Degradation Analysis of Epoxy Resin Surfaces Exposed to Partial Discharge

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***Abstract*- The purpose of this study is to investigate the degradation process of polymer insulation materials exposed to partial discharge. Active oxygen, ozone, nitrogen oxides, nitric acid, etc. are generated by partial discharge. The polymer insulation materials degrade for such chemical stress. Moreover, surface resistivity of insulation materials is reduced with humidity. Therefore, it is necessary to take the affection of humidity into consideration for partial discharge. The purpose of this study is to investigate the effects of humidity on the degradation of an epoxy resin surfaces exposed to partial discharge. Experimental conditions are air atmosphere, and relative humidity was varied to 0, 25, 50, and 75 %. The quantity of partial discharge pulses can be evaluated with number of pulses. The degradation characteristics of epoxy resin surfaces were analyzed FTIR and SEM.**

I. Introduction

Since cables and electric power apparatus were installed in the high-growth period of the Japanese economy, 30 to 40 years have passed and a lot of them have reached their design lifetimes and the time to replace. On the other hand, it is requested because of the cost reduction in the operation of the power equipment to understand degradation conditions of these electric power apparatus and prevent the loss due to their breakdown beforehand. Moreover, it is strongly requested to use the electric power apparatus for the life limit.

In order to meet these requests, it is necessary to apply the insulation degradation diagnosis based on the characteristic of the insulating material used for each electric power apparatus. The insulating material and the structure of the electric power apparatus are different according to the manufacturing age and voltage class. The purpose of the investigation committee in dielectric and electrical insulation of IEEJ is to investigate the transition and the insulation degradation diagnosis of these insulating materials, and to examine the latest deterioration diagnosis technology based on characteristics of the insulating materials in electric power apparatus [1].

Since a void cavity is one of the potential sources of PD activity in insulation which may cause degradation and breakdown, it is very important to study PD events associated with void cavities solid dielectric insulation [2]. The effect of an interface on the lifetime of epoxy resin samples and the growth characteristics of electrical trees were investigated [3]. It is shown that the presence of the interface appears to lead to a wider tree growing, which both slows the tree growth and extends time to breakdown. It is suggested that the wider tree is due to space charge accumulation at the interface modifying the electrical field, and this in turn reduces the field enhancement due to the tree itself, further extending the epoxy lifetime.

Active oxygen, ozone (O_3), nitrogen oxides (NOx), nitric acid (HNO_3), etc. are generated by partial discharge. The polymer insulation materials degrade for such chemical stress. Moreover, surface resistivity of insulation materials is reduced with humidity [4]. Therefore, it is necessary to take the affection of humidity into consideration for partial discharge.

Authors have been studying the effect of water on partial discharge for LDPE. In higher humidity, the time to reach the breakdown became long in order that moisture might inhibit discharge. However, in the air mixed with NO, humidity became high, and the breakdown time was slightly decreased with increased humidity [5].

The effects of humidity and NOx on bisphenol A type epoxy resin are also experimentally investigated by partial discharge degradation [6]. The time to reach the breakdown increased with increased humidity in the air atmosphere. However, in the air mixed with NO, humidity became high, and the breakdown time decreased with increased humidity.

The purpose of this study is to investigate the degradation process of polymer insulation materials exposed to partial discharge. Polymer insulation materials were used for the bisphenol A type epoxy resin (BPA). The accelerated testing of these insulation materials was conducted. Experimental conditions are air atmosphere, and relative humidity was varied to 0, 25, 50, and 75 percent. BPA were exposed under assigned partial discharge and were measured till breakdown. The quantity of partial discharge pulses can be evaluated with pulse number, average pulses, maximum of pulses, and summation of pulses during 20 ms. The degradation characteristics of epoxy resin surfaces were analyzed by Fourier transform infra-red absorption spectroscopy (FTIR) and scanning electron microscope (SEM).

