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Breakdown of LDPE Film under Heavy Water Absorption

Eka PW, T. Okazaki, Y. Murakami, N., Hozumi, and M. Nagao

***Abstract*—**The breakdown strength characteristic of Low Density Polyethylene films (LDPE) under DC voltage application and the effect of water absorption have been studied. Mainly, our experiment was investigated under two conditions; dry and heavy water absorption. Under DC ramp voltage, the result found that the breakdown strength under heavy water absorption has a lower value than dry condition. In order to clarify the effect, the temperature rise of film was observed using non contact thermograph until the occurrence of the electrical breakdown and the conduction current of the sample was also measured in correlation with the thermograph measurement. From the observations, it was shown that under the heavy water absorption, the hot spot in the samples appeared at lower voltage. At the same voltage the temperature of the hot spot and conduction current was higher than that under the dry condition. The measurement result has a good correlation between the existence of a critical field for conduction current and thermograph observation. In case of the heavy water absorption, the occurrence of the threshold field was earlier than the dry condition as result lead to higher of conduction current and the temperature rise appears after threshold field was significantly increased in increasing of field. The higher temperature rise was caused by the higher current conduction as the result the insulation leads to breakdown to the lower field application.

***Keywords*—**Low density polyethylene, heavy water absorption, conduction current, temperature rise.

I. Introduction

NOWADAYS, polymers are widely used in many areas of industry as an insulating material for medium and high voltage cables. One of the well known examples is the Low Density Poly Ethylene (LPDE) which is frequently used for the above purpose recently due to its excellent electrical and mechanical properties. However, in order to enhance the performance of cables, the improvement of electrical properties of LPDE is still actively investigated.

When the distorted electric field is strong enough, the initiation of the partial discharge will be easy to occur. The partial discharge has gradually degraded the surface of the insulating material [1]. With progress of time, then the surface tends to have many pits. The depth of these pits becomes large due to effect of partial discharge activity and consequently the electric field at the tip of the pit will increase. The breakdown occurs when the electric field at the local pit point reaches the critical value [2]. In addition, the critical value is also influenced by several factors. One of them is the condition of the insulation area.

In the real field, the insulating material in the tropical area is often used under high relative humidity and for all years. Moreover, at the heavy rainfall areas, this material is often wet for a significant time. Therefore application of insulations to absorb the water is needed. However, under their use under the certain time would lead to the environmental ageing factor. In the other side, the technical trends today in which the power apparatus are being weight-reduced and downsized to reduce power transmission costs, the insulation systems are subjected to higher stresses. Higher stresses play a very important role in the ageing and breakdown processes of electrical insulation systems. This condition is considered able to affect the breakdown of the insulation. Therefore, this paper is focused on investigation of the effect of water absorption on the electrical insulating characteristic in tropical area.

In this paper, the effect of water absorption on the electrical breakdown of LDPE film using DC ramp voltage was studied by observing the temperature rise due to local heating [3,4] and the conduction current until the breakdown takes a place.

II. Experimental Method

A. Specimen Condition

The used samples were low density polyethylene films with the thickness around 20 μm for observation of the temperature rise and conduction current and around 60 μm for measurement of the current conduction in the insulation. The effect of heavy water absorption in the samples was then compared with the samples under dry condition. The former was immersed into distilled water for more than 2 months at 50 ^{o}C, defining this treatment as the "heavy water absorption" case, and the latter was dried using the silica gel for more than 2 days, defining this treatment as "dry" case.

