Laboratory bench for the characterization of triboelectric properties of polymers

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Abstract. The use of polymers as materials for sliding machine components is due to their low cost, ease of manufacturing, as well as appropriate mechanical and thermal properties. The aim of this paper is to present the experimental bench designed for the study of the triboelectric charge generated in sliding conformal contacts between flat polymer materials. The experiments were performed with 4-mm-thick samples of polystyrene and 5-mm-thick samples of poly-vinyl-chloride. The normal contact force can be adjusted using an appropriate control system and measured by a force sensor (± 50 N). The translational back-and-forth motion of the samples is produced by a crank-shaft system that generates a sinusoidal translational speed profile, with amplitudes between 12 and 50 mm/s, for strokes of 36 to 60 mm. The distribution of charge at the surface of the samples is measured by the capacitive probe of an electrostatic voltmeter (± 10 kV). The experiments pointed out that this bench enables the evaluation of the non-uniformity of the electric charge accumulated on the sliding bodies and the study of the correlations that might exists between this charge and the external forces applied to the contact.

1. Introduction
Polymers are more and more frequently used as materials for sliding machine components. Their choice is due to their low cost, ease of manufacturing, as well as appropriate mechanical and thermal properties. The design of such components should take into consideration the tribological processes in both lubricated and dry polymer-on-polymer contacts [1].

Generation of electric charges through contact and friction between insulating materials has already been thoroughly studied [2], using various test methodologies [3]. This so-called “triboelectrification” effect affects friction and wear [4]. It strongly depends on the load and the speed of the sliding motion, on the state of the surfaces in contact, and on the ambient conditions [5].

Most of the triboelectrification studies were performed for non-conformal contacts [4] – [10]. The area of contact between non-conformal surfaces is very small (almost point or line contact); as a result, the contact pressure is high and the wear of the surfaces is significant even under low loads [6]. The respective experimental benches typically provide uni-directional relative movement of the bodies in contact: a pin and a rotating disk or two rolling rings. The rotational movement is accompanied by charge generation due to the continuous friction between the two bodies [4] - [10].

Fewer studies were made on the tribocharging phenomena associated to conformal contacts [11],[12], where the surface of the contact area is comparable with the size of the bodies involved [6]. The benches described in the literature were typically making use of crank – shaft mechanisms to provide back-and-forth motion between the bodies in contact [11], [12].
The characterization of the charging state of the surfaces in contact is a difficult challenge when the process involves two insulating materials. Some researchers employed the scanning electron microscopy method [3][11], others took advantage of surface electric potential measurements [4][10]. The latter is used in the present study, which is aimed at describing a laboratory bench designed to enable the repeatability of the tribocharging conditions in sliding conformal contacts between polymers.

2. Experimental bench
The design of the experimental set-up (figure 1) is such that a conformal contact is provided between two flat polymer samples (1) and (2). The top sample (1) is much smaller (80 mm x 15 mm) than the bottom sample (50 mm x 183 mm). The pressure is evenly distributed on the contact area, as the top sample holder (3) has a system by which the contact planarity between the two samples can be adjusted. The rail guide system (5) assures the horizontal displacement of the bottom sample holder (4). The vertical guiding bars system (6) maintains the normal force perpendicular to the surface of sample (2). This force can be adjusted using the mechanical force control system (7) and measured by the force sensor (N) (model STC 1205, JPRM, maximum force: ± 50 N resolution: 0.025 N).

The sliding bar (8) is parallel with the rail guide system (5) and used to transfer the back-and-forth motion (b) generated by the crank-shaft mechanism (9), which is entrained in rotational motion (c) by the electric motor (EM). The crank-shaft system generates translational motion with a sinusoidal speed profile, with amplitudes ranging between 12 and 50 mm/s, set by modifying the velocity of (EM). The stroke of the crank-shaft mechanism can be adjusted to 60 mm, 50 mm, 42 mm and 36 mm. A displacement sensor (D) (model LVDT L50R, TNC, resolution: 0.05 mm) is attached to the bottom sample holder. The tangential force is measured by a force sensor (T), similar to (N).

The three sensors (N), (T) and (D) are connected to a NI USB 6210 data acquisition board. The measurement data are transferred to a computer using LabView software. The same software and data acquisition board are used to trigger the start and stop of the back-and-forth motion, by controlling the power supply of the electric motor.

The electric potential at the surface of the bottom sample is measured by the capacitive probe (model 6300-7, TREK) of an electrostatic voltmeter (± 10 kV; resolution: 1 V; model P0865, TREK). The probe is mounted on translational stage that can adjust its position within a range of 25.4 mm (each turn of the control knob corresponds to a 1.2 mm step). The measurements are usually made from the center to the edge of the sample (figure 2). They enable the characterization of the charge distribution at the surface of the respective sample, and make possible the study of the correlations that exist between this distribution and the external forces applied to the contact.

**Figure 1.** Experimental bench schema.
1- Top sample,
2- Bottom sample,
3- Top sample holder,
4- Bottom sample holder,
5- Horizontal rail guide system,
6- Vertical bar guide system,
7- Vertical force control system,
8- Sliding bar,
9- Crank-shaft system
T, N- Force sensor,
D- Displacement sensor,
EM- Electric motor;
Figure 2. Surface potential measurements.

