

SURFACE POTENTIAL DISTRIBUTION ON POLYMER INSULATORS

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Abstract

The surface potential distribution on insulating polymers was measured by scanning of the probe of an electrostatic voltmeter. The measurements were done for two cases. In the first case, it was measured on the free surface of insulating films which had been inserted between plane electrodes after the removal of the upper brass disk electrode. In the second case, we measured the charging region between a circular and its opposing concentric ring electrodes after the removal of dc ramp voltage in air and nitrogen gas.

1. Introduction

There are some reports concerning the lateral extension of charges onto the surface of insulation materials from an evaporated electrode although the electrical properties of the dielectric surface have been studied much less than those in the bulk. Atkinson et. al found that the lateral extension of charges across the surface of polymer was only 1 mm beyond the edge of an evaporated electrode, even after prolonged application of +500 V to the electrode for about 6 months [1]. In contrast, Haenen reported facile

movement of charge from metal electrodes onto PMMA surfaces, regions as much as 6 cm from the electrode reaching the electrode potential in less than 1 hour [2]. Baum et. al showed that the migration of charges was practically non-existent at room temperature on the application of 500 V but charges of either sign moved laterally according to a diffusion law at elevated temperature [3]. We studied the charging phenomena in the neighborhood of an evaporated electrode on some insulating polymer films when a slowly increasing dc ramp voltage or a step voltage was applied [4,5]. The charging area front was uniformity along whole the line of the electrode when slowly rising voltage was

applied,

We also measured the potential distribution on the free surface of the polymer films, which had been inserted between plane electrodes after the removal of the upper brass disk electrode [6]. Considerable high potentials were observed though the electrodes were short circuited for a time. This implies that the charge transfer between the electrode and polymer surface is limited by some reasons.

2. Experimental

The surface potential distribution on polymer films was measured by scanning of the probe of an electrostatic voltmeter (TREK model 360SX). The voltage signals from the probe were transmitted to a computer store. The information could be displayed as three-dimensional relief maps. Measurement were done for two cases.

1) we measured the potential on the free surface of the film which was charged by micro discharges from the evaporated metal electrode. A dc ramp voltage was raised at the rate of about 500V/S to a given value and then removed by earthing. The tests were carried out in air (relative humidity 40~50%) and nitrogen gas of atmospheric pressure at room temperature,

2) We also measured the potential distribution on the free surface of the polymer films, which had been inserted between plane electrodes after the removal of the upper brass disk electrode. The film was set on a brass plate that was grounded and a brass disk (20 mm diameter) was put on the ring electrode. A step voltage was applied to the upper electrode for a time and then shorted for a period. After the brass disk electrode was removed, the potential distribution of the square region (20 × 20 mm) including the nonmetalized circular region was measured. For quantitative comparison of data for various conditions, we obtained the maximum, minimum and mean potential values from the data within the circular region of 10 mm diameter in the center of the measured nonmetalized region for each measurement.

3. Results and Discussion

Lateral charges spreading from electrode edge

Figure 1 shows potential distribution maps in air and in N₂ gas. The charging area and the charge density for the negative polarity in N₂ gas are much wider and much higher than those in other cases, for both polarities in air and for positive polarity in N₂ gas. In air, those for negative polarity is slightly narrower and lower than for positive polarity. The charge distribution patterns in air and nitrogen gas atmospheres are similar to each other for the positive polarity. The difference between atmospheres in the negative polarity must be attributed to oxygen molecules in air, which have high electron affinity. It should be noted that not only O₂ molecules in atmosphere but also those absorbed at surface region in LDPE have effect on the limitation of charge spreading.

