% \pm 1\%$

Fig. 4. Mappings of the electric potential measured at the surface of two PP samples after tribocharging by rubbing against Aluminum plates, at $T = 25\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$ and $RH = 80\% \pm 1\%$.

Only small patches of positive charges were detected. The asymmetry of the distribution of the higher absolute values of the generated potential, which attained 4970 V, is explained by the non-uniformity of the samples.

Surprisingly, the electric potential detected at the surface of each tribocharged PP sample was positive (Fig. 4). Like PVC, PP is also located on the negative side of the triboelectric series with respect to Al, but the long duration exposure of the samples to a high-humidity environment had definitely modified its triboelectric behavior.

B. Second test point ($T = 25\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$; $RH = 40\% \pm 1\%$)

The reduction of the relative humidity from 80% to 40% did not entrain a major change in the triboelectrical behavior of the PVC plates.

Contrary to PVC, the decrease in the relative humidity of ambient air level had an important influence on the electric charge generated on the surface of PP samples rubbed against Aluminum plates (Fig. 6). Large areas of both positive and negative electric potential were recorded at the surface of the samples, which used to be totally positively charged at RH.

C. Third test point ($T = 25\text{ }^{\circ}\text{C} \pm 1\text{ }^{\circ}\text{C}$; $RH = 20\% \pm 1\%$)

The PVC samples that charged negatively at $RH = 80\% \pm 1\%$, have drastically changed their triboelectric behavior at low levels of the relative humidity of ambient air. Positive values of electric potential were recorded on practically the whole surface of the samples, with only small negatively-charged areas as shown in Fig. 7.

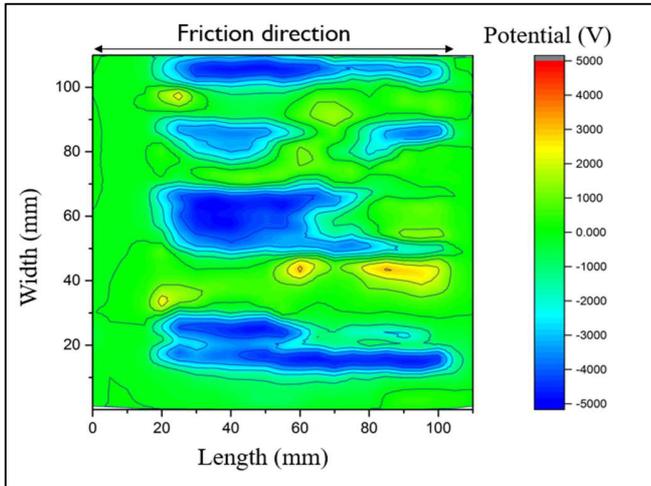
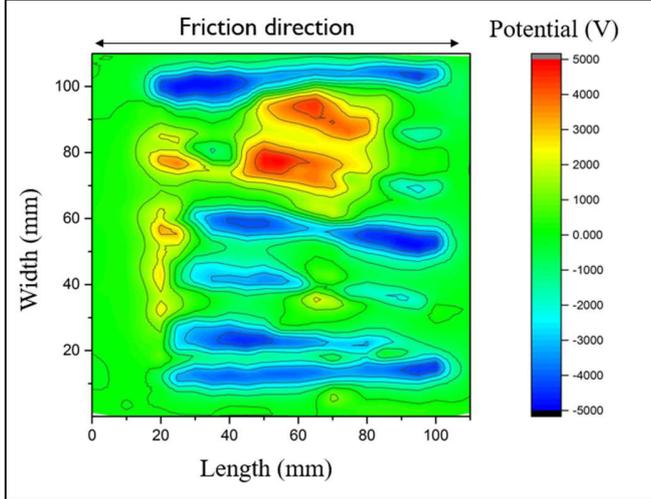


Fig. 5. Mappings of the electric potential measured at the surface of two PVC samples after tribocharging by rubbing against Aluminum plates, at $T = 25\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ and $RH = 40\% \pm 1\%$

In a similar way, the triboelectric behavior of the PP samples radically changed when reducing the relative humidity of the ambient air from $RH = 80\% \pm 1\%$ to $RH = 20\% \pm 1\%$. At low ambient air relative humidity, the electric potential recorded at the surface of tribocharged PP samples was negative on practically all the surface (Fig. 8).

