A study of the triboelectrification reduction efficiency of argon-nitrogen mixtures due to microgap discharge at atmospheric pressure

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***Abstract*—Triboelectrification due to sliding friction between a stainless steel pin and a fused quartz disk was measured in a vacuum and argon-nitrogen mixtures. The initial charge separation by friction was determined by the measurement in a vacuum. In the ambient gas of argon, nitrogen, or mixtures of the two, intermittent microgap gas discharges sometimes occurred during the continuous charge separation process caused by friction. The rate of residual charge was calculated as the net value of electrification in the ambient gas divided by amount of the initial charge measured in a vacuum. The rate in pure argon at 1 atm was less than 1%, which was much lower than the rate of 35% in pure nitrogen. The rate decreased with an increase in the partial pressure of argon in the mixture; at an argon purity of 50%, the rate was about 10%.**

I. Introduction

During friction between solids in a gas, a discharge occurs in the microgap between them near the contact because of the electric field produced by contact charge separation. This gas discharge is one of the well-known origins of triboluminescence [1]. The surface electrification after friction in the air, which is usually called static electricity, should be smaller than the amount of the separated charge. In other words, a well-optimized gas discharge reduces the triboelectrification.

In the previous study [1], the charge accumulation during friction was measured in a vacuum and in several gases at atmospheric pressure: nitrogen, dry air, humid room-temperature air (27 degrees centigrade and 66%), and argon. The efficiency of the charge reduction due to the gas discharge, i.e., the residual rate, was calculated from the amount of charge measured in the gas divided by that in a vacuum. At the pressure of 1 atm, the residual rate of humid air was 28%. The residual rates of nitrogen gas and dry air were 32% and 40%, respectively. That of argon gas was only 0.5%. Remarkably, the residual rate of charge was very small in the case of the ambient argon gas.