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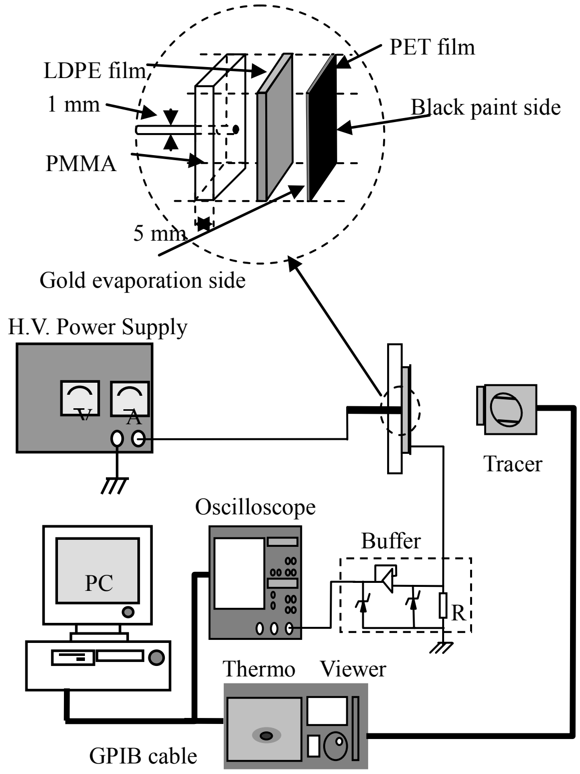

Fig. 1 Experimental system for detection of temperature rise and conduction current

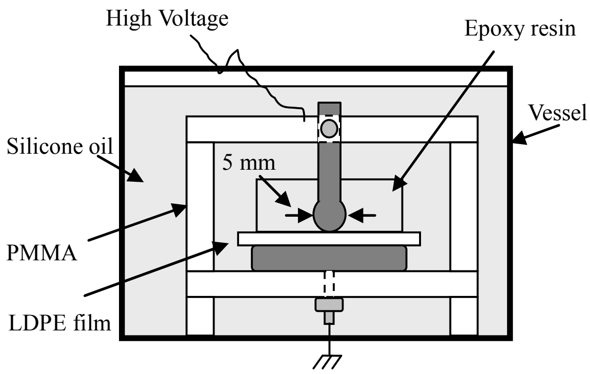

Fig. 2 Experiment set up for electrical breakdown of polymer

B. *Observation of Surface Temperature*

Temperature rise and conduction current under increasing of positive DC voltage were observed using configuration of flat needle-plane electrode with no distance between the sample surface and the needle tips as shown in Fig. The needle was fixed to polymethyl acrylic (PMMA) plane with the thickness around 5 mm. Another side of the sample was installed by the plane electrode (using 7 μm thick of Poly Ethylene Terephtalate /PET film). One side of this electrode was

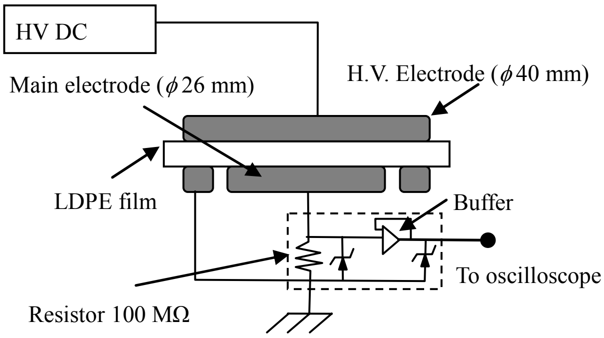

Fig. 3 Experiment set up electrical

evaporated by gold and another side was black painted in order to increase the infrared emission. The gold evaporation of sample was connected to ground. From the black side, the change of surface temperature distribution of specimen was observed by non contact thermometer, such as TH 2100 thermograph. The surface temperature distribution shown by the display was recorded to PC under GPIB interface. The duration of image can take about one frame/s and sensitivity of temperature is 0.1 ^{0}C. The conduction current was also measured simultaneously by oscilloscope and only the maximum of values was recorded in one frame. This data is also saved to PC simultaneously with thermal image. The ramp voltage with increase rate of 100 V/s was applied until the occurrence of breakdown. All measurements were totally controlled by PC and performed in the air at 20 ^{0}C.

C. *Measurement of Water Absorption*

The LDPE film with thickness 20 μm was used to measure the water absorption in the insulation due to direct dipping into the water. The specimen weight after drying in vacuum was measured as the base. The electronic balance was used to measure the specimen weight as a function of time. The moisture content M (%) can be calculated as follow:

$$M = (m-m_0) / m_0 \times 100\% \quad (1)$$

Were m is the specimen weight after being stored in water, and m_0 is the base weight.