II. Setup

A. Sample and electrode

A sample and electrode configuration used for this experiment was shown in Fig.1. The electrodes were composed by a needle and a plate. A stainless needle electrode

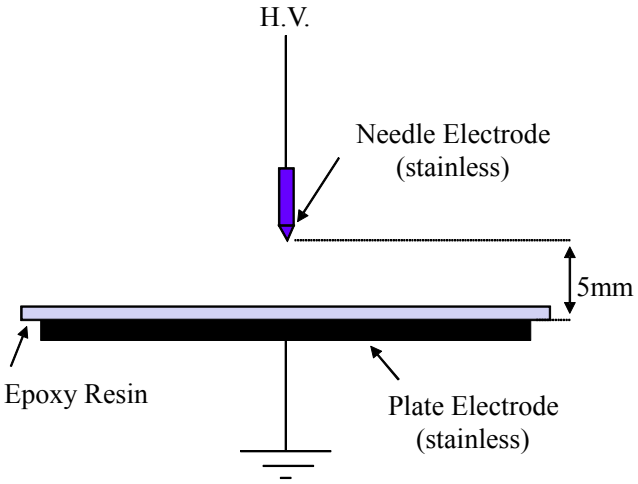

Fig. 1. A sample and electrode configuration

was 1mm in diameter with tip radius of 10μm. The gap length between the electrodes was 5mm. BPA sheet of 0.1mm thickness was put on the plate electrode.

B. *Experimental system*

Fig. 2 shows an experimental system. The electrode was placed into the chamber. The relative humidity was varied to 0, 25, 50, and 75 %. AC 50Hz high voltage was applied between the electrodes. The discharge power or discharge current was measure by Lissajous figures method and was 0.3W or 40μA. BPA sheet was exposed under the partial discharge and was measured till breakdown. The partial discharge pulse was detected by C-R detector and was observed by digital oscilloscope. The surfaces of the sample exposed by partial discharge were analyzed by FTIR and SEM. The characteristics of the gaseous discharge products were analyzed by FTIR [7].

III. Results and Discussion

In order to confirm the affection of humidity for partial discharge, relative humidity was varied to 10, 25, 50, and 75 % in the air atmosphere. The results at 0.3W discharge power were shown in Fig. 3. It was interesting to note that the time to reach the breakdown increased with increasing humidity. The longest breakdown time was over 400min when the relative humidity was 75 % within the experiments conducted. It is considered that the molecule of water carries out the trap of the electrons. Since discharge power is constant at 0.3W, the applied voltage is high and the discharge current is low as high humidity. Therefore, it is thought that the degradation of BPA was delayed with humidity because the discharge is inhibited with increasing the molecule of water.

The discharge pulse was measured at intervals of 15 minutes until breakdown in the air atmosphere. Fig. 4 shows a typical time dependency of pulse number of discharge for