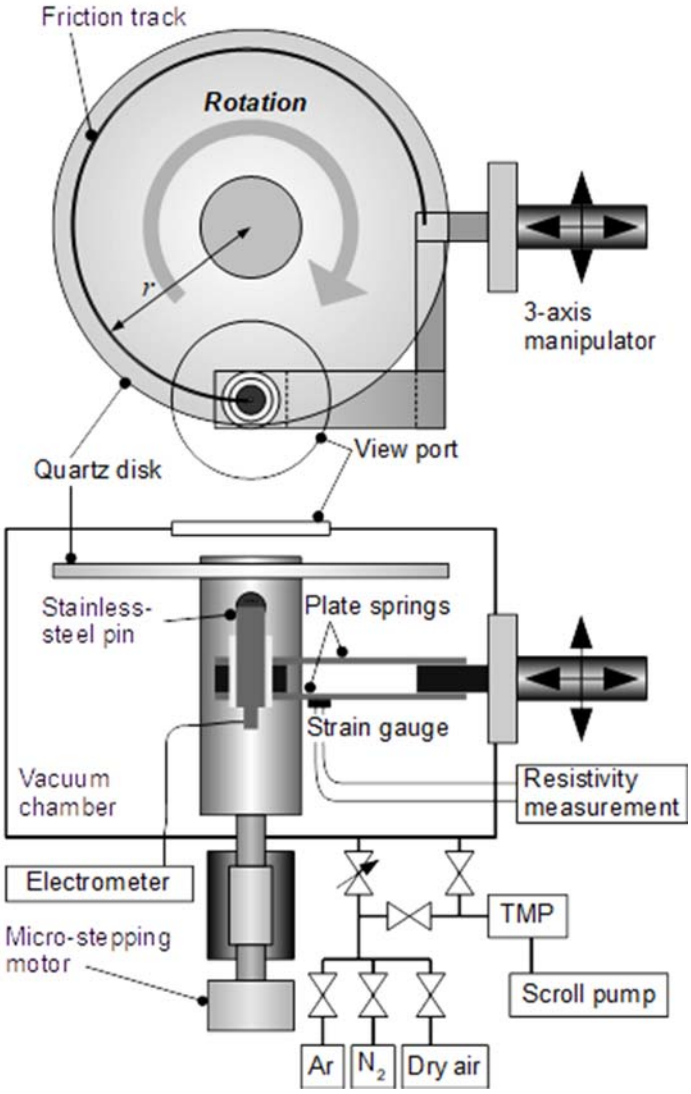

Fig. 1. Experimental setup

To prevent accidents caused by static electricity, such as explosion and fire at an industrial chemical plant, suppression of the charge accumulation is essential. We need to investigate the residual rate for the mixed gas of argon and nitrogen for industrial application; nitrogen is widely used to purge gas to prevent fire ignition, and argon gas is relatively inexpensive.

II. Experimental Setup

Figure 1 shows the experimental equipment used in the present study. One purpose of this study is to measure the static electricity generated by sliding friction between metals and insulators under controlled ambient gas conditions. The mechanics of sliding friction between solids is based on a pin-on-disk technique. This type of equipment has also been used in previous studies of triboluminescence [2].

The pin and the disk were settled in a vacuum chamber in order to control the ambient gas, such as the kind of gas, pressure, and humidity of the air. The gas was pumped out using a turbomolecular pump combined with a scroll pump as a fore-vacuum pump; the pumping system was completely operative without oil pollution, and the samples in the vacuum chamber were kept clean. The pressure was measured with a diaphragm gauge and an ion gauge: typically, the base pressure of the vacuum is 1×10^{-3} Pa, and this state is defined as a vacuum condition in this study.

The chamber is made of stainless steel and grounded electrically, so the friction is performed inside the electromagnetically shielded space: this gives higher reliability to the measurement of static electricity by means of an electrometer.

A pin made of stainless steel was used in this study. The tip of the pin was a spherical surface with a radius of 0.5 mm. The pin was held at the end of an arm with a pair of plate springs fixed on a 3-axis manipulator, as shown in Figure 1. The contact force of the friction could be adjusted by the manipulator from outside the chamber without breaking the vacuum and disrupting the gas condition. A strain gauge fixed on a plate-spring surface is sensitive to deformation, and normal force at the contact is detected. It was fixed to 130 mN in the experiments.

The disk was made of synthetic fused quartz, which is optically transparent; its diameter was 50 mm, and its thickness was 1 mm. The rotational speed of the disk is controlled with a microstep stepping motor at a fixed speed. The sliding velocity of friction in the present experiments was v = 0.77 mm/s (revolutions per second (rps) = 0.005 and r = 24.4 mm).

The pin was directly connected to the electrometer input, and the electrical charge generated on the stainless steel could be measured. The charge accumulation was monitored at an interval of 0.5 s during the sliding friction.

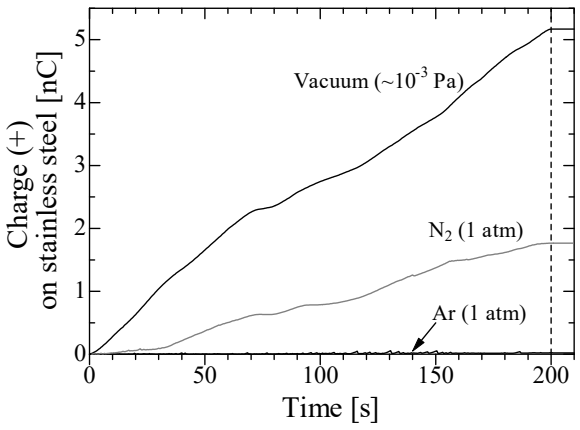

Fig. 2. Positive charge generated on a stainless steel pin by friction with a quartz disk.

III. Results and discussions

Figure 2 shows the experimental results: the charge accumulations during the sliding friction between stainless steel and fused quartz in a vacuum, as well as the nitrogen or argon at atmospheric pressure were measured. In a vacuum, the charge accumulation reached about +5.2 nC at one revolution in 200 s. In ambient nitrogen, the value was +1.8 nC, and the residual rate was calculated to be 35%. In case of argon, the charge was only 23 pC, and the residual rate was 0.44%.

