The Estimation of the Dielectric Strength Decrease of the Solid-solid Interfaces by using the Applied Voltage to Breakdown Time Characteristics

Cheol Gi Shin[a]
Department of Digital and Industrial Electronic Engineering, Bucheon College, 17 Wolgyesu 4st. Simgok-dong, Wonmi-gu, Bucheon-si, Gyeonggi 420-735, Korea

Duck Kweon Bae
Department of Safety Engineering, Chungju National University, 72 Daehak-no, Chungju-si, Chungbuk 380-702, Korea

[a]E-mail : cgshin@bc.ac.kr

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In the complex insulation system that is used in extra high voltage (EHV) devices, according to the trend for electric power equipment of high capacity and reduction of its size, macro interfaces between two different bulk materials which affect the stability of insulation system exist inevitably. In this paper, the dielectric strength decrease of the macro interfaces between epoxy and ethylene propylene diene terpolymer (EPDM) was estimated by using the applied voltage to breakdown time characteristics. Firstly, the AC short time dielectric strength of specimens was measured at room temperature. Then, the breakdown time was measured under the applied constant voltage which is 70 % of short time breakdown voltage. With these processes, the life exponent n was determined by inverse power law, and the long time breakdown voltage can be evaluated. The best condition of the interface was LOS (low viscosity (350 cSt) silicone oil spread specimen). When 30 years last on the specimens, the breakdown voltage was estimated 44 % of the short time breakdown voltage.

Keywords : Solid to solid interface, Inverse power law, Dielectric strength, Life component n

1. INTRODUCTION

Because the tendency of the electrical insulation in electric power equipments is multiple insulation system, solid-solid interfaces are existed in the equipments inevitably. The interface is not always a weak point, but many defects, such as voids, many contaminants, and dust are easy to be introduced at the interface. These defects make the interface to be a weak point in the electrical insulation. The interfacial breakdown between two internal dielectric surfaces is a main cause of failure in multiple insulation systems[1].

The interfacial dielectric breakdown is a complex phenomenon, and interfacial discharges leading to a dielectric failure and space charge formation due to different permittivity of the contacting dielectrics are main causes of breakdown[2].

In the process of the breakdown at the solid-solid interface, firstly, partial discharge (PD) initiates at the interface. The initiated PD propagated into the interface and degrades the electrical properties of the interface. Finally, electrical breakdown occurred at the interface. Many factors can affect the dielectric performance of an interface[3]. Among these factors interfacial pressure plays a major role in interfacial dielectric strength. In order to better understand this phenomenon, breakdown experiments were performed on the interface between epoxy and ethylene propylene diene terpolymer (EPDM) pressed one against the other. To archive this, interfacial dielectric strength tester with air-compress system was prepared. The short time dielectric strength of the interface measured with the tester firstly. Then, the breakdown time was measured under the applied constant voltage which is 70 % of short time breakdown voltage. With these processes, the life exponent n was determined by inverse power law, and the long time breakdown voltage can be evaluated.

2. EXPERIMENTS

2.1 Design of the specimen

To design a model specimen for the electrical properties at solid-solid interface, it is necessary for the specimen to have below conditions:

1) Electrodes do not contact interface.
2) Pressure can be applied to interface.
3) Between two electrodes, the direction of electric field is parallel to the surface of interface.
4) Interfacial effect such as oil, roughness and defects can be examined.

Figure 1 shows the structure of the specimen. The specimen consists of epoxy, EPDM, two electrodes. The structure of electrodes was designed to have electric potential longitudinally along the interface, and to have uniform electric field. The gap between metal electrodes and the surface of the interface was 50 μm.

2.2 Manufacture of the Specimen

The specimen consists of epoxy and EPDM. The epoxy was Bisphenol-A liquid type resin [100 phr] + MeTHPA (Methyl tetra Hydro Phthalic Anhydride) [100 phr].

