Analysis of electrically-charged polymer surfaces effect on friction coefficient in lubricated sliding contacts

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Abstract— **Rubbing two insulating materials against each other generates electric charges, which often represent a source of electrostatic hazards, but may also have a benefic effect. Different studies have shown that electric field associated with the presence of electric charges can influence the behavior of a lubricant or a liquid flow. The aim of this study was to evaluate the effect of the presence of electric charge at the surface of polymer slabs can have on the friction coefficient for lubricated sliding contact of polymers. The experiments were conducted with a linear tribometer with a back-and-forth movement. The electric charge was generated in a controlled environment, using a corona discharge. Different levels of charge were tested. The samples were cut from two polymers, polyvinyl chloride and acrylonitrile butadiene styrene. Two liquids were used as lubricants: water and ISO VG 46 oil. The presence of surface electric charges influences the friction between lubricated samples.**

I. Introduction

The increasingly use of polymers and polymer composites in numerous industrial applications, such as aerospace, automotive, railway, etc., is stimulated by their outstanding features. Compared with other materials, they can provide self-lubricant conditions, high strength/weight ratio, good mechanical and thermal properties, as well as a remarkable ease of manufacturing [1-5]. It is well known that rubbing together two insulators can provide an electrostatic charge generated at the surface of the bodies [6-8]. Studies are made to better control the electrostatic charge with the purposes to minimize it and avoid hazards (i.e. ignition in flammable environments) [9] or to maximize for industrial applications (i.e. electrostatic particle separation) [10].

The tribology theory is not simple, adding electrostatic phenomena increases its complexity. The study of electric charges through contact and friction between insulating materials has been an interest for many researchers. Because of multitude of factors involved, sliding charging is more complicated than simple contact charging [11-12].

The polymers used regularly in mechanical assemblies are brought up in relative sliding or rolling. The effects of the electrostatic charges generated in these functional conditions are merely known [13-23]. The aim of this study was to evaluate the effect the presence of electric charge at the surface of polymer slabs can have on the friction coefficient for lubricated sliding contact of polymers.

II. MATERIALS AND METHODS

Two types of samples, (A): ABS, 5 mm x 15 mm x 15 mm, and (B): PVC, 5 mm x 50 mm x 180 mm, were employed in the experiments. The residual charge at the surface of these samples was neutralized using an ionizing system (electrode ECA 88 BS and high-voltage supply SC 04 B, 5 kV, 7 mA, manufacturer: ELCOWA, Mulhouse, France).

The study of the frictional contact between the two polymers in the presence of lubricants (distilled water and oil ISO VG 46) was carried out using a linear tribometer (figure 1). The (A)-type sample was connected to a top holder (2) fixed in a vertical guiding system and using an adjustable arm (3) to precisely control the normal load. The (B)-type sample was placed in a holder attached to a back-and-forth sliding motion system (1), driven by an electric actuator (4). The tangential and normal loads, as well as the relative displacement of the samples were continuously measured. This laboratory bench enabled the control of several factors that affect the electrostatic charge generation: relative sliding speed, tangential displacement amplitude, normal contact load, and number of back-and-forth cycles. In all the experiments described hereafter the stroke was 55 mm and the number of cycles was 10. Room temperature and relative humidity were constantly read with a thermo- hygrometer and were kept in a certain interval of variation 23-25 C° respectively 35-45% RH, using a dehumidifier- heating system.

The experiments, each repeated three times, were conducted to show that the presence of an electric charge at the surface of the sample (B) may modify the frictional coefficient in lubricated sliding contact with the sample (A). The factors under study were the following: the sliding speed (range: 20 mm/s to 40 mm/s); the normal force (range 2 N to 18 N), and the electric potential at the surface of sample (B), which was pre-charged by exposure to the corona discharge generated by a triode-type electrode system (figure 2).

The response was the average driving tangential force, including the contact friction force and all the internal friction of the mechanical links, as measured by the sensor interposed between the linear electric motor drive and the sample (B) holder. The study was carried out using the Response Surface Methodology (RSM), which recommended the use of a Central Composite Face-Centered (CCF) experimental design (figure 3).