Fig.2 shows the one dimensional charge distribution profiles on LDPE film in air and in N₂ gas introduced into the test chamber after various evacuation periods of the chamber. The charge spreading distance increased with increasing the evacuation period until 3 hours above which it was constant. These results imply

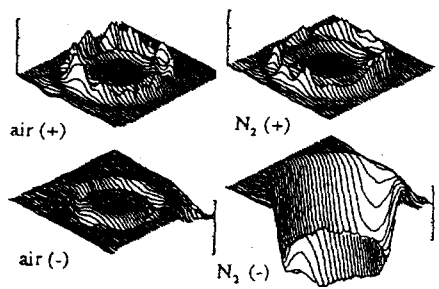


Fig. 1. Surface potential distribution maps on PET films surrounding circular electrode

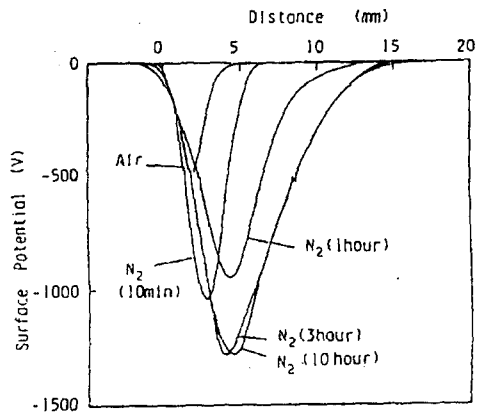


Fig.2. one dimension at potential distribution profiles on LDPE adjacent to electrode edge in air and N₂ gas after various evacuation times

that the charge spreading distance in N₂ gas increased as O₂ molecules absorbed in LDPE surface layer were replaced by N₂ molecules. The atmosphere in the test chamber could not be exchanged from air to other gas in a moment. The vacuum pump used could decrease the pressure in the chamber from 10 Pa (1 atmospheric pressure) to a constant value of about 1 Pa within 5 minutes. The oxygen density after 10 minutes evacuation must be very small as same as that after 3 hours evacuation. However, the charge spreading distance in N₂ after 10

minutes evacuation was considerably shorter than that after the evacuation for 3 hours. This result can be attributed to persisting O₂ molecules in LDPE which is high gas permeability polymer. Gas molecules absorbed in the free volume of LDPE are hardly extracted in even high vacuum. Judging from the result, it takes about 3 hours to extract O₂ molecules in LDPE, On the other hand, when the potential w

Potential after the removal of the disk electrode

Figure 3 shows the surface potential distribution maps on LDPE films just after the removal of the disk electrode for positive and negative various applied voltages. In both polarities, when the applied voltage was low the potential distribution of the inner region of the ring electrode was low and irregular. As the applied voltage was increased, the potential value increased to a constant value, resulting in the lateral uniform distribution. The interesting result was that the surface potential tended to increase with increasing short circuit time in LDPE, as shown in Fig.4. This apparently anomalous result is explained as follows. The charges are injected and drift into bulk of LDPE by the external field regardless of the polarity of the applied voltage. When the applied voltage is removed, the injected charges return back toward the electrode and they are blocked at the interface between the electrode and the sample during the short-circuiting if the internal field is not enough to cause the charge injection from the electrode. The more charges move back from the bulk to the upper surface of the sample during the longer short-circuiting time and thus higher potential is observed. If the brass electrode is removed after a brief short circuiting time, the observed potential is low because the injected charges stay in the bulk; it should be noted that the deeper charge from the surface of the film makes the lower potential on the film. The surface potential was not changed by short circuiting time in PP and PET. The reason for this is probably that the charges in PP and PET do not move during the short circuiting. In

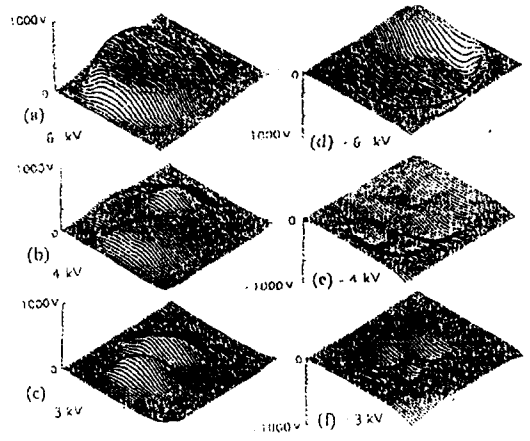


Fig.3. Surface potential distribution maps on LDPE films after the removal of the disk electrode. Voltage application time=10s.

any case, considerable high potentials were observed even though the electrodes were short circuited for a time. This implies that the charge transfer between the electrode and polymer surface is limited to some extent by some reasons. The charge transfer was probably influenced by the condition of interface between the electrode and the polymer surface because the lateral potential distribut

