

# ACED 2010

## 15th Asian Conference on Electrical Discharge

### PROGRAM

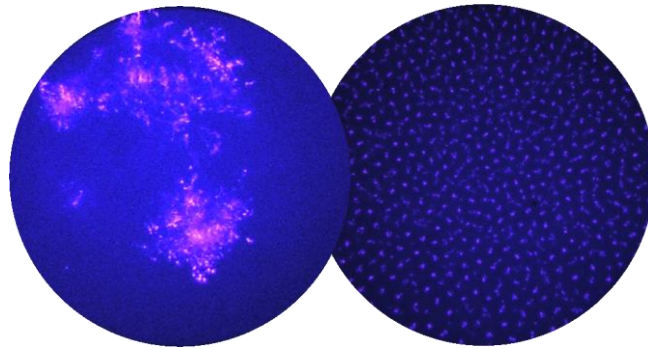
Xi'an Jiaotong University, Xi'an, China

November 7-10th, 2010

# ACED 2010

## Proceedings

### of the 15th Asian Conference on Electrical Discharge



November 7-10th, 2010

Xi'an, China

**Organized by :** State Key Lab of Electrical Insulation & Power Equipment, Xi'an Jiaotong University, China

**Co-Organized by :** State Key Lab of Power Transmission Equipment & System Security and New Technology, Chongqing University, China

**Supported by :** National Natural Science Foundation of China (NSFC), Chinese Society of Electrical Engineering (CSEE), China Electrotechnical Society (CES)



# PREFACE



## Welcome to ACED 2010 in China

On behalf of the organizing committee, I am honored to welcome all colleagues from around the world to attend the 15th Asian Conference on Electrical Discharge (ACED) in Xi'an, China on November 7-10th, 2010.

The conference is organized by Xi'an Jiaotong University, and co-organized by Chongqing University, China. The conference will be held at XJTU Nanyang Hotel, which is near Xi'an Jiaotong University with about 5 minute's walk.

ACED 2010 will be a great event in the field of electrical discharge, and also other related fields. More than 200 full papers have been accepted for the conference CD. Many world-famous experts and professors in electrical discharge will be invited to attend the Conference and make invited talks. ACED founders will be invited to make memorial lectures. You can attend the oral and poster sessions to discuss recent progress and exchange ideas in phenomena, characteristics and applications of electrical discharges, and also other interesting high voltage insulation issues.

We believe the conference will be a key stage to improve electrical discharge research level, especially in the Asian-Pacific region, show our great development to the world in the field of discharge and plasma academic research.

Xi'an is the provincial capital of Shaanxi Province, China, and it is the cultural and economic center of Western China. Historically 13 dynasties placed their capitals here for more than 1300 years. There are numerous famous historical sites waiting for your visit and discovery.

As the General Chair of 15th ACED, I would like to extend my warm welcome to all participants to attend ACED 2010.

I wish you a joyous and rewarding stay in Xi'an.

Nov.2010

A handwritten signature in cursive script that reads "yanming Li".

Prof. Yan-Ming Li

Chairman of ACED 2010

# **SCOPE**

The Asian Conference on Electrical Discharge (ACED) is a non-profit, international organization whose purpose is to encourage the advancement of the science and application of phenomena and applications of electrical discharges, primarily by conducting symposia for the exchange of scientific information. Symposia are held biennially (every two years).

The Conference is an interdisciplinary meeting for the exchange of results, presentation of progress and discussion of ideas and challenges for the future in the field of electrical discharges. Both fundamental and application aspects are covered. The Conference programs consist of memorial lectures, invited speeches, oral and poster presentations.

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# The Effect of Nano Filler Mixture on the Visual Aspects of Treeing Degradation in LDPE Based Composite

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**Abstract**—This paper deals with a nanocomposite of magnesium oxide (MgO) added to a low-density polyethylene (LDPE) which was subjected to an electrical treeing degradation. During propagation, there was an addition of tree branches within filled specimen compares to the pure LDPE. If the branches are assumed very closed enough then it may be more appropriately to consider the tree as a uniform conducting medium. This brought to higher local breakdown strength at the tree tip, leads to the suppression of propagation. Furthermore, even the tree had bridged the specimen the breakdown was not immediately to occur. There would be so-called time lag between bridging and final breakdown. LDPE with MgO excelled to suppress the increase of tree parameters than that of LDPE without MgO. The polymer nanocomposite seems to be more resistive against treeing degradation than their base material.