The glass transition temperature of epoxy and EPDM is 90~100 °C and -60 °C respectively. In other words, EPDM is a material has elasticity at operation temperature, but epoxy is not. Cavities of elastic materials are easily reduced by pressure. So the surface condition of epoxy is likely to affect electric properties of interface more.

The manufacturing process and configuration of specimen is shown in Fig. 2. After 1st curing, specimens were sanded with sandpaper, and electrodes were molded. And then 2nd curing was carried out.

Figure 3 shows schematic drawing of specimen. Each electrode consists of spherical stainless steel and cylindrical copper wire. In the process of specimen preparation, electrodes were inserted into epoxy to reduce the effect of charge transport from electrode in breakdown progress. The gap between electrode lower side and interface was 50 μm.

In this paper, three types of specimens were prepared. One was NOS (no oil spread on the interfacial surfaces of the specimens), another was LOS (350 cSt silicone oil spread on the interfacial surfaces of the specimens), and the other was HOS (12,500 cSt silicone oil spread on the interfacial surfaces of the specimens).

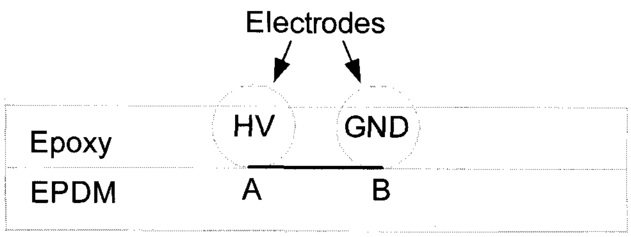

Fig. 1. Structure of specimen.

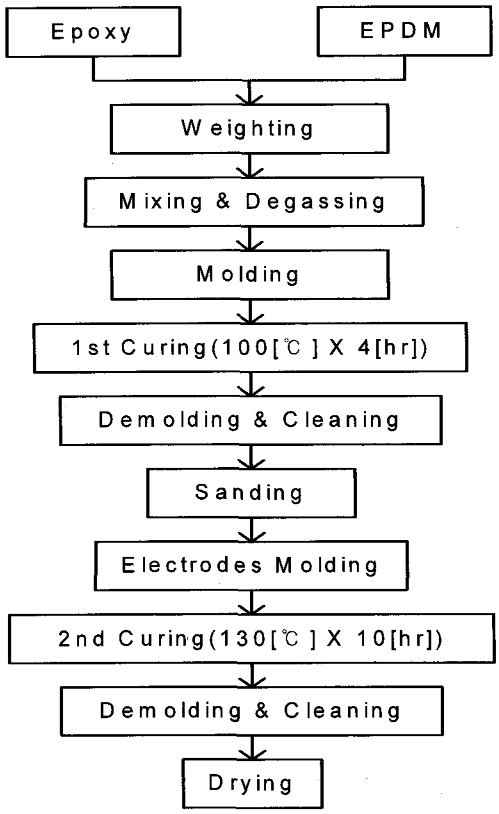

Fig. 2. Manufacturing process of epoxy specimen.

