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보이드에 의한 MPPF의 셀프힐링 특성 연구

(A Study on the Self Healing Characteristics of MPPF by Voids)

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요 약

본 논문은 교류전압 인가시 보이드 형상에 따른 금속증착 폴리프로필렌 필름(Metalized Polypropylene Film : MPPF)의 셀프힐링 특성에 대해 연구하였다.

보이드 결함으로 인해 발생하는 프리 셀프힐링의 횟수가 증가함에 따라 PDIV는 증가하였으며, 프리 셀프힐링은 PPF의 절연파괴전압보다 낮은 전압에서 발생하였다. 셀프힐링은 주로 핀형, 주름형, X/Y형 보이드의 에지, 주름선상 및 교차점에서 발생하였으며, 주셀프힐링 전압은 PPF의 두께에 따라 증가하였다. 또한, 셀프힐링시 증착금속의 비산면적은 인가전압에 따라 증가하였으며, 셀프힐링시의 피크전류는 MPPF에 인가된 전압에 따라 증가하였다.

Abstract

This paper describes the self healing characteristics of a metalized polypropylene film(MPPF) by voids under a.c condition.

PDIVs were increased with the number of pre-self healing due to void defects, and several pre-self healing events took place at lower voltage than the critical breakdown voltage of a PPF. Self healing mainly occurred at pin tips, wrinkle sides, and cross points of wrinkles, and the main self healing voltage was increased with PPF thickness. The burn out area at self healing was increased with the applied voltage, and the peak currents in a grounding conductor at self healing was also increased with the applied voltage.

1. Introduction

Recently, capacitors are widely used as an electrical equipment. In case of the capacitor which employs a metalized polymer film as a dielectric, the electrical characteristics has been considerably improved by self healing. The term 'self healing' implies the automatic insulation recovering phenomena occurring on a very thin metalized film, and was first used by Klein[1][2][3]. With the advance of polymer technology, self healing has greatly contributed to raising the energy density and the reliability of capacitors. Fig. 1 shows the self healing mechanism.

Fig. 1 Self healing mechanism

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As shown in Fig. 1, when a defect is in a dielectric, a breakdown occurs at this point. A very small hall is created at the breakdown, and metalization around the hall is evaporated. The burn out area of the metalized polymer film is electrically isolated like a melted fuse, therefore, continuous short current can be cut out. The dielectric can be self healed through the mechanism. Up to now, a study on self healing has been mainly focused on the gas generated at self healing, the factors affecting self healing, or the dielectric strength characteristics of metalized polymer films[1][4]-[8], but the self healing characteristic depending on the void shapes or a study on the self healing locations have not been reported. The defects may occur in various modes such as wrinkles or voids occurring in the winding and impregnating processes[4][9].

In this paper, PPF thickness and various shapes of defects which may be generated in capacitor manufacturing process because of unbalanced winding tension were selected as experimental parameters, and self healing characteristics were compared and analyzed by the PPF thickness and the defect shapes.

2. Experiment

2.1 Experimental setup

Fig. 2 shows the experimental setup to investigate the self healing characteristics of the MPPF with various shapes of voids under a.c condition.

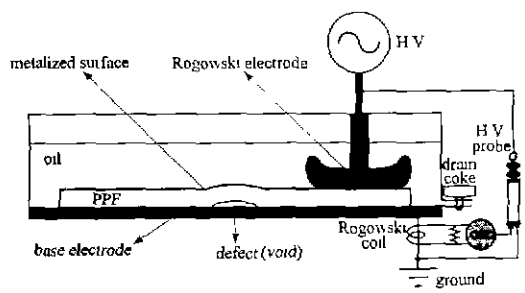

Fig. 2. Experimental setup

As shown in Fig. 2, various shaped void defects were imitated between the MPPF and the base electrode. The Rogowski electrode was connected to the high voltage generator(Hypotronics model:750-5CF) which could apply up to 50[kVac], and base electrode was grounded. A high voltage probe(Pulse Electronic Engineering model:EP-50K) was used to measure the applied voltage.

The metalization resistance is generally determined by 3~9[Ω], and it plays an important role in oxidizing and burning out the metalization at self healing. Higher resistance of metalization can be more effective from the viewpoint of the insulation ability of the burn out area, because the higher the metalization resistance is, the broader the burn out area becomes. However, the capacitance is getting reduced by self healing, and thus, the performance of a capacitor will be worse[4][9]. Table 1 shows the specification of the MPPF used in this experiment.