**Index Terms**—Nano filler MgO, LDPE, tree degradation, visual aspect, breakdown.

## I. INTRODUCTION

SINCE power apparatus are recently being weight reduced and downsized in order to reduce power transmission cost; the compact design of high quality of composite material with nano-filler has become attractive [1-3]. As for LDPE, which is widely used for cable insulations, a nano-composite material of MgO added to LDPE is the most attractive material to be investigated nowadays. Electrical treeing is one of the main factors for ageing of electrical insulation systems. It has been studied for more than 30 years. Since it has complex structural characteristics that are difficult to describe using Euclidean geometry, trees can be appropriately described using fractal geometry. Unlike homogeneous solid materials, in composite insulation system, the existence of filler may affect the fractal parameters of tree growing through the composite [4]. By using fractal geometry, it was obtained that the incorporation of MgO filler in LDPE has an effect on the tree structure with more branches [5]. If the branches are assumed very close then it may be more appropriate to consider the tree as a uniform conducting medium due to it shielded neighboring branches from very high field enhancement in the tree tips. Electrical

trees consist of connected channels few micrometers in diameter, with branches tens of micrometers long. The walls of the channels are not always carbonized and only weakly conducting; thus although a short circuit may occur if the tree bridges the insulation [6], this is not always immediately the case. However, it is also possible for a breakdown to be initiated before electrical trees completely bridge the insulations. Thus, the runaway stage of final breakdown mechanisms of electrical trees could be either “visual” or “not visual” aspect [6]. It is not so easy to discriminate experiment to investigate these mechanisms when it will become visual of not visual. In the previous paper [7-8], classification of both visual and not visual aspects of final breakdown mechanisms have been successfully conducted. In this classification, not visual aspect was investigated by breakdown voltage using large applied voltage compared to their inception level. While, visual aspect was investigated using applied voltage which lied exactly at the inception level. It was supposed that the higher voltage above their inception level is applied the higher tendency of final breakdown to change from visual to be not visual. The results are sketched in Fig. 1.

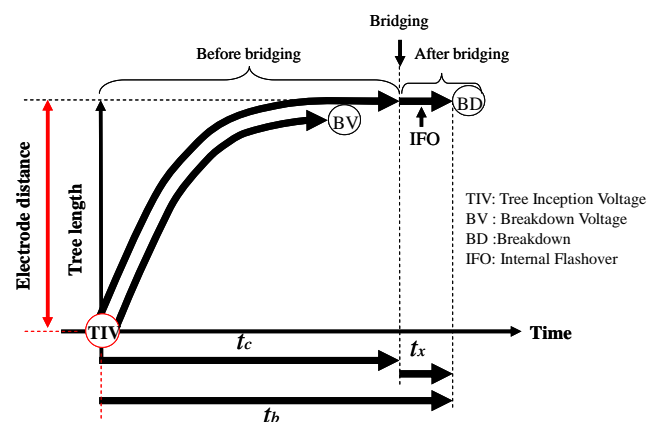


Fig. 1. Sketch of time to treeing breakdown.

Time to breakdown ( $t_b$ ) is the sum of the time the tree needs to



bridge the counter electrode ( $t_c$ ) and time lag to breakdown ( $t_x$ ). The recent paper is a digest on the visual aspect of final breakdown mechanisms before and after tree bridged the specimen.

## II. EXPERIMENT

### A. Specimen

A tungsten wire with 50  $\mu\text{m}$  in diameter was used as a needle electrode. Electrolytic polishing formed the needle tip; its tip radius was 2  $\mu\text{m}$ . The tungsten needle was sandwiched in between two nanocomposite films (each thickness was 80  $\mu\text{m}$ ) and hot-pressed down to about 150  $\mu\text{m}$  in thickness. The specimen sheet was fixed between a slide glass and cover glass by Aron Alfa adhesive (Toa Gosei Ltd.). Aluminium foil was applied as a counter electrode at a distance of 0.4 mm from the tip of tungsten needle. The leaf-like specimens (see Fig.2) were prepared with various concentrations of MgO fillers 0, 1, 5, and 10 phr (part per hundreds ratio).

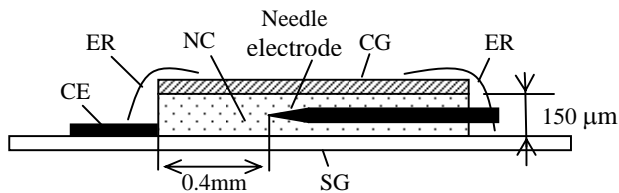


Fig. 2. Specimen configuration (NC: nanocomposite, CG: cover glass, SG: slide glass, CE: counter electrode, ER: epoxy resin).

### B. Treeing Tests

A schematic diagram of measuring system is shown in Fig. 3.

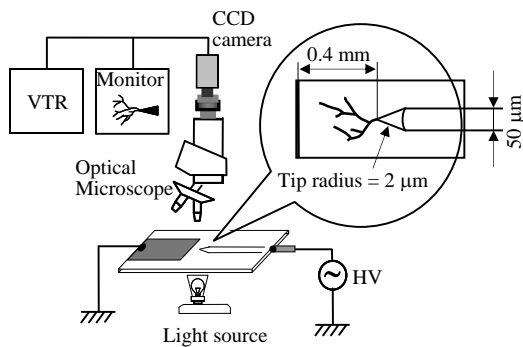


Fig. 3. Tree observation system.