D. *Measuring of Breakdown Strength and Conduction Current*

Fig. 2 shows the experiment set-up for breakdown strength using spherical plane electrodes. The first steel spherical electrode placed above the LPDE film was connected to a power supply, and the second electrode placed at the bottom of the film was connected to ground potential. The spherical conductor was covered by epoxy resin and the configuration system was placed in a vessel filled with silicone oil of 10 mm2/s (1000 cSt) in viscosity to avoid the partial discharge. The conductors was fixed to PMMA with thickness 5 mm to

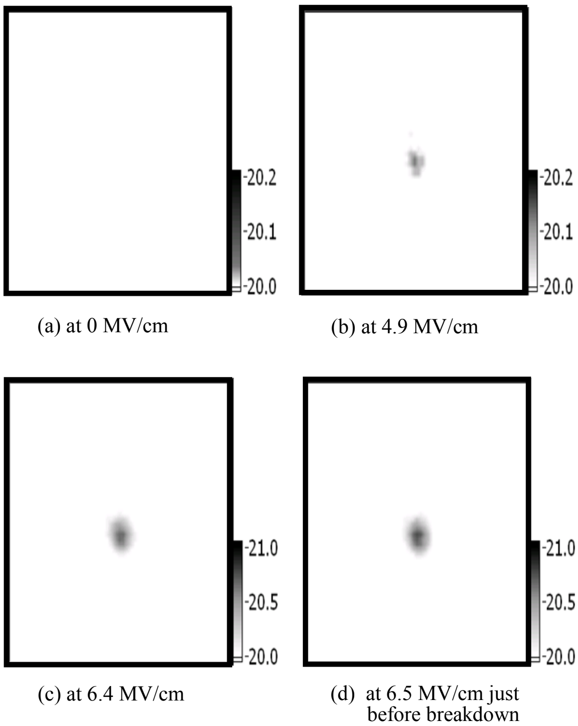

Fig. 4 Thermal image at dry condition as a function of electric strength application

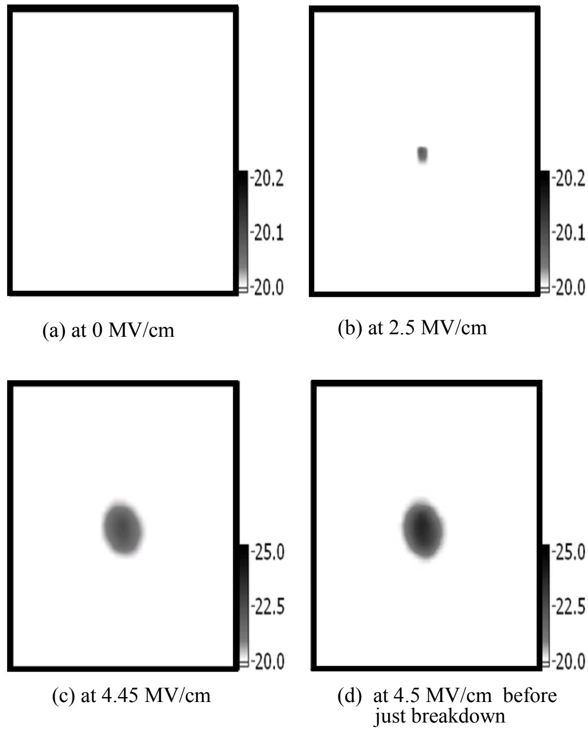

Fig. 5 Thermal image at heavy water absorption condition as a function of electric strength application

avoid of Coulomb force between conductors, with the result that the breakdown of polymer film only caused by electric strength field between conductors. The positive DC voltage was applied to spherical electrode, and then the breakdown strength was measured with the increase rate around 100 V/sec until the breakdown occurred. Moreover, around 10 samples were used in for each condition of absorption.