The significant decrease in ambient humidity was accompanied by a total reversal of the electrical potential generated on the surface of the two polymers, when compared to their position in the triboelectric series, which are obtained by other research groups at typically $20\text{ }^\circ\text{C}$ and $RH = 40\%$, and which remain highly consistent with each

other, despite differences in surface preparation, material contact modes and laboratory conditions. At a low humidity level, the PP and PVC samples get respectively negatively- and positively-charged when rubbed against Aluminum plates. At moderate relative humidity of the ambient air, both positive and negative electric potential areas were recorded at the surface of the two kinds of samples.

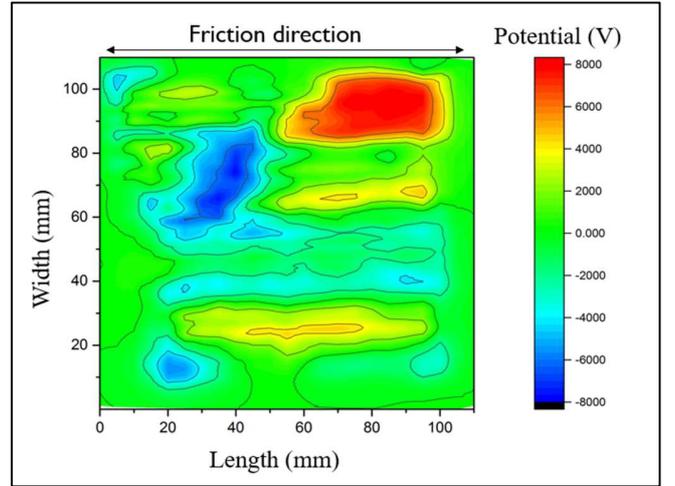
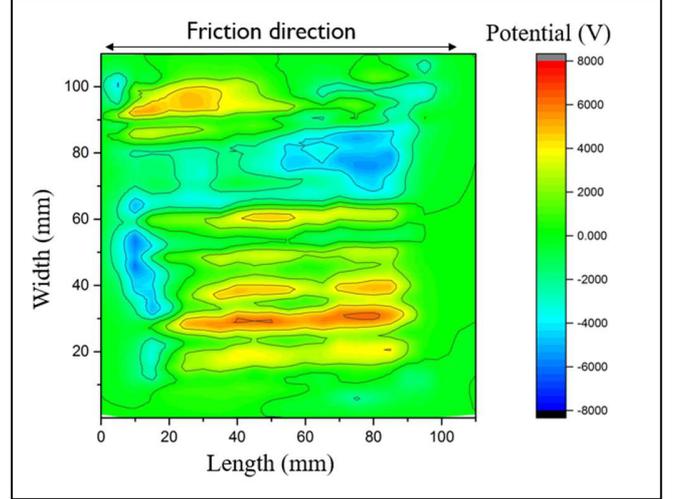


Fig 6. Mappings of the electric potential measured at the surface of two PP samples after tribocharging by rubbing against Aluminum plates, at $T = 25\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ and $RH = 40\% \pm 1\%$

The presence of a thin water layer at the surface of the samples exposed to high humidity ambient air is most likely at the origin of the reported experimental observations [13], [30]. The reversal of tribocharging behavior when the relative humidity of ambient air decreases from 80% to 20% is most certainly related to the different nature of the molecular chains of the two polymers and of the charge carriers, ions or electrons, involved in the process in the two situations.

IV. CONCLUSIONS

The objective of this work was to study the influence of the ambient air relative humidity on the triboelectric charging

of PP and PVC slabs in conformal contact with Al bars. The results obtained at high relative humidity were compared with those at low relative humidity levels, and shown that:

- The change in ambient conditions has a significant influence on triboelectric properties of both polymers under study; increasing *RH* from 20% to 80% causes the sign reversal of the electric potential generated on the surface of the polymers.