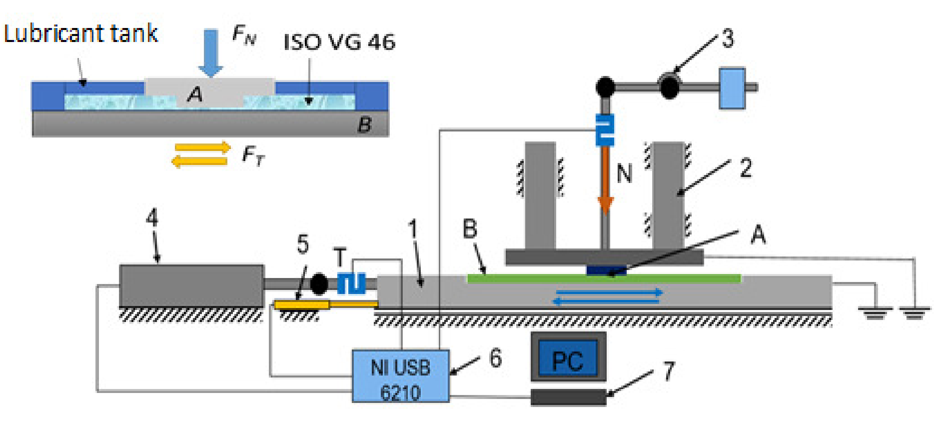

Figure 1. Schematic representation of the laboratory bench for triboelectric charging.

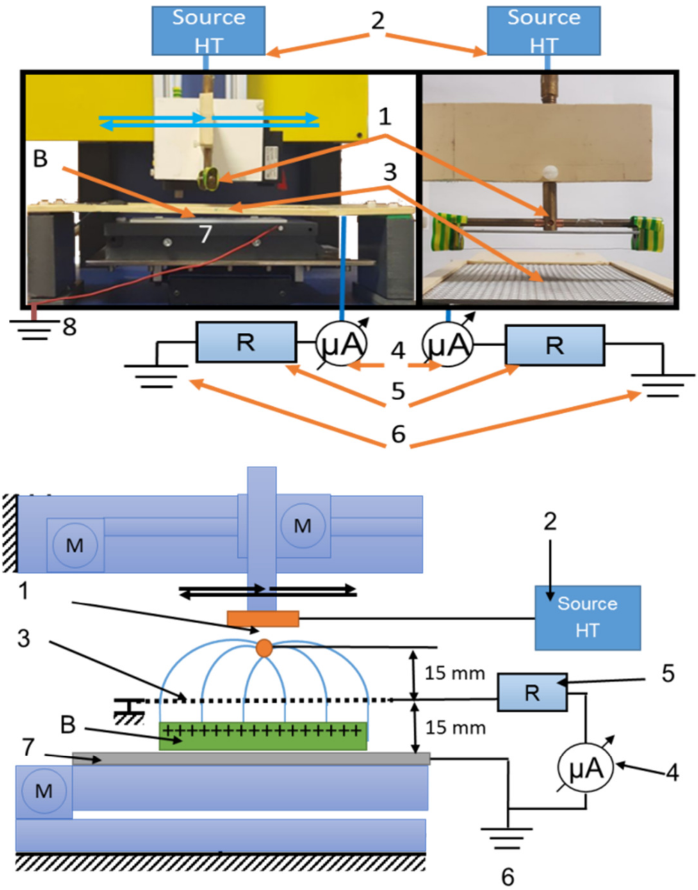

Figure 2. Triode-type corona charging electrode system
B – bottom sample ; 1 – wire electrode ; 2 – high-voltage supply ; 3 –grid electrode ;
4 – micro-ammeter; 5 – resistor ; 6 – ground connection ; 7 – sample holder.