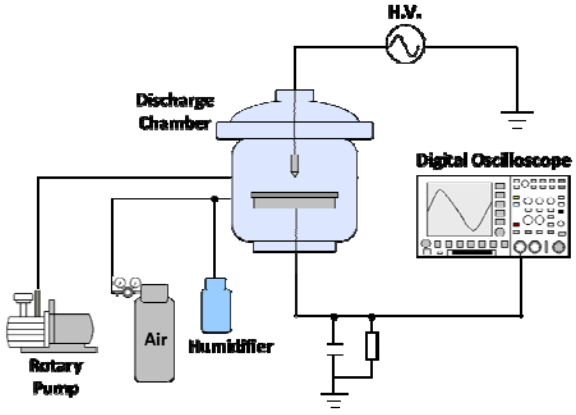

Fig. 2. An experimental system

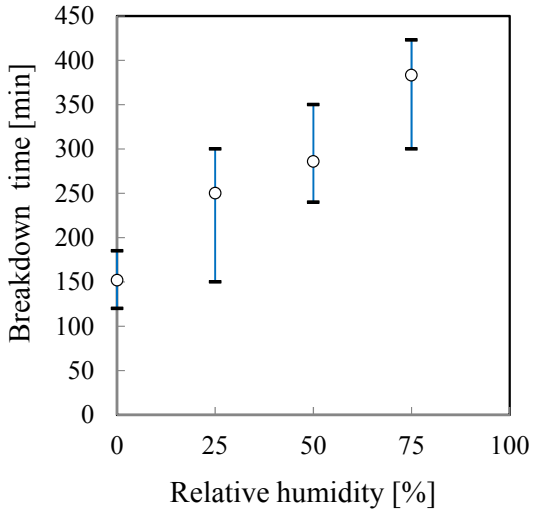

Fig. 3. Relative humidity and breakdown time relationship for BPA at 0.3W discharge power

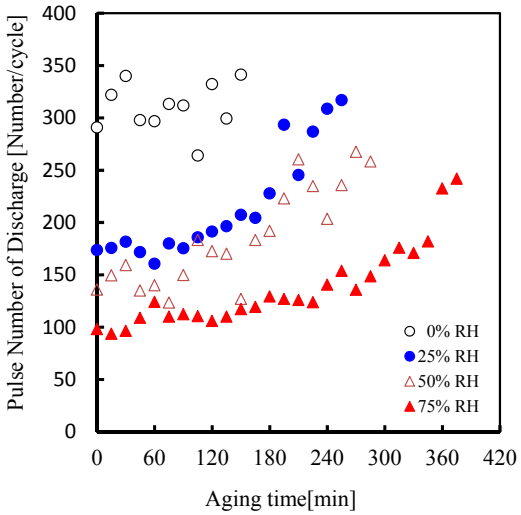

Fig. 4. Pulse number of discharge for BPA at 0.3W discharge power

BPA as a function of the aging time. The pulse number of discharge was in the range of 260 - 340 for relative humidity of 0 %, 170 -310 for 25% RH, 120 - 260 for 50% RH, and 90 - 240 for 75% RH. The pulse number of discharge has increased with increasing the aging time. The pulse number of discharge has increased with decreased relative humidity. It became clear that the discharge is inhibited with increasing the molecule of water.

Fig.5 shows the results of breakdown time at 40μA discharge current. It was interesting to note that the time to reach the breakdown decreased with increased humidity. The shortest breakdown time was less than 130 min when the relative humidity was 75 % within the experiments conducted. On any the humidity conditions, direct degradation by discharge is the same because the discharge current is constant at 40μA. OH radical and HNO_3 are generated by the discharge,

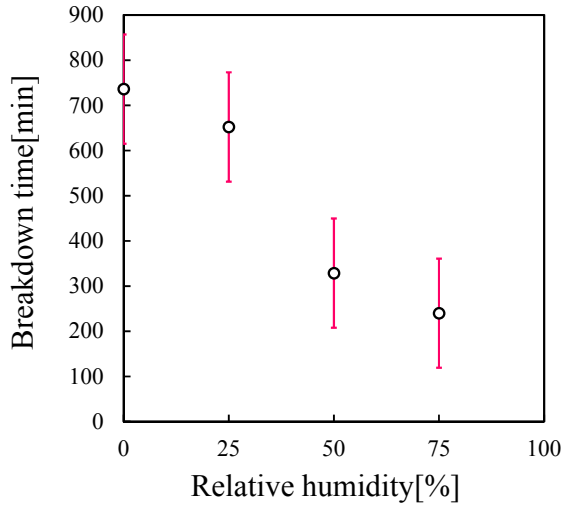

Fig. 5. Relative humidity and breakdown time relationship for BPA at 40μA discharge current