Because of the back-and-forth motion, the contact area of bottom sample is divided in two zones, one with permanent contact and one with non-permanent contact. The measurements are made after well-defined numbers of back-and-forth motions. All the data are collected from the electrostatic voltmeter through an electrometer connected to a computer, using LabView software.

3. Materials
The experiments are performed with 4-mm-thick samples of polystyrene (PS) and 5-mm-thick samples of poly-vinyl-chloride (PVC). The samples are cut in two sizes, (1): 80 mm x 15 mm, and (2): 50 mm x 183 mm. The samples (1) are fixed to the top sample holder (3) (Figure 1), while the samples (2) are disposed on a grounded metallic electrode (200 mm x 80 mm), placed on the bottom sample holder (4), attached to the variable-speed sliding system described in the previous section of the paper.

4. Results and Discussion
A set of three experiments are made in ambient air (temperature: 17.9 – 18.7°C; relative humidity: 55 – 59%) using PS for top sample and PVC for bottom sample. In each experiment the normal force is 1 N, the amplitude of the translational speed is 24 mm/s, the stroke of the bottom sample holder is 60 mm, and the duration of a tribocharging (rubbing) cycle is 60 s. The samples are subjected to 12 such rubbing cycles. After each cycle, the electric potential is measured in 11 points, starting from the center of the probe and distanced from each other at 2.4 mm.

The results displayed in figures 3 and 4 are obtained for one sample, but are typical of the data obtained for the whole set of experiments. The measurements show that the charge reaches a maximum level after 9 cycles, than it decreases and begins to stabilize after 12 cycles (figure 3). This saturation phenomenon is likely to be correlated with the various factors of the tribocharging process: nature of the surfaces in contact, normal force, translational speed, etc.

The samples continue to preserve part of the charge acquired by tribocharging. However, the decay rate of this charge is not uniform on the surface of the sample, as pointed out by the electric potential distribution curves recorded at 8 and 24 hours after the 12th and last tribocharging cycle and displayed in figure 4. In the zone of permanent contact, the potential level is close to zero after 24 hours, while a certain amount of charge can still be detected in the non-permanent contact zone.

The more or less rapid decrease of the charge after reaching the saturation might be related to the degradation of the material surface caused by the wear. This is one of the hypotheses that should be confirmed by further studies. Another hypothesis that needs experimental confirmation is related to the different nature of the charge carriers in the permanent and non-permanent contact zones of the bottom electrode. The differences in the charge decay rates of the two zones may be explained by the fact that during the tribocharging process the latter zone is periodically affected by the ions in the ambient air (non-permanent contact with the top sample), while the former is not.
5. Conclusions
(i) The experimental bench described in this paper enables the study of the tribocharging phenomena induced by the conformal contact between two flat polymers. Its design facilitates the accurate adjustment and monitoring of the normal and tangential contact forces, as well as of the stroke and the relative sliding speed between the two bodies.
(ii) The distribution of the electric charge at the surface of the samples can be investigated by measurements performed with the capacitive probe of an electrostatic voltmeter.
(iii) The absolute value of the surface potential increases with the number of tribocharging cycles, then it saturates at levels related to the specific sliding conditions.
(iv) The charge acquired by triboelectric effect decreases faster in the zones of permanent contact between the samples than in the areas only periodically exposed to friction.

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References
[1] Zeghloul T, Dascalescu L, Rouagdia K, Fatihou A, Renoux P and Souchet D 2014 Conf Rec. IEEE IAS Ann. Meet. Vancouver, Canada, DOI 10.1109/IAS.2014.6978340
[2] Bailey A G 2001 J. Electrost. 51-52 82-90
[3] Guerret-Piecourt C, Bec S and Tréheux D 2001 C. R. Acad. Sci. Paris IV 2 761–774
[4] Nakayama K 1996 Wear 194 185-189
[5] Hiratsuka K and Hosotani K 2012 Trib. Int. 55 87–99
[6] Johnson K L 1985 Contact mechanics (Cambridge:Cambridge Univ. Press) p107-196
[7] Medevielle A, Thévenot F and Tréheux D 1995 J. Euro. Ceram. Soci. 15 1193-99
[8] Harvey T J, Wood R J K, Denuault G and Powrie H E G 2002 Trib. Int. 35 605–614
[9] Lee D-Yo, Lee J, Hwang J and Choa S-H 2007 Trib. Int. 40 1253–57
[10] Ning L, Jian L, Yang S, Wang J, Ren J and Wang J 2010 Trib. Int. 43 568–576
[11] Changa Y-P, Yur J-P, Chou H-M and Chub H-M 2006 Trib. Int. 40 1253–57
[12] Kchaoua B, Turki C, Salvia M, Fakhfakh Z and Tréheux D 2008 Wear 265 763–771
[13] Antoniu A, Dascalescu L, Vacar I V, Plopeanu M C, Tabti B and Teodorescu H N 2011 IEEE Trans. Ind. Appl. 47 (2011) 1118-25