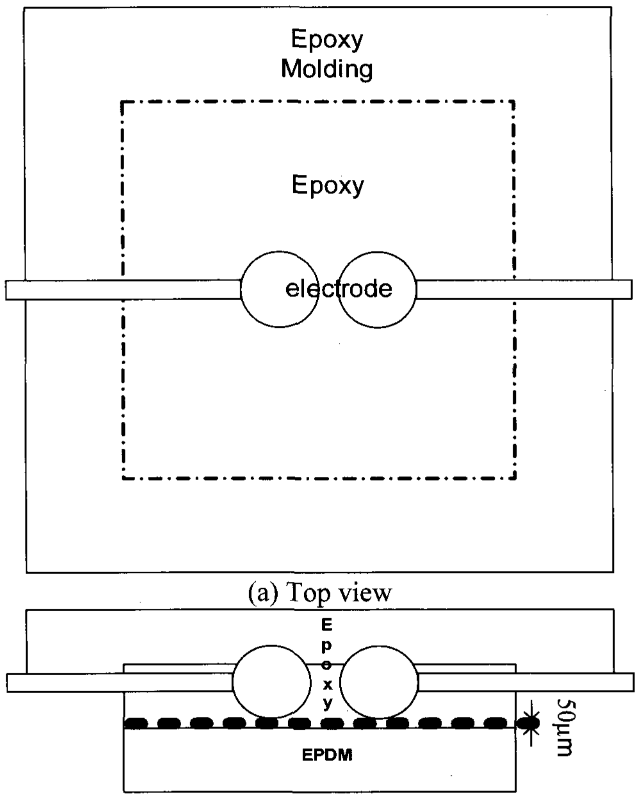

Fig. 3. Schematic drawing of specimen.

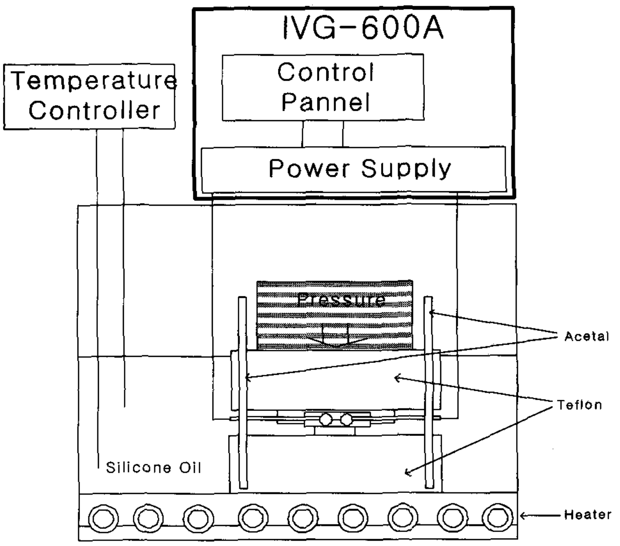

Fig. 4. Interfacial dielectric strength tester.

2.3 Interfacial dielectric strength tester

Test method was selected according to short-time test (current setting: 10 mA, rate-of-rise: 500 V/s) of ASTM D 149-95a (Dielectric breakdown voltage and dielectric strength of solid electrical insulating materials at commercial power frequencies). Figure 4 shows the interfacial dielectric strength tester. Interfacial dielectric strength tester was made of Teflon and Acetal. Air compress system was used to press the specimens.

2.4 Inverse power law and life component n

An electrical failure model may result in an equation that relates the applied test voltage to the time-to-failure. In general as the test voltage decreases, the failure times increase. The inverse power law is described by

$$V^n t = const. \tag{1}$$

Where, V is applied test voltage, n is life component, and t is time-to-failure at voltage V[4].

Life component n can be obtained by using the equation (1). Here, V_1 is short time breakdown voltage and t_1 is time-to-failure at V_1 and V_2 is applied constant voltage below V_1 and t_2 is the elapsed time to breakdown at V_2.

$$n = \frac{\ln \frac{t_2}{t_1}}{\ln V_1 - \ln V_2} \tag{2}$$

3. RESULTS ANS DISCUSSIONS

3.1 Short time dielectric strength

Interfacial dielectric failure is a complex phenomenon.

Table 1. Short time breakdown voltage according to the interfacial pressure and spread oils.

Interfacial pressure (kgf/cm2)	Breakdown Voltage (kV)		
	NOS	LOS	HOS
2	28.52	29.87	28.86
3	34.23	35.23	34.23
4	35.24	38.59	38.26
5	36.58	40.6	40.2
6	37.26	41.11	40.44
7	37.43	41.37	40.46

Space charge formation, due to the different permittivity of the contacting dielectrics, occurs on the boundaries, which results in a change of physical properties (loss tangent, permittivity) of the composite compared to the single component. Consequently, the dielectric losses may be increased due to interfacial polarization effect, and then it takes a higher heat generation in the dielectrics.