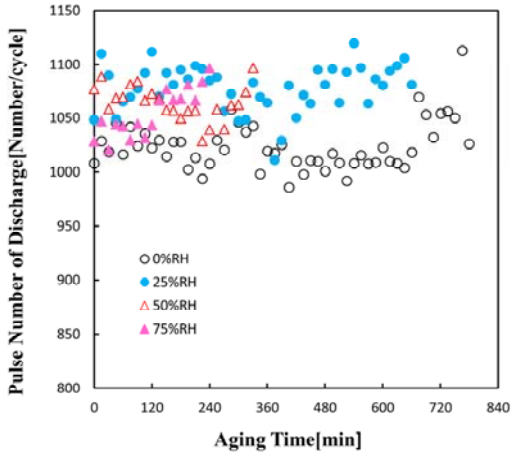

Fig. 6. Pulse number of discharge for BPA at 40μA discharge current

the quantity increases in proportion to humidity. Therefore, it is thought that the degradation of BPA was accelerated with humidity because a degradation factor increased with increasing the molecule of water.

The discharge pulse was measured at intervals of 15 minutes until breakdown as same as Fig.4. Fig. 6 shows a typical time dependency of pulse number of discharge for BPA as a function of the aging time at 40μA discharge current. This figure has many pulses because the detection sensitivity is high compared with Fig.4. The pulse number of discharge has increased with increasing the aging time. The difference in the characteristic by humidity is not shown. The pulse number of discharge is increasing in the last stage of degradation in any humidity.

The surfaces of the sample exposed by partial discharge were analyzed by Fourier transform infrared spectroscopy at intervals of 120 minutes. In this study, it took notice of combination of the carbonyl group considered as an index of oxidization degradation. Time dependency of carbonyl group for BPA was shown in Fig.7. The carbonyl group was

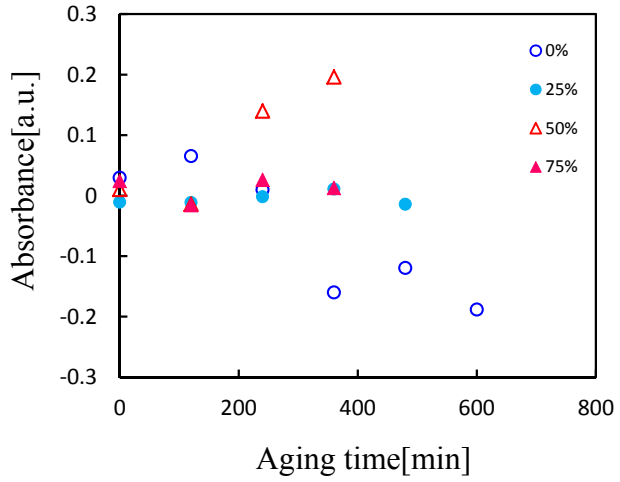

Fig. 7. Time dependency of carbonyl group for BPA

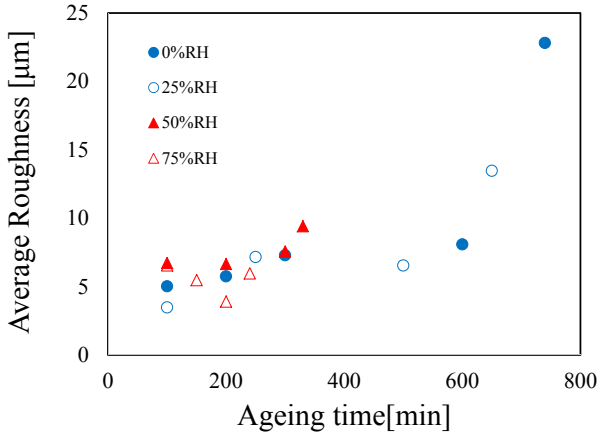

Fig. 8. Surface roughness of BPA

estimated by absorbance of 1720cm^{-1}. The carbonyl group is a decreasing tendency in low humidity. Therefore, it is thought that oxidization degradation has scarcely taken place with low humidity. However, the carbonyl group at 50% humidity is an increasing tendency. It is considered that a degradation mechanism changes with humidity from this result.