In the present study, when the mixing ratio of argon was 0%, i.e., pure nitrogen ambient gas, electrification could be reduced to 35% from the initial charge separation. However, this reduction level of the triboelectrification is the same as that in the humid air and dry air [1]. On the other hand, a 100% mixing ratio of argon gas can reduce electrification to less than 1%.

The dependence of the residual rate on the mixing ratio of argon was investigated. The results are shown in Figure 3. The residual rate decreased with the increasing mixing ratio of argon in nitrogen gas. Therefore, it is suggested that argon does the charge cancelling even in the argon-nitrogen mixed gas. When the mixing ratio of argon was greater than 10%, the residual rate was less than 17%. This is almost half the residual rate of pure nitrogen.

Figure 4 shows the results after shaking the polyethylene terephthalate (PET) bottles; they contained alumina balls (diameter = 0.5 mm) and were filled with argon gas (left) and dry air (right). In the bottle filled with dry air, triboelectrification was generated by friction between the alumina and PET surfaces, and the balls stuck on the inside wall of the PET bottle after shaking. In contrast, it seems that static electricity was not generated in the bottle filled with argon because the balls fell to the bottom of the PET bottle after shaking. This phenomenon might be interpreted to mean that the triboelectrification was largely cancelled out due to the microgap discharge occurring easily in the ambient argon gas.

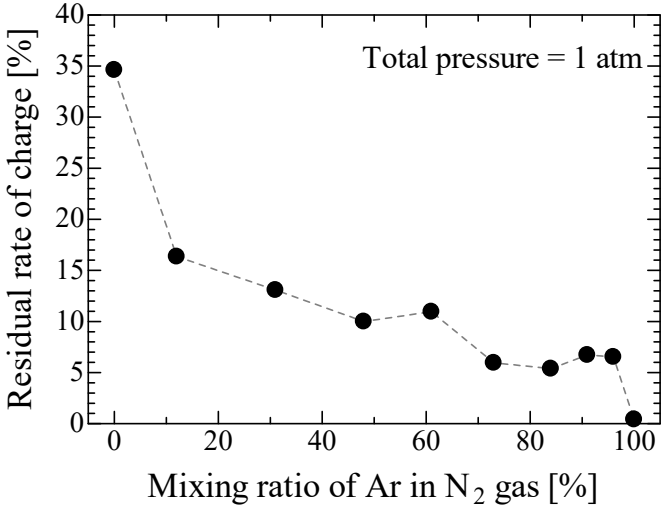

Fig. 3. Rate of residual charge as a function of the mixing ratio of argon gas with nitrogen gas.

Fig. 4. Results after shaking the PET bottles; they contained alumina balls (diameter = 0.5 mm) and were filled with argon gas (left) and dry air (right).

IV. Conclusion

Triboelectrification due to sliding friction between a stainless steel pin and a fused quartz disk was measured in a vacuum and in argon-nitrogen mixtures. In ambient gas of argon, nitrogen or mixtures of the two, the microgap gas discharge decreases the initial charge separation measured in a vacuum. The rate of residual charge was calculated as the net value of electrification in the ambient gas divided by amount of the initial charge. The rate in pure argon at atmospheric pressure was less than 1% which was much smaller than the rate of 35% in pure nitrogen. The rate decreased with an increase in the mixing ratio of argon with nitrogen; at 50% argon purity, the rate was about 10%; furthermore, even in an argon purity of only 10%, the rate was 17%, which is almost half the residual rate in pure nitrogen.

References

[1] T. Miura, "Observation of charge separation and gas discharge during sliding friction between metals and insulators," Journal of Physics: Conference Series, vol. 646, pp. 012057, 2015

[2] T. Miura and I. Arakawa,"Gas discharge caused by triboelectricity around a contact during friction between insulators," IEEE Trans. Dielectrics and Electrical Insulation vol. 14, pp. 560-565, 2007