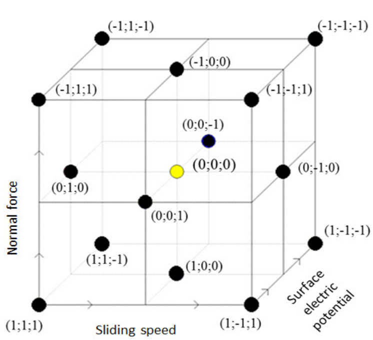

Figure 3. Schematic representation of the CCF experimental design for three factors.

III. RESULTS

A. Water lubricant

Based on the results of the 17 runs of the CCF experimental design carried out for positively-charged (B) samples, lubricated with water, MODDE 5.0 software calculated the coefficients of a quadratic model (Figure 4) which express the frictional force as a function of the normal force, the sliding speed and the electric surface potential. As expected, the frictional force increased with both the normal force and the sliding speed. The surface electric potential influenced to a less degree the frictional force (figure 5).

A similar behavior was observed at negative polarity of the (B) sample.

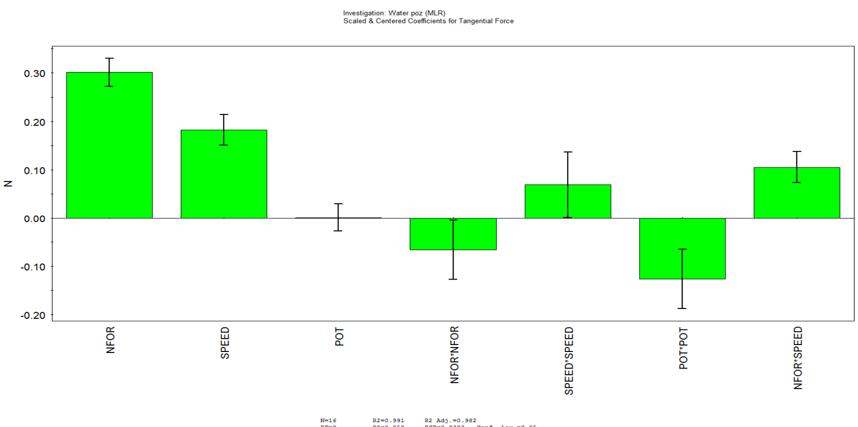

Figure 4. MODDE 5.0-calculated coefficients of the quadratic model of the frictional force, as a function of normal force (NOR), sliding speed (SPEED) and surface potential (POT), for the case of a positively-charged PVC sample; lubricant: water.

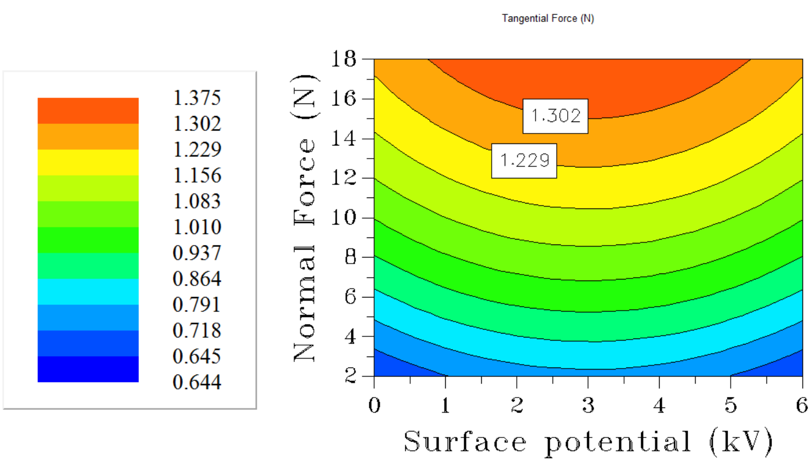

Figure 5. MODDE 5.0-calculated iso-response curves of the frictional force, expressed in N, as a function of normal force and surface potential (POT), for the case of a positively-charged PVC sample; lubricant: water.

B. Oil lubricant

When the positively pre-charged samples were lubricated with oil, the results of the 17 runs of the CCF experimental design, the frictional force could be also expressed by a quadratic model, the coefficients of which are given in figure 6. Similar to the case of water lubricated samples, the frictional force increased with both the normal force and the sliding speed. The effect of the surface electric potential can be evaluated by analyzing the iso-response curves given in figure 7.