Table 1. Specification of MPPF

PPF thickness	deposited metal / thickness	metalization resistance
5, 6, 10, 12[㎛]	Al / 300[Å]	7[Ω]

The insulation oil(SUN OHM C) was used as impregnant. The impregnant can be contaminated by the metallic oxide and the hydrocarbon gas generated at self healing, which makes insulation performance of the impregnant worse[1]. Therefore, the impregnant was refilled with new one every time the MPPF was changed. Table 2 shows the electrical and physical properties of oil.

Table 2. Electrical and physical properties of oil

specific weight	viscosity[cSt]	ε'	$\tan\delta$	dielectric strength[kV/2.5㎜]
0.916	12.3	2.8	0.03	72

To measure the currents at self healing, a Rogowski coil was installed at the grounding conductor, and it was connected to the input

terminal of an oscilloscope.

2.2 Experimental procedure

The MPPFs of 5, 6, 10 and 12[㎛] thickness were sheared by 6×15[㎝]. Each of them was put on the base electrode, and it was impregnated. After applying a.c voltage at the rate of 0.5[kV/s] using a high a.c voltage generator(corona free), PD(partial discharge) characteristics, applied voltages, burn out area and currents in the grounding conductor at self healing were observed and measured. Some of self healing events were recorded. This procedure was repeated every time the MPPFs were changed, so about 60 self healing data by each PPF thickness were acquired.

3. Results and discussion

3.1 Self healing of MPPF

The self healing of MPPF was taken by a digital camera(Kodak model:DC-290, resolution ability:1548*1032). Photo. 1 shows the burn out site of metalization due to self healing under a.c condition.

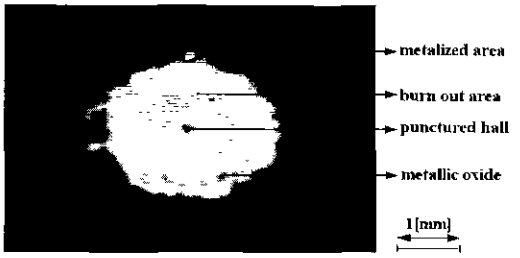

Photo. 1. Burn out site of metalization at self healing(12[㎛], 3[KV_{ac}])

As shown in Photo. 1, a very small hall was created at self healing, and the metalization around the hall was oxidized and evaporated. The edge of the burn out area was curved with coarse burrs, and metal oxides due to self healing were on the metal evaporated PPF. It is known that the metal oxide is Al_2O_3 insulator or ZnO semiconductor depending on what metal is deposited on the PPF[4][9]. In this experiment, it was also observed that there was a little voltage drop at self healing.

3.2 PD characteristics of MPPF

When a.c voltage was applied to the MPPF, PD was observed at much lower voltage than the breakdown voltage of a PPF, and in some cases, noise was emitted and the burn out area was expanded. Partial discharge inception voltages (PDIVs) were mostly increased with pre-self healing events before the main self healing voltage at which self healing begins to occur all over the MPPF area at the almost same time. It is considered that PDIV is getting increased during the several pre-self healing events since the weakest defect is first removed by pre-self healing. Generally, PDIV was regardless of PPF thickness, and it tended to be raised up to the main self healing voltage because the defects were removed by pre-self healing.

3.3 Main self healing voltage by PPF thickness

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. However, about 0.2~0.4[$kV_{ac}/㎛$] are usually considered the breakdown voltage of the PPF itself. Fig. 3 shows the main self healing voltages by PPF thickness, which are similar to early work[5][9].

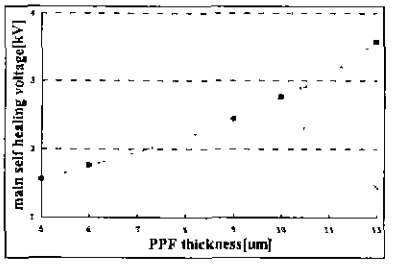

Fig. 3. Main self healing voltage by PPF thickness

As shown in Fig. 3, the main self healing voltage was increased at the rate of about 0.23[kV$_{ac}$/㎛] with PPF thickness.

3.4 Burn out area of metalization at self healing

Fig. 4 shows the burn out area of metalization due to self healing, by the applied voltage and PPF thickness.