Cavities existing in the interface between Epoxy and EPDM may be filled with air or gas whose permittivity and dielectric strength are considerably less than solid. Partial discharge will occur across the cavities when its peak stress is equal with the breakdown strength of air, and the voltage at which this occurs is known as the discharge inception voltage. Partial discharges occurred at cavities develop the tracking degradation propagation and lead to the dielectric failure. Discharge inception voltage of air in cavities is proportional to its pressure level. Interfacial pressure would reduce the volume and number of cavities and raise the air compress in cavities[5-7].

Table 1 shows the short time breakdown voltage of the specimens according to the applied interfacial pressure and spread oils. Applied voltage was AC voltage with 60 Hz and each data is the average of 10 measurements. AC dielectric strength should be improved by increasing interfacial pressure. Especially, it was saturated after interfacial pressure of 5 kgf/cm^2. Thus, the interfacial pressure to obtain the long time breakdown characteristics of the interface between epoxy and EPDM was fixed to 5 kgf/cm^2. In case of LOS and HOS, oiling plays an important role in eliminating cavities at interfacial surface. However, high viscosity silicone oil spreading may make voids at interface because of its poor flowage. So low viscosity oil spread specimens have higher dielectric strength than high viscosity oil spread specimens. AC breakdown voltage of NOS, LOS, and HOS was respectively 36.58, 40.6 and 40.2 kV.

Table 2. Elapsed time to breakdown of specimens.

Specimen type (Applied voltage)	Elapsed time to breakdown (hrs)					
	A	B	C	D	E	mean
NOS (25 kV)	18.48	17.92	13.52	16.41	15.6	16.39
LOS (28 kV)	35.86	35.24	33.23	32.82	37.85	35
HOS (28 kV)	25.23	25.65	28.31	30.22	24.28	26.74

3.2 Voltage to time characteristic

Table 2 shows elapsed time to breakdown of each specimen.

In this test, the elapsed time to breakdown of the specimen was measured with constant voltage applying. The applied test voltage was about 70 % of the short time breakdown voltage. As shown in the Table 2, the voltage of NOS was 25 kV and that of LOS and HOS was 28 kV. Five specimens were tested at each condition. The elapsed time to breakdown of NOS was very short than two other conditions. The LOS has the longest breakdown time. The measured time of NOS, LOS and HOS was respectively 16.39, 35 and 26.74 hrs. Although the difference of short time breakdown voltage between LOS and HOS was just 0.4 kV, the difference of the elapsed time to breakdown was over than 8 hrs with the same applied voltage. This means that the partial discharge of the void caused by the poor flowage of spread oil accelerates the speed of degradation at the solid to solid interface.

3.3 Estimation of long time breakdown voltage

Figure 5, 6, and 7 shows the breakdown voltage to time characteristics of NOS, LOS and HOS, respectively. The scale type of horizontal and vertical axis is all log scale. The line of the each graph represents the mean value of 5 measurements and the long time breakdown voltage can be estimated by extension of the line.

As shown in Table 3, the life component n and the long time breakdown voltage can be calculated with equation (2). The decrease of the dielectric strength was also estimated. The LOS also has the highest life component n. The life component n of NOS, LOS and HOS was 17.63, 19.72 and 19.63, respectively. In case of LOS, the estimated breakdown voltage after 30 years was about 44 % of the short time breakdown voltage. It is recommended, base on the results of this study, that the designed electrical stress of the epoxy and EPDM interface with low viscosity silicone oil spreading and interfacial pressure of 5 kgf/cm^2 should be higher than 200 % of its short time dielectric strength to have the life time over than 30 years.