Fig. 3 shows the experimental set-up for the measurement of the conduction current. The upper electrode with 40 mm in diameter was connected to positive polarity while the bottom of polymers side have electrode, the center of electrode also called as the main electrode, with 26 mm diameter was connected to the ground. Another is the guard electrode with 32 mm in inner diameter and 40 mm in outer diameter was placed parallel with the main electrode. The conduction current of the samples were measured at variation of dipping time interval into distilled water; those are 0, 2, 15, 30 and 60 days under DC voltage 10 kV. The conduction current at 10 minutes after the DC voltage application was employed to determine the conductivity. The conduction current density of the specimen was calculated by dividing the conduction current by sectional area of main electrode.

III. Result and Discussion

Fig. 4 shows the increment of thermal image observation correlated with the conduction current measurement. The ambient temperature was 20 ^oC. During the increment of electric strength caused by voltage application, a local temperature rise was not significant for the voltage which is lower than 4.9 MV/cm. Soon after the voltage reached the value of 4.9 MV/cm, the local higher temperature point will be appeared (see Fig. 4b). At this field, the initiation of temperature rise was about 0.1 ^oC, and above this point, the temperature rise will significantly increase (see Figs. 4c and 4d). Moreover, at the voltage around 6.4 and 6.5 MV/cm, the temperature rise increased about 0.5 and 0.6 ^oC. The breakdown was then occurred at this point. However, there was no certain indication that can be seen from the temperature rise to detect the occurrence of breakdown.

In case of heavy water absorption, the temperature rise of the samples due to increasing of the voltage application was observed by thermograph as shown in Fig. 5. The ambient temperature was almost similar to the previous case. By increasing the voltage application, The temperature rise around 0.1 ^oC was detected at the voltage 2.5 MV/cm, then the temperature rise will increase significantly (see Figs. 5c, 5d) to the 3.2^oC and 3.5 ^oC for the voltage 4.45 and 4.5 MV/cm respectively. At this point (4.5 MV/cm), the breakdown was then occurred. Comparing to the previous case, the temperature rise in this step was also increased significantly as a function of voltage application but with different temperature rise just before occurrence of the breakdown.

Fig. 6 shows the conduction current parallel with temperature rise of sample as a function of voltage increment. The increment surface temperature as a function of increment of electrical strength started from the hottest place at thermal image observation as shown in Fig. 6 or Fig. 7. The value can be searched automatically by computer under Labview program to show the result of measurement simultaneously

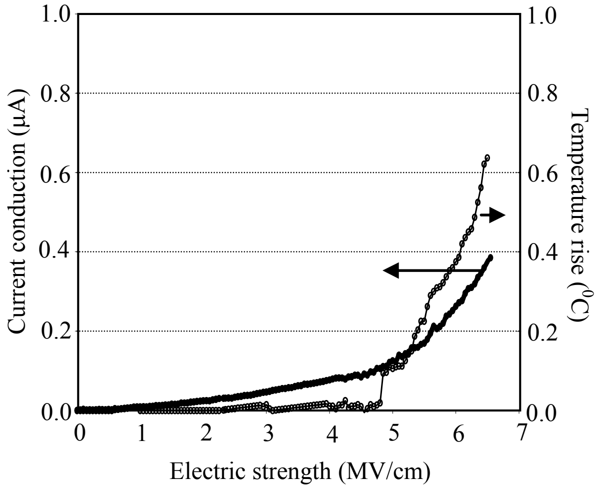

Fig. 6 Conduction current and temperature rise function of electric strength application at dry condition

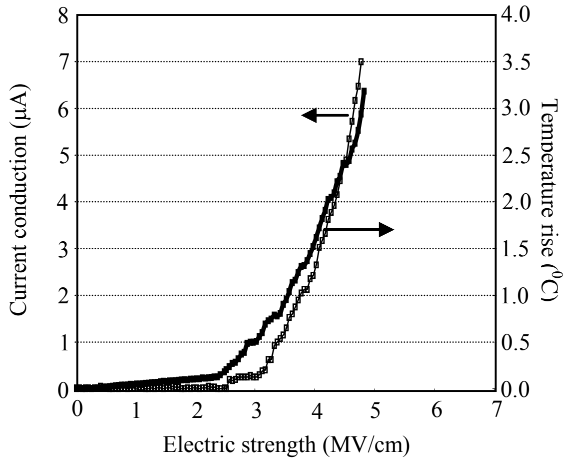

Fig. 7 Conduction current and temperature rise function of electric strength application at heavy absorption condition

