The Self Healing Characteristics of MPPF for Energy Storage Capacitors

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Abstract - This paper describes the self healing characteristics of a metallized polypropylene film(MPPF) used for energy storage capacitors.

In the experiment, a d.c. voltage was applied to the MPPF, and the partial discharge inception voltages(PDIVs), the applied voltages at self healing, the burn out area and the current in the grounding conductor were measured and recorded.

As a result, it was found that no PDs were found till the first pre-self healing occurred, and the applied voltage at self healing was increased with PPF thickness. Self healing was much more dependent on the shape of the air void than its diameter, and the burn out area and the current in the grounding conductor at self healing was also increased with the applied voltage at self healing.

1. Introduction

The term 'self healing' was first used by Klein from Germany during the second World War to express that the vapor deposited metal changes into an oxidized thin membrane through its burn out, in the process of the breakdown test of inorganic paper and polymer film with metallized surface. Self healing is the phenomenon that the thin polymer film with metallized electrode recovers the insulation ability as soon as it meets a breakdown, when defects exists on or in the polymer film with metallization or the voltage is over the critical breakdown voltage of the polymer with defects. Fig. 1 shows the schematic of self healing mechanism(1)(2)(3).

![Fig. 1 Schematic of self healing mechanism](image)

As shown in Fig. 1, when the dielectric with the defect reaches a breakdown, the short current flows across the dielectric. This current generates the local heat about 3,700~4,200°C at the failure point. Consequently, the dielectric is punctured with very small ball approximately 1~100(μm) in diameter, and the vapor deposited metal around the ball is oxidized and evaporated(3). The site where self healing occurs is electrically isolated because conductive metallization is burnt out and the burn out spot becomes an insulation material or a semiconductor. This action prevents the local failure due to the defects from spreading out larger failure of a capacitor unit(3)(4). In this paper, the various characteristics of self healing which plays important role of improving the performance of capacitors are studied.

2. MPPF capacitor

Out of the manufacturing processes of a capacitor element, an air void can be generated, if the winding tension is not constant or the impregnant is not permeated completely between the MPPF layers, in the winding and impregnating process, which can result in a local breakdown of the MPPF(2)(5). Fig. 2 shows the air void between the MPPF layers, generated in the manufacturing processes.

![Fig. 2 Air void between MPPF layers generated in manufacturing processes](image)

As shown in Fig. 2, the thickness of the air void between the PPF and the deposited electrode is almost constant all over the area except only the edge of the air void, by the winding tension determined as PPF thickness×PPF breadth×(1~1.5)(5).

3. Experiment

3.1 Experimental setup

Fig. 3 shows the experimental setup to investigate the self healing characteristics of the MPPF under d.c. condition.

![Fig. 3 Experimental setup](image)

As shown in Fig. 3, to imitate the air void between the MPPF layers in a capacitor, an injector was attached, by which the diameter of the air void could be adjusted.

The metallization resistance is generally determined by 3~9Ω, and it plays an important role in oxidation and burning out the vapor deposited metal at self healing event. Higher resistance of metallization can be more effective in that the insulation ability of the burn out area is excellent because the higher the vapor deposited
metal resistance is, the broader the burn out area becomes. However, the loss in capacitance is getting increased. The heat due to the loss leads to the reduction in capacitance, and the performance of the capacitor will be worse (4)(6). Table 1 shows the specification of the MPFP used in this experiment.

Table 1 Specification of MPFP used

<table>
<thead>
<tr>
<th>MPFP thickness</th>
<th>Deposited metal/thickness</th>
<th>Metalization resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 6 10 12(µm)</td>
<td>Al / 300(A)</td>
<td>7(Ω)</td>
</tr>
</tbody>
</table>

The impregnant can be contaminated by the metallic oxide and the hydrocarbon gas formed at self healing, which makes insulation performance of the impregnant worse (1). And thus, the impregnant was refilled with new one through the drain coke and the entrance every time the MPFP was changed. The insulation oil (SUN OHM C) manufactured for impregnating the PPW was used as the impregnant. Table 2 shows the electrical and physical properties of the impregnant.

Table 2 Electrical and physical properties of impregnant(80°C)

<table>
<thead>
<tr>
<th>Specific weight</th>
<th>Viscosity(cSt)</th>
<th>ε'</th>
<th>tan δ</th>
<th>Dielectric strength(kV/2.5µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.916</td>
<td>12.3</td>
<td>2.8</td>
<td>0.03</td>
<td>72</td>
</tr>
</tbody>
</table>

3.2 Experimental procedure

First of all, a sheet of the MPFP was put on the base electrode, and it was covered by the acrylic plate with a scale. The case was filled with impregnant. Second of all, the air void diameter was measured by the scale on the acrylic plate after inserting the air void with an arbitrary diameter ranging 1~3(cm), by an injector, since it is very difficult to accurately adjust the diameter of the air void. D.C voltage was applied to the MPFP, and the PDIVs, the applied voltages at self healing, the burn out area of vapor deposited metal at self healing and the current waves in the grounding conductor at self healing were measured and recorded. This procedure was repeated every time the MPFP's were changed, so 60~70 self healing data by each MPFP thickness were acquired.