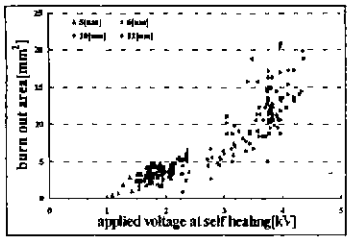

Fig. 4. Burn out area of metalization due to self healing by applied voltage and PPF thickness

As shown in Fig. 4, when a.c voltage was applied, the burn out area due to self healing was roughly getting broader with the applied voltage at self healing. It is considered because the applied voltage at self healing is increased with PPF thickness. Also, the burn out area was somewhat different even though the applied voltage was almost same. It is assumed because the MPPF thickness can not be same all over the MPPF area, which makes the metalization resistance of MPPF slightly different.

3.5 Current in grounding conductor at self healing

Fig. 5 shows the peak current, at self healing, in the grounding conductor connected the base electrode.

As shown in Fig. 5, the peak current in the grounding conductor was, as a whole, increased with the applied voltage at self healing. In case of 10, 12[㎛] PPFs, most of the peak currents were widely varied, and they were much increased compared to the PPFs of 5 and 6[㎛] thickness. In case of 5, 6[㎛] PPFs, each self healing was occurred at different spots, while it was frequently observed that, in case of 10, 12[㎛] PPFs, the burn out area of self healing was overlapped by subsequent self healing occurring near by the first self healing spot. Therefore, in case of the first self healing event, the current which radially flows from the punctured point evaporates the metalization. while in case of the subsequent self healing occurring near by the first self healing, the current hardly flows in the previously burned out area but flows through the metalized area. Therefore, it can be assumed that the peak current at the first self healing is far different from that at the subsequent self healing and it is also considered that the peak current range of 10, 12 [㎛] PPFs is wider than that of 5, 6[㎛] PPFs.

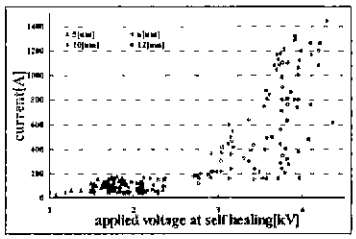

Fig. 5. Current at self healing

Fig. 6 shows the typical waveforms of the current in the grounding conductor at self healing, by PPF thickness.

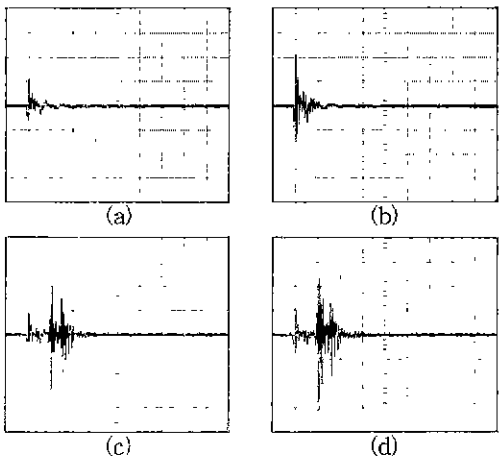

Fig. 6. Current waveforms at self healing (1[㎲/divx) : (a) 5[㎛], 1.82[KV], 40[A/divy], (b) 6[㎛], 2.08[KV], 40[A/divy], (c) 10[㎛], 3.16[KV], 200[A/divy], (d) 12[㎛], 3.82[KV], 200[A/divy])

As shown in Fig. 6, when a.c voltages were applied to the MPPF, the current in grounding conductor was oscillated and damped, and mostly tended to be zero within 3[μs]. Especially, the current peaks were somewhat delayed in case of 10 and 12[μm] PPFs. Also, the peak current in the grounding conductor was increased with the applied voltage at self healing.

3.6 Effect of defect shapes on self healing

In this experiment, void defects with various shapes were imitated to investigate the effect of the void defects between the MPPF and the base electrode and on self healing. When a.c voltage was applied to the MPPF, self healing events were observed. Photo. 2 shows the self healing spot taken, and Table 3 shows the self healing characteristics by the defect shapes.