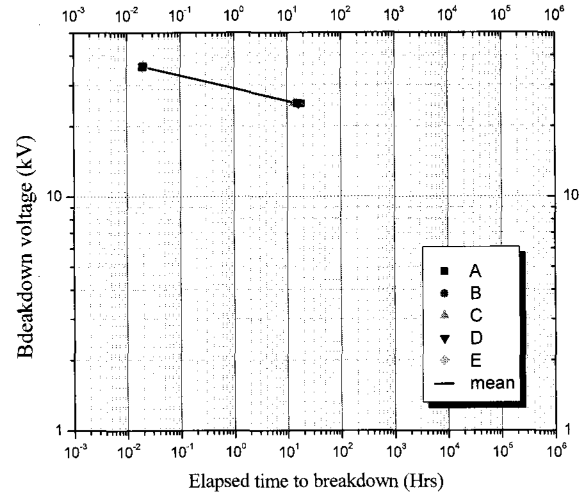

Fig. 5. Breakdown voltage to time characteristics of NOS.

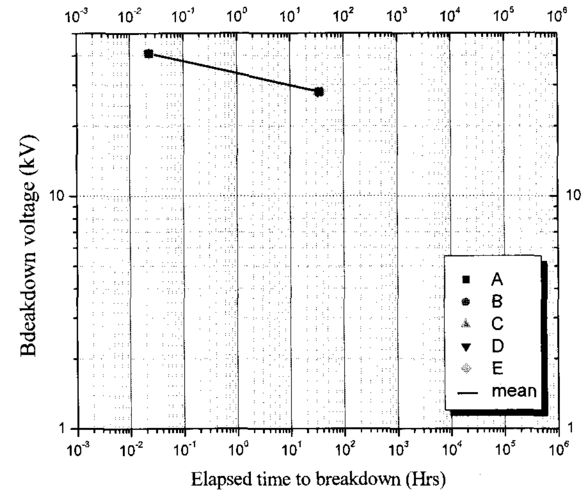

Fig. 6. Breakdown voltage to time characteristics of LOS.

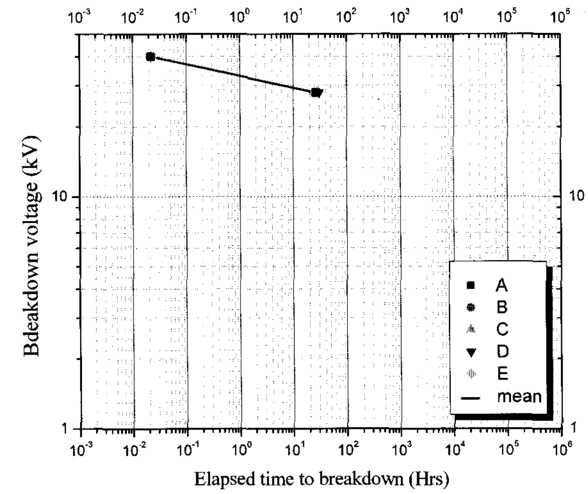

Fig. 7. Breakdown voltage to time characteristics of HOS.

Table 3. Estimated breakdown voltage.

Specimen type	Life component n	Estimated breakdown voltage (kV)			
		Short time	10 years	20 years	30 years
NOS	17.60	36.6	15.35	14.76	14.44
LOS	19.72	40.6	18.83	18.18	17.81
HOS	19.64	40.2	18.54	17.90	17.52

4. SUMMARY

In this study, the interface between epoxy and EPDM was selected as a solid to solid interface and the long time dielectric strength was estimated. In the process of the estimation, short time breakdown voltage was measured firstly. Then the applied voltage to breakdown time characteristic was evaluated with the test voltage of 70 % of short time breakdown voltage.

The dielectric strength of solid to solid interface was improved by increasing of interfacial pressure and it was saturated after interfacial pressure of 5 kgf/cm^2. In case of LOS and HOS, oiling plays an important role in eliminating cavities at interfacial surface. However, high viscosity silicone oil spreading may make voids at interface because of its poor flowage. So low viscosity oil spread specimens have higher dielectric strength than high viscosity oil spread specimens.

The best condition of the interface was LOS (low viscosity (350 cSt) silicone oil spread specimen). It is recommended, base on the results of this study, that the designed electrical stress of the epoxy and EPDM interface with low viscosity silicone oil spreading and interfacial pressure of 5 kgf/cm^2 should be higher than 200 % of its short time dielectric strength to have the life time over than 30 years.

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