Tribology International 55 (2012) 87–99

Contents lists available at SciVerse ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Effects of friction type and humidity on triboelectrification and triboluminescence among eight kinds of polymers

Ken'ichi Hiratsuka*, Kazumasa Hosotani

Department of Mechanical Science and Engineering, Chiba Institute of Technology, 2-17-1, Tsudanuma, Narashino-shi, Chiba 275-8588, Japan

ARTICLE INFO

Article history:
Received 2 October 2011
Received in revised form
2 May 2012
Accepted 22 May 2012
Available online 5 June 2012

Keywords:
Triboelectrification
Triboluminescence
Polymer
Humidity

ABSTRACT

Triboelectrification and triboluminescence were measured from the sliding or rolling frictional contacts between polymers of PA66, POM, ABS, PET, PP, PVC, PE, and PTFE in various humidity conditions. As compared to the rolling friction, triboluminescence intensity was higher in sliding friction. However, the saturation values of triboelectrification were almost the same in both friction types. The saturation charges of all the sliding couples showed their maxima at the humidity from 10 to 30%. It is attributed to the humidity effect; it enhanced charge transfer which resulted in the increase or decrease of electrification.

1. Introduction

Triboelectrification and triboluminescence have been investigated mainly by physicists and not always related to the chemical reactions. However, physical phenomena such as nascent surface generation and triboemission are closely related to tribochemical reactions at the interface [1–3]. Fig. 1 illustrates the mechanical, physical, chemical and materialistic processes in tribology in terms of "Triboemission cycle". Since tribology is an interdisciplinary field among these sciences, their interrelation is of particular importance. Friction is a resistance force between two solids in relative motion. It takes place at the interfacial materials, which have been modified by the chemical reactions between solids and either adsorbed gases or liquids. Chemical reactions are governed by the energy state of solid/molecules. This is determined by the physical interactions between solids of sliding/rolling contacts. Therefore, the physical processes during friction should be highlighted to better understand subsequent reactions and surface layer formation. The contact/separation process leads to the charge transfer between dissimilar materials. When charges are accumulated, they are measured as triboelectrification. When a bond is broken by the shear stress, it generates dangling bonds. The bond breakage also induces the electron emission from the insulator. The emitted electrons are accelerated by the electric field between charged surfaces which originated from tribolectrification. When electrons attack surrounding molecules, they induce electron avalanche and photon emission from surrounding gases [4]. Therefore, charges on the surfaces and photon intensity relate to the energy state of the tribological interface and must be crucial parameters to predict subsequent chemical reactions.

The terms of triboelecrification and triboluminescence have older history than that of tribology [5,6]. Although they were already known during the Greek period, the mechanisms have not been completely established. One reason is the lack of repeatability as many other tribological phenomena have. Another reason is that only one of these has been studied, although charge and discharge are closely related. For instance, Matsuyama et.al [7] developed the "charge relaxation model" and later Ireland [8] used it to account for the charge accumulation including the relaxation process after charge transfer. In their experiments, only charge was measured. From our point of view, the relationship between triboelectrification and triboluminescence is important, because charge relaxes through a discharge process and it is difficult to understand how charge is accumulated without understanding triboluminescence mechanisms.

Although simultaneous measurements are essential to unveil the hidden connection between the two, it is difficult to carry out such an experiment, because of the frictional configurations in normal tribometers. Pin-on-disk type tribometers have been commonly used for studying triboelectrification and triboluminescence [9,10]. This type of tribometer, when used for these studies, has several disadvantages which are listed below:

1) The charges on both specimens cannot be measured simultaneously without breaking the experiment because the pin specimen is always in rubbing contact.
2) The length of the friction track of the pin is notably shorter than that of the disk, which inevitably brings the asymmetrical contact.

* Corresponding author. Tel.: +81 47 478 0503; fax: +81 47 478 0299.
E-mail address: hiratsuka@sea.it-chiba.ac.jp (K. Hiratsuka).

0301-679X/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.triboint.2012.05.017

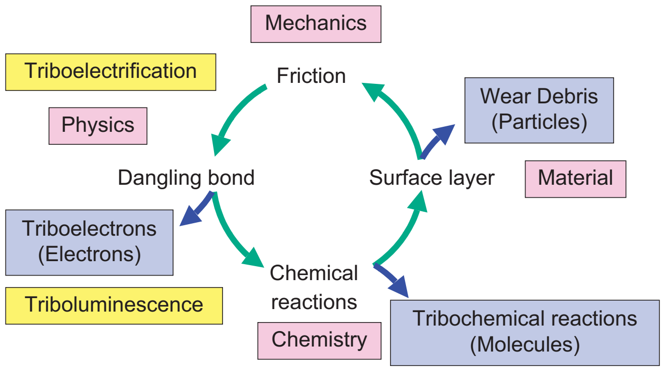

Fig. 1. Mechanical, physical, chemical and materialistic processes in tribology (Triboemission Cycle).