with conduction current result. The conduction current result shows that from 0 V until 2.2 MV/cm the current increased from 0 to 0.08 μA and the increment of current in this range was linearly increased as a function of voltage application and a linear relation ship between conduction current and the applied voltage is Ohmic. However, from 4.15 MV/cm until the point just before breakdown (around 5.85 MV/cm), the conduction current increased significantly as a function of electric strength from 0.08 to 0.2 μA, and the increment of current conduction is singled out above which the transition between low slope to the high slope characteristic occur or like wise. The point of conduction current as a function of voltage application that changed between low to high slope characteristic was defined by initiation threshold point.

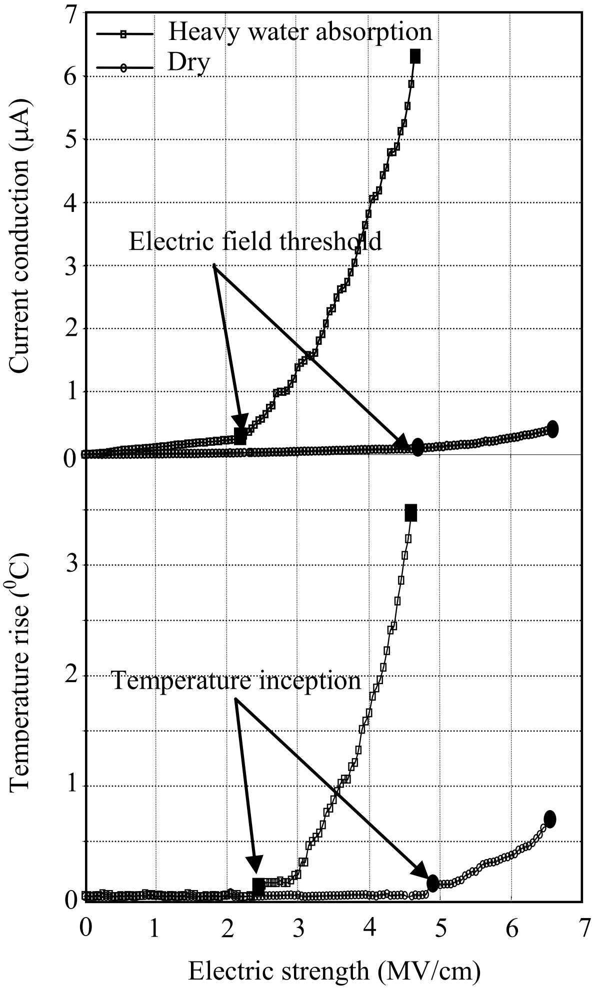

Fig. 8 Conduction current in the company with temperature rise function of electric strength application with difference condition

Below the initiation threshold point, the conduction current in this region was quite low, therefore the increment of temperature could not be observed by thermograph. While, above the initiation threshold point, the conduction current increased remarkably as a function of voltage application. In this range the electric power was dissipated and this is enough to initiate the increase of the sample temperature. Moreover, the temperature will continue to increase under increasing of the voltage application until the occurrence of the breakdown. At one second before the breakdown point, it was difficult to observe the change of the current conduction because it rose very abruptly.

Fig. 7 shows the conduction current as a function of the voltage increment for heavy water absorption cases. From 0 V until 2 MV/cm, the conduction current increased linearly from 0 to 0.25 μA as a function of the voltage application, while from 2 MV/cm to the point just before breakdown (4.5 kV), the conduction current increased from 0.25 to 6.37 μA. Similarly, the current conduction in this range was also increased significantly as a function of voltage application but with different initiation threshold point value. The heavy water absorption showed a lower threshold point than the dry condition.

Comparison of the results for both conditions is shown in Fig. 8. There are two results are discussed. The first is the conduction current as shown by the upper figure and another is the temperature rise as shown by the lower figure. For the first result, it can be seen that, for both conditions, a significant conduction current was found when the electric field exceeds a threshold field. Here, the heavy water absorption showed a lower value of the threshold field and a large value conduction current until the occurrence of the breakdown than the dry condition. For the second result, it can be also found that the heavy water absorption presented a large value of temperature rise until breakdown than the dry condition. With the earlier threshold field occurred the results show the higher conduction current and lead to higher temperature rise and lead to lower value.