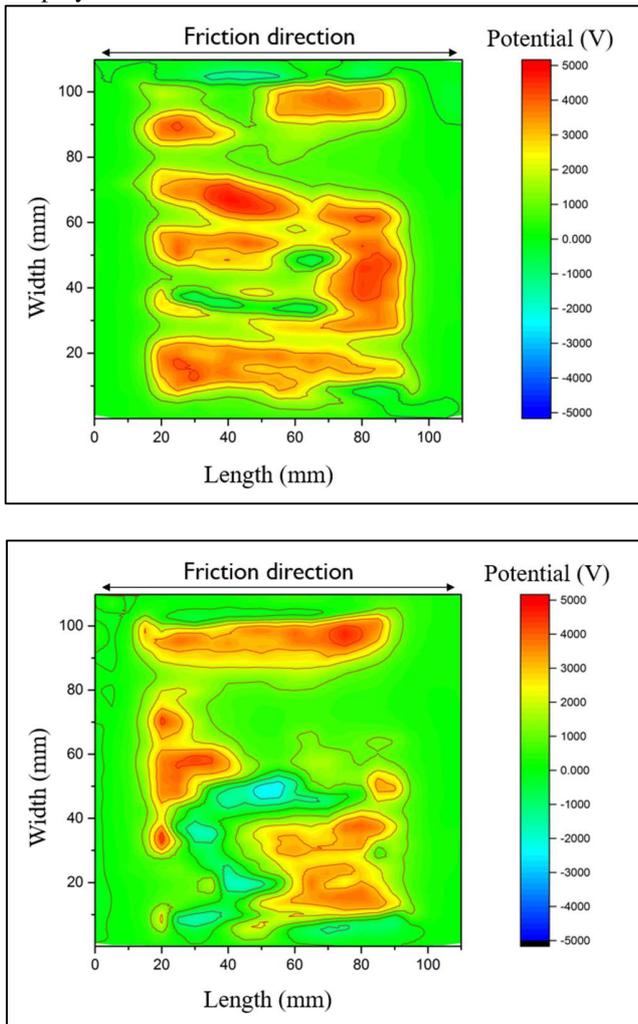


Fig. 7. Mappings of the electric potential measured at the surface of two PVC samples after tribocharging by rubbing against Aluminum plates, at $T = 25 \text{ }^\circ\text{C} \pm 1 \text{ }^\circ\text{C}$ and $RH = 20\% \pm 1\%$

- At moderate ambient air relative humidity ($H = 40\% \pm 2\%$), patches of both positive and negative electric potential can be detected on the surface of the same sample.

Additional experiments, with a larger panel of both hydrophilic and hydrophobic polymers, are necessary for explaining the intimate physical mechanisms of this polarity sign reversal of the tribocharge acquired by rubbing at different ambient conditions. Further work is also needed to study the influence of the temperature on the electric charge

generated by triboelectric effect at the surface of polymers when rubbed against metals.

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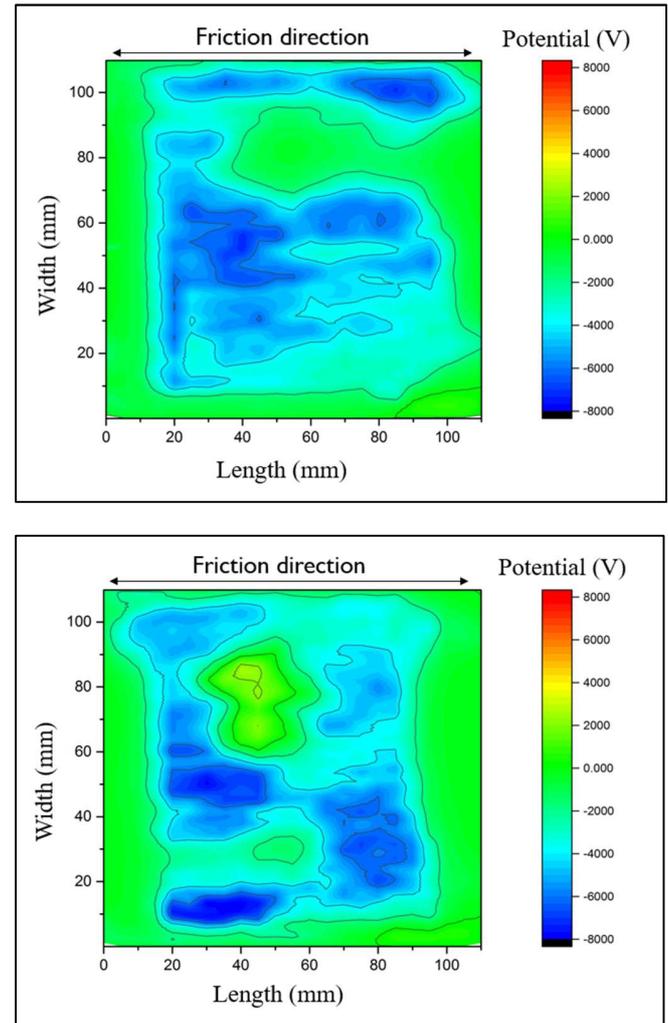


Fig. 8. Mappings of the electric potential measured at the surface of two PP samples after tribocharging by rubbing against Aluminum plates, at $T = 25 \text{ }^\circ\text{C} \pm 1 \text{ }^\circ\text{C}$ and $RH = 20\% \pm 1\%$

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