An ac ramp voltage of 60 Hz was applied between the needle and counter electrodes at a continuous rising speed (0.5 kV/s), however, as soon as tree had been observed, the voltage was kept at the constant value to observe the tree propagation until bridging the counter electrode and leading to final breakdown. It was recorded by VTR (video tape recorder) through CCD (charge couple device) camera that mounted on the microscope.

The tree inception voltage was defined as the voltage when the tree length observed by CCD camera had exceeded 10  $\mu\text{m}$  [6]. When applying voltage, the specimens were placed in a vessel filled with silicone oil of 10  $\text{mm}^2/\text{s}$  (10 cSt) in viscosity to avoid surface flashover. All tests are carried out under ambient temperature.

## III. RESULTS AND DISCUSSIONS

### A. Effect of Nano Filler MgO on Trees before Bridging

After inception, the tree grew up towards the counter electrode. The MgO nano filler acted as barrier against tree propagation. During propagation, there was an addition of fractal dimension on tree within filled specimen compares to the pure LDPE, as shown in Table I .

TABLE I FRACTAL DIMENSIONS OF TREE GROWTH IN THE NANOCOMPOSITE

Tree Length ( $\mu\text{m}$ )	Fractal Dimension of Tree			
	0 phr	1 phr	5 phr	10 phr
<b>86.96</b>	1.2061	1.3149	1.3278	1.4530
<b>115.94</b>	1.2342	1.3517	1.4192	1.5094
<b>144.93</b>	1.3474	1.3849	1.4425	1.5659
<b>173.91</b>	1.3965	1.4091	1.5076	1.6060
<b>202.90</b>	1.4113	1.4594	1.5295	1.6429
<b>231.88</b>	1.5253	1.5326	1.5793	1.6668
<b>260.87</b>	1.5432	1.5577	1.6036	1.6727
<b>289.85</b>	1.5620	1.5619	1.6194	1.6919
<b>318.84</b>	1.5827	1.5859	1.6631	1.7176
<b>347.82</b>	1.6037	1.6241	1.6668	1.7465
<b>376.81</b>	1.6110	1.6428	1.6931	1.7918
<b>405.79</b>	1.6307	1.6531	1.7006	1.8092

The introduction of filler brought the rise in fractal dimension due to the increase of branches. It should be noted that the larger fractal dimension means more branching pattern of tree propagation. However, the characteristics are not necessarily connected to the meaning that the material is easy to destroy when its fractal dimension is large.

According to Dissado [6], free volume is an intrinsic feature of polymeric insulation in crystalline and amorphous regions. It might be considered that the fillers change the state of crystallization and restrict the formation of free volume. All the crystals must have a core in their structure. If a better packing is brought by introducing filler particle as a cores, then the formation of free volume may be restricted. The local breakdown strength at the tree tip may be high if the imperfection such as free volume in the insulation could be restricted.

Fig. 4 compares the tree growth in pure LDPE and 5 phr MgO/LDPE nanocomposite. The tree propagation in pure LDPE is characterized with not so many branches. However, the incorporation of filler in LDPE has an effect on the tree structure with more branches. The tree branches shielded neighboring branches from very high field enhancement and if the branches are assumed very close then it may be more

appropriate to consider the tree as a uniform conducting medium.

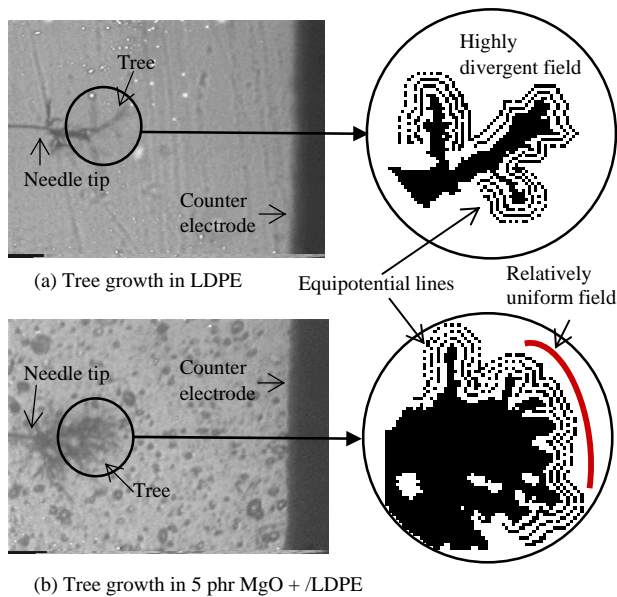


Fig. 4. Tree growth in (a) LDPE and (b) phr MgO/LDPE Nanocomposite.