3) Wear rates of both specimens are different, resulting in the intensity difference of triboluminescence and triboelectrification.
4) The pin surface meets all the friction track of the disk surface, preventing the pin and the disk surfaces from having one-to-one correspondence.
5) The asymmetric sliding contact, which appears in the pin-on-disk tribometer, causes electrification even if both specimens are made of the same material.
6) The periods of non-friction time for both specimens are different, leading to the different effects of atmosphere [11], especially of humidity, on electrification. Humidity is particularly important for surface charging. That is why non-friction time should be the same for both specimens.

The twin-ring tribometer developed by the authors is, thus, the most suitable, because it achieves symmetrical sliding/rolling contact and to avoid problems listed above [12]. In addition, the twin-ring tribometer has some advantages as follows:

1) The sliding or rolling contact is established simply by switching the rotational direction of either of the rings.
2) Slip ratio can be controlled.
3) Charges on both specimens are easily monitored without breaking the experiment, because the surfaces are exposed to the probes all the time.
4) Simultaneous measurements of both triboelectrification and triboluminescence are realized.

From the reasons above, the twin-ring tribometer was previously employed for the study of triboelectrification between a metal and a polymer [13]. In the present study, the twin-ring tribometer was also applied to simultaneous measurements of triboelectrification and triboluminescence.

Environmental humidity is one of the most influential factors in triboelectrification. Charge and discharge associated with the rubbing between shoes and carpet are less experienced in summer rather than in winter. It indicates that the charge is suppressed in higher humidity. Experimental data have exemplified this tendency [14,15]. However, other data show that water molecules on the surfaces convey charges in the form of ions to enhance charge separation between two surfaces [16,17]. These contradictory results require precise measurement of the effect of humidity on charge generation. Charge generation is affected by discharge. Therefore, this paper is devoted to understand the relationship between triboelectrification and triboluminescence in terms of the effect of humidity. The effect of friction type, sliding or rolling, is also investigated for a wide range of friction pairs, before going into detail of the role of humidity.

2. Experimental procedure

The diagram of the test rig is drawn on Fig. 2. The twin ring tribometer developed by the authors was installed in the modified chamber of a chemiluminescence analyzer (Tohoku Electronic Industrial Co. Ltd., CLD-100). Photons passing through a filter were later on detected by the photomultiplier. Charges induced by friction on the surfaces were measured by the electrometers (ADC Corporation, Digital Electrometer 8252) through their probe electrodes which were set at the farthest ends of the specimens without contact. The rotations of the friction pair, along with the detections of photons and surface charges, were fully controlled by a single personal computer.

The number of photons emitted from the rubbing interface was counted by the chemiluminescence analyzer using the single photon counting method. Photon count was summed up after every second.

The size of electrodes used to detect surface charges on both specimens was 5×15 mm. The electrodes had the same curvature that kept the distance between the electrode and the specimen constant at 8mm. In fact, the electrometer measured the induced voltage. It was then multiplied by the capacitance (100 pF) inside the electrometer to show the induced charge on the electrodes. Although the measured charge is not the same as that on the friction surface, the two values are in proportional. Therefore, all the discussions will be made using the measured charge. The sampling rate of the charge measurement was 10 Hz.

The polymer specimens employed were polyamide (PA66), polyoxymethylene (POM), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polyethylene (PE) and polytetrafluoroethylene (PTFE), written according to their relative polarity in the triboelectric series, i.e., from the most positively charged to the most negatively charged one.

The specimen preparation procedure was as follows. Each kind of specimen was cut out from one large board of 10 mm in thickness to avoid the irregularity of the material, because the properties of polymers have variations from lot to lot. After the rings of 15 mm in diameter were shaped, their outer peripheries were filed until barrel shapes were obtained; their curvature radii were 17 mm. The barrel surfaces were then polished by #1000 abrasive paper with ethanol to reduce frictional heat during polishing. All the specimens were rinsed for 5 min twice in ultrasonic bath with fresh ethanol each time. After drying up the specimens with warm air, they were fixed to the shafts of the rig. Since specimens were prepared under fluorescent light, they emitted phosphorescence. Due to the phosphorescence, photon

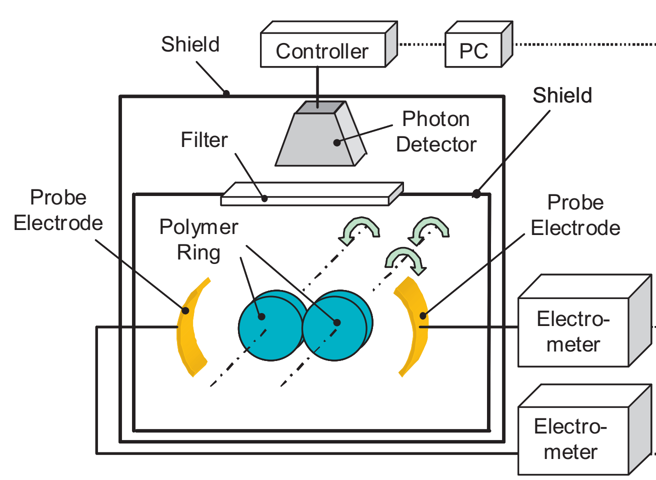

Fig. 2. Experimental setup.