Since the difference in a degradation mechanism was thought from the Fourier transform infrared spectroscopy analysis, it considers by observing the surface analysis of BPA. The surface of BPA deteriorates by partial discharge and it becomes rough. Fig. 8 shows a typical time dependency of average roughness of BPA surface as a function of the aging time. The roughness of BPA was in the range of 5 - 24μm for relative humidity of 0 %, 3 -14μm for 25% RH, 6 - 9μm for 50% RH, and 4 - 6μm for 75% RH. The average roughness of BPA surface has increased with increasing the aging time. The average roughness of BPA surface has increased with decreased relative humidity.

Photographs of BPA surface by SEM was shown in Fig.9. Original is undeteriorated sample. Central holes are the marks at the time of breakdown. In the low humidity, the erosion and roughness in the near the hole were confirmed. However, the erosion and roughness aren't observed so much in high humidity. In low humidity, partial discharge degradation erodes in a surface large area. On the other hand, in high humidity, the erosion and oxidization degradation by partial discharge occur locally. Therefore, it is considered that the roughness in the high humidity is smooth compared with the low humidity and breakdown time also becomes short.

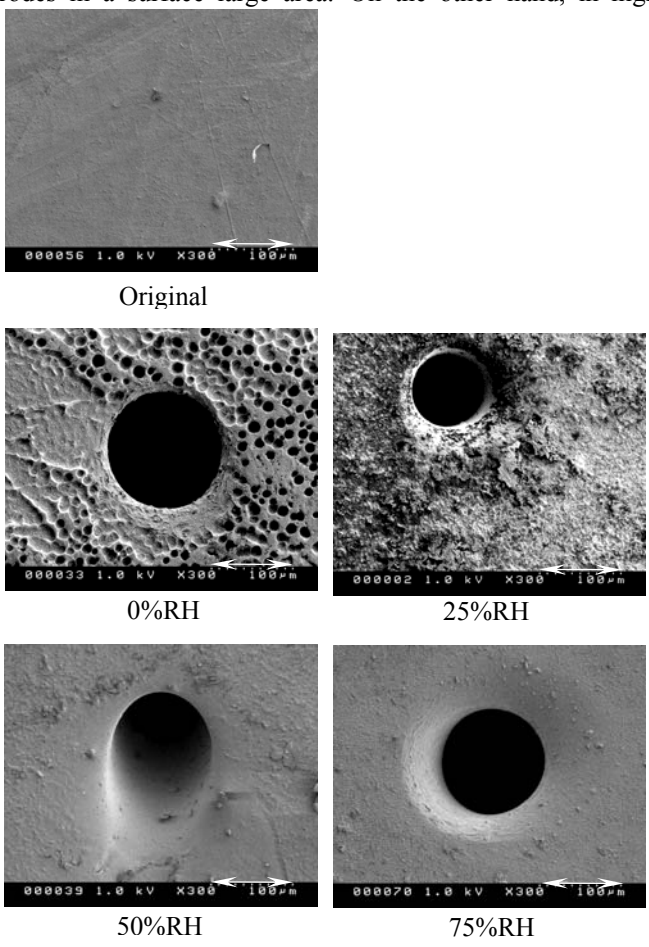

Fig. 9. Photographs of BPA surface by SEM

IV. Conclusions

The effects of humidity on bisphenol A type epoxy resin are experimentally investigated by partial discharge degradation. The degradation process was investigated by surface analysis. The time to reach the breakdown increased with increased humidity at 0.3W discharge power. However, at 40μA discharge current, the time to reach the breakdown decreased with increased humidity. The carbonyl group at 50% humidity is increasing tendencies by the partial discharge degradation. In high humidity, the erosion and oxidization degradation by partial discharge occur locally compared with the low humidity.

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