### B. Effect of Nano Filler MgO on Trees after Bridging

Based on the observation, after about several minutes depending on the filler concentrations, the tree arrived at the counter electrode and stopped the growth at there. However, even the tree had bridged the counter electrode; the breakdown was not immediately to occur. There was time lag between bridging and final breakdown. During the period of time lag, as the active tree channel had bridged the counter electrode, the partial discharges occurred within this channel. It occurrences could be seen clearly as a very bright light (just like lightning strike in the nature) from the needle tip towards the counter electrode. It is called as internal flashover (IFO). The tree channels were eroded by this flashover. Fig. 5 shows the photograph of tree propagation when it bridged the counter electrode at the first time (a) and then just prior to the final breakdown (b).

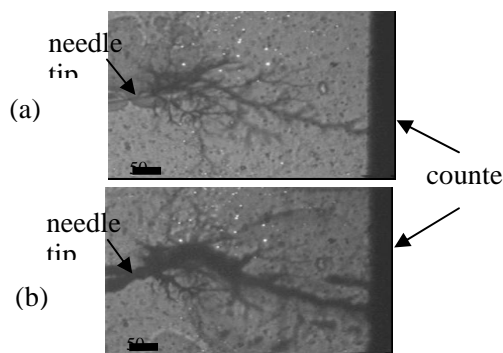


Fig. 5. Photograph of tree propagation when it bridged the counter electrode at the first time (a), and then just prior to the final breakdown (b).

By comparing Fig. 5 (a) and (b); it seen that the tree channel became thicker as the internal flashover occurrence more intense. There would be several internal flashover occurrences before the specimens were completely broken down. The effect of MgO filler on the tree parameters is shown in Table II.

TABLE II FILLER EFFECT ON TREEING PARAMETERS

Tree Parameters	0 phr	1 phr	5 phr	10 phr
Tree inception voltage (kV)				
Time to bridging (minutes)	3.84	5.13	8.15	10.51
Time to breakdown (minutes)	5.27	7.11	10.32	14.57
Time-lag to breakdown (minutes)	0.78	1.51	2.23	4.39
Internal flashover rate (number/minutes)	58.11	9.85	6.88	2.15

The change of diameter of trees growth in the composite with various concentrations of nano filler is shown more detail in Fig. 6.

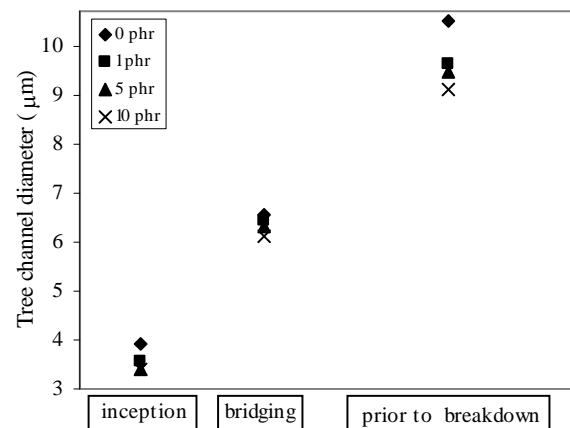


Fig. 6. Comparison of tree channel diameter changes from inception, first time of bridging and just prior to final breakdown under various MgO concentrations.

The time to bridging, time to breakdown and time lag to breakdown increased with increasing of MgO concentration in LDPE. The incorporation of nano filler MgO tends to make longer time lag since the filler particle would increase the electron affinities on the tree channel wall and finally could significantly restrain the occurrence of internal flashover during this period, as illustrated in Fig. 7. At the low diameter ( $D = 6 \mu\text{m}$ ) the effect of filler would be significant in restraining the internal flashover (IFO). If, the occurrence of internal flashover more intense, the tree diameter will get wider. And according to the simulated tree channel, it is believed that, there was a maximum tree diameter above which the effect of MgO would be very small. In this case, time to treeing breakdown is interpreted as a measure of the life time that an insulation material can withstand under a certain electric field until it breakdown. As time lag to breakdown is included in

time to breakdown, the MgO nano filler would suppress the tree propagation and finally the life time of the insulation systems.

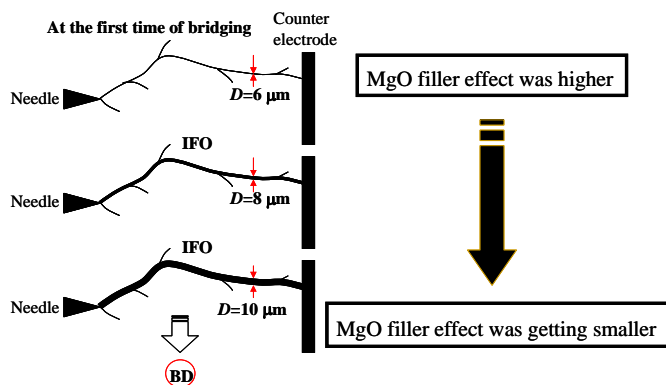


Fig. 7. Illustration of MgO filler effect on the tree channel changes after bridging the counter electrode.