(a) outside of circular void (b) edge of pin void

(c) side of wrinkle (d) cross point of X/Y void

Photo. 2 Self healing spot

As shown in Table 3, when a.c voltage was applied to the MPPF after imitating various shaped defects, self healing mainly took place at pin tips of a pin void, wrinkle tips and sides of the wrinkle, and its tips, sides and cross points of an X/Y wrinkles. In addition, as shown in Photo. 2(a), self healing at a circular void hardly occurred. Even though self healing occurred at the circular void, the self healing site was limited to its edge. In case that self healing took place at the edge of the circular void, the air in the circular void was released into the impregnant and the MPPF was

Table 3. Self healing (S.H) characteristics by void defect shapes

	circular void	pin void	wrinkle	X/Y wrinkles
S.H event probability	very low	high	high	high
S.H location	· edges	· tips	· tips · sides	· tips · sides · cross points
feature	· Subsequent self healing at the edge of burn out spot due to self healing observed  · bubbles generated at self healing → dissapeared when voltage applied and increased			
void shape				

· pin void : void equal or less than 1[cm] in length
· wrinkle : void more than 1[cm] in length
· X/Y wrinkles : wrinkle with cross points

attracted by the electrostatic force to the base electrode as soon as self healing occurred. Moreover, when the voids experienced the a.c stress, their diameter was reduced in all cases, because the MPPF was attracted to the base electrode. In some cases, however, the void slowly moved between the MPPF and the base electrode without any regularity, and it was slipped out into the impregnant. It was sometimes observed that the voids vibrated at one position without moving here and there. As a result, it was verified that the self healing events mainly took place at the tips and sides of the void defects.

4. Conclusion

After observing the self healing characteristics of the MPPF with various shapes of void defects, they were compared and analyzed.

As a result, this paper concludes as follows;

(1) PDs were generally observed at relatively low voltage, and the PDIVs tended to be

increased with the number of pre-self healing due to void defects.

(2) The main self healing voltage was increased with PPF thickness.

(3) The burn out area at self healing of the metalization was roughly increased with the applied voltage at self healing.

(4) The peak current in the grounding conductor at self healing was increased with the applied voltage at self healing, and it was oscillated and damped with time.

(5) Self healing mainly took place at pin tips of a pin void, tips and sides of the wrinkle, and tips, sides and cross points of an X/Y wrinkles, and self healing at a circular void hardly occurred. Even though self healing occurred at the circular void, the self healing location was limited to its edge.

(6) Subsequent self healing took place at the edge of the burn out area due to self healing.

Various factors such as metalization resistance, metalization thickness and the viscosity of the impregnant, etc., besides the parameters used in this paper, affect self healing characteristics. In this paper, only the defect occurring in manufacturing was taken into account to analyze the self healing characteristics of the MPPF, and the experimental results were compared. In the future, further study using the simulation like electric field analysis on self healing has to be carried out to the various factors.

References

[1] C. W. Reed and S. W. Cichanowski, "The Fundamentals of Aging in HV Polymer-film Capacitors," IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 1, No. 5, pp 904-922, October 1994.

[2] "Technical Trend of Capacitor Films," OHM, pp. 36-40, October 1998.

[3] R. Bartnikas and R.M. Eichhorn, Engineering Dielectrics-Electrical Properties of Solid Insulating Materials : Molecular Structure and Electrical Behavior, ASTM Special Technical Publication, Vol. IIA, pp 505-509, 1983.

[4] D.G. Shaw, S.W. Cichanowski and A. Yializis, "A Changing Capacitor Technology-Failure Mechanisms and Design Innovations," IEEE Transactions on Electrical Insulation, Vol. EI-16, No. 5, pp. 399-412, October 1981.

[5] Shalabh Tandon, Modelling of Stresses in Cylindrically Wound Capacitors : Characterization and the Influence of Stress on Dielectric Breakdown of Polymeric Film, Ph.D. Thesis, University of Massachusettes Amherst, USA, pp. 3-8, September 1997.

[6] Y. Muramoto, M. Nagao and M. Kosaki, "Self-healing breakdown of polyimide thin films in the cryogenic temperature region," 13th. International Cryogenic Engineering Conference, Vol. 35, No. 11, pp. 791-793, 1995.

[7] Yasunobu Yoshida and Takashi Muraoka, "The Development of High Voltage Power Capacitor Technology in Japan," IEEE Electrical Insulation Magazine, Vol. 11, No.1, pp. 32-45, January/February 1995.

[8] Y. Yoshida and M. Nishimatsu, "Power Capacitors," IEEE Transactions on Electrical Insulation, Vol. EI-21, No. 6, pp 963-973, December 1986.

[9] K.S. Kim, "The Manufacture Technology in Power Condenser," Monthly of Electrical Technology, pp. 65-69, November 1999.

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