When the applied voltage exceeded about 800 V the appreciable surface potential was detected for both polarities on PET film of 50 μm. This suggests that the charge injection from the electrode must occur by the application of greater voltage than 800 V. This value of 800 V gives a critical field strength E at the interface to be 4.8×10^7 (V/m) from the equation $E = \epsilon rV/d$, where ϵr is relative permittivity of the dielectric (3.0 for PET). If the field strength is smaller than the critical value after the circuit is shoited, all the injected charges remain at the surface of the film: It is assumed that the charges are not injected into the bulk in PET. It is interesting to note that the applied voltages V were higher than the surface potentials by 800 V: The observed surface potential was $\pm 200V$ for $V_{ap} = \pm 1000V$ and $700V$ for $V_{ap} = 1500V$, as shown in Fig.5. If the greater field strength than the critical value is induced by

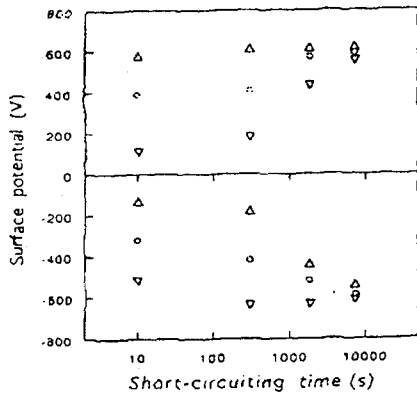


Fig. 4. The dependence of the surface potential values on the short-circuiting time for LDPE. Applied voltage= 4kV, voltage application time=10s.

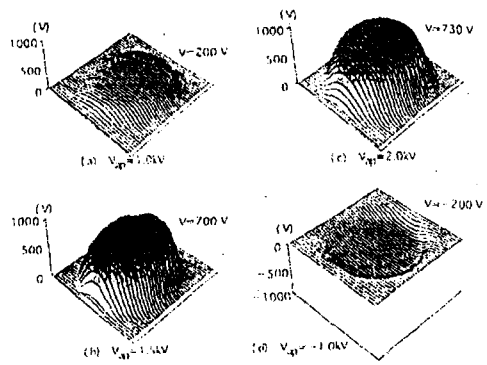


Fig. 5. Surface potential distribution maps on PET films after the removal of the disk electrode which was closely contacted with the film

the charges transferred to the film surface by the application of higher voltage, the excess charges flow out to the electrode or the charges of opposite polarity flow in from the electrode. Therefore, it is expected that the residual charges would induce the surface potential of 800 V after the upper electrode is removed. However, observed potential was 730 V, which was slightly lower than 800 V. This is probably attributed to the air discharge in the gap between the film and the upper electrode when the electrode was

removed [7].

4. Conclusions

When slowly rising dc voltage was applied to a circular electrode on polymer film, the surface potential distribution surrounding the electrode was measured. The charging area and the charge density for the negative polarity in N₂ gas are much wider and much higher than those in other cases, for both polarities in air and for positive polarity in N₂ gas. In air, those for negative polarity is slightly narrower and lower than for positive polarity. The charge distribution patterns in air and nitrogen gas atmospheres are similar to each other for the positive polarity. The difference between atmospheres in the negative polarity must be attributed to oxygen molecules in air, which have high electron affinity. The charge spreading distance on LDPE in N₂ gas increased with increasing the evacuation period before introducing N₂ gas to the test chamber until 3 hours above which it was constant. This is because oxygen molecules absorbed at surface region in LDPE have effect on the limitation of charge spreading.

Surface potential was measured on the face surface of insulating films which had been inserted between plane electrodes after the removal of the upper brass disk electrode. The charge transfer between the electrode and the film surface was limited by some reasons.

The residual charges resulted in the considerably high potential after the removal of upper electrode although a applied step voltage had been shorter. The surface potential increased to a constant value with increasing applied voltage. The surface potential tended to increase with increasing short circuit time in LDPE, while it did not change in PET and PP. The maximum value was limited by air discharge between the polymer surface and the upper electrode when the potential difference exceeded the breakdown voltage of air gap as they separated.

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