#### IV. CONCLUSION

Effect of MgO nano filler mixture on the visual aspect of treeing degradation in LDPE based composite has been studied. The main results are summarized as follows. The filler suppressed tree propagation. The incorporation of filler into LDPE brought the rise in fractal dimension number of trees due to the increase of its branches. The tree branches shielded neighboring branches from very high field enhancement and if the branches are assumed very close then it may be more appropriate to consider that the tree as a uniform conducting medium. This would lead to the higher local breakdown strength at the tree tip. Therefore, the filler effectively reduces field enhancements arising from electrical trees and leading to the suppression of tree propagation. Even the had bridged the specimen; the breakdown was not immediately to occur. There was time lag between bridging and final breakdown. During the time lag, the tree channel was eroded by the occurrence of internal flashover in it. The more nano filler concentration, the longer times needed to make tree channel diameter thicker enough for breakdown to occur. The time lag to treeing breakdown characteristics of LDPE could be significantly improved by adding a few percents of nano size MgO filler, which is very beneficial for tree aging performance of polymer nanocomposite materials.

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**Zainuddin Nawawi** was born in Lubuk-Linggau, Indonesia on March 3<sup>rd</sup> 1959. He received his B.S. degree in Electrical Engineering from Sriwijaya University, Indonesia in 1984 and became an assistant lecture in the Department of Electrical Engineering of Sriwijaya University. He is currently as a doctor course student at Universiti Teknologi Malaysia.

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# An Experiment on Discharge Time Lag Affected by Humidity and Rough Surface in a PMMA Closed Void

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**Abstract**—The discharge time lag due to deteriorations of high humidity and rough dielectric surface in insulation-gap-metal system has been studied using CIGRE Method II (CM II) electrode. The sample was polymethylmethacrylate (PMMA). The residual probability of time lag was becoming shorter as the relative humidity (RH) rises. It is considered due to the electrons detached from water molecule. The characteristics time lag at 36.8 % of residual probability made the positive polarity shorter than the negative. Time lag with positive polarity was more sensitive to the applied voltage than the negative one. A rough surface brought by plasma exposure would enhance electrical field so that the discharge would be easier to take place with shorter time lag. Decrease in discharge time lag would make possible for partial discharge (PD) occurred with large number of small discharges. After 20 and 60 minutes of recovery times, the time lag of 16 and 21 seconds of exposure levels were not change significantly. However, at 3 seconds of exposure level, 60 minutes of recovery time was long enough to shift the curve to the longer time lag compares to that of 20 minutes. It seems that the treatment changes the surface properties of material only, not the bulk properties.

**Index Terms**—CM II, cumulative and residual probabilities, partial discharge, plasma, PMMA, relative humidity.

## I. INTRODUCTION

THE breakdown due to rapidly changing voltages or impulse voltages is of great importance phenomena in outdoor insulation systems. It has been recognized that there is a time difference between the application of a voltage sufficient to cause breakdown and the occurrence of breakdown itself. This time difference is called time lag. Most of the electrical apparatus use air as the insulating medium because of their simplicity and enormous availability in the nature. Time lags are very important in practical engineering designs. Especially, in insulation coordination the volt-time characteristics of different electrical apparatus are very important to identify [1]. The requirement for protective devices such as rod gaps is that their volt-time curve must lie below the withstand level of the protected insulation in any time region in which protection is needed [2]. As consequence, the margin of the two curves must be adequate to allow for the effects of distance, polarity,

variations in relative air density, humidity, ageing of the insulation and likely changes in the characteristics of the protective devices.

Time lag test on protective devices under deteriorations such as wet/humid condition or surface erosion in real situation suffer from the difficulty that uniform heavy rain accompanied by humid space is hard to achieve, and random errors are therefore large. Different insulation arrangements have different characteristics; this adds enormously to the test load. For that reason, even today the available information within this domain is neither definite nor complete.

To avoid this difficulty yet still enable to study the discharge time lag, artificial small size of gap has been successfully employed using CM II electrode system in the previous paper [3]. In this paper, it was concluded that some features of the pattern can qualitatively be explained by the voltage dependence of the discharge time lag. However, the discharge time lag characteristic due to humidity and surface roughness is not yet clarified. Accordingly, in the recent paper, investigations are conducted to ascertain the characteristics of discharge time lag affected by the humidity and roughness of the air gap and insulation surface, respectively.

## II. EXPERIMENTAL

The employed specimen was CM II electrode system as shown in Fig. 1. One side of the flat gap was in contact with a metallic electrode, and the other side with insulation. The insulation was a 1 mm thick plate of PMMA. In the first test, in order to evaluate the humidity effect on the discharge time lag, two slits of 10 mm in wide were made at the spacer. The specimens were placed in the chamber controlled at constant humidity. Humidity of the space surrounding specimen was conditioned using saturated salt solutions at 33 %, 75 %, and 98 % RH [4]. The specimens were conditioned for 24 hours to ensure stability of the RH prior to measurement. In the second test, the insulation surface was roughened by plasma. Before plasma treatment the sample surface was cleaned by ethanol. Then the samples were subjected to arc plasma sprayer (Keyence ST-7010). The exposure times were 3, 6, 11, 16, and

21 seconds. Soon after stopping the plasma exposure the sample was assembled into the CM II electrode system.