4. Results and discussion

The MPFP suffered several pre-self healing events, due to the defects sparsely locating between the MPFP and the base electrode, which occurred at lower voltages than the breakdown voltage of the PPF(1)(3). In addition, when the applied voltage was continuously increased, self heating events took place all over the MPFP area as soon as the applied voltage was near the breakdown voltage of the PPF.

4.1 PDIV characteristics under d.c. condition

In this experiment, the PD was not observed until several pre-self healing events occurred, and this is considered because the leakage current path bridges between the edge of the burn out spot due to self healing and the base electrode. The number of pre-self healing that PD began to be observed with PPF thickness equal or more than 2~3 pre-self healing events in case of 5(µm) PPF, and equal or more than 4~5 pre-self healing events in case of 12(µm) PPF. Comparing both cases, the PD magnitude between them was far different. From this result, it can be assumed that the PD is closely related to the insulation ability due to burn out area at self healing.

4.2 Effect of air void diameter and PPF thickness on self healing

Table 3 shows the self healing characteristics by the air void shape.

Table 3 Self healing characteristics by air void shape

<table>
<thead>
<tr>
<th>S.H event</th>
<th>probability</th>
<th>feature</th>
<th>shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>circular void</td>
<td>very low</td>
<td>Subsequent self healing at the edge of burn out spot due to self healing observed</td>
<td>pin void: void equal or less than 1(cm) in length</td>
</tr>
<tr>
<td>pin void</td>
<td></td>
<td></td>
<td>wrinkled void: void more than 1(cm) in length</td>
</tr>
<tr>
<td>wrinkle void</td>
<td></td>
<td>gas generated at self healing</td>
<td>X or Y void: void with cross point</td>
</tr>
<tr>
<td>X or Y void</td>
<td></td>
<td>voltage applied and increased</td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table 3, self healing mainly took place in case of a pin void equal or less than 1(cm) in length, a wrinkle void shaped very long pin void and X or Y voids with cross point of wrinkle. In this case, self healing was found at pin tips, wrinkle sides, cross points of the wrinkles, respectively. Moreover, several subsequent self healing events were observed at the edge of the burn out spot at or after self healing, as shown in Table 3.

The breakdown voltages of the PPF has been somewhat differently reported depending on the testing condition and the various factors: the PPF manufacturing type, the film stretching and its surface treatment, etc. In this country, about 0.4~0.5(Wa/µm) is usually considered the breakdown voltage of the PPF itself, and about 0.2(Wa/µm) lesser is taken into account in manufacturing capacitors (5). In this experiment, the initial applied voltage belonging to the voltage group whose self healing frequency was most was taken as the applied voltage at self healing at PPF thickness, and Fig. 4 shows the result.

Fig. 4 Applied voltage at self healing with PPF thickness

As shown in Fig. 4, the applied voltage at self healing was increased at the rate of about 0.4(kV/µm) with PPF thickness.
4.3 Burn out area of vapor deposited metal at self healing

Photo. 1 shows the burn out spot of the vapor deposited metal at self healing.

![Photo 1](image-url)

As shown in Photo. 1, the MPPF was punctured due to self healing, and the vapor deposited metal around the very small hole was oxidized and evaporated. In most of self healing events, gas was generated. According to early reports, it consists of hydrocarbon with the molecular structure of C₁₀H₈ in case of the PPF(1). This gas was getting disappeared with the applied voltage. Fig. 5 shows the burn out area of the vapor deposited metal at self healing with the applied voltage at self healing and PPF thickness.

![Fig. 5](image-url)

4.4 Current in grounding conductor at self healing

Fig. 6 shows the peak current, at self healing, in the grounding conductor connected the base electrode.

![Fig. 6](image-url)

As shown in Fig. 6, the peak current in the grounding conductor was increased with the applied voltage at self heating. In case of 10(μm) and 12(μm) PPFs, it was widely varied.

Fig. 7 shows the typical waveforms of the current in the grounding conductor at self healing by PPF thickness.

(a) 5(μm), 2.55(V), 20(A/div.), (b) 6(μm), 3.25(V), 20(A/div.),
(c) 10(μm), 4.55(V), 40(A/div.), (d) 12(μm), 6.15(V), 100(A/div.)

Fig. 7 Current waveforms at self healing (1(μs/div.))

As shown in Fig. 7, the current in grounding conductor was oscillated and damped, and mostly tended to be zero within 5(μs).

5. Conclusion

As a result to investigate the self healing characteristics of the MPPF employed as the dielectric in energy storage capacitors, this paper concludes as follows:

1. Pre-self healing frequently took place, and it was abruptly reduced with time.
2. No PDs had been found till the first pre-self healing occurred, and they could be observed after several pre-self healing events occurred.
3. The applied voltage was increased with PPF thickness.
4. Self healing mainly took place at the edge of a pin void, a wrinkle void and X or Y voids, and self healing at the circular void hardly occurred. Even though self healing occurred at the circular air void, it was limited to the edge of the circular air void.
5. The burn out area of the vapor deposited metal at self healing was linearly increased with the applied voltage in case of thinner PPF.
6. The peak current in the grounding conductor at self healing was increased with the applied voltage, and the current in the grounding conductor was oscillated and damped. After all, it was mostly to be zero within 5(μs).

References