TRIBOEMISSION FROM THE SLIDING CONTACT OF ALUMINA SYSTEMS

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SUMMARY
Experimental research work is presented seeking a better understanding of the triboemission of negatively-charged and positively-charged particles from the sliding contacts of alumina-on-alumina systems. A new tribometer, which is based in a channel electron multiplier detector in high vacuum, was employed to measure the charge intensity of charged trioparticles. The emission of charged particles from alumina and other insulators when scratched by a diamond pin (B-on-A sliding systems) was previously reported by the authors and other researchers [1,2]. This paper reports that triboemission of negatively-charged particles from alumina-on-alumina (A-on-A) sliding systems occurs for the same contact conditions for which triboemission was observed from B-on-A systems. Emission of positively-charged particles was found negligible. These results are discussed with a focus on the possible role of charged particle emission in tribocemical processes.

Keywords: triboemission, exoemission, alumina,tribochemistry, tribopolymerisation.

1 INTRODUCTION
Friction and wear of solid surfaces produce a variety of material and energy outputs, e.g., material debris, heat, acoustic emission, charged particles and various radiation. From this general point of view, all energy and material tribological outputs might be called triboemission. This term is reserved, however, for the emission of electrons, ions, neutral particles, photons, radiation and acoustic emission under conditions of tribological damage.

Triboemission of electrons and other charged particles particularly concerns the experimental research presented in this paper. Although the detailed physics by which charged-particle triboemission proceeds is unknown, triboemitted electrons are known to pertain to the general phenomenon of exoelectron emission, and they are also called triboemitted exoelectrons [3].

Early research was carried out by Nakayama et al. [4] on charged-particle emission from scratching diamonds on rotating disks of metals, ceramics and semiconductors. They reported burst-type negative- and positive-charge current outputs. Although signal-level was well above background, the Faraday-cup-type detector may have measured charges both emitted and of electrostatic origin.

Dickinson et al. performed important research on triboemission [2]. They investigated electron and photon emission from reciprocating scratching of MgO with diamond. Significant burst-type intensity of electron emission was measured by a channel electron multiplier in vacuum. They reported that the rate of electron triboemission vs. the kinetic-energy (i.e., the retarding-grid voltage) abruptly dropped from a maximum rate of emission (i.e., at zero-Volt grid) to a fraction smaller than 10% of that maximum at -100V grid. They also found marginal emission for energies of -1,000V and higher, which they hypothesized of initial low-energy emission, to be further accelerated by the electrostatic potential of charged patches on the rubbing surfaces.

Molina et al. recently presented relevant research [1,5,6] on the intensity and retarded-energy spectrum of triboemission from sliding contact of diamond on three related materials: alumina, single-crystal sapphire and aluminum. Significant burst-type negatively-charged emission was observed from diamond-on-alumina and from diamond-on-sapphire systems. Decaying negatively-charged triboemission, although of low level, was detected after the contact ceased. The retarded-energy spectra showed that a significant fraction of such emission had energies less than 5 eV, while a small fraction had energies extending to 48 eV and higher. Molina et al. [1,5,6] also observed negligible positively-charged triboemission from these diamond-on-aluminum-oxide systems, and marginal negatively-charged emission from aluminum scratching. No positively-charged triboemission was found from aluminum scratching.

Low-energy triboemitted electrons are thought to play a significant role in tribocemical reactions under wear conditions, particularly in the mechanism of tribopolymerisation, a new boundary lubrication concept
developed by Furey and Kajdas [7]: it is defined as the planned and continuous formation of protective polymeric films directly on rubbing surfaces to reduce wear and damage by the use of minor concentrations of selected monomers. Furey and Kajdas’ extensive experimental research [8-10] demonstrated that high surface temperatures play an important role in tribopolymerisation of condensation type monomers, and that emission of charged particles may be the main factor in initiating and controlling such process for addition-type monomers. In this, they hypothesised that addition-type monomers polymerising by an anionic mechanism will form tribopolymers on the presence of low-energy electrons, while addition-type monomers polymerising by a cationic mechanism will tribopolymerise on the presence of cations. Molina et al. experimental findings on triboemission [1,5] provided strong support to such hypotheses. However, the experimental differences found between the tribopolymerisation effects of monomers in a liquid carrier (e.g., in hexadecane [9]) and same compounds in vapor phase [10] show that the initiating mechanisms for tribopolymerization are still unclear.

The experimental research presented in this paper deals with triboemission of charged particles from alumina-on-alumina sliding systems under the same load and sliding speed ranges for which Molina et al. investigated triboemission from diamond-on-alumina systems.

2 EXPERIMENTAL

A new high-vacuum triboemission instrument – that is based on a Channel-Electron Multiplier (CEM) in the pulse-counting mode – was designed, constructed and employed for the following presented measurements of charge intensity. A biased-grid is placed between the emitting surfaces and the detector. Detailed descriptions of the instrument’s features, operating ranges and measurement and data acquisition capabilities were presented elsewhere [1,5,6,11].

The measurements of triboemission from alumina-on-alumina systems were performed for 0.125-inch diameter alumina-balls (99.5% alumina, grade 25) sliding on one-inch-diameter revolving alumina-disks (99.5% isostatically-pressed alumina). A vacuum lower than 2 x 10^{-8} Torr was obtained for testing and detector-gain and background-noise characterizations. Such level of vacuum, together with appropriate grounding and shielding, kept the background-noise lower than 1 count/sec. The employed low load and sliding speed prevented thermionic emission from sliding contacts.