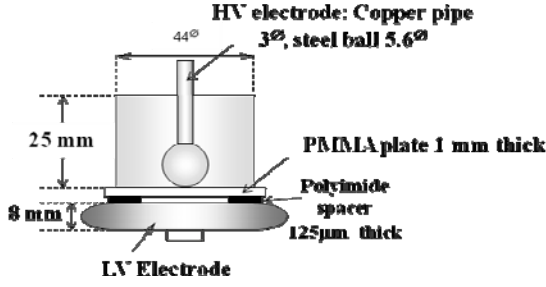


Fig. 1. Configuration of CM II specimen.

The PD measurement is shown in Fig. 2; the voltage was applied to the spherical electrode side of specimen, while the lower was connected to the measurement system.

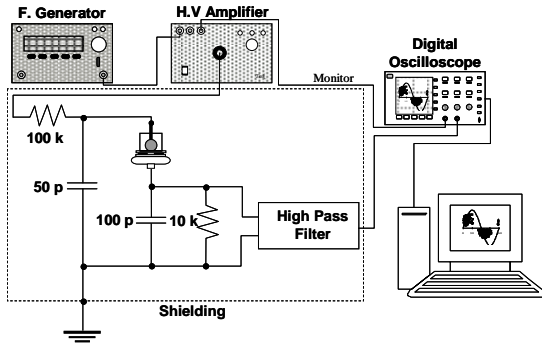


Fig. 2. Schematic diagram of PD measurement system.

The discharge current through the specimen was integrated by the capacitance-resistance (CR) circuit and was digitized using the peak detecting function of the digitizing oscilloscope. Discharge time lag under a step voltage was measured by applying periodical square HV pulses with 10 milliseconds in pulse width. The intervals of pulse application was 20 milliseconds, being corresponded to 50 Hz. Time lag between the leading edge of square pulse and the discharge pulse was measured as shown in Fig. 3.

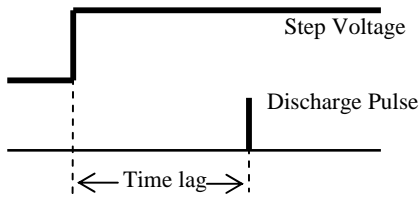


Fig. 3. Illustration for the measurement of discharge time lag.

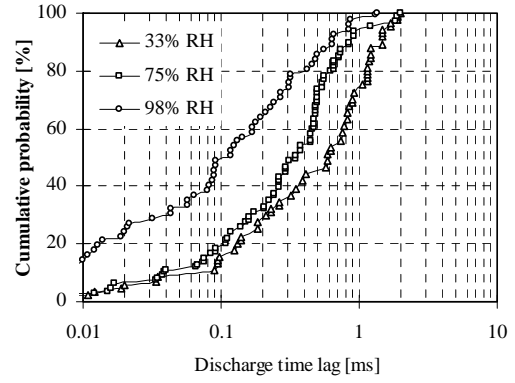
The measurements through 64 pulses were performed to statistically analyze the time lag using identical voltage under several levels of RH and plasma exposures. The rising time of the pulse was as short as 40 microseconds. The polarity of the voltage was defined by that applied to the spherical electrode in Fig. 1, the polarity being identical to that applied to the insulation side of the void. All experiments were performed

under room temperature.

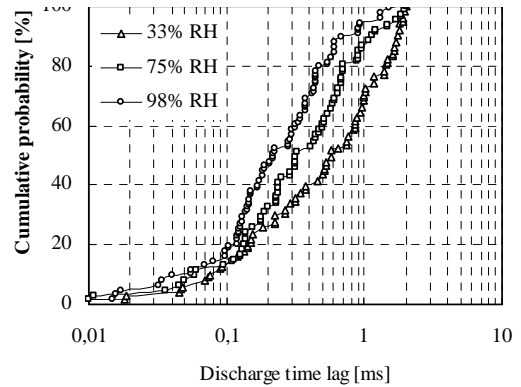
### III. EXPERIMENTAL RESULTS AND DISCUSSION

#### A. Effect of Humidity on the Discharge Time Lag

Fig. 4 shows the cumulative probability as a function of discharge time lag with each RH.



(a) Positive polarity



(b) Negative polarity

Fig. 4. Cumulative probability of the PD time lag of (a) positive and (b) negative polarities for relative humidity of 33 %, 75 % and 98 %.