Fig. 9 shows the influence of water absorption on DC breakdown strength under DC ramp voltage. DC breakdown strength was calculated by dividing the breakdown voltage by the film thickness. The breakdown strength values in the graph, scatterings of minimum and maximum value were from average and standard deviation, respectively. Breakdown strength of heavy water absorption decreased compared with that of dry condition. This result indicated that the water absorption creates the insulation become weaker and lead breakdown to the lower value.

Fig. 10 shows conduction current parallel with moisture content as a function of the time interval of the sample dipping into the distilled water. It can be seen that the water absorption increased as a function of the time, and on the other hand the conduction current also increased significantly after one month to be dipped into the distilled water.

The heavy water absorption is like impurities in the insulation. It makes the conduction current become higher. The increasing of conduction current generated by dissociation of impurities in LDPE film by water absorption leads to the increasing of charge density. The dissociation not only occur inside of film but also at interface of film [4,5]. In addition, the maximum field across the specimen suggesting that an increase current due to the generation and/or injection [6]. It leads to the breakdown at the lower electric strength.

It is remarkable that the breakdown strength decreased by close to half when it was dipped into hot water for only 60 days. It suggests that the insulation, which passed the initial withstand voltage test, may loose its performance very quickly, depending on the condition. It is known that the absorption of water by a polymer material depends on its hydrophilic property. Polyethylene is one of very hydrophobic materials. Considering that the influence of humidity was this significant with polyethylene, some other materials with higher hydrophilic property may loose their insulation performance much more quickly. From such a point of view, a special care should be taken when polymer insulations are used in tropical areas.

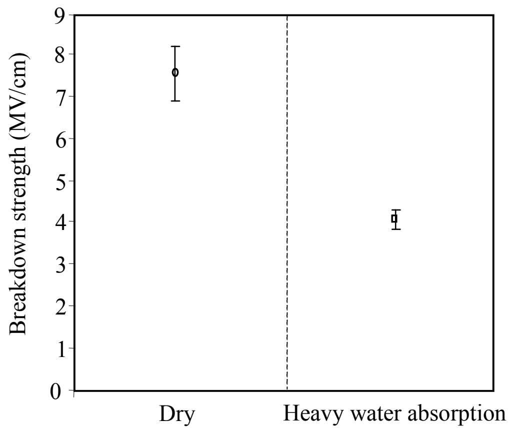

Fig. 9 Breakdown strength with difference condition

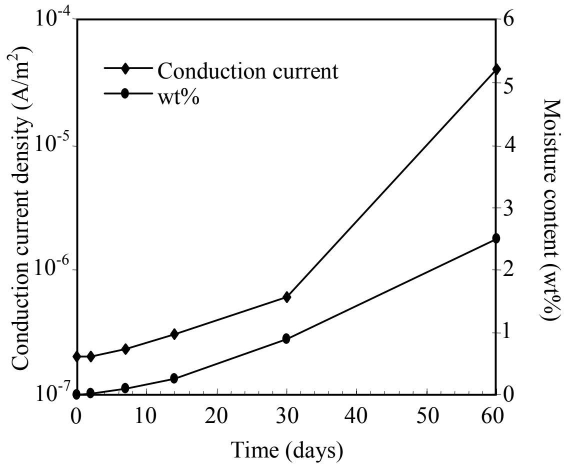

Fig. 10 Conduction current analogous with moisture content function of time

IV. Conclusion

The electrical breakdown phenomena in LDPE film in influence of dry and heavy water absortion was discussed, and some results are described as follows:

1. Voltage breakdown using the ramp voltage decreased under heavy water absorption.
2. Temperature rise at the point nearly breakdown for the heavy water absorption cases was higher than the dry condition under DC ramp voltage.
3. A higher temperature rise at the point just before breakdown occured for the heavy water absortion cases was caused by the significant increase of conduction current.

Acknowledgment

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