At both positive and negative polarity of the (B) sample, the frictional forces were higher than in the case of water lubrication, and this independently of the presence of the electric charges.

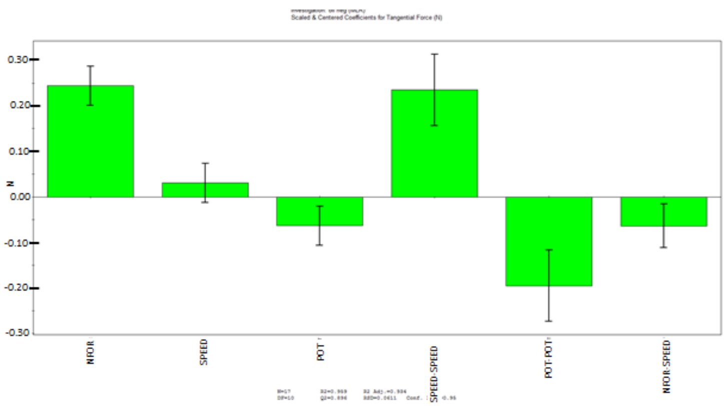

Figure 6. MODDE 5.0-calculated coefficients of the quadratic model of the frictional force, as a function of normal force (NOR), sliding speed (SPEED) and surface potential (POT), for the case of a positively-charged PVC sample; lubricant: oil.

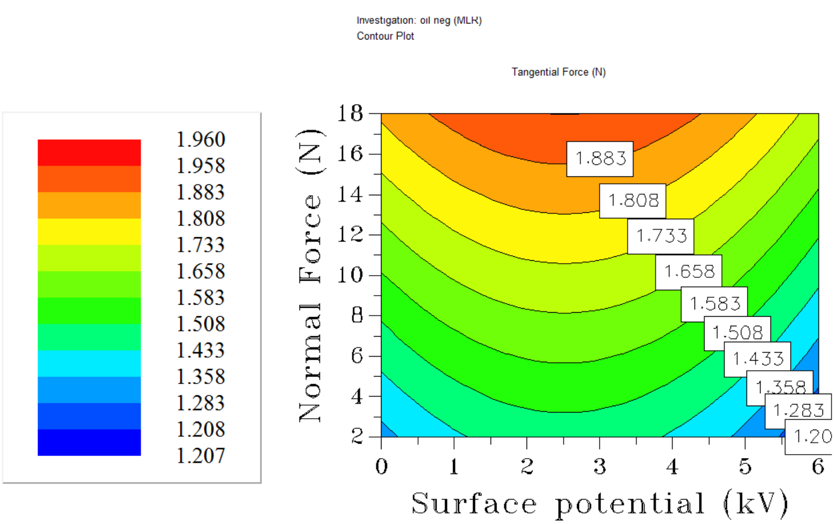

Figure 7. MODDE 5.0-calculated iso-response curves of the frictional force, expressed in N, as a function of normal force and surface potential (POT), for the case of a positively-charged PVC sample; lubricant: oil.

IV. Conclusions

This study had the objective to show the influence of the presence of electric charges on the frictional sliding contact between polymers, in pre presence of a lubricant.

1) Response Surface Methodology proved to be an efficient tool for modeling the tribo-electrostatic behavior of electrically-charged polymers.

2) The normal force and the sliding speed are, in this order, the most influential factors of the frictional force that occurs at the contact between two plastic slabs, in the presence of a lubricant.

3) The sliding speed has a stronger influence in the case of water lubrication, while the effect of the electric potential is more significant on oil-lubricated contacts.

4) For the two lubricants considered in the present study, the frictional force tends to increase with the electric potential at the surface of the (B) sample. Beyond a certain threshold, this tendency is reversed. Further researches, carried out with a larger number of different polymers, are needed in order to investigate the physical mechanisms that might explain this behavior.

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