The cumulative probability is determined from the equation as follow.

$$P = \frac{n_t}{n_0} \quad (1)$$

Where  $n_t$  was the number of certain time lag occurred within applied pulses, and  $n_0$  was the number of applied pulses (64 pulses). The curve was not dependent on biasing DC voltage of the square wave; the voltage was applied so that it changes negative to positive or negative across 0 V as the centre. The voltage across the void would be determined by the capacitance and resistance of both void and insulation. The DC component of applied voltage would be negligible because the resistance through the insulation was very large. It is seen from the Figure. that the curve shifts to the shorter time as the RH rises, in both polarities. It might be due to electrons detached from water molecules.

At 33 % and 75 % of RH, the time lag showed almost the same period both positive and negative polarity. However, at 98 % RH, the negative polarity showed a little bit longer time lag compares to that of positive, along the horizontal axis.

The statistical time lag of discharge is often explained by the Laue's theory. Assuming that the initial electron which triggers the discharge appears with the same rate, the probability that the discharge does not take place until  $t$  after the application of a step voltage is expressed by

$$R = \exp\left(\frac{-t}{\tau}\right) \quad (2)$$

Where  $R$  is the residual probability and  $\tau$  is the characteristic time lag. The residual probability could be related to the cumulative probability as follow.

$$R = 1 - P \quad (3)$$

A Laue plot is therefore plotted with  $\log R$  as the vertical axis and  $t$  as the horizontal axis. Fig. 5 shows the Laue plots based on the data in Fig. 4. Laue plots showed more clearly than the cumulative probability plots. In both polarities, the discharge time lag becomes shorter with increasing RH. The negative polarities have longer time lag than the positive polarities along periods of (0.6 – 1.7) ms, (0.4 – 1.1) ms, and (0 – 0.6) ms, for 33 %, 75 % and 98 % of RH, respectively.

Sawa et al. measured the time lag of the discharge through a short air gap between metal-metal electrodes. They reported that a large resistance inserted into the discharge circuit brought a glow discharge and the statistical distribution of discharge time lag followed the Laue's theory, whereas a small resistance brought an arc discharge and a large deviation from the Laue's theory was observed [5]. As the discharges were triggered successfully on the identical electrode, they suggested that the change in surface condition by the arc discharges brought the deviation from the Laue's theory. In case of partial discharge through a void in contact with insulation, the discharge current is limited by extremely large resistance of the insulation so that the damage on the surface by discharge would be very small. The discharge time lag of the present experiment would thus follow the Laue's theory.

At  $t = \tau$ , the probability will become 63.2 % or 36.8 % for cumulative or residual probability, respectively. Fig. 6 shows the RH dependent characteristic on discharge time lag  $\tau$ .

The characteristic time lag of positive polarity was shorter than negative polarity. This means that the discharge time lag with positive polarity was more sensitive to the applied voltage than the negative polarity.

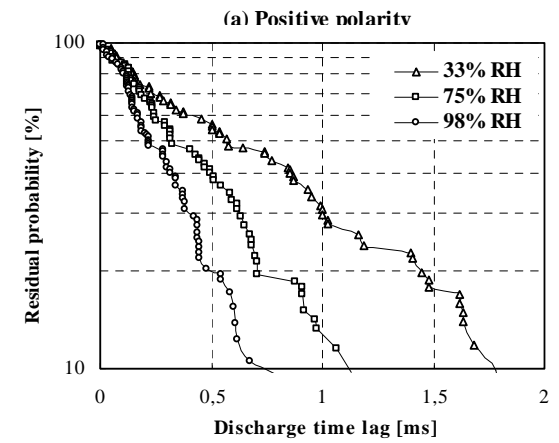
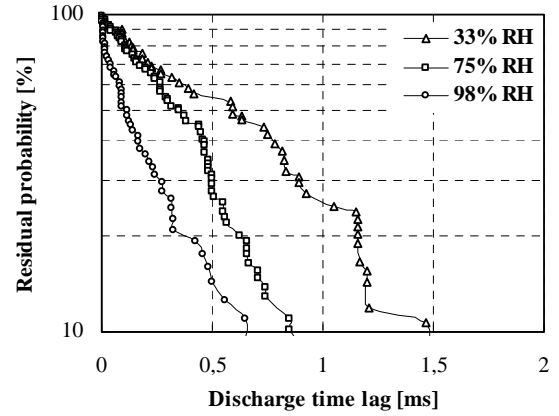


Fig. 5. Residual probability of the PD time lag of (a) positive and (b) negative polarities for relative humidity of 33 %, 75 %, and 98 %.

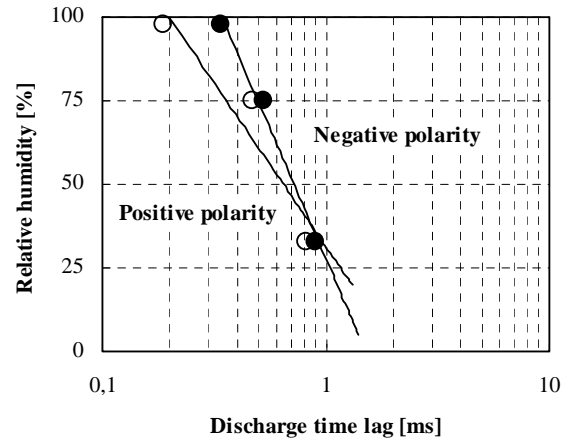


Fig. 6. Plot of the characteristic time lag as a function of RH.