A typical measurement of triboemission from alumina-on-alumina during contact and the post-contact emission is shown in Figure 1. Applied load was 2N and the employed sliding speed was 0.14cm/second during a 45second contact-period, after which contact ceased.

![Figure 1. Negatively-charged triboemission from alumina-on-alumina sliding contact. Grid bias: 0 Volt (ground). Pressure 1.5 x 10^{-8} Torr](image-url)
The gaps of data acquisition in Figure 1 were needed to save acquired data at the employed data-acquisition rate of 10 milliseconds-window. While some small bursts of triboemission show for about 45 seconds after the starting of sliding contact, the largest burst (of 603 counts in the 10 milliseconds-window) appears only after this relatively long period of contact. This particularly large burst also initiated sustained high-level post-contact emission after the contact cease.

Figure 2 shows two measurements of negatively-charged triboemission from the same alumina-on-alumina specimen. A first run of contact was carried out, after which the contact ceased and decaying post-contact emission was detected. On the same wear track a following 45-second was run. The same contact conditions (i.e., 2N applied load and 0.14 cm/second sliding speed) and data-acquisition window (10 milliseconds) were applied.

Figure 2. Negatively-charged triboemission from two consecutive runs on same wear track of alumina-on-alumina sliding contact. Grid bias: 0 Volt (ground). Pressure $1.5 \times 10^{-8}$ Torr.  

The results of Figures 1 and 2 suggest that an initial period of low emission may be typical of this alumina-on-alumina system, at least for the applied load and sliding speed. Large bursts of triboemission will follow if sliding contact is run on the same wear track. Figure 2 also suggests that prolonged sliding contact of a minute or longer may be needed for the occurrence of large bursts of triboemission from this material system. Positively-charged emission from alumina-on-alumina sliding contacts also was investigated. Low positively-charged triboemission, barely above background-level, was observed, even for contact load (20N) and speed (0.48 cm/s) higher than those for negative-charge measurements. Table 1 summarizes these results.

<table>
<thead>
<tr>
<th>Negative-charge (*)</th>
<th>Negative-charge (**)</th>
<th>Negative-charge (***)</th>
<th>Positive-charge (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.9 to 710</td>
<td>38,417</td>
<td>$1.21 \times 10^6$</td>
<td>~0.4</td>
</tr>
</tbody>
</table>

(*) Average rate during 320 seconds contact tests, and maximum rates
(**) for one minute
(***) for one second around largest burst of emission.

Table 1. Triboemission rates during contact (in counts/sec) for alumina-ball on alumina-disk. (For three ball-and-disk specimen sets).

A study on the statistical significance of these results and others previously reported vs. CEM background can be found in [6]. Such study demonstrated statistical significance for the measured negatively-charged triboemission from alumina-on-alumina, while found no significant difference for the average positively-charged triboemission during such contact.

3 DISCUSSION OF RESULTS AND CONCLUSIONS

All the performed measurements of negative-charges from alumina-on-alumina (A-on-A system) showed burst-type triboemission, clearly associated with sliding contact, and important decaying emission after contact ceased. This burst-type electron emission was not substantially different than that from diamond-on-ceramics (B-on-A system) sliding, as previously reported by Molina et al [1,5]. One important difference, however, regards the considerable lag between the application of sliding contact and the occurrence of the largest bursts of triboemission – at least for the speed and load used – that is found for the A-on-A system. No significant positively-charged triboemission was observed from alumina-on-alumina sliding contacts, even when relatively higher contact loads and/or sliding speeds were applied. These findings give additional support to Furey and Kajdas’ tribopolymerisation hypotheses.

These results show that neither different material (as for B-on-A systems) nor the severe plowing of diamond scratching are needed for negatively-charged triboemission to occur. It was found that alumina-on-alumina contacts may produce negatively-charged triboemission at higher intensity than that from diamond-on-alumina, and that high-level post-contact emission may be sustained for longer periods after the contact ceased. It is thought the wear behavior may account for the observed differences in triboemission: different wear conditions resulting from the different contacts (i.e., diamond cone versus alumina ball) and different material systems (i.e., hard-on-soft material versus same hardness).

The observed negatively-charged triboemission is thought to proceed by initiation and growing of surface microfracture, from a mechanism similar to that of
Dickinsons’ frictoemission [2,12]. Cho et al. [13] demonstrated that wear of alumina presents two consecutives regimes, which are called mild (i.e., of plastic deformation and negligible wear at the beginning of sliding) and severe (i.e., related to the occurrence of surface microfracture). It is believed that, in the triboemission-test conditions for diamond-on-alumina (i.e., of severe plowing) the mild regime is negligible, while such regime may exist for alumina-ball on alumina-disk for a short period (e.g., of about 45 seconds for the presented results) after the initiation of sliding contact. But the large bursts of triboemission, which follow after that initial period for alumina on alumina, seem to relate to the severe regime of alumina wear, at least for the load and speed used. Triboemission, however, may also be related to time-dependent creation of fresh surfaces through wear, and the origin of triboemission is still unclear.

4 ACKNOWLEDGMENTS

The authors want to acknowledge the Surface Engineering and Tribology Program, National Science Foundation for its support under grant number CMS-9531661.

5 REFERENCES