### B. Effect of Plasma Exposure Time on Discharge Time Lag

In order to explain this phenomenon, the partial discharge time lag of each level exposure time soon after exposed by plasma was investigated. As shown in Fig. 7, the time lag becomes shorter with increasing exposure time. This would be explained by assuming that the initial electron is easier to be supplied from the metallic electrode. A rough surface brought

by plasma exposure would emphasize electrical field so that the discharge with longer exposure time would be easier to take place. Decrease in discharge time lag would make possible the PD occurred with a large number of small discharges.

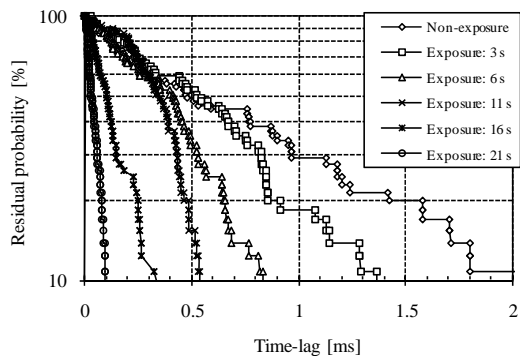


Fig. 7. Laue plots of PD time lag of each level of exposure time.

Fig. 8(a) and (b) show the Laue plots of PD time lag for 20 and 60 minutes after exposure by plasma. In this investigation the exposure time levels respectively 3, 16, and 21 seconds.

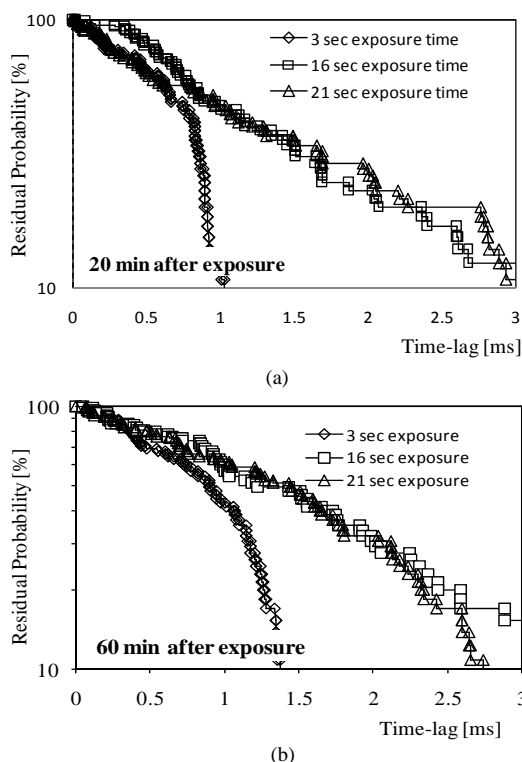


Fig. 8. Laue plots of PD time lag for (a) 20 minutes and (b) 60 minutes after being exposed by arc plasma.

As shown in Fig. 8, in case of 16 s and 21 s of exposure levels, the partial discharge time lags after 20 minutes of exposure seemed not much change compares to that of 60 minutes. However, in case of 3 s of exposure level, there was a significant change between 20 and 60 minutes. The time lag after 60 minutes seemed to be longer than that of 20 minutes. The time lag becomes longer probably related to the recovery

time of material properties. Collections of ions and electrons remove gradually from void surface. The ions and electrons are accompanying the exposure should be disappear gradually. It means that, following the time the effect of plasma exposure should be disappear. When the plasma effect was disappeared, it would make possible the discharge occur with longer time lag. This clarified that, for short exposure time the plasma treatment changes the surface properties of material only, not the bulk properties.

#### IV. CONCLUSION

The discharge time lag due to deteriorations of high humidity and rough dielectric surface in insulation-gap-metal system has been carried out using CM II electrode system. The main results are summarized as follows.

1. In both polarities, the time lag was become shorter as the RH rises from 33 % to 98 %.
2. The characteristic time lag of positive polarity was shorter than negative polarity. This means that the discharge time lag with positive polarity was more sensitive to the applied voltage than the negative polarity.
3. The time lag also becomes shorter with increasing exposure time. It seems the initial electron is easier to be supplied from metallic electrode. A rough surface brought by plasma exposure would emphasize electrical field so that the discharge with longer exposure time would be easier to take place. Decreased in discharge time lag would make possible the PD occurred with large number of small discharges.
4. At 16 and 21 seconds of exposure levels, the time lag after 20 or 60 minutes seemed not quite different; however, at 3 seconds of exposure level, the time lag was shifted to the longer time. Short exposure level of plasma still gave any possibility for recovery of material properties.

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